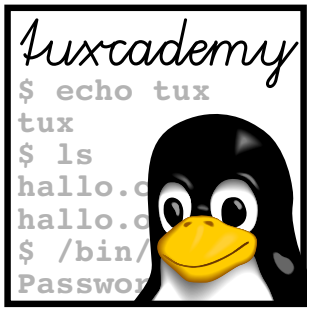
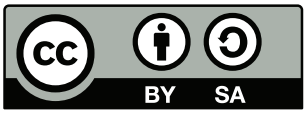
Concise Linux

An Introduction to Linux Use and Administration





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`grd1:be27bba8095b329b:2015-08-04` 1–9, B
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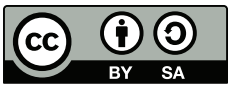

Authors: Tobias Elsner, Thomas Erker, Anselm Lingnau
Technical Editor: Anselm Lingnau ⟨*anselm.lingnau@linupfront.de*⟩
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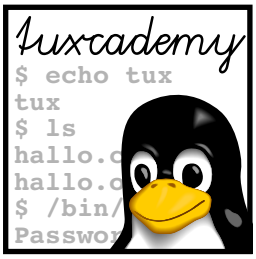

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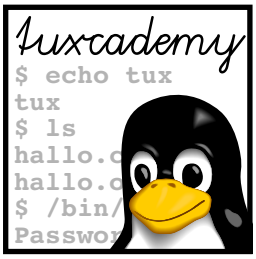

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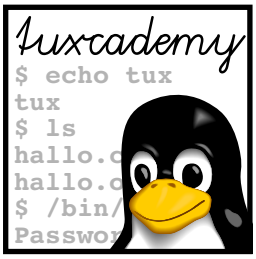

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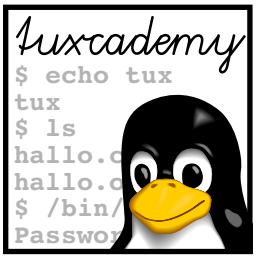

Preface

This manual offers a concise introduction to the use and administration of Linux. It is aimed at students who have had some experience using other operating systems and want to transition to Linux, but is also suitable for use at schools and universities.

Topics include a thorough introduction to the Linux shell, the `vi` editor, and the most important file management tools as well as a primer on basic administration tasks like user, permission, and process management. We present the organisation of the file system and the administration of hard disk storage, describe the system boot procedure, the configuration of services, the time-based automation of tasks and the operation of the system logging service. The course is rounded out by an introduction to TCP/IP and the configuration and operation of Linux hosts as network clients, with particular attention to troubleshooting, and chapters on the Secure Shell and printing to local and network printers.

Together with the subsequent volume, *Concise Linux—Advanced Topics*, this manual covers all of the objectives of the *Linux Professional Institute*'s LPIC-1 certificate exams and is therefore suitable for exam preparation.

This courseware package is designed to support the training course as efficiently as possible, by presenting the material in a dense, extensive format for reading along, revision or preparation. The material is divided in self-contained chapters detailing a part of the curriculum; a chapter's goals and prerequisites are summarized clearly at its beginning, while at the end there is a summary and (where appropriate) pointers to additional literature or web pages with further information.

chapters
goals
prerequisites

Additional material or background information is marked by the "lightbulb" icon at the beginning of a paragraph. Occasionally these paragraphs make use of concepts that are really explained only later in the courseware, in order to establish a broader context of the material just introduced; these "lightbulb" paragraphs may be fully understandable only when the courseware package is perused for a second time after the actual course.

Paragraphs with the "caution sign" direct your attention to possible problems or issues requiring particular care. Watch out for the dangerous bends!

Most chapters also contain exercises, which are marked with a "pencil" icon at the beginning of each paragraph. The exercises are numbered, and sample solutions for the most important ones are given at the end of the courseware package. Each exercise features a level of difficulty in brackets. Exercises marked with an exclamation point ("!") are especially recommended.

exercises

Excerpts from configuration files, command examples and examples of computer output appear in `typewriter type`. In multiline dialogs between the user and the computer, user input is given in **`bold typewriter type`** in order to avoid misunderstandings. The "◁◁◁◁◁" symbol appears where part of a command's output had to be omitted. Occasionally, additional line breaks had to be added to make things fit; these appear as "▷
◁". When command syntax is discussed, words enclosed in angle brackets ("⟨*Word*⟩") denote "variables" that can assume different values; material in

brackets ("[`-f` ⟨*file*⟩]") is optional. Alternatives are separated using a vertical bar ("`-a|-b`").

Important concepts definitions

Important concepts are emphasized using "marginal notes" so they can be easily located; **definitions** of important terms appear in bold type in the text as well as in the margin.

References to the literature and to interesting web pages appear as "[GPL91]" in the text and are cross-referenced in detail at the end of each chapter.

We endeavour to provide courseware that is as up-to-date, complete and error-free as possible. In spite of this, problems or inaccuracies may creep in. If you notice something that you think could be improved, please do let us know, e.g., by sending e-mail to

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info@tuxcademy.org
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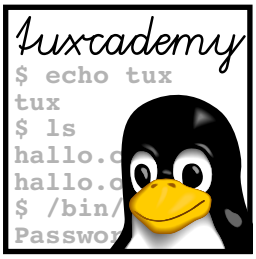
(For simplicity, please quote the title of the courseware package, the revision ID on the back of the title page and the page number(s) in question.) Thank you very much!

LPIC-1 Certification

These training materials are part of a recommended curriculum for LPIC-1 preparation. Refer to Appendix C for further information.



1

Introduction

Contents

Goals

- Knowing about Linux, its properties and its history
- Differentiating between the Linux kernel and Linux distributions
- Understanding the terms “GPL”, “free software”, and “open-source software”

Prerequisites

- Knowledge of other operating systems is useful to appreciate similarities and differences

1.1 What is Linux?

Linux is an operating system. As such, it manages a computer's basic functionality. Application programs build on the operating system. It forms the interface between the hardware and application programs as well as the interface between the hardware and people (users). Without an operating system, the computer is unable to "understand" or process our input.

Various operating systems differ in the way they go about these tasks. The functions and operation of Linux are inspired by the Unix operating system.

1.2 Linux History

The history of Linux is something special in the computer world. While most other operating systems are commercial products produced by companies, Linux was started by a university student as a hobby project. In the meantime, hundreds of professionals and enthusiasts all over the world collaborate on it—from hobbyists and computer science students to operating systems experts funded by major IT corporations to do Linux development. The basis for the existence of such a project is the Internet: Linux developers make extensive use of services like electronic mail, distributed version control, and the World Wide Web and, through these, have made Linux what it is today. Hence, Linux is the result of an international collaboration across national and corporate boundaries, now as then led by Linus Torvalds, its original author.

To explain about the background of Linux, we need to digress for a bit: Unix, the operating system that inspired Linux, was begun in 1969. It was developed by
Bell Laboratories Ken Thompson and his colleagues at Bell Laboratories (the US telecommunication giant AT&T's research institute)[1]. Unix caught on rapidly especially at universities, because Bell Labs furnished source code and documentation at cost (due to an anti-trust decree, AT&T was barred from selling software). Unix was, at first, an operating system for Digital Equipment's PDP-11 line of minicomputers, but was ported to other platforms during the 1970s—a reasonably feasible endeavour, since the Unix software, including the operating system kernel, was mostly written in Dennis Ritchie's purpose-built **C** programming language. Possibly most important of all Unix ports was the one to the PDP-11's successor platform, the
C
VAX VAX, at the University of California in Berkeley, which came to be distributed as "BSD" (short for *Berkeley Software Distribution*). By and by, various computer manufacturers developed different Unix derivatives based either on AT&T code or on BSD (e. g., Sinix by Siemens, Xenix by Microsoft (!), SunOS by Sun Microsystems, HP/UX by Hewlett-Packard or AIX by IBM). Even AT&T was finally allowed to
System V market Unix—the commercial versions System III and (later) System V. This led to a fairly incomprehensible multitude of different Unix products. A real standardisation never happened, but it is possible to distinguish roughly between BSD-like and System-V-like Unix variants. The BSD and System V lines of development
SVR4 were mostly unified by "System V Release 4", which exhibited the characteristics of both factions.

The very first parts of Linux were developed in 1991 by Linus Torvalds, then a 21-year-old student in Helsinki, Finland, when he tried to fathom the capabilities of his new PC's Intel 386 processor. After a few months, the assembly language experiments had matured into a small but workable operating system ker-
Minix nel that could be used in a Minix system—Minix was a small Unix-like operating system that computer science professor Andrew S. Tanenbaum of the Free University of Amsterdam, the Netherlands, had written for his students. Early Linux had properties similar to a Unix system, but did not contain Unix source code. Linus Torvalds made the program's source code available on the Internet, and the

[1] The name "Unix" is a pun on "Multics", the operating system that Ken Thompson and his colleagues worked on previously. Early Unix was a lot simpler than Multics. How the name came to be spelled with an "x" is no longer known.

Figure 1.1: Ken Thompson (sitting) and Dennis Ritchie (standing) with a PDP-11, approx. 1972. (Photograph courtesy of Lucent Technologies.)

idea was eagerly taken up and developed further by many programmers. Version 0.12, issued in January, 1992, was already a stable operating system kernel. There was—thanks to Minix—the GNU C compiler (`gcc`), the `bash` shell, the `emacs` editor and many other GNU tools. The operating system was distributed world-wide by anonymous FTP. The number of programmers, testers and supporters grew very rapidly. This catalysed a rate of development only dreamed of by powerful software companies. Within months, the tiny kernel grew into a full-blown operating system with fairly complete (if simple) Unix functionality.

The "Linux" project is not finished even today. Linux is constantly updated and added to by hundreds of programmers throughout the world, catering to millions of satisfied private and commercial users. In fact it is inappropriate to say that the system is developed "only" by students and other amateurs—many contributors to the Linux kernel hold important posts in the computer industry and are among the most professionally reputable system developers anywhere. By now it is fair to claim that Linux is the operating system with the widest supported range of hardware ever, not just with respect to the platforms it is running on (from PDAs to mainframes) but also with respect to driver support on, e. g., the Intel PC platform. Linux also serves as a research and development platform for new operating systems ideas in academia and industry; it is without doubt one of the most innovative operating systems available today.

Exercises

1.1 [4] Use the Internet to locate the famous (notorious?) discussion between Andrew S. Tanenbaum and Linus Torvalds, in which Tanenbaum says that, with something like Linux, Linus Torvalds would have failed his (Tanenbaum's) operating systems course. What do you think of the controversy?

1.2 [2] Give the version number of the oldest version of the Linux source code that you can locate.

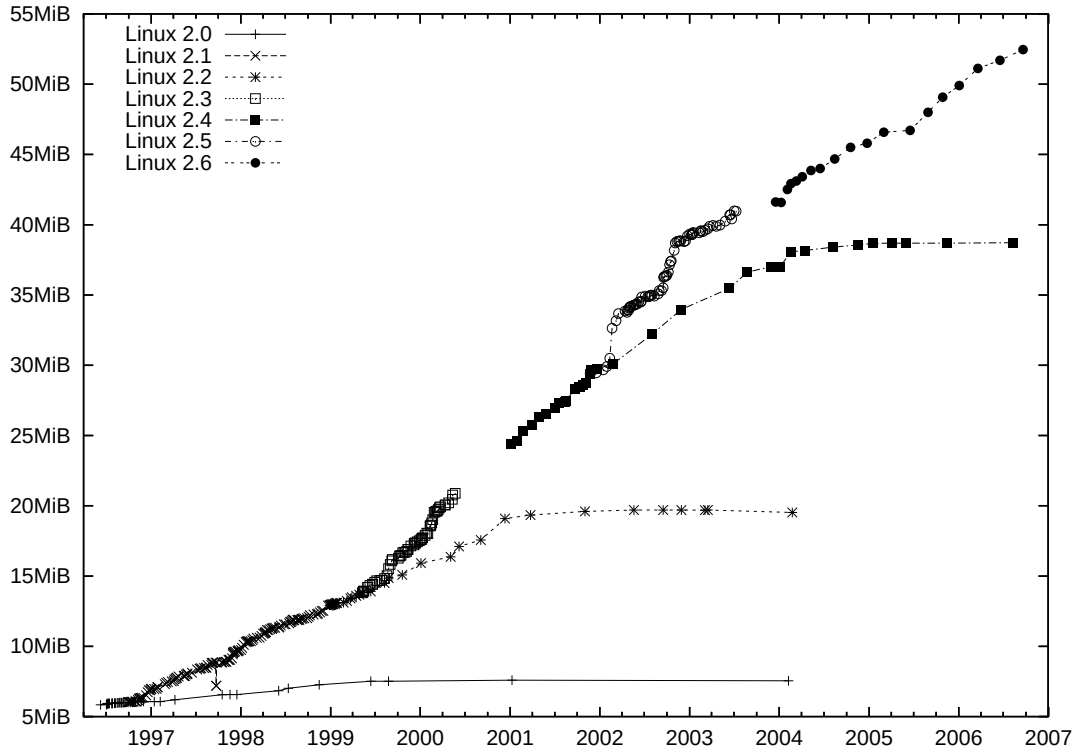


Figure 1.2: Linux development, measured by the size of `linux-*.tar.gz`. Each marker corresponds to a Linux version. During the 10 years between Linux 2.0 and Linux 2.6.18, the size of the compressed Linux source code has roughly increased tenfold.

1.3 Free Software, "Open Source" and the GPL

GPL
Free Software Foundation
Free Software
Open Source

From the very beginning of its development, Linux was placed under the *GNU General Public License* (**GPL**) promulgated by the *Free Software Foundation* (FSF). The FSF was founded by Richard M. Stallman, the author of the Emacs editor and other important programs, with the goal of making high-quality software "freely" available—in the sense that users are "free" to inspect it, to change it and to redistribute it with or without changes, not necessarily in the sense that it does not cost anything[2]. In particular, he was after a freely available Unix-like operating system, hence "GNU" as a (recursive) acronym for *"GNU's Not Unix"*. The main tenet of the GPL is that software distributed under it may be changed as well as sold at any time, but that the (possibly modified) source code must always be passed along—thus *Open Source*—and that the recipient must receive the same rights of modification and redistribution. Thus there is little point in selling GPL software "per seat", since the recipient must be allowed to copy and install the software as often as wanted. (It is of course permissible to sell support for the GPL software "per seat".) New software resulting from the extension or modification of GPL software must, as a "derived work", also be placed under the GPL.

Therefore, the GPL governs the distribution of software, not its use, and allows the recipient to do things that he would not be allowed to do otherwise—for example, the right to copy and distribute the software, which according to copyright law is the *a priori* prerogative of the copyright owner. Consequently, it differs markedly from the "end user license agreements" (EULAs) of "proprietary" software, whose owners try to *take away* a recipient's rights to do various things. (For example, some EULAs try to forbid a software recipient from talking critically—or

[2] The FSF says "free as in speech, not as in beer"

at all—about the product in public.)

The GPL is a *license*, not a contract, since it is a one-sided grant of rights to the recipient (albeit with certain conditions attached). The recipient of the software does not need to "accept" the GPL explicitly. The common EULAs, on the other hand, are *contracts*, since the recipient of the software is supposed to waive certain rights in exchange for being allowed to use the software. For this reason, EULAs must be explicitly accepted. The legal barriers for this may be quite high—in many jurisdictions (e. g., Germany), any EULA restrictions must be known to the buyer before the actual sale in order to become part of the sales contract. Since the GPL does not in any way restrict a buyer's rights (in particular as far as use of the software is concerned) compared to what they would have to expect when buying any other sort of goods, these barriers do not apply to the GPL; the additional rights that the buyer is conferred by the GPL are a kind of extra bonus.

Currently two versions of the GPL are in widespread use. The newer version 3 (also called "GPLv3") was published in July, 2007, and differs from the older version 2 (also "GPLv2") by more precise language dealing with areas such as software patents, the compatibility with other free licenses, and the introduction of restrictions on making changes to theoretically "free" devices impossible by excluding them through special hardware ("Tivoisation", after a Linux-based personal video recorder whose kernel is impossible to alter or exchange). In addition, GPLv3 allows its users to add further clauses. – Within the community, the GPLv3 was not embraced with unanimous enthusiasm, and many projects, in particular the Linux kernel, have intentionally stayed with the simpler GPLv2. Many other projects are made available under the GPLv2 "or any newer version", so you get to decide which version of the GPL you want to follow when distributing or modifying such software.

GPLv3

Neither should you confuse GPL software with "public-domain" software. The latter belongs to nobody, everybody can do with it what he wants. A GPL program's copyright still rests with its developer or developers, and the GPL states very clearly what one may do with the software and what one may not.

Public Domain

It is considered good form among free software developers to place contributions to a project under the same license that the project is already using, and in fact most projects insist on this, at least for code that is supposed to become part of the "official" version. Indeed, some projects insist on "copyright assignments", where the code author signs the copyright over to the project (or a suitable organisation). The advantage of this is that, legally, only the project is responsible for the code and that licensing violations—where only the copyright owner has legal standing—are easier to prosecute. A side effect that is either desired or else explicitly unwanted is that copyright assignment makes it easier to change the license for the complete project, as this is an act that only the copyright owner may perform.

In case of the Linux operating system kernel, which explicitly does not require copyright assignment, a licensing change is very difficult to impossible in practice, since the code is a patchwork of contributions from more than a thousand authors. The issue was discussed during the GPLv3 process, and there was general agreement that it would be a giant project to ascertain the copyright provenance of every single line of the Linux source code, and to get the authors to agree to a license change. In any case, some Linux developers would be violently opposed, while others are impossible to find or even deceased, and the code in question would have to be replaced by something similar with a clear copyright. At least Linus Torvalds is still in the GPLv2 camp, so the problem does not (yet) arise in practice.

GPL and Money

The GPL does not stipulate anything about the price of the product. It is utterly legal to give away copies of GPL programs, or to sell them for money, as long as you provide source code or make it available upon request, and the software recipient gets the GPL rights as well. Therefore, GPL software is not necessarily "freeware".

You can find out more by reading the GPL [GPL91], which incidentally must accompany every GPLlicensed product (including Linux).

Other "free" licenses

There are other "free" software licenses which give similar rights to the software recipient, for example the "BSD license" which lets appropriately licensed software be included in non-free products. The GPL is considered the most thorough of the free licenses in the sense that it tries to ensure that code, once published under the GPL, *remains* free. Every so often, companies have tried to include GPL code in their own non-free products. However, after being admonished by (usually) the FSF as the copyright holder, these companies have always complied with the GPL's requirements. In various jurisdictions the GPL has been validated in courts of law—for example, in the Frankfurt (Germany) *Landgericht* (state court), a Linux kernel developer obtained a judgement against D-Link (a manufacturer of network components, in this case a Linux-based NAS device) in which the latter was sued for damages because they did not adhere to the GPL conditions when distributing the device [GPL-Urteil06].

Why does the GPL work? Some companies that thought the GPL conditions onerous have tried to declare or have it declared it invalid. For example, it was called "un-American" or "unconstitutional" in the United States; in Germany, anti-trust law was used in an attempt to prove that the GPL amounts to price fixing. The general idea seems to be that GPL-ed software can be used by anybody if something is demonstrably wrong with the GPL. All these attacks ignore one fact: Without the GPL, nobody except the original author has the right to do *anything* with the code, since actions like sharing (let alone selling) the code are the author's prerogative. So if the GPL goes away, all other interested parties are worse off than they were.

A lawsuit where a software author sues a company that distributes his GPL code without complying with the GPL would approximately look like this:

Judge What seems to be the problem?

Software Author Your Lordship, the defendant has distributed my software without a license.

Judge (to the defendant's counsel) Is that so?

At this point the defendant can say "yes", and the lawsuit is essentially over (except for the verdict). They can also say "no" but then it is up to them to justify why copyright law does not apply to them. This is an uncomfortable dilemma and the reason why few companies actually do this to themselves—most GPL disagreements are settled out of court.

If a manufacturer of proprietary software violates the GPL (e. g., by including a few hundreds of lines of source code from a GPL project in their product), this does not imply that all of that product's code must now be released under the terms of the GPL. It only implies that they have distributed GPL code without a license. The manufacturer can solve this problem in various ways:

- They can remove the GPL code and replace it by their own code. The GPL then becomes irrelevant for their software.
- They can negotiate with the GPL code's copyright holder (if he is available and willing to go along) and, for instance, agree to pay a license fee. See also the section on multiple licenses below.
- They can release their entire program under the GPL *voluntarily* and thereby comply with the GPL's conditions (the most unlikely method).

Independently of this there may be damages payable for the prior violations. The copyright status of the proprietary software, however, is not affected in any way.

Freedom criteria
Debian Free Software Guidelines

When is a software package considered "free" or "open source"? There are no definite criteria, but a widely-accepted set of rules are the *Debian Free Software Guidelines* [DFSG]. The FSF summarizes its criteria as the *Four Freedoms* which must hold for a free software package:

- The freedom to use the software for any purpose (freedom 0)
- The freedom to study how the software works, and to adapt it to one's requirements (freedom 1)
- The freedom to pass the software on to others, in order to help one's neighbours (freedom 2)
- The freedom to improve the software and publish the improvements, in order to benefit the general public (freedom 3)

Access to the source code is a prerequisite for freedoms 1 and 3. Of course, common free-software licenses such as the GPL or the BSD license conform to these freedoms.

Multiple licenses

In addition, the owner of a software package is free to distribute it under different licenses at the same time, e.g., the GPL and, alternatively, a "commercial" license that frees the recipient from the GPL restrictions such as the duty to make available the source code for modifications. This way, private users and free software authors can enjoy the use of a powerful programming library such as the "Qt" graphics package (published by Qt Software—formerly Troll Tech—, a Nokia subsidiary), while companies that do not want to make their own source code available may "buy themselves freedom" from the GPL.

Exercises

1.3 [!2] Which of the following statements concerning the GPL are true and which are false?

1. GPL software may not be sold.
2. GPL software may not be modified by companies in order to base their own products on it.
3. The owner of a GPL software package may distribute the program under a different license as well.
4. The GPL is invalid, because one sees the license only after having obtained the software package in question. For a license to be valid, one must be able to inspect it and accept it before acquiring the software.

1.4 [4] Some software licenses require that when a file from a software distribution is changed, it must be renamed. Is software distributed under such a license considered "free" according to the DFSG? Do you think this practice makes sense?

1.4 Linux—The Kernel

Strictly speaking, the name "Linux" only applies to the operating system "kernel", which performs the actual operating system tasks. It takes care of elementary functions like memory and process management and hardware control. Application programs must call upon the kernel to, e.g., access files on disk. The kernel validates such requests and in doing so can enforce that nobody gets to access

other users' private files. In addition, the kernel ensures that all processes in the system (and hence all users) get the appropriate fraction of the available CPU time.

Versions

Of course there is not just one Linux kernel, but there are many different versions. Until kernel version 2.6, we distinguished stable "end-user versions" and unstable "developer versions" as follows:

stable version

- In version numbers such as 1.*x*.*y* or 2.*x*.*y*, *x* denotes a stable version if it is even. There should be no radical changes in stable versions; mistakes should be corrected, and every so often drivers for new hardware components or other very important improvements are added or "back-ported" from the development kernels.

development version

- Versions with odd *x* are development versions which are unsuitable for productive use. They may contain inadequately tested code and are mostly meant for people wanting to take active part in Linux development. Since Linux is constantly being improved, there is a constant stream of new kernel versions. Changes concern mostly adaptations to new hardware or the optimization of various subsystems, sometimes even completely new extensions.

kernel 2.6

The procedure has changed in kernel 2.6: Instead of starting version 2.7 for new development after a brief stabilisation phase, Linus Torvalds and the other kernel developers decided to keep Linux development closer to the stable versions. This is supposed to avoid the divergence of developer and stable versions that grew to be an enormous problem in the run-up to Linux 2.6—most notably because corporations like SUSE and Red Hat took great pains to backport interesting properties of the developer version 2.5 to their versions of the 2.4 kernel, to an extent where, for example, a SUSE 2.4.19 kernel contained many hundreds of differences to the "vanilla" 2.4.19 kernel.

The current procedure consists of "test-driving" proposed changes and enhancements in a new kernel version which is then declared "stable" in a shorter timeframe. For example, after version 2.6.37 there is a development phase during which Linus Torvalds accepts enhancements and changes for the 2.6.38 version. Other kernel developers (or whoever else fancies it) have access to Linus' internal development version, which, once it looks reasonable enough, is made available as the "release candidate" 2.6.38-rc1. This starts the stabilisation phase, where this release candidate is tested by more people until it looks stable enough to be declared the new version 2.6.38 by Linus Torvalds. Then follows the 2.6.39 development phase and so on.

release candidate

In parallel to Linus Torvalds' "official" version, Andrew Morton maintains a more experimental version, the so-called "`-mm` tree". This is used to test larger and more sweeping changes until they are mature enough to be taken into the official kernel by Linus.

`-mm` tree

Some other developers maintain the "stable" kernels. As such, there might be kernels numbered 2.6.38.1, 2.6.38.2, …, which each contain only small and straightforward changes such as fixes for grave bugs and security issues. This gives Linux distributors the opportunity to rely on kernel versions maintained for longer periods of time.

version 3.0

On 21 July 2011, Linus Torvalds officially released version 3.0 of the Linux kernel. This was really supposed to be version 2.6.40, but he wanted to simplify the version numbering scheme. "Stable" kernels based on 3.0 are accordingly numbered 3.0.1, 3.0.2, …, and the next kernels in Linus' development series are 3.1-rc1, etc. leading up to 3.1 and so forth.

Linus Torvalds insists that there was no big difference in functionality between the 2.6.39 and 3.0 kernels—at least not more so than between any two other consecutive kernels in the 2.6 series—, but that there was just a renumbering. The idea of Linux's 20th anniversary was put forward.

You can obtain source code for "official" kernels on the Internet from `ftp.kernel.org`. However, only very few Linux distributors use the original kernel sources. Distribution kernels are usually modified more or less extensively, e. g., by integrating additional drivers or features that are desired by the distribution but not part of the standard kernel. The Linux kernel used in SUSE's *Linux Enterprise Server 8*, for example, reputedly contained approximately 800 modifications to the "vanilla" kernel source. (The changes to the Linux development process have succeeded to an extent where the difference is not as great today.)

Kernel structure

Today most kernels are *modular*. This was not always the case; former kernels consisted of a single piece of code fulfilling all necessary functions such as the support of particular devices. If you wanted to add new hardware or make use of a different feature like a new type of file system, you had to compile a new kernel from sources—a very time-consuming process. To avoid this, the kernel was endowed with the ability to integrate additional features by way of modules.

Modules

Modules are pieces of code that can be added to the kernel dynamically (at runtime) as well as removed. Today, if you want to use a new network adapter, you do not have to compile a new kernel but merely need to load a new kernel module.

hardware recognition

Modern Linux distributions support automatic hardware recognition, which can analyze a system's properties and locate and configure the correct driver modules.

Exercises

1.5 [1] What is the version number of the current stable Linux kernel? The current developer kernel? Which Linux kernel versions are still being supported?

1.5 Linux Properties

As a modern operating system kernel, Linux has a number of properties, some of which are part of the "state of the art" (i. e., exhibited by similar systems in an equivalent form) and some of which are unique to Linux.

- Linux supports a large selection of processors and computer architectures, ranging from mobile phones (the very successful "Android" operating system by Google, like some other similar systems, is based on Linux) through PDAs and tablets, all sorts of new and old PC-like computers and server systems of various kinds up to the largest mainframe computers (the vast majority of the machines on the list of the fastest computers in the world is running Linux).

  processors

  A huge advantage of Linux in the mobile arena is that, unlike Microsoft Windows, it supports the energy-efficient and powerful ARM processors that most mobile devices are based upon. In 2012, Microsoft released an ARM-based, partially Intel-compatible, version of Windows 8 under the name of "Windows RT", but that did not exactly prove popular in the market.

- Of all currently available operating systems, Linux supports the broadest selection of hardware. For the very newest components there may not be drivers available immediately, but on the other hand Linux still works with devices that systems like Windows have long since left behind. Thus, your investments in printers, scanners, graphic boards, etc. are protected optimally.

  hardware

- Linux supports "preemptive multitasking", that is, several processes are running—virtually or, on systems with more than one CPU, even actually—in parallel. These processes cannot obstruct or damage one another; the kernel ensures that every process is allotted CPU time according to its priority.

  multitasking


This is nothing special today; when Linux was new, this was much more remarkable.

On carefully configured systems this may approach real-time behaviour, and in fact there are Linux variants that are being used to control industrial plants requiring "hard" real-time ability, as in guaranteed (quick) response times to external events.

several users
- Linux supports several users on the same system, even at the same time (via the network or serially connected terminals, or even several screens, keyboards, and mice connected to the same computer). Different access permissions may be assigned to each user.

virtualisation
- Linux can effortlessly be installed alongside other operating systems on the same computer, so you can alternately start Linux or another system. By means of "virtualisation", a Linux system can be split into independent parts that look like separate computers from the outside and can run Linux or other operating systems. Various free or proprietary solutions are available that enable this.

efficiency
- Linux uses the available hardware efficiently. The dual-core CPUs common today are as fully utilised as the 4096 CPU cores of a SGI Altix server. Linux does not leave working memory (RAM) unused, but uses it to cache data from disk; conversely, available working memory is used reasonably in order to cope with workloads that are much larger than the amount of RAM inside the computer.

POSIX, System V and BSD
- Linux is source-code compatible with POSIX, System V and BSD and hence allows the use of nearly all Unix software available in source form.

file systems
- Linux not only offers powerful "native" file systems with properties such as journaling, encryption, and logical volume management, but also allows access to the file systems of various other operating systems (such as the Microsoft Windows FAT, VFAT, and NTFS file systems), either on local disks or across the network on remote servers. Linux itself can be used as a file server in Linux, Unix, or Windows networks.

TCP/IP
- The Linux TCP/IP stack is arguably among the most powerful in the industry (which is due to the fact that a large fraction of R&D in this area is done based on Linux). It supports IPv4 and IPv6 and all important options and protocols.

graphical environments
- Linux offers powerful and elegant graphical environments for daily work and, in X11, a very popular network-transparent base graphics system. Accelerated 3D graphics is supported on most popular graphics cards.

productivity applications
- All important productivity applications are available—office-type programs, web browsers, programs to access electronic mail and other communication media, multimedia tools, development environments for a diverse selection of programming languages, and so on. Most of this software comes with the system at no cost or can be obtained effortlessly and cheaply over the Internet. The same applies to servers for all important Internet protocols as well as entertaining games.

embedded systems
The flexibility of Linux not only makes it possible to deploy the system on all sorts of PC-class computers (even "old chestnuts" that do not support current Windows can serve well in the kids' room, as a file server, router, or mail server), but also helps it make inroads in the "embedded systems" market, meaning complete appliances for network infrastructure or entertainment electronics. You will, for example, find Linux in the popular AVM FRITZ!Box and similar WLAN, DSL or telephony devices, in various set-top boxes for digital television, in PVRs, digital cameras, copiers, and many other devices. Your author has seen the bottle bank

in the neighbourhood supermarket boot Linux. This is very often not trumpeted all over the place, but, in addition to the power and convenience of Linux itself the manufacturers appreciate the fact that, unlike comparable operating systems, Linux does not require licensing fees "per unit sold".

Another advantage of Linux and free software is the way the community deals with security issues. In practice, security issues are as unavoidable in free software as they are in proprietary code—at least nobody so far has written and published a software system of interesting size that proved completely free of them in the long run. In particular, it would be improper to claim that free software has no security issues. The differences are more likely to be found on a philosophical level:

security issues

- As a rule, a vendor of proprietary software has no interest in fixing security issues in their code—they will try to cover up problems and to talk down possible dangers for as long as they possibly can, since constantly publishing "patches" means, in the best case, terrible PR ("where there is smoke, there must be a fire"; the competition, which just happens not to be in the spotlight of scrutiny at the moment, is having a secret laugh), and, in the worst case, great expense and lots of hassle if exploits are around that make active use of the security holes. Besides, there is the usual danger of introducing three new errors while fixing one known one, which is why fixing bugs in released software is normally not an econonomically viable proposition.
- A free-software publisher does not gain anything by sitting on information about security issues, since the source code is generally available, and everybody can find the problems. It is, in fact, a matter of pride to fix known security issues as quickly as possible. The fact that the source code is publically available also implies that third parties find it easy to audit code for problems that can be repaired proactively. (A common claim is that the availability of source code exerts a very strong attraction on crackers and other unsavoury vermin. In fact, these low-lifes do not appear to have major difficulties identifying large numbers of security issues in proprietary systems such as Windows, whose source code is *not* generally available. Thus any difference, if it exists, must be minute indeed.)
- Especially as far as software dealing with cryptography (the encryption and decryption of confidential information) is concerned, there is a strong argument that availability of source code is an indispensable prerequisite for trust that a program really does what it is supposed to do, i. e., that the claimed encryption algorithm has been implemented completely and correctly. Linux does have an obvious advantage here.

Linux is used throughout the world by private and professional users—companies, research establishments, universities. It plays an important role particularly as a system for web servers (Apache), mail servers (Sendmail, Postfix), file servers (NFS, Samba), print servers (LPD, CUPS), ISDN routers, X terminals, scientific/engineering workstations etc. Linux is an essential part of industrial IT departments. Widespread adoption of Linux in public administration, such as the city of Munich, also serves as a signal. In addition, many reputable IT companies such as IBM, Hewlett-Packard, Dell, Oracle, Sybase, Informix, SAP, Lotus etc. are adapting their products to Linux or selling Linux versions already. Furthermore, ever more computers ("netbooks")— come with Linux or are at least tested for Linux compability by their vendors.

Linux in companies

Public administration

Support by IT companies

Exercises

1.6 [4] Imagine you are responsible for IT in a small company (20–30 employees). In the office there are approximately 20 desktop PCs and two servers (a file and printer server and a mail and Web proxy server). So far everything runs on Windows. Consider the following scenarios:

- The file and printer server is replaced by a Linux server using Samba (a Linux/Unix-based server for Windows clients).
- The mail and proxy server is replaced by a Linux server.
- The twenty office desktop PCs are replaced by Linux machines.

Comment on the different scenarios and draw up short lists of their advantages and disadvantages.

1.6 Linux Distributions

Distributions

Linux in the proper sense of the word only consists of the operating system kernel. To accomplish useful work, a multitude of system and application programs, libraries, documentation etc. is necessary. "Distributions" are nothing but up-to-date selections of these together with special programs (usually tools for installation and maintenance) provided by companies or other organisations, possibly together with other services such as support, documentation, or updates. Distributions differ mostly in the selection of software they offer, their administration tools, extra services, and price.

Red Hat and Fedora

"Fedora" is a freely available Linux distribution developed under the guidance of the US-based company, Red Hat. It is the successor of the "Red Hat Linux" distribution; Red Hat has withdrawn from the private end-user market and aims their "Red Hat" branded distributions at corporate customers. Red Hat was founded in 1993 and became a publically-traded corporation in August, 1999; the first Red Hat Linux was issued in 1994, the last (version 9) in late April, 2004. "Red Hat Enterprise Linux" (RHEL), the current product, appeared for the first time in March, 2002. Fedora, as mentioned, is a freely available offering and serves as a development platform for RHEL; it is, in effect, the successor of Red Hat Linux. Red Hat only makes Fedora available for download; while Red Hat Linux was sold as a "boxed set" with CDs and manuals, Red Hat now leaves this to third-party vendors.

SUSE

The SUSE company was founded 1992 under the name "Gesellschaft für Software und Systementwicklung" as a Unix consultancy and accordingly abbreviated itself as "S.u.S.E." One of its products was a version of Patrick Volkerding's Linux distribution, Slackware, that was adapted to the German market. (Slackware, in turn, derived from the first complete Linux distribution, "Softlanding Linux System" or SLS.) S.u.S.E. Linux 1.0 came out in 1994 and slowly differentiated from Slackware, for example by taking on Red Hat features such as the RPM package manager or the `/etc/ sysconfig` file. The first version of S.u.S.E. Linux that no longer looked like Slackware was version 4.2 of 1996. SuSE (the dots were dropped at some point) soon gained market leadership in German-speaking Europe and published SuSE Linux in a "box" in two flavours, "Personal" and "Professional"; the latter was markedly more expensive and contained more server software. Like Red Hat, SuSE offered an enterprise-grade Linux distribution called "SuSE Linux Enterprise Server" (SLES), with some derivatives like a specialised server for mail and groupware ("SuSE Linux OpenExchange Server" or SLOX). In addition, SuSE endeavoured to make their distribution available on IBM's mid-range and mainframe computers.

Novell takeover

In November 2003, the US software company Novell announced their intention of taking over SuSE for 210 million dollars; the deal was concluded in January 2004. (The "U" went uppercase on that occasion). Like Red Hat, SUSE has by now taken the step to open the "private customer" distribution and make it freely available as "openSUSE" (earlier versions appeared for public download only after a delay of several months). Unlike Red Hat,

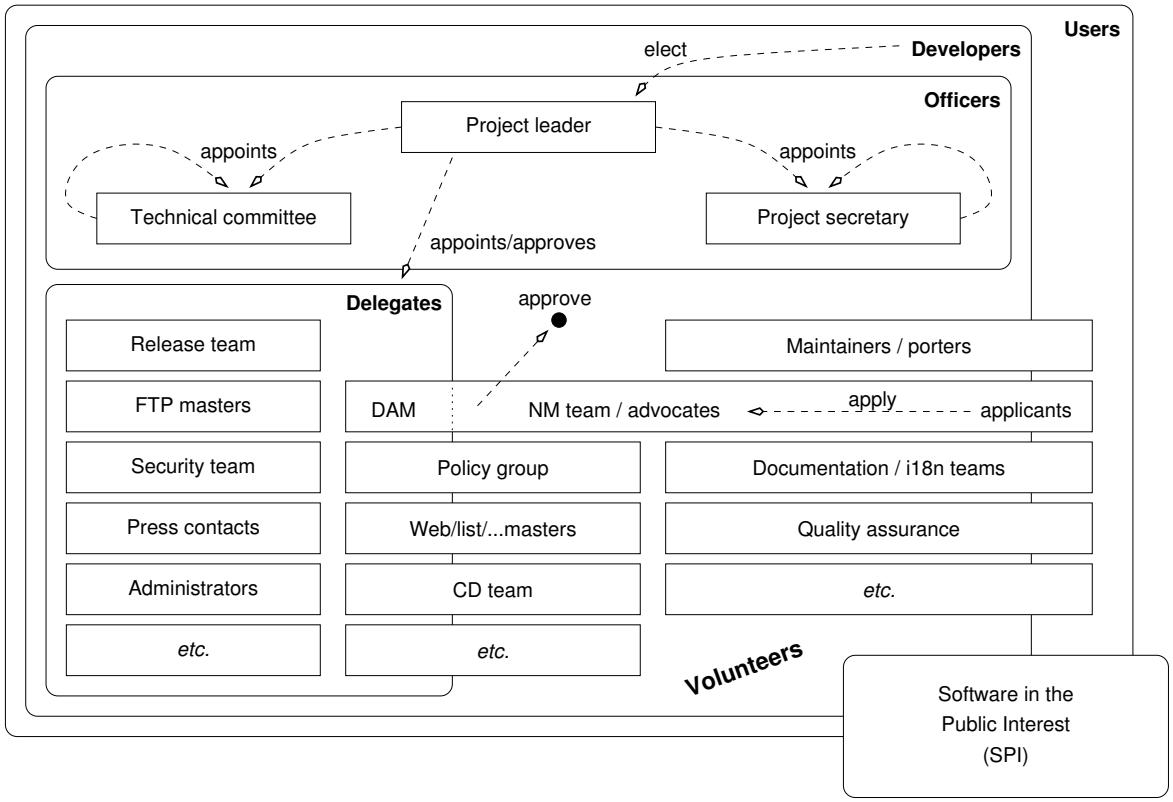


Figure 1.3: Organizational structure of the Debian project. (Graphic by Martin F. Krafft.)

Novell/SUSE still offers a "boxed" version containing additional proprietary software. Among others, SUSE still sells SLES and a corporate desktop platform called "SUSE Linux Enterprise Desktop" (SLED).

Attachmate
Micro Focus

In early 2011, Novell was acquired by Attachmate, which in turn was taken over by Micro Focus in 2014. Both are companies whose main field of business is traditional mainframe computers and which so far haven not distinguished themselves in the Linux and open-source arena. These maneuverings, however, have had fairly little influence on SUSE and its products.

YaST

A particular property of SUSE distributions is "YaST", a comprehensive graphical administration tool.

Debian project

Unlike the two big Linux distribution companies Red Hat and Novell/SUSE, the **Debian project** is a collaboration of volunteers whose goal is to make available a high-quality Linux distribution called "Debian GNU/Linux". The Debian project was announced on 16 August 1993 by Ian Murdock; the name is a contraction of his first name with that of his then-girlfriend (now ex-wife) Debra (and is hence pronounced "debb-ian"). By now the project includes more than 1000 volunteers.

Debian is based on three documents:

- The *Debian Free Software Guidelines* (DFSG) define which software the project considers "free". This is important, since only DFSG-free software can be part of the Debian GNU/Linux distribution proper. The project also distributes non-free software, which is strictly separated from the DFSG-free software on the distribution's servers: The latter is in subdirectory called `main`, the former in `non-free`. (There is an intermediate area called `contrib`; this contains software that by itself would be DFSG-free but does not work without other, non-free, components.)

- The *Social Contract* describes the project's goals.
- The *Debian Constitution* describes the project's organisation.

versions

At any given time there are at least three versions of Debian GNU/Linux: New or corrected versions of packages are put into the `unstable` branch. If, for a certain period of time, no grave errors have appeared in a package, it is copied to the `testing` branch. Every so often the content of `testing` is "frozen", tested very thoroughly, and finally released as `stable`. A frequently-voiced criticism of Debian GNU/Linux is the long timespan between `stable` releases; many, however, consider this an advantage. The Debian project makes Debian GNU/Linux available for download only; media are available from third-party vendors.

derivative projects

By virtue of its organisation, its freedom from commercial interests, and its clean separation between free and non-free software, Debian GNU/Linux is a sound basis for derivative projects. Some of the more popular ones include Knoppix (a "live CD" which makes it possible to test Linux on a PC without having to install it first), SkoleLinux (a version of Linux especially adapted to the requirements of schools), or commercial distributions such as Xandros. Limux, the desktop Linux variant used in the Munich city administration, is also based on Debian GNU/Linux.

Ubuntu

goal

One of the most popular Debian derivatives is Ubuntu, which is offered by the British company, Canonical Ltd., founded by the South African entrepreneur Mark Shuttleworth. ("Ubuntu" is a word from the Zulu language and roughly means "humanity towards others".) The goal of Ubuntu is to offer, based on Debian GNU/Linux, a current, capable, and easy-to-understand Linux which is updated at regular intervals. This is facilitated, for example, by Ubuntu being offered on only three computer architectures as opposed to Debian's ten, and by restricting itself to a subset of the software offered by Debian GNU/Linux. Ubuntu is based on the `unstable` branch of Debian GNU/Linux and uses, for the most part, the same tools for software distribution, but Debian and Ubuntu software packages are not necessarily mutually compatible.

Ubuntu vs. Debian

Some Ubuntu developers are also active participants in the Debian project, which ensures a certain degree of exchange. On the other hand, not all Debian developers are enthusiastic about the shortcuts Ubuntu takes every so often in the interest of pragmatism, where Debian might look for more comprehensive solutions even if these require more effort. In addition, Ubuntu does not appear to feel as indebted to the idea of free software as does Debian; while all of Debian's infrastructure tools (such as the bug management system) are available as free software, this is not always the case for those of Ubuntu.

Ubuntu vs. SUSE/Red Hat

Ubuntu not only wants to offer an attractive desktop system, but also take on the more established systems like RHEL or SLES in the server space, by offering stable distributions with a long life cycle and good support. It is unclear how Canonical Ltd. intends to make money in the long run; for the time being the project is mostly supported out of Mark Shuttleworth's private coffers, which are fairly well-filled since he sold his Internet certificate authority, Thawte, to Verisign …

More distributions

In addition to these distributions there are many more, such as Mageia or Linux Mint as smaller "generally useful" distributions, various "live systems" for different uses from firewalls to gaming or multimedia platforms, or very compact systems usable as routers, firewalls, or rescue systems.

Commonalities

Even though there is a vast number of distributions, most look fairly similar in daily life. This is due, on the one hand, to the fact that they use the same basic programs—for example, the command line interpreter is nearly always `bash`. On

the other hand, there are standards that try to counter rank growth. The "Filesystem Hierarchy Standard" (FHS) or "Linux Standard Base" (LSB) must be mentioned.

Exercises

1.7 [2] Some Linux hardware platforms have been enumerated above. For which of those platforms are there actual Linux distributions available? (Hint: `http://www.distrowatch.org/`)

Summary

- Linux is a Unix-like operating system.
- The first version of Linux was developed by Linus Torvalds and made available on the Internet as "free software". Today, hundreds of developers all over the world contribute to updating and extending the system.
- The GPL is the best-known "free software" license. It tries to ensure that the recipients of software can modify and redistribute the package, and that these "freedoms" are passed on to future recipients. GPL software may also be sold.
- To the user, "open source" means approximately the same as "free software".
- There are other free licenses besides the GPL. Software may also be distributed by the copyright owner under several licenses at the same time.
- Linux is actually just the operating system kernel. We distinguish "stable" and "development kernels"; with the former, the second part of the version number is even and with the latter, odd. Stable kernels are meant for end users, while development kernels are not necessarily functional, representing interim versions of Linux development.
- There are numerous Linux distributions bringing together a Linux kernel and additional software, documentation and installation and administration tools.

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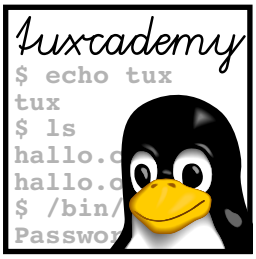


2

Using the Linux System

Contents

Goals

- Logging on and off the system
- Understanding the difference between normal user accounts and the system administrator's account

Prerequisites

- Basic knowledge of using computers is helpful

Figure 2.1: The login screens of some common Linux distributions

2.1 Logging In and Out

The Linux system distinguishes between different users. Consequently, it may be impossible to start working right after the computer has been switched on. First you have to tell the computer who you are—you need to "log in" (or "on"). Based on the information you provide, the system can decide what you may do (or may not do). Of course you need access rights to the system (an "account") – the system administrator must have entered you as a valid user and assigned you a user name (e. g., `joe`) and a password (e. g., `secret`). The password is supposed to ensure that only you can use your account; you must keep it secret and should not make it known to anybody else. Whoever knows your user name and password can pretend to be you on the system, read (or delete) all your files, send electronic mail in your name and generally get up to all kinds of shenanigans.

access rights

Modern Linux distributions want to make it easy on you and allow you to skip the login process on a computer that only you will be using anyway. If you use such a system, you will not have to log in explicitly, but the computer boots straight into your session. You should of course take advantage of this only if you do not foresee that third parties have access to your computer; refrain from this in particular on laptop computers or other mobile systems that tend to get lost or stolen.

Logging in in a graphical enviroment These days it is common for Linux workstations to present a graphical environment (as they should), and the login process takes place in a graphical environment as well. Your computer shows a dialog

that lets you enter your user name and password (Figure 2.1 shows some representative examples.)

Don't wonder if you only see asterisks when you're entering your password. This does not mean that your computer misunderstands your input, but that it wants to make life more difficult for people who are watching you over your shoulder in order to find out your password.

After you have logged in, the computer starts a graphical session for you, in which you have convenient access to your application programs by means of menus and icons (small pictures on the "desktop" background). Most graphical environments for Linux support "session management" in order to restore your session the way it was when you finished it the time before (as far as possible, anyway). That way you do not need to remember which programs you were running, where their windows were placed on the screen, and which files you had been using.

Logging out in a graphical environment If you are done with your work or want to free the computer for another user, you need to log out. This is also important because the session manager needs to save your current session for the next time. How logging out works in detail depends on your graphical environment, but as a rule there is a menu item somewhere that does everything for you. If in doubt, consult the documentation or ask your system administrator (or knowledgeable buddy).

Logging in on a text console Unlike workstations, server systems often support only a text console or are installed in draughty, noisy machine halls, where you don't want to spend more time than absolutely necessary. So you will prefer to log into such a computer via the network. In both cases you will not see a graphical login screen, but the computer asks you for your user name and password directly. For example, you might simply see something like

```
computer login: _
```

(if we stipulate that the computer in question is called "`computer`"). Here you must enter your user name and finish it off with the ↩ key. The computer will continue by asking you for your password:

```
Password: _
```

Enter your password here. (This time you won't even see asterisks—simply nothing at all.) If both the user name and password were correct, the system will accept your login. It starts the command line interpreter (the *shell*), and you can enter commands and invoke programs. After logging in you will be placed in your "home directory", where you will be able to find your files.

If you use the "secure shell", for example, to log in to another machine over the network, the user name question is usually skipped, since unless you specify otherwise the system will assume that your user name on the remote computer will be the same as on the computer you are initiating the session from. The details are beyond the scope of this manual; the secure shell is discussed in detail in the Linup Front training manual *Linux Administration II*.

Logging out on a text console On the text console, you can log out using, for example, the `logout` command:

```
$ logout
```

Once you have logged out, on a text console the system once more displays the start message and a login prompt for the next user. With a secure shell session, you simply get another command prompt from your local computer.

Exercises

2.1 [!1] Try logging in to the system. After that, log out again. (You will find a user name and password in your system documentation, or—in a training centre—your instructor will tell you what to use.)

2.2 [!2] What happens if you give (a) a non-existing user name, (b) a wrong password? Do you notice anything unusual? What reasons could there be for the system to behave as it does?

2.2 Switching On and Off

A Linux computer can usually be switched on by whoever is able to reach the switch (local policy may vary). On the other hand, you should not switch off a Linux machine on a whim—there might be data left in main memory that really belong on disk and will be lost, or—which would be worse—the data on the hard disk could get completely addled. Besides, other users might be logged in to the machine via the network, be surprised by the sudden shutdown, and lose valuable work. For this reason, important computers are usually only "shut down" by the system administrator. Single-user workstations, though, can usually be shut down cleanly via the graphical desktop; depending on the system's settings normal user privileges may suffice, or you may have to enter the administrator's password.

Exercises

2.3 [2] Check whether you can shut down your system cleanly as a normal (non-administrator) user, and if so, try it.

2.3 The System Administrator

As a normal user, your privileges on the system are limited. For example, you may not write to certain files (most files, actually—mostly those that do not belong to you) and not even read some files (e. g., the file containing the encrypted passwords of all users). However, there is a user account for system administration which is not subject to these restrictions—the user "`root`" may read and write all files, and do various other things normal users aren't entitled to. Having administrator (or "root") rights is a privilege as well as a danger—therefore you should only log on to the system as `root` if you actually want to exercise these rights, not just to read your mail or surf the Internet.

Simply pretend you are Spider-Man: "With great power comes great responsibility". Even Spider-Man wears his Spandex suit only if he must …

GUI as `root`: risky

In particular, you should avoid logging in as `root` via the graphical user interface, since all of the GUI will run with `root`'s privileges. This is a possible security risk—GUIs like KDE contain lots of code which is not vetted as thoroughly for security holes as the textual shell (which is, by comparison, relatively compact).

Assuming `root`'s identity

Normally you can use the command "`/bin/su -`" to assume `root`'s identity (and thus `root`'s privileges). `su` asks for `root`'s password and then starts a new shell, which lets you work as if you had logged in as `root` directly. You can leave the shell again using the `exit` command.

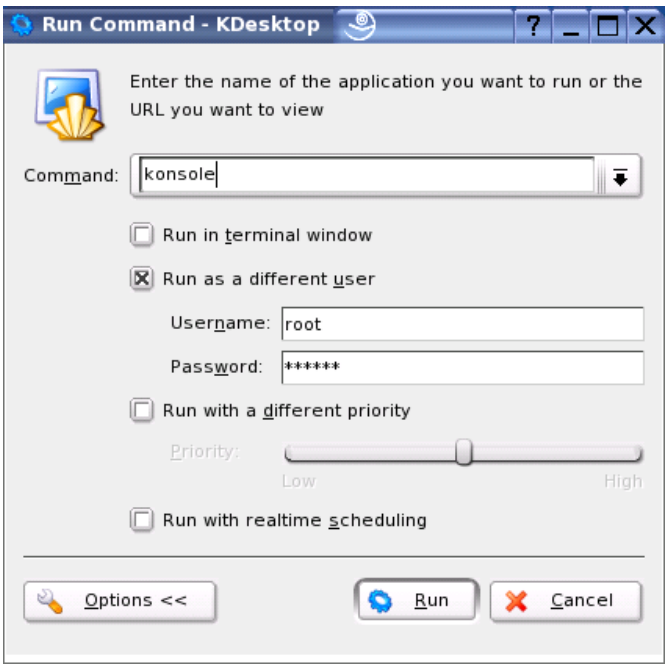


Figure 2.2: Running programs as a different user in KDE

You should get used to invoking `su` via its full path name—"`/bin/su -`". Otherwise, a user could trick you by calling you to her computer, getting you to enter "`su`" in one of her windows and to input the `root` password. What you don't realize at that moment is that the clever user wrote her own "Trojan" `su` command—which doesn't do anything except write the password to a file, output the "wrong password" error message and remove itself. When you try again (gritting your teeth) you get the correct `su`—and your user possesses the coveted administrator's privileges …

`root`'s shell prompt

You can usually tell that you actually have administrator privileges by looking at the shell prompt—for `root`, it customarily ends with the "`#`" character. (For normal users, the shell prompt usually ends in "`$`" or "`>`").

In Ubuntu you can't even log in as `root` by default. Instead, the system allows the first user created during installation to execute commands with administrator privileges by prefixing them with the `sudo` command. With

```
$ sudo chown joe file.txt
```

for example, he could sign over the `file.txt` file to user `joe` – an operation that is restricted to the system administrator.

Recent versions of Debian GNU/Linux offer a similar arrangement to Ubuntu.

`root` and KDE

Incidentally, with the KDE GUI, it is very easy to start arbitrary programs as `root`: Select "Run command" from the "KDE" menu (usually the entry at the very left of the command panel—the "Start" menu on Windows systems), and enter a command in the dialog window. Before executing the command, click on the "Settings" button; an area with additional settings appears, where you can check "As different user" (`root` is helpfully set up as the default value). You just have to enter the `root` password at the bottom (Figure 2.2).

kdesu

Alternatively, you can put "kdesu" in front of the actual command in the dialog window (or indeed any shell command line in a KDE session). This will ask you for root's password before starting the command with administrator privileges.

Exercises

2.4 [!1] Use the su command to gain administrator privileges, and change back to your normal account.

2.5 [5] (For programmers.) Write a convincing "Trojan" su program. Use it to try and fool your system administrator.

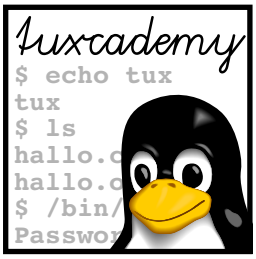
2.6 [2] Try to run the id program as root in a terminal session under KDE, using "Run command …". Check the appropriate box in the extended settings to do so.

Commands in this Chapter

exit	Quits a shell	bash(1)	34
kdesu	Starts a program as a different user on KDE	KDE: help:/kdesu	35
logout	Terminates a shell session	bash(1)	33
su	Starts a shell using a different user's identity	su(1)	34
sudo	Allows normal users to execute certain commands with administrator privileges	sudo(8)	35

Summary

- Before using a Linux system, you have to log in giving your user name and password. After using the system, you have to log out again.
- Normal access rights do not apply to user root, who may do (essentially) everything. These privileges should be used as sparingly as possible.
- You should not log in to the GUI as root but use (e. g.) su to assume administrator privileges if necessary.



3

Who's Afraid Of The Big Bad Shell?

Contents

Goals

- Appreciating the advantages of a command-line user interface
- Knowing about common Linux shells
- Working with Bourne-Again Shell (Bash) commands
- Understanding the structure of Linux commands

Prerequisites

- Basic knowledge of using computers is helpful

3.1 Why?

More so than other modern operating systems, Linux (like Unix) is based on the idea of entering textual commands via the keyboard. This may sound antediluvial to some, especially if one is used to systems like Windows, who have been trying for 15 years or so to brainwash their audience into thinking that graphical user interfaces are the be-all and end-all. For many people who come to Linux from Windows, the comparative prominence of the command line interface is at first a "culture shock" like that suffered by a 21-century person if they suddenly got transported to King Arthur's court – no cellular coverage, bad table manners, and dreadful dentists!

However, things aren't as bad as all that. On the one hand, nowadays there are graphical interfaces even for Linux, which are equal to what Windows or MacOS X have to offer, or in some respects even surpass these as far as convenience and power are concerned. On the other hand, graphical interfaces and the text-oriented command line are not mutually exclusive, but in fact complementary (according to the philosophy "the right tool for every job").

At the end of the day this only means that you as a budding Linux user will do well to *also* get used to the text-oriented user interface, known as the "shell". Of course nobody wants to prevent you from using a graphical desktop for everything you care to do. The shell, however, is a convenient way to perform many extremely powerful operations that are rather difficult to express graphically. To reject the shell is like rejecting all gears except first in your car[1]. Sure, you'll get there eventually even in first gear, but only comparatively slowly and with a horrible amount of noise. So why not learn how to really floor it with Linux? And if you watch closely, we'll be able to show you another trick or two.

3.1.1 What Is The Shell?

Users cannot communicate directly with the operating system kernel. This is only possible through programs accessing it via "system calls". However, you must be able to start such programs in some way. This is the task of the shell, a special user program that (usually) reads commands from the keyboard and interprets them (for example) as commands to be executed. Accordingly, the shell serves as an "interface" to the computer that encloses the actual operating system like a shell (as in "nutshell"—hence the name) and hides it from view. Of course the shell is only one program among many that access the operating system.

Even today's graphical "desktops" like KDE can be considered "shells". Instead of reading text commands via the keyboard, they read graphical commands via the mouse—but as the text commands follow a certain "grammar", the mouse commands do just the same. For example, you select objects by clicking on them and then determine what to do with them: opening, copying, deleting, …

Even the very first Unix—end-1960s vintage—had a shell. The oldest shell to be found outside museums today was developed in the mid-1970s for "Unix version 7" by Stephen L. Bourne. This so-called "Bourne shell" contains most basic functions and was in very wide-spread use, but is very rarely seen in its original form today. Other classic Unix shells include the C shell, created at the University of California in Berkeley and (very vaguely) based on the C programming language, and the largely Bourne-shell compatible, but functionally enhanced, Korn shell (by David Korn, also at AT&T).

Bourne shell

C shell

Korn shell

Bourne-again shell

Standard on Linux systems is the Bourne-again shell, `bash` for short. It was developed under the auspices of the Free Software Foundation's GNU project by Brian Fox and Chet Ramey and unifies many functions of the Korn and C shells.

[1] This metaphor is for Europeans and other people who can manage a stick shift; our American readers of course all use those wimpy automatic transmissions. It's like they were all running Windows.

Besides the mentioned shells, there are many more. On Unix, a shell is simply an application program like all others, and you need no special privileges to write one—you simply need to adhere to the "rules of the game" that govern how a shell communicates with other programs.

shells: normal programs

Shells may be invoked interactively to read user commands (normally on a "terminal" of some sort). Most shells can also read commands from files containing pre-cooked command sequences. Such files are called "shell scripts".

shell scripts

A shell performs the following steps:

1. Read a command from the terminal (or the file)
2. Validate the command
3. Run the command directly or start the corresponding program
4. Output the result to the screen (or elsewhere)
5. Continue at step 1.

In addition to this standard command loop, a shell generally contains further features such as a programming language. This includes complex command structures involving loops, conditions, and variables (usually in shell scripts, less frequently in interactive use). A sophisticated method for recycling recently used commands also makes a user's life easier.

programming language

Shell sessions can generally be terminated using the `exit` command. This also applies to the shell that you obtained immediately after logging in.

Terminating shell sessions

Although, as we mentioned, there are several different shells, we shall concentrate here on `bash` as the standard shell on most Linux distributions. The LPI exams also refer to `bash` exclusively.

If there are several shells available on the system (the usual case), you can use the following commands to switch between them:

Changing shell

`sh` for the classic Bourne shell (if available—on most Linux systems, `sh` refers to the Bourne-again shell).

`bash` for the Bourne-again shell (bash).

`ksh` for the Korn shell.

`csh` for the C shell.

`tcsh` for the "Tenex C shell", an extended and improved version of the normal C shell. On many Linux systems, the `csh` command really refers to `tcsh`.

In case you cannot remember which shell you are currently running, the "`echo $0`" command should work in any shell and output the current shell's name.

Exercises

3.1 [2] How many different shells are installed on your system? Which ones? (*Hint:* Check the file `/etc/shells`.)

3.2 [2] Log off and on again and check the output of the "`echo $0`" command in the login shell. Start a new shell using the "`bash`" command and enter "`echo $0`" again. Compare the output of the two commands. Do you notice anything unusual?

3.2 Commands

3.2.1 Why Commands?

A computer's operation, no matter which operating system it is running, can be loosely described in three steps:

1. The computer waits for user input
2. The user selects a command and enters it via the keyboard or mouse
3. The computer executes the command

In a Linux system, the shell displays a "prompt", meaning that commands can be entered. This prompt usually consists of a user and host (computer) name, the current directory, and a final character:

```
joe@red:/home > _
```

In this example, user `joe` works on computer `red` in the `/home` directory.

3.2.2 Command Structure

A command is essentially a sequence of characters which is ends with a press of the ↩ key and is subsequently evaluated by the shell. Many commands are vaguely inspired by the English language and form part of a dedicated "command language". Commands in this language must follow certain rules, a "syntax", for the shell to be able to interpret them.

syntax

words

First word: command

parameters

To interpret a command line, the shell first tries to divide the line into words. Just like in real life, words are separated by spaces. The first word on a line is usually the actual command. All other words on the line are parameters that explain what is wanted in more detail.

DOS and Windows users may be tripped up here by the fact that the shell distinguishes between uppercase and lowercase letters. Linux commands are usually spelled in lowercase letters only (exceptions prove the rule) and not understood otherwise. See also Section 3.2.4.

When dividing a command into words, one space character is as good as many – the difference does not matter to the shell. In fact, the shell does not even insist on spaces; tabulator characters are also allowed, which is however mostly of importance when reading commands from files, since the shell will not let you enter tab character directly (not without jumping through hoops, anyway).

You may even use the line terminator (↩) to distribute a long command across several input lines, but you must put a "Token\" immediately in front of it so the shell will not consider your command finished already.

A command's parameters can be roughly divided into two types:

options

- Parameters starting with a dash ("`-`") are called options. These are usually, er, optional—the details depend on the command in question. Figuratively spoken they are "switches" that allow certain aspects of the command to be switched on or off. If you want to pass several options to a command, they can (often) be accumulated behind a single dash, i. e., the options sequence "`-a -l -F`" corresponds to "`-alF`". Many programs have more options than can be conveniently mapped to single characters, or support "long options" for readability (frequently in addition to equivalent single-character options). Long options most often start with two dashes and cannot be accumulated: "`foo --bar --baz`".

- Parameters with no leading dash are called arguments. These are often the names of files that the command should process. arguments

The general command structure can be displayed as follows: command structure

- Command—"What to do?"
- Options—"How to do it?"
- Arguments—"What to do it with?"

Usually the options follow the command and precede the arguments. However, not all commands insist on this—with some, arguments and options can be mixed arbitrarily, and they behave as if all options came immediately after the command. With others, options are taken into account only when they are encountered while the command line is processed in sequence.

The command structure of current Unix systems (including Linux) has grown organically over a period of almost 40 years and thus exhibits various inconsistencies and small surprises. We too believe that there ought to be a thorough clean-up, but 30 years' worth of shell scripts are difficult to ignore completely … Therefore be prepared to get used to little weirdnesses every so often.

3.2.3 Command Types

In shells, there are essentially two kinds of commands:

Internal commands These commands are made available by the shell itself. The Bourne-again shell contains approximately 30 such commands, which can be executed very quickly. Some commands (such as `exit` or `cd`) alter the state of the shell itself and thus cannot be provided externally.

External commands The shell does not execute these commands by itself but launches executable files, which within the file system are usually found in directories like `/bin` or `/usr/bin`. As a user, you can provide your own programs, which the shell will execute like all other external commands.

You can use the `type` command to find out the type of a command. If you pass a command name as the argument, it outputs the type of command or the corresponding file name, such as External or internal?

```
$ type echo
echo is a shell builtin
$ type date
date is /bin/date
```

(`echo` is an interesting command which simply outputs its parameters:

```
$ echo Thou hast it now, king, Cawdor, Glamis, all
Thou hast it now, king, Cawdor, Glamis, all
```

`date` displays the current date and time, possibly adjusted to the current time zone and language setup:

```
$ date
Mon May  7 15:32:03 CEST 2012
```

You will find out more about `echo` and `date` in Chapter 8.)

You can obtain help for internal Bash commands via the `help` command: help

```
$ help type
type: type [-afptP] name [name ...]
  For each NAME, indicate how it would be interpreted if used as a
  command name.

  If the -t option is used, `type' outputs a single word which is one of
  `alias', `keyword', `function', `builtin', `file' or `', if NAME is an
◁◁◁◁◁
```

Exercises

3.3 [2] With bash, which of the following programs are provided externally and which are implemented within the shell itself: `alias`, `echo`, `rm`, `test`?

3.2.4 Even More Rules

As mentioned above, the shell distinguishes between uppercase and lowercase letters when commands are input. This does not apply to commands only, but consequentially to options and parameters (usually file names) as well.

space character

Furthermore, you should be aware that the shell treats certain characters in the input specially. Most importantly, the already-mentioned space character is used to separate words on teh command line. Other characters with a special meaning include

```
$&;(){}[]*?!<>"'
```

"Escaping" characters

If you want to use any of these characters without the shell interpreting according to its the special meaning, you need to "escape" it. You can use the backslash "\" to escape a single special character or else single or double quotes (`'…'`, `"…"`) to excape several special characters. For example:

```
$ touch 'New File'
```

Due to the quotes this command applies to a single file called `New File`. Without quotes, two files called `New` and `File` would have been involved.

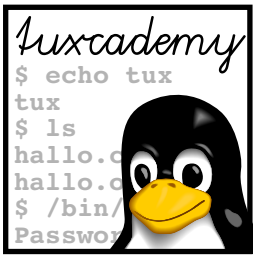
We can't explain all the other special characters here. Most of them will show up elsewhere in this manual – or else check the Bash documentation.

Commands in this Chapter

bash	The "Bourne-Again-Shell", an interactive command interpreter	bash(1) 38, 39
csh	The "C-Shell", an interactive command interpreter	csh(1) 39
date	Displays the date and time	date(1) 41
echo	Writes all its parameters to standard output, separated by spaces	bash(1), echo(1) 41
help	Displays on-line help for bash commands	bash(1) 41
ksh	The "'Korn shell"', an interactive command interpreter	ksh(1) 39
sh	The "Bourne shell", an interactive command interpreter	sh(1) 39
tcsh	The "Tenex C shell", an interactive command interpreter	tcsh(1) 39
type	Determines the type of command (internal, external, alias)	bash(1) 41

Summary

- The shell reads user commands and executes them.
- Most shells have programming language features and support shell scripts containing pre-cooked command sequences.
- Commands may have options and arguments. Options determine *how* the command operates, and arguments determine what it operates *on*.
- Shells differentiate between *internal* commands, which are implemented in the shell itself, and *external* commands, which correspond to executable files that are started in separate processes.



4

Getting Help

Contents

Goals

- Being able to handle manual and info pages
- Knowing about and finding HOWTOs
- Being familiar with the most important other information sources

Prerequisites

- Linux Overview
- Basic command-line Linux usage (e. g., from the previous chapters)

4.1 Self-Help

Linux is a powerful and intricate system, and powerful and intricate systems are, as a rule, complex. Documentation is an important tool to manage this complexity, and many (unfortunately not all) aspects of Linux are documented very extensively. This chapter describes some methods to access this documentation.

"Help" on Linux in many cases means "self-help". The culture of free software implies not unnecessarily imposing on the time and goodwill of other people who are spending their free time in the community by asking things that are obviously explained in the first few paragraphs of the manual. As a Linux user, you do well to have at least an overview of the available documentation and the ways of obtaining help in cases of emergency. If you do your homework, you will usually experience that people will help you out of your predicament, but any tolerance towards lazy individuals who expect others to tie themselves in knots on their behalf, on their own time, is not necessarily very pronounced.

If you would like to have somebody listen around the clock, seven days a week, to your not-so-well-researched questions and problems, you will have to take advantage of one of the numerous "commercial" support offerings. These are available for all common distributions and are offered either by the distribution vendor themselves or else by third parties. Compare the different service vendors and pick one whose service level agreements and pricing suit you.

4.2 The `help` Command and the `--help` Option

Internal `bash` commands

In `bash`, internal commands are described in more detail by the `help` command, giving the command name in question as an argument:

```
$ help exit
exit: exit [n]
    Exit the shell with a status of N.
    If N is omitted, the exit status
    is that of the last command executed.
$ _
```

More detailed explanations are available from the shell's manual page and info documentation. These information sources will be covered later in this chapter.

Many external commands (programs) support a `--help` option instead. Most commands display a brief listing of their parameters and syntax.

Not every command reacts to `--help`; frequently the option is called `-h` or `-?`, or help will be output if you specify any invalid option or otherwise illegal command line. Unfortunately there is no universal convention.

4.3 The On-Line Manual

4.3.1 Overview

Nearly every command-line program comes with a "manual page" (or "man page"), as do many configuration files, system calls etc. These texts are generally installed with the software, and can be perused with the "`man` ⟨*name*⟩" command.

Command `man`

Table 4.1: Manual page sections

Section	Content
NAME	Command name and brief description
SYNOPSIS	Description of the command syntax
DESCRIPTION	Verbose description of the command's effects
OPTIONS	Available options
ARGUMENTS	Available Arguments
FILES	Auxiliary files
EXAMPLES	Sample command lines
SEE ALSO	Cross-references to related topics
DIAGNOSTICS	Error and warning messages
COPYRIGHT	Authors of the command
BUGS	Known limitations of the command

Here, ⟨*name*⟩ is the command or file name that you would like explained. "`man bash`", for example, produces a list of the aforementioned internal shell commands.

However, the manual pages have some disadvantages: Many of them are only available in English; there are sets of translations for different languages which are often incomplete. Besides, the explanations are frequently very complex. Every single word can be important, which does not make the documentation accessible to beginners. In addition, especially with longer documents the structure can be obscure. Even so, the value of this documentation cannot be underestimated. Instead of deluging the user with a large amount of paper, the on-line manual is always available with the system.

Many Linux distributions pursue the philosophy that there should be a manual page for every command that can be invoked on the command line. This does not apply to the same extent to programs belonging to the graphical desktop environments KDE and GNOME, many of which not only do not come with a manual page at all, but which are also very badly documented even inside the graphical environment itself. The fact that many of these programs have been contributed by volunteers is only a weak excuse.

4.3.2 Structure

Man page outline

The structure of the man pages loosely follows the outline given in Table 4.1, even though not every manual page contains every section mentioned there. In particular, the EXAMPLES are frequently given short shrift.

The BUGS heading is often misunderstood: Read *bugs* within the implementation get fixed, of course; what is documented here are usually restrictions which follow from the *approach* the command takes, which are not able to be lifted with reasonable effort, and which you as a user ought to know about. For example, the documentation for the `grep` command points out that various constructs in the regular expression to be located may lead to the `grep` process using very much memory. This is a consequence of the way `grep` implements searching and not a trivial, easily fixed error.

Man pages are written in a special input format which can be processed for text display or printing by a program called `groff`. Source code for the manual pages is stored in the `/usr/share/man` directory in subdirectories called `man`*n*, where *n* is one of the chapter numbers from Table 4.2.

You can integrate man pages from additional directories by setting the `MANPATH` environment variable, which contains the directories which will be searched by `man`, in order. The `manpath` command gives hints for setting up `MANPATH`.

Table 4.2: Manual Page Topics

No.	Topic
1	User commands
2	System calls
3	C language library functions
4	Device files and drivers
5	Configuration files and file formats
6	Games
7	Miscellaneous (e. g. `groff` macros, ASCII tables, …)
8	Administrator commands
9	Kernel functions
n	»New« commands

4.3.3 Chapters

Chapters

Every manual page belongs to a "chapter" of the conceptual "manual" (Table 4.2). Chapters 1, 5 and 8 are most important. You can give a chapter number on the `man` command line to narrow the search. For example, "`man 1 crontab`" displays the man page for the `crontab` command, while "`man 5 crontab`" explains the format of `crontab` files. When referring to man pages, it is customary to append the chapter number in parentheses; we differentiate accordingly between `crontab`(1), the `crontab` command manual, and `crontab`(5), the description of the file format.

`man -a`

With the `-a` option, `man` displays all man pages matching the given name; without this option, only the first page found (generally from chapter 1) will be displayed.

4.3.4 Displaying Manual Pages

The program actually used to display man pages on a text terminal is usually `less`, which will be discussed in more detail later on. At this stage it is important to know that you can use the cursor keys ↑ and ↓ to navigate within a man page. You can search for keywords inside the text by pressing / —after entering the word and pressing the return key, the cursor jumps to the next occurrence of the word (if it does occur at all). Once you are happy, you can quit the display using q to return to the shell.

Using the KDE web browser, Konqueror, it is convenient to obtain nicely formatted man pages. Simply enter the URL "`man:/`⟨*name*⟩" (or even "`#`⟨*name*⟩")

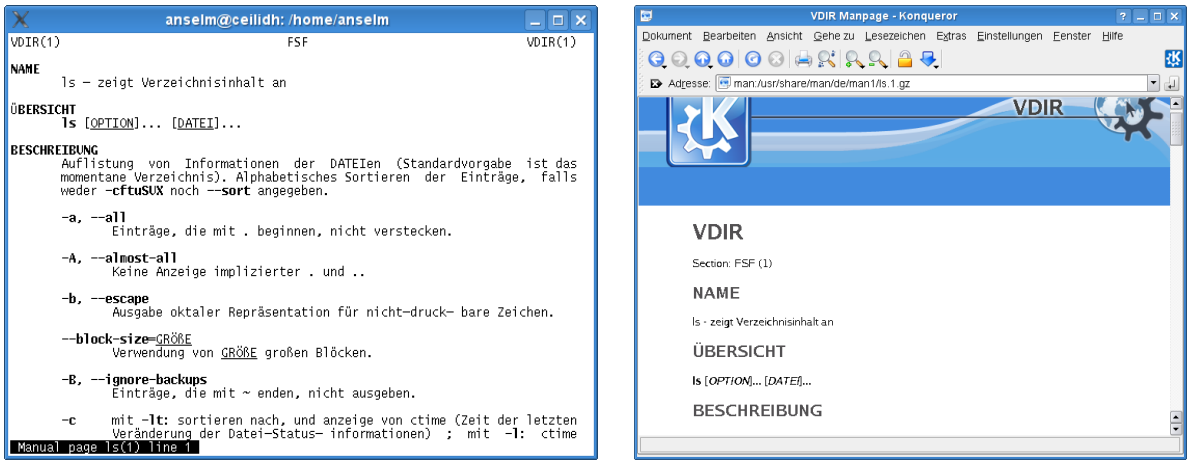


Figure 4.1: A manual page in a text terminal (left) and in Konqueror (right)

in the browser's address line. This also works on the KDE command line (Figure 2.2).

Before rummaging aimlessly through innumerable man pages, it is often sensible to try to access general information about a topic via `apropos`. This command works just like "`man -k`"; both search the "NAME" sections of all man pages for a keyword given on the command line. The output is a list of all manual pages containing the keyword in their name or description. Keyword search

A related command is `whatis`. This also searches all manual pages, but for a command (file, …) *name* rather than a keyword—in other words, the part of the "NAME" section to the left of the dash. This displays a brief description of the desired command, system call, etc.; in particular the second part of the "NAME" section of the manual page(s) in question. `whatis` is equivalent to "`man -f`". `whatis`

Exercises

4.1 [!1] View the manual page for the `ls` command. Use the text-based `man` command and—if available—the Konqueror browser.

4.2 [2] Which manual pages on your system deal (at least according to their "NAME" sections) with processes?

4.3 [5] (Advanced.) Use a text editor to write a manual page for a hypothetical command. Read the `man`(7) man page beforehand. Check the appearance of the man page on the screen (using "`groff -Tascii -man` ⟨*file*⟩ `| less`") and as printed output (using something like "`groff -Tps -man` ⟨*file*⟩ `| gv -`").

4.4 Info Pages

For some commands—often more complicated ones—there are so-called "info pages" instead of (or in addition to) the more usual man pages. These are usually more extensive and based on the principles of hypertext, similar to the World Wide Web. hypertext

The idea of info pages originated with the GNU project; they are therefore most frequently found with software published by the FSF or otherwise belonging to the GNU project. Originally there was supposed to be *only* info documentation for the "GNU system"; however, since GNU also takes on board lots of software not created under the auspices of the FSF, and GNU tools are being used on systems pursuing a more conservative approach, the FSF has relented in many cases.

Analogously to man pages, info pages are displayed using the "`info` ⟨*command*⟩" command (the package containing the `info` program may have to be installed explicitly). Furthermore, info pages can be viewed using the `emacs` editor or displayed in the KDE web browser, Konqueror, via URLs like "`info:/`⟨*command*⟩".

One advantage of info pages is that, like man pages, they are written in a source format which can conveniently be processed either for on-screen display or for printing manuals using PostScript or PDF. Instead of `groff`, the TEX typesetting program is used to prepare output for printing.

Exercises

4.4 [!1] Look at the info page for the `ls` program. Try the text-based `info` browser and, if available, the Konqueror browser.

4.5 [2] Info files use a crude (?) form of hypertext, similar to HTML files on the World Wide Web. Why aren't info files written in HTML to begin with?

4.5 HOWTOs

Problem-oriented documentation

Both manual and info pages share the problem that the user must basically know the name of the program to use. Even searching with `apropos` is frequently nothing but a game of chance. Besides, not every problem can be solved using one single command. Accordingly, there is "problem-oriented" rather than "command-oriented" documentation is often called for. The HOWTOs are designed to help with this.

HOWTOs are more extensive documents that do not restrict themselves to single commands in isolation, but try to explain complete approaches to solving problems. For example, there is a "DSL HOWTO" detailing ways to connect a Linux system to the Internet via DSL, or an "Astronomy HOWTO" discussing astronomy software for Linux. Many HOWTOs are available in languages other than English, even though the translations often lag behind the English-language originals.

HOWTO packages

Most Linux distributions furnish the HOWTOs (or significant subsets) as packages to be installed locally. They end up in a distribution-specific directory—`/usr/share/doc/howto` for SUSE distributions, `/usr/share/doc/HOWTO` for Debian GNU/Linux—, typically either als plain text or else HTML files. Current versions of all HOWTOs and other formats such as PostScript or PDF can be found on the Web on the site of the "Linux Documentation Project" (`http://www.tldp.org`) which also offers other Linux documentation.

HOWTOs on the Web

4.6 Further Information Sources

Additional information

You will find additional documentation and example files for (nearly) every installed software package under `/usr/share/doc` or `/usr/share/doc/packages` (depending on your distribution). Many GUI applications (such as those from the KDE or GNOME packages) offer "help" menus. Besides, many distributions offer specialized "help centers" that make it convenient to access much of the documentation on the system.

Independently of the local system, there is a lot of documentation available on the Internet, among other places on the WWW and in USENET archives.

WWW
USENET

Some of the more interesting web sites for Linux include:

`http://www.tldp.org/` The "Linux Documentation Project", which is in charge of man pages and HOWTOs (among other things).

`http://www.linux.org/` A general "portal" for Linux enthusiasts.

`http://www.linuxwiki.de/` A "free-form text information database for everything pertaining to Linux" (in German).

`http://lwn.net/` *Linux Weekly News*—probably the best web site for Linux news of all sorts. Besides a daily overview of the newest developments, products, security holes, Linux advocacy in the press, etc., on Thursdays there is an extensive on-line magazine with well-researched background reports about the preceding week's events. The daily news are freely available, while the weekly issues must be paid for (various pricing levels starting at US-$5 per month). One week after their first appearance, the weekly issues are made available for free as well.

`http://freecode.com/` This site publishes announcements of new (predominantly free) software packages, which are often available for Linux. In addition to this there is a database allowing queries for interesting projects or software packages.

`http://www.linux-knowledge-portal.de/` A site collecting "headlines" from other interesting Linux sites, including LWN and Freshmeat.

If there is nothing to be found on the Web or in Usenet archives, it is possible to ask questions in mailing lists or Usenet groups. In this case you should note that many users of these forums consider it very bad form to ask questions answered already in the documentation or in a "FAQ" (frequently answered questions) resource. Try to prepare a detailed description of your problem, giving relevant excerpts of log files, since a complex problem like yours is difficult to diagnose at a distance (and you will surely be able to solve non-complex problems by yourself).

A news archive is accessible on `http://groups.google.com/` (formerly DejaNews)

Interesting *news groups* for Linux can be found in the English-language `comp.os.linux.*` or the German-language `de.comp.os.unix.linux.*` hierarchies. Many Unix groups are appropriate for Linux topics; a question about the shell should be asked in a group dedicated to shell programming rather than a Linux group, since shells are usually not specific to Linux.

Linux-oriented mailing lists can be found, for example, at `majordomo@vger.kernel.org`. You should send an e-mail message including "`subscribe LIST`" to this address in order to subscribe to a list called LIST. A commented list of all available mailing lists on the system may be found at `http://vger.kernel.org/vger-lists.html`.

An established strategy for dealing with seemingly inexplicable problems is to search for the error message in question using Google (or another search engine you trust). If you do not obtain a helpful result outright, leave out those parts of your query that depend on your specific situation (such as domain names that only exist on your system). The advantage is that Google indexes not just the common web pages, but also many mailing list archives, and chances are that you will encounter a dialogue where somebody else had a problem very like yours.

search engine

Incidentally, the great advantage of open-source software is not only the large amount of documentation, but also the fact that most documentation is restricted as little as the software itself. This facilitates collaboration between software developers and documentation authors, and the translation of documentation into different languages is easier. In fact, there is ample opportunity for non-programmers to help with free software projects, e. g., by writing good documentation. The free-software scene should try to give the same respect to documentation authors that it does to programmers—a paradigm shift that has begun but is by no means finished yet.

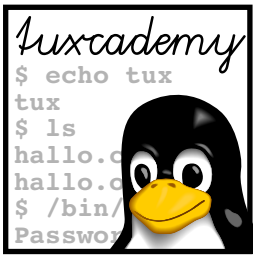
Free documentation

Commands in this Chapter

apropos	Shows all manual pages whose NAME sections contain a given keyword	apropos(1) 49
groff	Sophisticated typesetting program	groff(1) 47, 49
help	Displays on-line help for bash commands	bash(1) 46
info	Displays GNU Info pages on a character-based terminal	info(1) 49
less	Displays texts (such as manual pages) by page	less(1) 48
man	Displays system manual pages	man(1) 46
manpath	Determines the search path for system manual pages	manpath(1) 47
whatis	Locates manual pages with a given keyword in its description	whatis(1) 49

Summary

- "`help` ⟨*command*⟩" explains internal `bash` commands. Many external commands support a `--help` option.
- Most programs come with manual pages that can be perused using `man`. `apropos` searches all manual pages for keywords, `whatis` looks for manual page names.
- For some programs, info pages are an alternative to manual pages.
- HOWTOs form a problem-oriented kind of documentation.
- There is a multitude of interesting Linux resources on the World Wide Web and USENET.



5

The vi Editor

Contents

Goals

- Becoming familiar with the vi editor
- Being able to create and change text files

Prerequisites

- Basic shell operation (qv. Chapter 2)

5.1 Editors

Most operating systems offer tools to create and change text documents. Such programs are commonly called "editors" (from the Latin "edire", "to work on").

Generally, text editors offer functions considerably exceeding simple text input and character-based editing. Good editors allow users to remove, copy or insert whole words or lines. For long files, it is helpful to be able to search for particular sequences of characters. By extension, "search and replace" commands can make tedious tasks like "replace every `x` by a `u`" considerably easier. Many editors contain even more powerful features for text processing.

Difference to word processors

In contrast to widespread "word processors" such as OpenOffice.org Writer or Microsoft Word, text editors usually do not offer markup elements such as various fonts (Times, Helvetica, Courier, …), type attributes (boldface, italic, underlined, …), typographical features (justified type, …) and so on—they are predominantly intended for the creation and editing of pure text files, where these things would really be a nuisance.

Of course there is nothing wrong with using a text editor to prepare input files for typesetting systems such as `groff` or LaTeX that offer all these typographic features. However, chances are you won't see much of these in your original input—which can really be an advantage: After all, much of the typography serves as a distraction when writing, and authors are tempted to fiddle with a document's appearance while inputting text, rather than concentrating on its content.

Syntax highlighting

Most text editors today support syntax highlighting, that is, identifying certain elements of a program text (comments, variable names, reserved words, strings) by colours or special fonts. This does look spiffy, even though the question of whether it really helps with programming has not yet been answered through suitable psychological studies.

In the rest of the chapter we shall introduce the possibly most important Linux editor, `vi`. However, we shall restrict ourselves to the most basic functionality; it would be easy to conduct multi-day training courses for each of the two. As with the shells, the choice of text editor is up to a user's own personal preference.

Exercises

5.1 [2] Which text editors are installed on your system? How can you find out?

5.2 The Standard—`vi`

5.2.1 Overview

The only text editor that is probably part of every Linux system is called `vi` (from "visual", not Roman 6—usually pronounced "vee-i"). For practical reasons, this

`vi`: today a clone

usually doesn't mean the original `vi` (which was part of BSD and is decidedly long in the tooth today), but more modern derivatives such as `vim` (from "`vi` improved") or `elvis`; these editors are, however, sufficiently close to the original `vi`, to be all lumped together.

`vi`, originally developed by Bill Joy for BSD, was one of the first "screen-oriented" editors in widespread use for Unix. This means that it allowed users to use the whole screen for editing rather than let them edit just one line at a time. This is today considered a triviality, but used to be an innovation—which is not to say that earlier programmers were too stupid to figure it out, but that text terminals allowing free access to arbitrary points on the screen (a mandatory feature for programs like `vi`) had only just become affordable. Out of consideration for older

systems using teletypes or "glass ttys" (terminals that could only add material at the bottom of the screen), vi also supports a line-oriented editor under the name of ex.

Even with the advanced terminals of that time, one could not rely on the availability of keyboards with special keys for cursor positioning or advanced functions—today's standard PC keyboards would have been considered luxurious, if not overloaded. This justifies vi's unusual concepts of operation, which today could rightly be considered antediluvian. It cannot be taken amiss if people reject vi because of this. In spite of this, having rudimentary knowledge of vi cannot possibly hurt, even if you select a different text editor for your daily work—which you should by all means do if vi does not agree with you. It is not as if there was no choice of alternatives, and we shall not get into childish games such as "Whoever does not use vi is not a proper Linux user". Today's graphical desktops such as KDE do contain very nice and powerful text editors.

Keyboard restrictions

There is, in fact, an editor which is even cruder than vi—the ed program. The title "the only editor that is guaranteed to be available on any Unix system" rightfully belongs to ed instead of vi, but ed as a pure line editor with a teletype-style user interface is too basic for even hardcore Unix advocates. (ed can be roughly compared with the DOS program, EDLIN; ed, however, is vastly more powerful than the Redmond offering.) The reason why ed is still available in spite of the existence of dozens of more convenient text editors is unobvious, but very Unix-like: ed accepts commands on its standard input and can therefore be used in shell scripts to change files programmatically. ed allows editing operations that apply to the whole file at once and is, thus, more powerful than its colleague, the "stream editor" sed, which copies its standard input to its standard output with certain modifications; normally one would use sed and revert to ed for exceptional cases, but ed is still useful every so often.

5.2.2 Basic Functions

The Buffer Concept vi works in terms of so-called **buffers**. If you invoke vi with a file name as an argument, the content of that file will be read into a buffer. If no file exists by that name, an empty buffer is created.

buffers

All the modifications made with the editor are only applied inside the buffer. To make these modifications permanent, the buffer content must be explicitly written back to the file. If you really want to discard the modifications, simply leave vi without storing the buffer content—the file on the storage medium will remain unchanged.

In addition to a file name as an argument, you can pass options to vi as usual. Refer to the documentation for the details.

Modes As mentioned earlier, one of the characteristics of vi is its unusual manner of operation. vi supports three different working "modes":

Command mode All keyboard input consists of commands that do not appear on screen and mostly do not need to be finalized using the return key. After invoking vi, you end up in this mode. Be careful: Any key press could invoke a command.

Insert mode All keyboard input is considered text and displayed on the screen. vi behaves like a "modern" editor, albeit with restricted navigation and correction facilities.

Command-line mode This is used to enter long commands. These usually start with a colon (":") and are finished using the return key.

In insert mode, nearly all navigation or correction commands are disabled, which requires frequent alternation between insert and command modes. The fact that

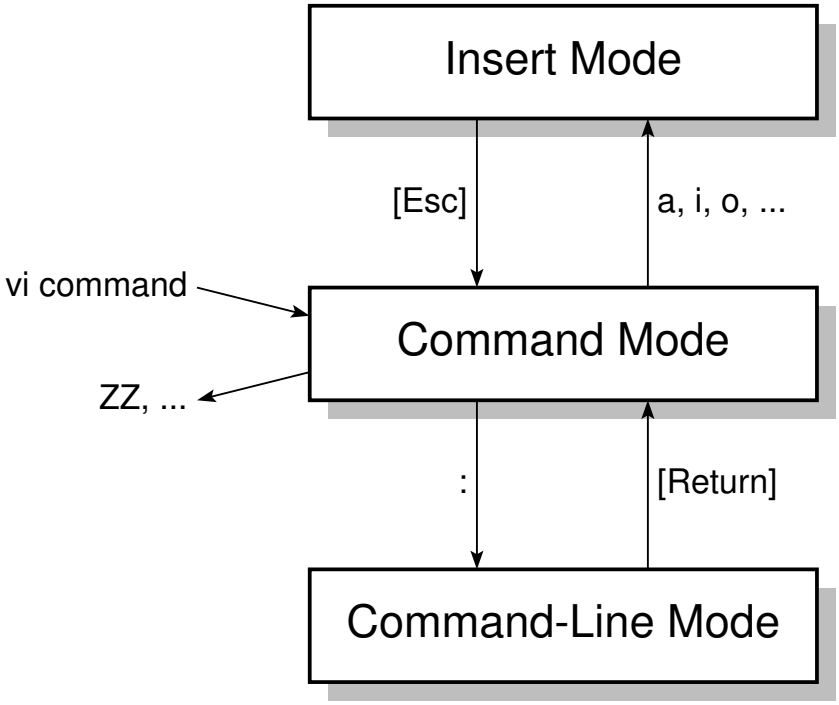


Figure 5.1: vi's modes

Table 5.1: Insert-mode commands for vi

Command	Result
a	Appends new text after the cursor
A	Appends new text at the end of the line
i	Inserts new text at the cursor position
I	Inserts new text at the beginning of the line
o	Inserts a new line below the line containing the cursor
O	Inserts a new line above the line containing the cursor

it may be difficult to find out which mode the editor is currently in (depending on the vi implementation used and its configuration) does not help to make things easier for beginners. An overview of vi modes may be found in Figure 5.1.

Consider: vi started when keyboards consisting only of the "letter block" of modern keyboards were common (127 ASCII characters). There was really no way around the scheme used in the program.

command mode

After invoking vi without a file name you end up in command mode. In contrast to most other editors, direct text input is not possible. There is a cursor at the top left corner of the screen above a column filled with tildes. The last line, also called the "status line", displays the current mode (maybe), the name of the file currently being edited (if available) and the current cursor position.

If your version of vi does not display status information, try your luck with Esc :set showmode ↩.

Shortened by a few lines, this looks similar to Das sieht (um einige Zeilen verkürzt) etwa so aus:

```
_
~
~
```

Table 5.2: Cursor positioning commands in vi

Command	Cursor moves …
h or ←	one character to the left
l or →	one character to the right
k or ↑	one character up
j or ↓	one character down
0	to the beginning of the line
$	to the end of the line
w	to the next word
b	to the previous word
f ⟨*character*⟩	to the next ⟨*character*⟩ on the line
Strg + F	to the next page (screenful)
Strg + B	to the previous page
G	to the last line of the file
⟨*n*⟩ G	to line no. ⟨*n*⟩

```
~
Empty Buffer                          0,0-1
```

Only after a command such as a ("append"), i ("insert"), or o ("open") will vi change into "insert mode". The status line displays something like "-- INSERT --", and keyboard input will be accepted as text. insert mode

The possible commands to enter insert mode are listed in Table 5.1; note that lower-case and upper-case commands are different. To leave insert mode and go back to command mode, press the Esc key. In command mode, enter Z Z to write the buffer contents to disk and quit vi.

If you would rather discard the modifications you made, you need to quit the editor without saving the buffer contents first. Use the command : q! ↩. The leading colon emphasises that this is a command-line mode command.

When : is entered in command mode, vi changes to command-line mode. You can recognize this by the colon appearing in front of the cursor on the bottom line of the screen. All further keyboard input is appended to that colon, until the command is finished with the return key (↩); vi executes the command and reverts to command mode. In command-line mode, vi processes the line-oriented commands of its *alter ego*, the ex line editor. command-line mode

There is an ex command to save an intermediate version of the buffer called : w ("write"). Commands : x and : wq save the buffer contents and quit the editor; both commands are therefore identical to the Z Z command.

Movement Through the Text In insert mode, newly entered characters will be put into the current line. The return key starts a new line. You can move about the text using cursor keys, but you can remove characters only on the current line using ⇐—an inheritance of vi's line-oriented predecessors. More extensive navigation is only possible in command mode (Table 5.2).

Once you have directed the cursor to the proper location, you can begin correcting text in command mode.

Deleting characters The d command is used to delete characters; it is always followed by another character that specifies exactly what to delete (Table 5.3). To make editing easier, you can prefix a repeat count to each of the listed commands. For example; the 3 x command will delete the next three characters. repeat count

If you have been too eager and deleted too much material, you can revert the last change (or even all changes one after the other) using the u ("undo") com- undo

Table 5.3: Editing commands in vi

Command	Result
x	Deletes the character below the cursor
X	Deletes the character to the left of the cursor
r ⟨*char*⟩	Replaces the character below the cursor by ⟨*char*⟩
d w	Deletes from cursor to end of current word
d $	Deletes from cursor to end of current line
d 0	Deletes from cursor to start of current line
d f ⟨*char*⟩	Deletes from cursor to next occurrence of ⟨*char*⟩ on the current line
d d	Deletes current line
d G	Deletes from current line to end of text
d 1 G	Deletes from current line to beginning of text

Table 5.4: Replacement commands in vi

Command	Result
c w	Replace from cursor to end of current word
c $	Replace from cursor to end of current line
c 0	Replace from cursor to start of current line
c f ⟨*char*⟩	Replace from cursor to next occurrence of ⟨*char*⟩ on the current line
c / abc	Replace from cursor to next occurrence of character sequence abc

mand. This is subject to appropriate configuration settings.

Overwriting **Replacing characters** The c command ("change") serves to overwrite a selected part of the text. c is a "combination command" similar to d, requiring an additional specification of what to overwrite. vi will remove that part of the text before changing to insert mode automatically. You can enter new material and return to command mode using Esc. (Table 5.4).

5.2.3 Extended Commands

Cutting, Copying, and Pasting Text A frequent operation in text editing is to move or copy existing material elsewhere in the document. vi offers handy combination commands to do this, which take specifications similar to those for the c command. y ("yank") copies material to an interim buffer without changing the original text, whereas d moves it to the interim buffer, i. e., it is removed from its original place and only available in the interim buffer afterwards. (We have introduced this as "deletion" above.)

Of course there is a command to re-insert (or "paste") material from an interim buffer. This is done using p (to insert after the current cursor position) or P (to insert at the current cursor position).

26 buffers A peculiarity of vi is that there is not just one interim buffer but 26. This makes it easy to paste different texts (phrases, …) to different places in the file. The interim buffers are called "a" through "z" and can be invoked using a combination of double quotes and buffer names. The command sequence " c y 4 w, for instance, copies the next four words to the interim buffer called c; the command sequence " g p inserts the contents of interim buffer g after the current cursor position.

Regular-Expression Text Search Like every good editor, vi offers well-thought-out search commands. "Regular expressions" make it possible to locate character sequences that fit elaborate search patterns. To start a search, enter a slash / in command mode. This will appear on the bottom line of the terminal followed by the cursor. Enter the search pattern and start the search using the return key. vi will start at the current cursor position and work towards the end of the document. To search towards the top, the search must be started using ? instead of / . Once vi has found a matching character sequence, it stops the search and places the cursor on the first character of the sequence. You can repeat the same search towards the end using n ("next") or towards the beginning using N.

Searching and Replacing Since locating character sequences is often not all that is desired. Therefore, vi also allows replacing found character sequences by others. The following ex command can be used:

```
:[⟨start line⟩,⟨end line⟩]s/⟨regexp⟩/⟨replacement⟩[/q]
```

The parts of the command within square brackets are optional. What do the different components of the command mean?

⟨*Start line*⟩ and ⟨*end line*⟩ determine the range of lines to be searched. Without these, only the current line will be looked at! Instead of line numbers, you can use a dot to specify the current line or a dollar sign to specify the last line—but do not confuse the meanings of these characters with their meanings within regular expressions: range of lines

```
:5,$s/red/blue/
```

replaces the first occurrence of red on each line by blue, where the first four lines are not considered.

```
:5,$s/red/blue/g
```

replaces *every* occurrence of red in those lines by blue. (Watch out: Even Fred Flintstone will become Fblue Flintstone.)

Instead of line numbers, ".", and "$", vi also allows regular expressions within slashes as start and end markers:

```
:/^BEGIN/,/^END/s/red/blue/g
```

replaces red by blue only in lines located between a line starting with BEGIN

After the command name s and a slash, you must enter the desired regular expression. After another slash, ⟨*replacement*⟩ gives a character sequence by which the original text is to be replaced.

There is a special function for this argument: With a & character you can "reference back" to the text matched by the ⟨*regexp*⟩ in every actual case. That is, ":s/bull/& frog" changes every bull within the search range to a bull frog—a task which will probably give genetic engineers trouble for some time to come. Back reference

Command-line Mode Commands So far we have described some command-line mode (or "ex mode") commands. There are several more, all of which can be accessed from command mode by prefixing them with a colon and finishing them with the return key (Table 5.5).

Exercises

5.2 [5] (For systems with vim, e. g., the SUSE distributions.) Find out how to access the interactive vim tutorial and work through it.

Table 5.5: ex commands in vi

Command	Result
: w ⟨*file name*⟩	Writes the complete buffer content to the designated file
: w! ⟨*file name*⟩	Writes to the file even if it is write-protected (if possible)
: e ⟨*file name*⟩	Reads the designated file into the buffer
: e #	Reads the last-read file again
: r ⟨*file name*⟩	Inserts the content of the designated file after the line containing the cursor
: ! ⟨*shell command*⟩	Executes the given shell command and returns to vi afterwards
: r! ⟨*shell command*⟩	Inserts the output of ⟨*shell command*⟩ after the line containing the cursor
: s/⟨*regexp*⟩/⟨*replacement*⟩	Searches for ⟨*regexp*⟩ and replaces by ⟨*replacement*⟩
: q	Quits vi
: q!	Quits vi even if the buffer contents is unsaved
: x oder :e wq	Saves the buffer contents and quits vi

5.3 Other Editors

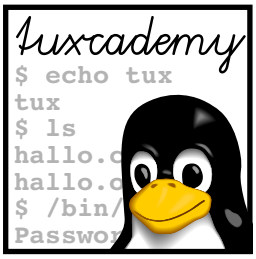
We have already alluded to the fact that your choice of editor is just as much down to your personal preferences and probably says as much about you as a user as your choice of car: Do you drive a polished BMW or are you happy with a dented Astra? Or would you rather prefer a Land Rover? As far as choice is concerned, the editor market offers no less than the vehicle market. We have presented the possibly most important Linux editor, but of course there are many others. kate on KDE and gedit on GNOME, for example, are straightforward and easy-to-learn editors with a graphical user interface that are perfectly adequate for the requirements of a normal user. GNU Emacs, however, is an extremely powerful and customisable editor for programmers and authors, and its extensive "ecosystem" of extensions leaves few desires uncatered for. Do browse through the package lists of your distribution and check whether you will find the editor of your dreams there.

Commands in this Chapter

ed	Primitive (but useful) line-oriented text editor	ed(1)	55
elvis	Popular "clone" of the vi editor	elvis(1)	54
ex	Powerful line-oriented text editor (really vi)	vi(1)	54
sed	Stream-oriented editor, copies its input to its output making changes in the process	sed(1)	55
vi	Screen-oriented text editor	vi(1)	54
vim	Popular "clone" of the vi editor	vim(1)	54

Summary

- Text editors are important for changing configuration files and programming. They often offer special features to make these tasks easier.
- `vi` is a traditional, very widespread and powerful text editor with an idiosyncratic user interface.



6

Files: Care and Feeding

Contents

Goals

- Being familiar with Linux conventions concerning file and directory names
- Knowing the most important commands to work with files and directories
- Being able to use shell filename search patterns

Prerequisites

- Using a shell (qv. Chapter 2)
- Use of a text editor (qv. Chapter 5)

6.1 File and Path Names

6.1.1 File Names

One of the most important services of an operating system like Linux consists of storing data on permanent storage media like hard disks or USB keys and retrieving them later. To make this bearable for humans, similar data are usually collected into "files" that are stored on the medium under a name.

files

Even if this seems trivial to you, it is by no means a given. In former times, some operating systems made it necessary to know abominations like track numbers on a disk in order to retrieve one's data.

Thus, before we can explain to you how to handle files, we need to explain to you how Linux *names* files.

Allowed characters

In Linux file names, you are essentially allowed to use any character that your computer can display (and then some). However, since some of the characters have a special meaning, we would recommend against their use in file names. Only two characters are completely disallowed, the slash and the zero byte (the character with ASCII value 0). Other characters like spaces, umlauts, or dollar signs may be used freely, but must usually be escaped on the command line by means of a backslash or quotes in order to avoid misinterpretations by the shell.

Letter case

An easy trap for beginners to fall into is the fact that Linux distinguishes uppercase and lowercase letters in file names. Unlike Windows, where uppercase and lowercase letters in file names are displayed but treated the same, Linux considers `x-files` and `X-Files` two different file names.

Under Linux, file names may be "quite long"—there is no definite upper bound, since the maximum depends on the "file system", which is to say the specific way bytes are arranged on the medium (there are several methods on Linux). A typical upper limit is 255 characters—but since such a name would take somewhat more than three lines on a standard text terminal this shouldn't really cramp your style.

suffixes

A further difference from DOS and Windows computers is that Linux does not use suffixes to characterise a file's "type". Hence, the dot is a completely ordinary character within a file name. You are free to store a text as `mumble.txt`, but `mumble` would be just as acceptable in principle. This should of course not turn you off using suffixes completely—you do after all make it easier to identify the file content.

Some programs insist on their input files having specific suffixes. The C compiler, `gcc`, for example, considers files with names ending in "`.c`" C source code, those ending in "`.s`" assembly language source code, and those ending in "`.o`" precompiled object files.

special characters

You may freely use umlauts and other special characters in file names. However, if files are to be used on other systems it is best to stay away from special characters in file names, as it is not guaranteed that they will show up as the same characters elsewhere.

locale settings

What happens to special characters also depends on your locale settings, since there is no general standard for representing characters exceeding the ASCII character set (128 characters covering mostly the English language, digits and the most common special characters). Widely used encodings are, for example, ISO 8859-1 and ISO 8859-15 (popularly know as ISO-Latin-1 and ISO-Latin-9, respectively … don't ask) as well as ISO 10646, casually and not quite correctly called "Unicod" and usually encoded as "UTF-8". File names you created while encoding *X* was active may look completely different when you look at the directory while encoding *Y* is in force. The whole topic is nothing you want to think about during meals.

Should you ever find yourself facing a pile of files whose names are encoded according to the wrong character set, the `convmv` program, which can convert file names between various character encodings, may be able to help you. (You will probably have to install it yourself since it is not part of the standard installation of most distributions.) However, you should really get down to this only after working through the rest of this chapter, as we haven't even explained the regular `mv` yet …

`convmv`

Portable file names

All characters from the following set may be used freely in file names:

```
ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz
0123456789+-._
```

However, you should pay attention to the following hints:

- To allow moving files between Linux and older Unix systems, the length of a file name should be at most 14 characters. (Make that "ancient", really.)
- File names should always start with one of the letters or a digit; the other four characters can be used without problems only inside a file name.

These conventions are easiest to understand by looking at some examples. Allowable file names would be, for instance:

```
X-files
foo.txt.bak
50.something
7_of_9
```

On the contrary, problems would be possible (if not likely or even assured) with:

`-10°F`	*Starts with "-", includes special character*
`.profile`	*Will be hidden*
`3/4-metre`	*Contains illegal character*
`Smörrebröd`	*Contains umlauts*

Hidden files

As another peculiarity, file names starting with a dot (".") will be skipped in some places, for example when the files within a directory are listed—files with such names are considered "hidden". This feature is often used for files containing settings for programs and which should not distract users from more important files in directory listings.

For DOS and Windows experts: These systems allow "hiding" files by means of a "file attribute" which can be set independently of the file's name. Linux and Unix do not support such a thing.

6.1.2 Directories

Since potentially many users may work on the same Linux system, it would be problematic if each file name could occur just once. It would be difficult to make clear to user Joe that he cannot create a file called `letter.txt` since user Sue already has a file by that name. In addition, there must be a (convenient) way of ensuring that Joe cannot read all of Sue's files and the other way round.

For this reason, Linux supports the idea of hierarchical "directories" which are used to group files. File names do not need to be unique within the whole system, but only within the same directory. This means in particular that the system can assign different directories to Joe and Sue, and that within those they may call their files whatever they please without having to worry about each other's files.

In addition, we can forbid Joe from accessing Sue's *directory* (and vice versa) and no longer need to worry about the individual files within them.

On Linux, directories are simply files, even though you cannot access them using the same methods you would use for "plain" files. However, this implies that the rules we discussed for file names (see the previous section) also apply to the names of directories. You merely need to learn that the slash ("/") serves to separate file names from directory names and directory names from one another. `joe/letter.txt` would be the file `letter.txt` in the directory `joe`.

slash

Directories may contain other directories (this is the term "hierarchical" we mentioned earlier), which results in a tree-like structure (inventively called a "directory tree"). A Linux system has a special directory which forms the root of the tree and is therefore called the "root directory". Its name is "/" (slash).

directory tree

In spite of its name, the root directory has nothing to do with the system administrator, `root`. It's just that their names are similar.

The slash does double duty here—it serves both as the name of the root directory and as the separator between other directory names. We'll come back to this presently.

The basic installation of common Linux distributions usually contains tens of thousands of files in a directory hierarchy that is mostly structured according to certain conventions. We shall tell you more about this directory hierarchy in Chapter 9.

6.1.3 Absolute and Relative Path Names

Every file in a Linux system is described by a name which is constructed by starting at the root directory and mentioning every directory down along the path to the one containing the file, followed by the name of the file itself. For example, `/home/joe/letter.txt` names the file `letter.txt`, which is located within the `joe` directory, which in turn is located within the `home` directory, which in turn is a direct descendant of the root directory. A name that starts with the root directory is called an "absolute path name"—we talk about "path names" since the name describes a "path" through the directory tree, which may contain directory and file names (i. e., it is a collective term).

absolute path name

Each process within a Linux system has a "current directory" (often also called "working directory"). File names are searched within this directory; `letter.txt` is thus a convenient abbreviation for "the file called `letter.txt` in the current directory", and `sue/letter.txt` stands for "the file `letter.txt` within the `sue` directory within the current directory". Such names, which start from the current directory, are called "relative path names".

relative path names

It is trivial to tell absolute from relative path names: A path name starting with a "/" is absolute; all others are relative.

The current directory is "inherited" between parent and child processes. So if you start a new shell (or any program) from a shell, that new shell uses the same current directory as the shell you used to start it. In your new shell, you can change into another directory using the `cd` command, but the current directory of the old shell does not change—if you leave the new shell, you are back to the (unchanged) current directory of the old shell.

shortcuts

There are two convenient shortcuts in relative path names (and even absolute ones): The name ".." always refers to the directory *above* the directory in question in the directory tree—for example, in the case of `/home/joe`, `/home`. This frequently allows you to refer conveniently to files in a "side branch" of the directory tree as viewed from the current directory, without having to resort to absolute path names. Assume `/home/joe` has the subdirectories `letters` and `novels`. With `letters` as the current directory, you could refer to the `ivanhoe.txt` file within the `novels`

directory by means of the relative path name `../novels/ivanhoe.txt`, without having to use the unwieldy absolute path name `/home/joe/novels/ivanhoe.txt`.

The second shortcut does not make quite as obvious sense: the "`.`" name within a directory always stands for the directory itself. It is not immediately clear why one would need a method to refer to a directory which one has already reached, but there are situations where this comes in quite handy. For example, you may know (or could look up in Chapter 8) that the shell searches program files for external commands in the directories listed in the environment variable `PATH`. If you, as a software developer, want to invoke a program, let's call it `prog`, which (a) resides in a file within the current directory, and (b) this directory is not listed in `PATH` (always a good idea for security reasons), you can still get the shell to start your file as a program by saying

```
$ ./prog
```

without having to enter an absolute path name.

As a Linux user you have a "home directory" which you enter immediately after logging in to the system. The system administrator determines that directory's name when they create your user account, but it is usually called the same as your user name and located below `/home`—something like `/home/joe` for the user `joe`.

6.2 Directory Commands

6.2.1 The Current Directory: `cd` & Co.

Changing directory

You can use the `cd` shell command to change the current directory: Simply give the desired directory as a parameter:

```
$ cd letters                    Change to the letters directory
$ cd ..                         Change to the directory above
```

If you do not give a parameter you will end up in your home directory:

```
$ cd
$ pwd
/home/joe
```

current directory

You can output the absolute path name of the current directory using the `pwd` ("print working directory") command.

prompt

Possibly you can also see the current directory as part of your prompt: Depending on your system settings there might be something like

```
joe@red:~/letters> _
```

where `~/letters` is short for `/home/joe/letters`; the tilde ("~") stands for the current user's home directory.

The "`cd -`" command changes to the directory that used to be current before the most recent `cd` command. This makes it convenient to alternate between two directories.

Exercises

6.1 [2] In the shell, is `cd` an internal or an external command? Why?

6.2 [3] Read about the `pushd`, `popd`, and `dirs` commands in the `bash` man page. Convince yourself that these commands work as described there.

Table 6.1: Some file type designations in `ls`

File type	Colour	Suffix (`ls -F`)	Type letter (`ls -l`)
plain file	black	none	`-`
executable file	green	`*`	`-`
directory	blue	`/`	`d`
link	cyan	`@`	`l`

Table 6.2: Some `ls` options

Option	Result
`-a` or `--all`	Displays hidden files as well
`-i` or `--inode`	Displays the unique file number (inode number)
`-l` or `--format=long`	Displays extra information
`-o` or `--no-color`	Omits colour-coding the output
`-p` or `-F`	Marks file type by adding a special character
`-r` or `--reverse`	Reverses sort order
`-R` or `--recursive`	Recurses into subdirectories (DOS: `DIR/S`)
`-S` or `--sort=size`	Sorts files by size (longest first)
`-t` or `--sort=time`	Sorts file by modification time (newest first)
`-X` or `--sort=extension`	Sorts file by extension ("file type")

6.2.2 Listing Files and Directories—`ls`

To find one's way around the directory tree, it is important to be able to find out which files and directories are located within a directory. The `ls` ("list") command does this.

Tabular format

Without options, this information is output as a multi-column table sorted by file name. With colour screens being the norm rather than the exception today, it has become customary to display the names of files of different types in various colours. (We have not talked about file types yet; this topic will be mentioned in Chapter 9.)

Thankfully, by now most distributions have agreed about the colours to use. Table 6.1 shows the most common assignment.

On monochrome monitors—which can still be found—, the options `-F` or `-p` recommend themselves. These will cause special characters to be appended to the file names according to the file's type. A subset of these characters is given in Table 6.1.

Hidden files

Additional information

You can display hidden files (whose names begin with a dot) by giving the `-a` ("all") option. Another very useful option is `-l` (a lowercase "L", for "long", rather than the digit "1"). This displays not only the file names, but also some additional information about each file.

Some Linux distributions pre-set abbreviations for some combinations of helpful options; the SUSE distributions, for example, use a simple `l` as an abbreviation of "`ls -alF`". "`ll`" and "`la`" are also abbreviations for `ls` variants.

Here is an example of `ls` without and with `-l`:

```
$ ls
file.txt
file2.dat
$ ls -l
```

```
-rw-r--r--  1  joe users   4711  Oct 4 11:11 file.txt
-rw-r--r--  1  joe users    333  Oct 2 13:21 file2.dat
```

In the first case, all visible (non-hidden) files in the directory are listed; the second case adds the extra information.

The different parts of the long format have the following meanings: The first character gives the file type (see Chapter 9); plain files have "`-`", directories "`d`" and so on ("type character" in Table 6.1). Long format

The next nine characters show the access permissions. Next there are a reference counter, the owner of the file (`joe` here), and the file's group (`users`). After the size of file in bytes, you can see the date and time of the last modification of the file's content. On the very right there is the file's name.

Depending on the language you are using, the date and time columns in particular may look completely different than the ones in our example (which we generated using the minimal language environment "`C`"). This is usually not a problem in interactive use, but may prove a major nuisance if you try to take the output of "`ls -l`" apart in a shell script. (Without wanting to anticipate the training manual *Advanced Linux*, we recommend setting the language environment to a defined value in shell scripts.)

If you want to see the extra information for a directory (such as `/tmp`), "`ls -l /tmp`" doesn't really help, because `ls` will list the data for all the files within `/tmp`. Use the `-d` option to suppress this and obtain the information about `/tmp` itself.

`ls` supports many more options than the ones mentioned here; a few of the more important ones are shown in Table 6.2.

In the LPI exams, *Linux Essentials* and LPI-101, nobody expects you to know all 57 varieties of `ls` options by heart. However, you may wish to commit the most import half dozen or so—the content of Table 6.2, approximately—to memory.

Exercises

6.3 [1] Which files does the `/boot` directory contain? Does the directory have subdirectories and, if so, which ones?

6.4 [2] Explain the difference between `ls` with a file name argument and `ls` with a directory name argument.

6.5 [2] How do you tell `ls` to display information about a *directory* rather than the *files* in that directory, if a directory name is passed to the program? (*Hint:* Documentation.)

6.2.3 Creating and Deleting Directories: `mkdir` and `rmdir`

To keep your own files in good order, it makes sense to create new directories. You can keep files in these "folders" according to their subject matter (for example). Of course, for further structuring, you can create further directories within such directories—your ambition will not be curbed by arbitrary limits.

To create new directories, the `mkdir` command is available. It requires one or more directory names as arguments, otherwise you will only obtain an error message instead of a new directory. To create nested directories in a single step, you can use the `-p` option, otherwise the command assumes that all directories in a path name except the last one already exist. For example: Creating directories

```
$ mkdir pictures/holiday
mkdir: cannot create directory `pictures/holiday': No such file▷
 ◁ or directory
$ mkdir -p pictures/holiday
$ cd pictures
$ ls -F
holiday/
```

Removing directories

Sometimes a directory is no longer required. To reduce clutter, you can remove it using the `rmdir` ("remove directory") command.

As with `mkdir`, at least one path name of a directory to be deleted must be given. In addition, the directories in question must be empty, i. e., they may not contain entries for files, subdirectories, etc. Again, only the last directory in every name will be removed:

```
$ rmdir pictures/holiday
$ ls -F
◁◁◁◁◁
pictures/
◁◁◁◁◁
```

With the `-p` option, all empty subdirectories mentioned in a name can be removed in one step, beginning with the one on the very right.

```
$ mkdir -p pictures/holiday/summer
$ rmdir pictures/holiday/summer
$ ls -F pictures
pictures/holiday/
$ rmdir -p pictures/holiday
$ ls -F pictures
ls: pictures: No such file or directory
```

Exercises

6.6 [!2] In your home directory, create a directory `grd1-test` with subdirectories `dir1`, `dir2`, and `dir3`. Change into directory `grd1-test/dir1` and create (e. g., using a text editor) a file called `hello` containing "`hello`". In `grd1-test/dir2`, create a file `howdy` containing "`howdy`". Check that these files do exist. Delete the subdirectory `dir3` using `rmdir`. Next, attempt to remove the subdirectory `dir2` using `rmdir`. What happens, and why?

6.3 File Search Patterns

6.3.1 Simple Search Patterns

You will often want to apply a command to several files at the same time. For example, if you want to copy all files whose names start with "`p`" and end with "`.c`" from the `prog1` directory to the `prog2` directory, it would be quite tedious to have to name every single file explictly—at least if you need to deal with more than a couple of files! It is much more convenient to use the shell's search patterns.

search patterns

asterisk

If you specify a parameter containing an asterisk on the shell command line—like

```
prog1/p*.c
```

—the shell replaces this parameter in the actual program invocation by a sorted list of all file names that "match" the parameter. "Match" means that in the actual file name there may be an arbitrary-length sequence of arbitrary characters in place of the asterisk. For example, names like

```
prog1/p1.c
prog1/polly.c
prog1/pop-rock.c
prog1/p.c
```

are eligible (note in particular the last name in the example—"arbitrary length" does include "length zero"!). The only character the asterisk will not match is—can you guess it?—the slash; it is usually better to restrict a search pattern like the asterisk to the current directory.

You can test these search patterns conveniently using `echo`. The

```
$ echo prog1/p*.c
```

command will output the matching file names without any obligation or consequence of any kind.

If you really want to apply a command to all files in the *directory tree* starting with a particular directory, there are ways to do that, too. We will discuss this in Section 6.4.4.

All files

The search pattern "*" describes "all files in the current directory"—excepting hidden files whose name starts with a dot. To avert possibly inconvenient surprises, search patterns diligently ignore hidden files unless you explicitly ask for them to be included by means of something like ".*".

You may have encountered the asterisk at the command line of operating systems like DOS or Windows[1] and may be used to specifying the "*.*" pattern to refer to all files in a directory. On Linux, this is not correct—the "*.*" pattern matches "all files whose name contains a dot", but the dot isn't mandatory. The Linux equivalent, as we said, is "*".

question mark

A question mark as a search pattern stands for exactly one arbitrary character (again excluding the slash). A pattern like

```
p?.c
```

thus matches the names

```
p1.c
pa.c
p-.c
p..c
```

(among others). Note that there must be one character—the "nothing" option does not exist here.

You should take particular care to remember a very important fact: *The expansion of search pattern is the responsibility of the shell!* The commands that you execute usually know nothing about search patterns and don't care about them, either. All they get to see are lists of path names, but not where they come from—i. e., whether they have been typed in directly or resulted from the expansion of search patterns.

[1] You're probably too young for CP/M.

Incidentally, nobody says that the results of search patterns always need to be interpreted as path names. For example, if a directory contains a file called "`-l`", a "`ls *`" in that directory will yield an interesting and perhaps surprising result (see Exercise 6.9).

What happens if the shell cannot find a file whose name matches the search pattern? In this case the command in question is passed the search pattern as such; what it makes of that is its own affair. Typically such search patterns are interpreted as file names, but the "file" in question is not found and an error message is issued. However, there are commands that can do useful things with search patterns that you pass them—with them, the challenge is really to ensure that the shell invoking the command does *not* try to cut in with its own expansion. (Cue: quotes)

6.3.2 Character Classes

A somewhat more precise specification of the matching characters in a search pattern is offered by "character classes": In a search pattern of the form

```
prog[123].c
```

the square brackets match exactly those characters that are enumerated within them (no others). The pattern in the example therefore matches

```
prog1.c
prog2.c
prog3.c
```

but not

`prog.c`	*There needs to be exactly one character*
`prog4.c`	*4 was not enumerated*
`proga.c`	*a neither*
`prog12.c`	*Exactly one character, please*

ranges As a more convenient notation, you may specify ranges as in

```
prog[1-9].c
[A-Z]bracadabra.txt
```

The square brackets in the first line match all digits, the ones in the second all uppercase letters.

Note that in the common character encodings the letters are not contiguous: A pattern like

```
prog[A-z].c
```

not only matches `progQ.c` and `progx.c`, but also `prog_.c`. (Check an ASCII table, e. g. using "`man ascii`".) If you want to match "uppercase and lowercase letters only", you need to use

```
prog[A-Za-z].c
```

A construct like

```
prog[A-Za-z].c
```

does not catch umlauts, even if they look suspiciously like letters.

As a further convenience, you can specify negated character classes, which are interpreted as "all characters except these": Something like

negated classes

```
prog[!A-Za-z].c
```

matches all names where the character between "g" and "." is *not* a letter. As usual, the slash is excepted.

6.3.3 Braces

The expansion of braces in expressions like

```
{red,yellow,blue}.txt
```

is often mentioned in conjunction with shell search patterns, even though it is really just a distant relative. The shell replaces this by

```
red.txt yellow.txt blue.txt
```

In general, a word on the command line that contains several comma-separated pieces of text within braces is replaced by as many words as there are pieces of text between the braces, where in each of these words the whole brace expression is replaced by one of the pieces. *This replacement is purely based on the command line text and is completely independent of the existence or non-existence of any files or directories*—unlike search patterns, which always produce only those names that actually exist as path names on the system.

You can have more than one brace expression in a word, which will result in the cartesian product, in other words all possible combinations:

cartesian product

```
{a,b,c}{1,2,3}.dat
```

produces

```
a1.dat a2.dat a3.dat b1.dat b2.dat b3.dat c1.dat c2.dat c3.dat
```

This is useful, for example, to create new directories systematically; the usual search patterns cannot help there, since they can only find things that already exist:

```
$ mkdir -p revenue/200{8,9}/q{1,2,3,4}
```

Exercises

6.7 [!1] The current directory contains the files

```
prog.c   prog1.c  prog2.c  progabc.c  prog
p.txt    p1.txt   p21.txt  p22.txt    p22.dat
```

Which of these names match the search patterns (a) `prog*.c`, (b) `prog?.c`, (c) `p?*.txt`, (d) `p[12]*`, (e) `p*`, (f) `*.*`?

6.8 [!2] What is the difference between "`ls`" and "`ls *`"? (*Hint:* Try both in a directory containing subdirectories.)

6.9 [2] Explain why the following command leads to the output shown:

Table 6.3: Options for `cp`

Option		Result
`-b`	(*backup*)	Makes backup copies of existing target files by appending a tilde to their names
`-f`	(*force*)	Overwrites existing target files without prompting
`-i`	(engl. *interactive*)	Asks (once per file) whether existing target files should be overwritten
`-p`	(engl. *preserve*)	Tries to preserve all attributes of the source file for the copy
`-R`	(engl. *recursive*)	Copies directories with all their content
`-u`	(engl. *update*)	Copies only if the source file is newer than the target file (or the target file doesn't exist)
`-v`	(engl. *verbose*)	Displays all activity on screen

```
$ ls
-l  file1  file2  file3
$ ls *
-rw-r--r-- 1 joe users 0 Dec 19 11:24 file1
-rw-r--r-- 1 joe users 0 Dec 19 11:24 file2
-rw-r--r-- 1 joe users 0 Dec 19 11:24 file3
```

6.10 [2] Why does it make sense for "*" not to match file names starting with a dot?

6.4 Handling Files

6.4.1 Copying, Moving and Deleting—`cp` and Friends

Copying files

You can copy arbitrary files using the `cp` ("copy") command. There are two basic approaches:

1 : 1 copy

If you tell `cp` the source and target file names (two arguments), then a 1 : 1 copy of the content of the source file will be placed in the target file. Normally `cp` does not ask whether it should overwrite the target file if it already exists, but just does it—caution (or the `-i` option) is called for here.

You can also give a target directory name instead of a target file name. The source file will then be copied to that directory, keeping its old name.

```
$ cp list list2
$ cp /etc/passwd .
$ ls -l
-rw-r--r--  1  joe  users   2500  Oct 4 11:11 list
-rw-r--r--  1  joe  users   2500  Oct 4 11:25 list2
-rw-r--r--  1  joe  users   8765  Oct 4 11:26 passwd
```

In this example, we first created an exact copy of file `list` under the name `list2`. After that, we copied the `/etc/passwd` file to the current directory (represented by the dot as a target directory name). The most important `cp` options are listed in Table 6.3.

List of source files

Instead of a single source file, a longer list of source files (or a shell wildcard pattern) is allowed. However, this way it is not possible to copy a file to a different name, but only to a different directory. While in DOS it is possible to use "`COPY *.TXT *.BAK`" to make a backup copy of every `TXT` file to a file with the same name and a `BAK` suffix, the Linux command "`cp *.txt *.bak`" usually fails with an error message.

To understand this, you have to visualise how the shell executes this command. It tries first to replace all wildcard patterns with the corresponding file names, for example `*.txt` by `letter1.txt` and `letter2.txt`. What happens to `*.bak` depends on the expansion of `*.txt` and on whether there are matching file names for `*.bak` in the current directory—but the outcome will almost never be what a DOS user would expect! Usually the shell will pass the `cp` command the unexpanded `*.bak` wildcard pattern as the final argument, which fails from the point of view of `cp` since this is (unlikely to be) an existing directory name.

While the `cp` command makes an exact copy of a file, physically duplicating the file on the storage medium or creating a new, identical copy on a different storage medium, the `mv` ("move") command serves to move a file to a different place or change its name. This is strictly an operation on directory contents, unless the file is moved to a different file system—for example from a hard disk partition to a USB key. In this case it is necessary to move the file around physically, by copying it to the new place and removing it from the old.

Move/rename files

The syntax and rules of `mv` are identical to those of `cp`—you can again specify a list of source files instead of merely one, and in this case the command expects a directory name as the final argument. The main difference is that `mv` lets you rename directories as well as files.

The `-b`, `-f`, `-i`, `-u`, and `-v` options of `mv` correspond to the eponymous ones described with `cp`.

```
$ mv passwd list2
$ ls -l
-rw-r--r--  1  joe  users   2500  Oct 4 11:11 list
-rw-r--r--  1  joe  users   8765  Oct 4 11:26 list2
```

In this example, the original file `list2` is replaced by the renamed file `passwd`. Like `cp`, `mv` does not ask for confirmation if the target file name exists, but overwrites the file mercilessly.

The command to delete files is called `rm` ("remove"). To delete a file, you must have write permission in the corresponding directory. Therefore you are "lord of the manor" in your own home directory, where you can remove even files that do not properly belong to you.

Deleting files

Write permission on a file, on the other hand, is completely irrelevant as far as deleting that file is concerned, as is the question to which user or group the file belongs.

`rm` goes about its work just as ruthlessly as `cp` or `mv`—the files in question are obliterated from the file system without confirmation. You should be especially careful, in particular when shell wildcard patterns are used. Unlike in DOS, the dot in a Linux file name is a character without special significance. For this reason, the "`rm *`" command deletes all non-hidden files from the current directory. Subdirectories will remain unscathed; with "`rm -r *`" they can also be removed.

Deleting is forever!

As the system administrator, you can trash the whole system with a command such as "`rm -rf /`"; utmost care is required! It is easy to type "`rm -rf foo *`" instead of "`rm -rf foo*`".

Where `rm` removes all files whose names are passed to it, "`rm -i`" proceeds a little more carefully:

```
$ rm -i lis*
rm: remove 'list'? n
rm: remove 'list2'? y
$ ls -l
-rw-r--r--  1  joe  users   2500  Oct 4 11:11 list
```

The example illustrates that, for each file, `rm` asks whether it should be removed ("y" for "yes") or not ("n" for "no").

Desktop environments such as KDE usually support the notion of a "dustbin" which receives files deleted from within the file manager, and which makes it possible to retrieve files that have been removed inadvertently. There are similar software packages for the command line.

In addition to the `-i` and `-r` options, `rm` allows `cp`'s `-v` and `-f` options, with similar results.

Exercises

6.11 [!2] Create, within your home directory, a copy of the file `/etc/services` called `myservices`. Rename this file to `srv.dat` and copy it to the `/tmp` directory (keeping the new name intact). Remove both copies of the file.

6.12 [1] Why doesn't `mv` have an `-R` option (like `cp` has)?

6.13 [!2] Assume that one of your directories contains a file called "`-file`" (with a dash at the start of the name). How would you go about removing this file?

6.14 [2] If you have a directory where you do not want to inadvertently fall victim to a "`rm *`", you can create a file called "`-i`" there, as in

```
$ > -i
```

(will be explained in more detail in Chapter 7). What happens if you now execute the "`rm *`" command, and why?

6.4.2 Linking Files—`ln` and `ln -s`

Linux allows you to create references to files, so-called "links", and thus to assign several names to the same file. But what purpose does this serve? The applications range from shortcuts for file and directory names to a "safety net" against unwanted file deletions, to convenience for programmers, to space savings for large directory trees that should be available in several versions with only small differences.

The `ln` ("link") command assigns a new name (second argument) to a file in addition to its existing one (first argument):

```
$ ln list list2
$ ls -l
-rw-r--r--  2  joe  users   2500  Oct 4 11:11 list
-rw-r--r--  2  joe  users   2500  Oct 4 11:11 list2
```

A file with multiple names
reference counter

The directory now appears to contain a new file called `list2`. Actually, there are just two references to the same file. This is hinted at by the **reference counter** in the second column of the "`ls -l`" output. Its value is 2, denoting that the file really has two names. Whether the two file names really refer to the same file can only be decided using the "`ls -i`" command. If this is the case, the file number in the first column must be identical for both files. File numbers, also called **inode numbers**, identify files uniquely within their file system:

inode numbers

```
$ ls -i
876543 list  876543 list2
```


"Inode" is short for "indirection node". Inodes store all the information that the system has about a file, except for the name. There is exactly one inode per file.

If you change the content of one of the files, the other's content changes as well, since in fact there is only one file (with the unique inode number 876543). We only gave that file another name.


Directories are simply tables mapping file names to inode numbers. Obviously there can be several entries in a table that contain different names but the same inode number. A directory entry with a name and inode number is called a "link".

You should realise that, for a file with two links, it is quite impossible to find out which name is "the original", i. e., the first parameter within the `ln` command. From the system's point of view both names are completely equivalent and indistinguishable.


Incidentally, links to directories are not allowed on Linux. The only exceptions are "." and "..", which the system maintains for each directory. Since directories are also files and have their own inode numbers, you can keep track of how the file system fits together internally. (See also Exercise 6.19).

Deleting one of the two files decrements the number of names for file no. 876543 (the reference counter is adjusted accordingly). Not until the reference counter reachers the value of 0 will the file's content actually be removed.

```
$ rm list
$ ls -li
876543 -rw-r--r--  1  joe  users   2500  Oct 4 11:11 list2
```


Since inode numbers are only unique within the same physical file system (disk partition, USB key, …), such links are only possible within the same file system where the file resides.


The explanation about deleting a file's content was not exactly correct: If the last file name is removed, a file can no longer be opened, but if a process is still using the file it can go on to do so until it explicitly closes the file or terminates. In Unix software this is a common idiom for handling temporary files that are supposed to disappear when the program exits: You create them for reading and writing and "delete" them immediately afterwards without closing them within your program. You can then write data to the file and later jump back to the beginning to reread them.


You can invoke `ln` not just with two file name arguments but also with one or with many. In the first case, a link with the same name as the original will be created in the current directory (which should really be different from the one where the file is located), in the second case all named files will be "linked" under their original names into the diréctory given as the last argument (think `mv`).

You can use the "`cp -l`" command to create a "link farm". This means that instead of copying the files to the destination (as would otherwise be usual), links to the originals will be created:

link farm

```
$ mkdir prog-1.0.1                                    New directory
$ cp -l prog-1.0/* prog-1.0.1
```

The advantage of this approach is that the files still exist only once on the disk, and thus take up space only once. With today's prices for disk storage this may not be compellingly necessary—but a common application of this idea, for example, consists of making periodic backup copies of large file hierarchies which should appear on the backup medium (disk or remote computer) as separate, date-stamped file hierarchies. Experience teaches that most files only change very rarely, and if these files then need to be stored just once instead of over and over again, this tends to add up over time. In addition, the files do not need to be written to the backup medium time and again, and that can save considerable time.

Backup packages that adopt this idea include, for example, Rsnapshot (`http://www.rsnapshot.org/`) or Dirvish (`http://www.dirvish.org/`).

This approach should be taken with a certain amount of caution. Using links may let you "deduplicate" identical files, but not identical directories. This means that for every date-stamped file hierarchy on the backup medium, all directories must be created anew, even if the directories only contain links to existing files. This can lead to very complicated directory structures and, in the extreme case, to consistency checks on the backup medium failing because the computer does not have enough virtual memory to check the directory hierarchy.

You will also need to watch out if – as alluded to in the example – you make a "copy" of a program's source code as a link farm (which in the case of, e. g., the Linux source code could really pay off): Before you can modify a file in your newly-created version, you will need to ensure that it is really a separate file and not just a link to the original (which you will very probably not want to change). This means that you either need to manually replace the link to the file by an actual copy of the file, or else use an editor which writes modified versions as separate files automatically[2].

This is not all, however: There are two different kinds of link in Linux systems. The type explained above is the default case for the `ln` command and is called a "hard link". It always uses a file's inode number for identification. In addition, there are **symbolic links** (also called "soft links" in contrast to "hard links"). Symbolic links are really files containing the name of the link's "target file", together with a flag signifying that the file is a symbolic link and that accesses should be redirected to the target file. Unlike with hard links, the target file does not "know" about the symbolic link. Creating or deleting a symbolic link does not impact the target file in any way; when the target file is removed, however, the symbolic link "dangles", i.e., points nowhere (accesses elicit an error message).

symbolic links

Links to directories

In contrast to hard links, symbolic links allow links to directories as well as files on different physical file systems. In practice, symbolic links are often preferred, since it is easier to keep track of the linkage by means of the path name.

Symbolic links are popular if file or directory names change but a certain backwards compatibility is desired. For example, it was agreed that user mailboxes (that store unread e-mail) should be stored in the `/var/mail` directory. Traditionally, this directory was called `/var/spool/mail`, and many programs hard-code this value internally. To ease a transition to `/var/mail`, a distribution can set up a symbolic link under the name of `/var/spool/mail` which points to `/var/mail`. (This would be impossible using hard links, since hard links to directories are not allowed.)

To create a symbolic link, you must pass the `-s` option to `ln`:

```
$ ln -s /var/log short
$ ls -l
```

[2] If you use Vim (a. k. a `vi`, you can add the "`set backupcopy=auto,breakhardlink`" command to the `.vimrc` file in your home directory.

```
-rw-r--r--  1  joe  users   2500  Oct 4 11:11 liste2
lrwxrwxrwx  1  joe  users     14  Oct 4 11:40 short -> /var/log
$ cd short
$ pwd -P
/var/log
```

Besides the `-s` option to create "soft links", the `ln` command supports (among others) the `-b`, `-f`, `-i`, and `-v` options discussed earlier on.

To remove symbolic links that are no longer required, delete them using `rm` just like plain files. *This* operation applies to the link rather than the link's target.

```
$ cd
$ rm short
$ ls
liste2
```

As you have seen above, "`ls -l`" will, for symbolic links, also display the file that the link is pointing to. With the `-L` and `-H` options, you can get `ls` to resolve symbolic links directly:

```
$ mkdir dir
$ echo XXXXXXXXXX >dir/file
$ ln -s file dir/symlink
$ ls -l dir
total 4
-rw-r--r-- 1 hugo users 11 Jan 21 12:29 file
lrwxrwxrwx 1 hugo users  5 Jan 21 12:29 symlink -> file
$ ls -lL dir
-rw-r--r-- 1 hugo users 11 Jan 21 12:29 file
-rw-r--r-- 1 hugo users 11 Jan 21 12:29 symlink
$ ls -lH dir
-rw-r--r-- 1 hugo users 11 Jan 21 12:29 file
lrwxrwxrwx 1 hugo users  5 Jan 21 12:29 symlink -> file
$ ls -l dir/symlink
lrwxrwxrwx 1 hugo users 5 Jan 21 12:29 dir/symlink -> file
$ ls -lH dir/symlink
-rw-r--r-- 1 hugo users 11 Jan 21 12:29 dir/symlink
```

The difference between `-L` and `-H` is that the `-L` option *always* resolves symbolic links and displays information about the actual file (the name shown is still always the one of the link, though). The `-H`, as illustrated by the last three commands in the example, does that only for links that have been directly given on the command line.

`cp` and symbolic links

By analogy to "`cp -l`", the "`cp -s`" command creates link farms based on symbolic links. These, however, are not quite as useful as the hard-link-based ones shown above. "`cp -a`" copies directory hierarchies as they are, keeping symbolic links as they are; "`cp -L`" arranges to replace symbolic links by their targets in the copy, and "`cp -P`" precludes that.

Exercises

6.15 [!2] In your home directory, create a file with arbitrary content (e. g., using "`echo Hello >~/hello`" or a text editor). Create a hard link to that file called `link`. Make sure that the file now has two names. Try changing the file with a text editor. What happens?

6.16 [!2] Create a symbolic link called `~/symlink` to the file in the previous exercise. Check whether accessing the file via the symbolic link works. What happens if you delete the file (name) the symbolic link is pointing to?

Table 6.4: Keyboard commands for `more`

Key	Result
↩	Scrolls up a line
␣	Scrolls up a screenful
b	Scrolls back a screenful
h	Displays help
q	Quits `more`
/ ⟨*word*⟩ ↩	Searches for ⟨*word*⟩
! ⟨*command*⟩ ↩	Executes ⟨*command*⟩ in a subshell
v	Invokes editor (`vi`)
Ctrl + l	Redraws the screen

6.17 [!2] What directory does the `..` link in the "`/`" directory point to?

6.18 [3] Consider the following command and its output:

```
$ ls -ai /
     2 .      330211 etc         1 proc   4303 var
     2 ..          2 home    65153 root
  4833 bin    244322 lib    313777 sbin
228033 boot   460935 mnt    244321 tmp
330625 dev    460940 opt    390938 usr
```

Obviously, the `/` and `/home` directories have the same inode number. Since the two evidently cannot be the same directory—can you explain this phenomenon?

6.19 [3] We mentioned that hard links to directories are not allowed. What could be a reason for this?

6.20 [3] How can you tell from the output of "`ls -l ~`" that a *subdirectory* of `~` contains no further subdirectories?

6.21 [2] How do "`ls -lH`" and "`ls -lL`" behave if a symbolic link points to a different symbolic link?

6.22 [3] What is the maximum length of a "chain" of symbolic links? (In other words, if you start with a symbolic link to a file, how often can you create a symbolic link that points to the previous symbolic link?)

6.23 [4] (Brainteaser/research exercise:) What requires more space on disk, a hard link or a symbolic link? Why?

6.4.3 Displaying File Content—`more` and `less`

display of text files

A convenient display of text files on screen is possible using the `more` command, which lets you view long documents page by page. The output is stopped after one screenful, and "`--More--`" appears in the final line (possibly followed by the percentage of the file already displayed). The output is continued after a key press. The meanings of various keys are explained in Table 6.4.

Options

`more` also understands some options. With `-s` ("squeeze"), runs of empty lines are compressed to just one, the `-l` option ignores page ejects (usually represented by "`^L`") which would otherwise stop the output. The `-n` ⟨*number*⟩ option sets the number of screen lines to ⟨*number*⟩, otherwise `more` takes the number from the terminal definition pointed to by `TERM`.

`more`'s output is still subject to vexing limitations such as the general impossibility of moving back towards the beginning of the output. Therefore, the improved

Table 6.5: Keyboard commands for `less`

Key	Result
↓ or e or j or ↩	Scrolls up one line
f or ␣	Scrolls up one screenful
↑ or y or k	Scrolls back one line
b	Scrolls back one screenful
Home or g	Jumps to the beginning of the text
End or Shift ⇑ + g	Jumps to the end of the text
p ⟨*percent*⟩ ↩	Jumps to position ⟨*percent*⟩ (in %) of the text
h	Displays help
q	Quits `less`
/ ⟨*word*⟩ ↩	Searches for ⟨*word*⟩ towards the end
n	Continues search towards the end
? ⟨*word*⟩ ↩	Searches for ⟨*word*⟩ towards the beginning
Shift ⇑ + n	Continues search towards the beginning
! ⟨*command*⟩ ↩	Executes ⟨*command*⟩ in subshell
v	Invokes editor (`vi`)
r or Ctrl + l	Redraws screen

version `less` (a weak pun—think "less is more") is more [sic!] commonly seen today. `less` lets you use the cursor keys to move around the text as usual, the search routines have been extended and allow searching both towards the end as well as towards the beginning of the text. The most common keyboard commands are summarised in Table 6.5. `less`

As mentioned in Chapter 4, `less` usually serves as the display program for manual pages via `man`. All the commands are therefore available when perusing manual pages.

6.4.4 Searching Files—`find`

Who does not know the following feeling: "There used to be a file `foobar` … but where did I put it?" Of course you can tediously sift through all your directories by hand. But Linux would not be Linux if it did not have something handy to help you.

The `find` command searches the directory tree recursively for files matching a set of criteria. "Recursively" means that it considers subdirectories, their subdirectories and so on. `find`'s result consists of the path names of matching files, which can then be passed on to other programs. The following example introduces the command structure:

```
$ find . -user joe -print
./list
```

This searches the current directory including all subdirectories for files belonging to the user `joe`. The `-print` command displays the result (a single file in our case) on the terminal. For convenience, if you do not specify what to do with matching files, `-print` will be assumed.

Note that `find` needs some arguments to go about its task.

Starting Directory The starting directory should be selected with care. If you pick the root directory, the required file(s)—if they exist—will surely be found, but the search may take a long time. Of course you only get to search those files where you have appropriate privileges.

Absolute or relative path names?

An absolute path name for the start directory causes the file names in the output to be absolute, a relative path name for the start directory accordingly produces relative path names.

Directory list

Instead of a single start directory, you can specify a list of directories that will be searched in turn.

Test Conditions These options describe the requirements on the files in detail. Table 6.6 shows the most important tests. The `find` documentation explains many more.

Table 6.6: Test conditions for `find`

Test	Description
`-name`	Specifies a file name pattern. All shell search pattern characters are allowed. The `-iname` option ignores case differences.
`-type`	Specifies a file type (see Section 9.2). This includes: `b` block device file `c` character device file `d` directory `f` plain file `l` symbolic link `p` FIFO (named pipe) `s` Unix domain socket
`-user`	Specifies a user that the file must belong to. User names as well as numeric UIDs can be given.
`-group`	Specifies a group that the file must belong to. As with `-user`, a numeric GID can be specified as well as a group name.
`-size`	Specifies a particular file size. Plain numbers signify 512-byte blocks; bytes or kibibytes can be given by appending `c` or `k`, respectively. A preceding plus or minus sign stands for a lower or upper limit; `-size +10k`, for example, matches all files bigger than 10 KiB.
`-atime`	(engl. *access*) allows searching for files based on the time of last access (reading or writing). This and the next two tests take their argument in days; …`min` instead of …`time` produces 1-minute accuracy.
`-mtime`	(engl. *modification*) selects according to the time of modification.
`-ctime`	(engl. *change*) selects according to the time of the last inode change (including access to content, permission change, renaming, etc.)
`-perm`	Specifies a set of permissions that a file must match. The permissions are given as an octal number (see the `chmod` command. To search for a permission in particular, the octal number must be preceded by a minus sign, e.g., `-perm -20` matches all files with group write permission, regardless of their other permissions.
`-links`	Specifies a reference count value that eligible files must match.
`-inum`	Finds links to a file with a given inode number.

Multiple tests

If multiple tests are given at the same time, they are implicitly ANDed together—all of them must match. `find` does support additional logical operators (see Table 6.7).

In order to avoid mistakes when evaluating logical operators, the tests are best enclosed in parentheses. The parentheses must of course be escaped from the shell:

```
$ find . \( -type d -o -name "A*" \) -print
./.
```

Table 6.7: Logical operators for `find`

Option	Operator	Meaning
`!`	Not	The following test must not match
`-a`	And	Both tests to the left and right of `-a` must match
`-o`	Or	At least one of the tests to the left and right of `-o` must match

```
./..
./bilder
./Attic
$ _
```

This example lists all names that either refer to directories or that begin with "`A`" or both.

Actions As mentioned before, the search results can be displayed on the screen using the `-print` option. In addition to this, there are two options, `-exec` and `-ok`, which execute commands incorporating the file names. The single difference between `-ok` and `-exec` is that `-ok` asks the user for confirmation before actually executing the command; with `-exec`, this is tacitly assumed. We will restrict ourselves to discussing `-exec`.

Executing commands

There are some general rules governing the `-exec` option:

- The command following `-exec` must be terminated with a semicolon ("`;`"). Since the semicolon is a special character in most shells, it must be escaped (e.g., as "`\\;`" or using quotes) in order to make it visible to `find`.
- Two braces ("`{}`") within the command are replaced by the file name that was found. It is best to enclose the braces in quotes to avoid problems with spaces in file names.

For example:

```
$ find . -user joe -exec ls -l '{}' \;
-rw-r--r--  1  joe  users   4711  Oct 4 11:11 file.txt
$ _
```

This example searches for all files within the current directory (and below) belonging to user `test`, and executes the "`ls -l`" command for each of them. The following makes more sense:

```
$ find . -atime +13 -exec rm -i '{}' \;
```

This interactively deletes all files within the current directory (and below) that have not been accessed for two weeks.

Sometimes—say, in the last example above—it is very inefficient to use `-exec` to start a new process for every single file name found. In this case, the `xargs` command, which collects as many file names as possible before actually executing a command, can come in useful:

```
$ find . -atime +13 | xargs -r rm -i
```

`xargs` reads its standard input up to a (configurable) maximum of characters or lines and uses this material as arguments for the specified command (here `rm`). On input, arguments are separated by space characters (which can be escaped using quotes or "`\`") or newlines. The command is invoked as often

as necessary to exhaust the input.—The `-r` option ensures that `rm` is executed only if `find` actually sends a file name; otherwise it would be executed at least once.

Weird filenames can get the `find`/`xargs` combination in trouble, for example ones that contain spaces or, indeed, newlines which may be mistaken as separators. The silver bullet consists of using the "`-print0`" option to `find`, which outputs the file names just as "`-print`" does, but uses null bytes to separate them instead of newlines. Since the null byte is not a valid character in path names, confusion is no longer possible. `xargs` must be invoked using the "`-0`" option to understand this kind of input:

```
$ find . -atime +13 -print0 | xargs -0r rm -i
```

Exercises

6.24 [!2] Find all files on your system which are longer than 1 MiB, and output their names.

6.25 [2] How could you use `find` to delete a file with an unusual name (e. g., containing invisible control characters or umlauts that older shells cannot deal with)?

6.26 [3] (Second time through the book.) How would you ensure that files in `/tmp` which belong to you are deleted once you log out?

6.4.5 Finding Files Quickly—`locate` and `slocate`

The `find` command searches files according to many different criteria but needs to walk the complete directory tree below the starting directory. Depending on the tree size, this may take considerable time. For the typical application—searching files with particular names—there is an accelerated method.

The `locate` command lists all files whose names match a given shell wildcard pattern. In the most trivial case, this is a simple string of characters:

```
$ locate letter.txt
/home/joe/Letters/letter.txt
/home/joe/Letters/grannyletter.txt
/home/joe/Letters/grannyletter.txt~
◁◁◁◁◁
```

Although `locate` is a fairly important service (as emphasised by the fact that it is part of the LPIC1 curriculum), not all Linux distributions include it as part of the default installation.

For example, if you are using a SUSE distribution, you must explicitly install the `findutils-locate` package before being able to use `locate`.

The "`*`", "`?`", and "`[…]`" characters mean the same thing to `locate` as they do to the shell. But while a query *without* wildcard characters locates all file names that contain the pattern anywhere, a query *with* wildcard characters returns only those names which the pattern describes *completely*—from beginning to end. Therefore pattern queries to `locate` usually start with "`*`":

```
$ locate "*/letter.t*"
/home/joe/Letters/letter.txt
/home/joe/Letters/letter.tab
◁◁◁◁◁
```


Be sure to put quotes around `locate` queries including shell wildcard characters, to keep the shell from trying to expand them.

The slash ("/") is not handled specially:

```
$ locate Letters/granny
/home/joe/Letters/grannyletter.txt
/home/joe/Letters/grannyletter.txt~
```

`locate` is so fast because it does not walk the file system tree, but checks a "database" of file names that must have been previously created using the `updatedb` program. This means that `locate` does not catch files that have been added to the system since the last database update, and conversely may output the names of files that have been deleted in the meantime.


You can get `locate` to return existing files only by using the "`-e`" option, but this negates `locate`'s speed advantage.

The `updatedb` program constructs the database for `locate`. Since this may take considerable time, your system administrator usually sets this up to run when the system does not have a lot to do, anyway, presumably late at night.


The `cron` service which is necessary for this will be explained in detail in *Advanced Linux*. For now, remember that most Linux distributions come with a mechanism which causes `updatedb` to be run every so often.

As the system administrator, you can tell `updatedb` which files to consider when setting up the database. How that happens in detail depends on your distribution: `updatedb` itself does not read a configuration file, but takes its settings from the command line and (partly) environment variables. Even so, most distributions call `updatedb` from a shell script which usually reads a file like `/etc/updatedb.conf` or `/etc/sysconfig/locate`, where appropriate environment variables can be set up.


You may find such a file, e.g., in `/etc/cron.daily` (details may vary according to your distribution).

You can, for instance, cause `updatedb` to search certain directories and omit others; the program also lets you specify "network file systems" that are used by several computers and that should have their own database in their root directories, such that only one computer needs to construct the database.


An important configuration setting is the identity of the user that runs `updatedb`. There are essentially two possibilities:

- `updatedb` runs as `root` and can thus enter every file in its database. This also means that users can ferret out file names in directories that they would not otherwise be able to look into, for example, other users' home directories.
- `updatedb` runs with restricted privileges, such as those of user `nobody`. In this case, only names within directories readable by `nobody` end up in the database.


The `slocate` program—an alternative to the usual `locate`—circumvents this problem by storing a file's owner, group and permissions in the database in addition to the file's name. It outputs a file name only if the user who runs `slocate` can, in fact, access the file in question. `slocate` comes with an `updatedb` program, too, but this is merely another name for `slocate` itself.


In many cases, `slocate` is installed such that it can also be invoked using the `locate` command.

Exercises

6.27 [!1] `README` is a very popular file name. Give the absolute path names of all files on your system called `README`.

6.28 [2] Create a new file in your home directory and convince yourself by calling `locate` that this file is not listed (use an appropriately outlandish file name to make sure). Call `updatedb` (possibly with administrator privileges). Does `locate` find your file afterwards? Delete the file and repeat these steps.

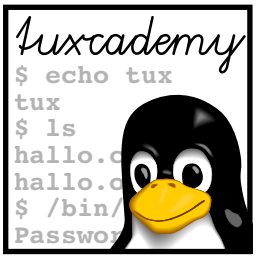
6.29 [1] Convince yourself that the `slocate` program works, by searching for files like `/etc/shadow` as normal user.

Commands in this Chapter

cd	Changes a shell's current working directory	bash(1)	67
convmv	Converts file names between character encodings	convmv(1)	64
cp	Copies files	cp(1)	74
find	Searches files matching certain given criteria	find(1), Info: find	81
less	Displays texts (such as manual pages) by page	less(1)	80
ln	Creates ("hard" or symbolic) links	ln(1)	76
locate	Finds files by name in a file name database	locate(1)	84
ls	Lists file information or directory contents	ls(1)	67
mkdir	Creates new directories	mkdir(1)	69
more	Displays text data by page	more(1)	80
mv	Moves files to different directories or renames them	mv(1)	75
pwd	Displays the name of the current working directory	pwd(1), bash(1)	67
rm	Removes files or directories	rm(1)	75
rmdir	Removes (empty) directories	rmdir(1)	70
slocate	Searches file by name in a file name database, taking file permissions into account	slocate(1)	85
updatedb	Creates the file name database for `locate`	updatedb(1)	85
xargs	Constructs command lines from its standard input	xargs(1), Info: find	83

Summary

- Nearly all possible characters may occur in file names. For portability's sake, however, you should restrict yourself to letters, digits, and some special characters.
- Linux distinguishes between uppercase and lowercase letters in file names.
- Absolute path names always start with a slash and mention all directories from the root of the directory tree to the directory or file in question. Relative path names start from the "current directory".
- You can change the current directory of the shell using the `cd` command. You can display its name using `pwd`.
- `ls` displays information about files and directories.
- You can create or remove directories using `mkdir` and `rmdir`.
- The `cp`, `mv` and `rm` commands copy, move, and delete files and directories.
- The `ln` command allows you to create "hard" and "symbolic" links.
- `more` and `less` display files (and command output) by pages on the terminal.
- `find` searches for files or directories matching certain criteria.



7

Standard I/O and Filter Commands

Contents

Goals

- Mastering shell I/O redirection
- Knowing the most important filter commands

Prerequisites

- Shell operation (see Chapter 2)
- Use of a text editor (see Chapter 5)
- File and directory handling (see Chapter 6)

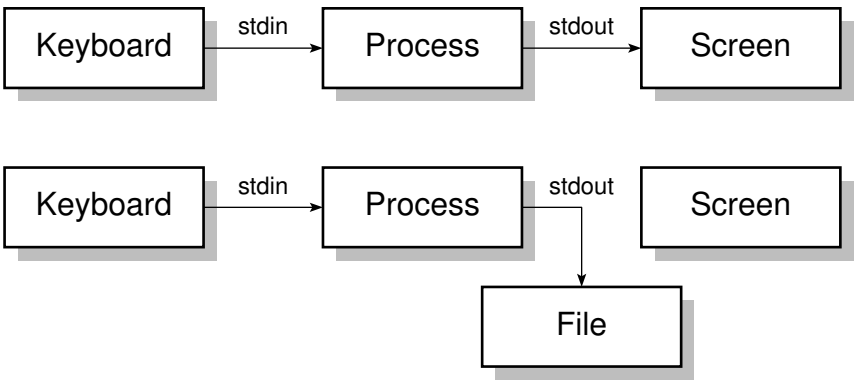


Figure 7.1: Standard channels on Linux

7.1 I/O Redirection and Command Pipelines

7.1.1 Standard Channels

Many Linux commands—like `grep` and friends—are designed to read input data, manipulate it in some way, and output the result of these manipulations. For example, if you enter

```
$ grep xyz
```

you can type lines of text on the keyboard, and `grep` will only let those pass that contain the character sequence, "xyz":

```
$ grep xyz
abc def
xyz 123
xyz 123
aaa bbb
YYYxyzZZZ
YYYxyzZZZ
Ctrl + d
```

(The key combination at the end lets `grep` know that the input is at an end.)

standard input
standard output
standard error output

We say that `grep` reads data from "standard input"—in this case, the keyboard—and writes to "standard output"—in this case, the console screen or, more likely, a terminal program in a graphical desktop environment. The third of these "standard channels" is "standard error output"; while the "payload data" `grep` produces are written to standard output, standard error output takes any error messages (e. g., about a non-existent input file or a syntax error in the regular expression).

In this chapter you will learn how to redirect a program's standard output to a file or take a program's standard input from a file. Even more importantly, you will learn how to feed one program's output directly (without the detour via a file) into another program as that program's input. This opens the door to using the Linux commands, which taken on their own are all fairly simple, as building blocks to construct very complex applications. (Think of a Lego set.)

We will not be able to exhaust this topic in this chapter. Do look forward to the manual, *Advanced Linux*, where constructing shell scripts with the commands from the Unix "toolchest" plays a very important rôle! Here is where you learn the very important fundamentals of cleverly combining Linux commands even on the command line.

Table 7.1: Standard channels on Linux

Channel	Name	Abbreviation	Device	Use
0	standard input	`stdin`	keyboard	Input for programs
1	standard output	`stdout`	screen	Output of programs
2	standard error output	`stderr`	screen	Programs' error messages

The **standard channels** are summarised once more in Table 7.1. In the patois, they are normally referred to using their abbreviated names—`stdin`, `stdout` and `stderr` for standard input, standard output, and standard error output. These channels are respectively assigned the numbers 0, 1, and 2, which we are going to use later on. standard channels

The shell can redirect these standard channels for individual commands, without the programs in question noticing anything. These always use the standard channels, even though the output might no longer be written to the screen or terminal window but some arbitrary other file. That file could be a different device, like a printer—but it is also possible to specify a text file which will receive the output. That file does not even have to exist but will be created if required. Redirection

The standard input channel can be redirected in the same way. A program no longer receives its input from the keyboard, but takes it from the specified file, which can refer to another device or a file in the proper sense.

The keyboard and screen of the "terminal" you are working on (no matter whether this is a Linux text console, a "genuine" terminal on a serial port, a terminal window in a graphical environment, or a network session using, say, the secure shell) can be accessed by means of the `/dev/tty` file—if you want to read data this means the keyboard, for output the screen (the other way round would be quite silly). The

```
$ grep xyz /dev/tty
```

would be equivalent to our example earlier on in this section. You can find out more about such "special files" from Chapter 9.)

7.1.2 Redirecting Standard Channels

You can redirect the standard output channel using the shell operator ">" (the "greater-than" sign). In the following example, the output of "`ls -laF`" is redirected to a file called `filelist`; the screen output consists merely of Redirecting standard output

```
$ ls -laF >filelist
$ __
```

If the `filelist` file does not exist it is created. Should a file by that name exist, however, its content will be overwritten. The shell arranges for this even before the program in question is invoked—the output file will thus be created even if the actual command invocation contained typos, or if the program did not indeed write any output at all (in which case the `filelist` file will remain empty).

If you want to avoid overwriting existing files using shell output redirection, you can give the `bash` command "`set -o noclobber`". In this case, if output is redirected to an existing file, an error occurs. Protecting existing files

You can look at the `filelist` file in the usual way, e. g., using `less`:

```
$ less inhalt
total 7
```

```
drwxr-xr-x  12 joe    users     1024 Aug 26 18:55 ./
drwxr-xr-x   5 root   root      1024 Aug 13 12:52 ../
drwxr-xr-x   3 joe    users     1024 Aug 20 12:30 photos/
-rw-r--r--   1 joe    users        0 Sep  6 13:50 filelist
-rw-r--r--   1 joe    users    15811 Aug 13 12:33 pingu.gif
-rw-r--r--   1 joe    users    14373 Aug 13 12:33 hobby.txt
-rw-r--r--   2 joe    users     3316 Aug 20 15:14 chemistry.txt
```

If you look closely at the content of `filelist`, you can see a directory entry for `filelist` with size 0. This is due to the shell's way of doing things: When parsing the command line, it notices the output redirection first and creates a new `filelist` file (or removes its content). After that, the shell executes the command, in this case `ls`, while connecting `ls`'s standard output to the `filelist` file instead of the terminal.

The file's length in the `ls` output is 0 because the `ls` command looked at the file information for `filelist` before anything was written to that file – even though there are three other entries above that of `filelist`. This is because `ls` first reads all directory entries, then sorts them by file name, and only then starts writing to the file. Thus `ls` sees the newly created (or emptied) file `filelist`, with no content so far.

Appending standard output to a file

If you want to append a command's output to an existing file without replacing its previous content, use the `>>` operator. If that file does not exist, it will be created in this case, too.

```
$ date >> filelist
$ less filelist
total 7
drwxr-xr-x  12 joe    users     1024 Aug 26 18:55 ./
drwxr-xr-x   5 root   root      1024 Aug 13 12:52 ../
drwxr-xr-x   3 joe    users     1024 Aug 20 12:30 photos/
-rw-r--r--   1 joe    users        0 Sep  6 13:50 filelist
-rw-r--r--   1 joe    users    15811 Aug 13 12:33 pingu.gif
-rw-r--r--   1 joe    users    14373 Aug 13 12:33 hobby.txt
-rw-r--r--   2 joe    users     3316 Aug 20 15:14 chemistry.txt
Wed Oct 22 12:31:29 CEST 2003
```

In this example, the current date and time was appended to the `filelist` file.

command substitution

Another way to redirect the standard output of a command is by using "backticks" (`` `…` ``). This is also called **command substitution**: The standard output of a command in backticks will be inserted into the command line instead of the command (and backticks); whatever results from the replacement will be executed. For example:

```
$ cat dates                                              Our little diary
22/12 Get presents
23/12 Get Christmas tree
24/12 Christmas Eve
$ date +%d/%m                                            What's the date?
23/12
$ grep `^date +%d/%m.` dates                             What's up?
23/12 Get Christmas tree
```

A possibly more convenient syntax for "`` `date` ``" is "`$(date)`". This makes it easier to nest such calls. However, this syntax is only supported by modern shells such as `bash`.

Redirecting standard input

You can use `<`, the "less-than" sign, to redirect the standard input channel. This will read the content of the specified file instead of keyboard input:

```
$ wc -w <frog.txt
1397
```

In this example, the `wc` filter command counts the words in file `frog.txt`.

There is no << redirection operator to concatenate multiple input files; to pass the content of several files as a command's input you need to use `cat`:

```
$ cat file1 file2 file3 | wc -w
```

(We shall find out more about the "|" operator in the next section.) Most programs, however, do accept one or more file names as command line arguments.

You can, however, use the << operator to take input data for a command from the lines following the command invocation in the shell. This is less interesting for interactive use than it is for shell scripts, but must be mentioned here for completeness. The feature is called a "here document". For example, in

```
$ grep Linux <<END
Roses are red,
Violets are blue,
Linux is lovely,
I know this is true.
END
```

the input to `grep` consists of the lines following the `grep` call up to the line containing only "`END`". The output of the command is

```
Linux is lovely,
```

If you specify the "end string" of a here document without quotes, shell variables will be evaluated and command substitution (using `` `…` `` or `$(…)`) will be performed on the lines of the here document. However, if the end string is quoted (single or double quotes), the here document will be processed verbatim. Compare the output of

```
$ cat <<EOF
Today's date: `date`
EOF
```

to that of

```
$ cat <<"EOF"
Today's date: `date`
EOF
```

Finally: If the here document is introduced by "<<-" instead of "<<", all tab characters will be removed from the beginning of the here document's lines. This lets you indent here documents properly in shell scripts.

Simultaneous redirection

Of course, standard input and standard output may be redirected at the same time. The output of the word-count example is written to a file called `wordcount` here:

```
$ wc -w <frog.txt >wordcount
$ cat wordcount
1397
```

standard error output

Besides the standard input and standard output channels, there is also the standard error output channel. If errors occur during a program's operation, the corresponding messages will be written to that channel. That way you will see them even if standard output has been redirected to a file. If you want to redirect standard error output to a file as well, you must state the channel number for the redirection operator—this is optional for `stdin` (`0<`) and `stdout` (`1>`) but mandatory for `stderr` (`2>`).

You can use the `>&` operator to redirect a channel to a different one:

```
make >make.log 2>&1
```

redirects standard output *and* standard error output of the `make` command to `make.log`.

Watch out: Order is important here! The two commands

```
make >make.log 2>&1
make 2>&1 >make.log
```

lead to completely different results. In the second case, standard error output will be redirected to wherever standard output goes (`/dev/tty`, where standard error output would go anyway), and then standard output will be sent to `make.log`, which, however, does not change the target for standard error output.

Exercises

7.1 [2] You can use the `-U` option to get `ls` to output a directory's entries without sorting them. Even so, after "`ls -laU >filelist`", the entry for `filelist` in the output file gives length zero. What could be the reason?

7.2 [!2] Compare the output of the commands "`ls /tmp`" and "`ls /tmp >ls-tmp.txt`" (where, in the second case, we consider the content of the `ls-tmp.txt` to be the output). Do you notice something? If so, how could you explain the phenomenon?

7.3 [!2] Why isn't it possible to replace a file by a new version in one step, for example using "`grep xyz file >file`"?

7.4 [!1] And what is wrong with "`cat foo >>foo`", assuming a non-empty file `foo`?

7.5 [2] In the shell, how would you output an error message such that it goes to standard error output?

7.1.3 Command Pipelines

Output redirection is frequently used to store the result of a program in order to continue processing it with a different command. However, this type of intermediate storage is not only quite tedious, but you must also remember to get rid of the intermediate files once they are no longer required. Therefore, Linux offers a way of linking commands directly via **pipes**: A program's output automatically becomes another program's input.

pipes

direct connection of several commands

pipeline

This direct connection of several commands into a **pipeline** is done using the `|` operator. Instead of first redirecting the output of "`ls -laF`" to a file and then looking at that file using `less`, you can do the same thing in one step without an intermediate file:

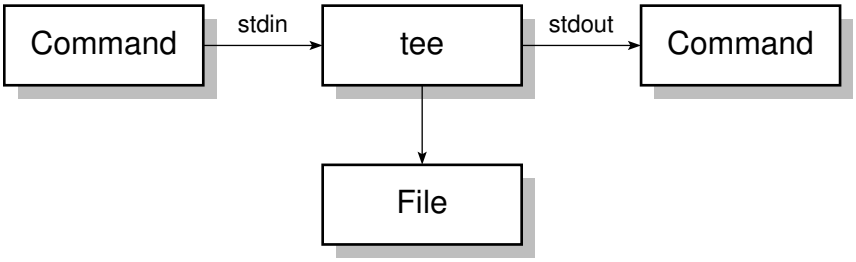


Figure 7.2: The `tee` command

```
$ ls -laF | less
total 7
drwxr-xr-x  12 joe    users     1024 Aug 26 18:55 ./
drwxr-xr-x   5 root   root      1024 Aug 13 12:52 ../
drwxr-xr-x   3 joe    users     1024 Aug 20 12:30 photos/
-rw-r--r--   1 joe    users      449 Sep  6 13:50 filelist
-rw-r--r--   1 joe    users    15811 Aug 13 12:33 pingu.gif
-rw-r--r--   1 joe    users    14373 Aug 13 12:33 hobby.txt
-rw-r--r--   2 joe    users     3316 Aug 20 15:14 chemistry.txt
```

These command pipelines can be almost any length. Besides, the final result can be redirected to a file:

```
$ cut -d: -f1 /etc/passwd | sort | pr -2 >userlst
```

This command pipeline takes all user names from the first comma-separated column of `/etc/passwd` file, sorts them alphabetically and writes them to the `userlst` file in two columns. The commands used here will be described in the remainder of this chapter.

Sometimes it is helpful to store the data stream inside a command pipeline at a certain point, for example because the intermediate result at that stage is useful for different tasks. The `tee` command copies the data stream and sends one copy to standard output and another copy to a file. The command name should be obvious if you know anything about plumbing (see Figure 7.2).

intermediate result

The `tee` command with no options creates the specified file or overwrites it if it exists; with `-a` (“append”), the output can be appended to an existing file.

```
$ ls -laF | tee list | less
total 7
drwxr-xr-x  12 joe    users     1024 Aug 26 18:55 ./
drwxr-xr-x   5 root   root      1024 Aug 13 12:52 ../
drwxr-xr-x   3 joe    users     1024 Aug 20 12:30 photos/
-rw-r--r--   1 joe    users      449 Sep  6 13:50 content
-rw-r--r--   1 joe    users    15811 Aug 13 12:33 pingu.gif
-rw-r--r--   1 joe    users    14373 Aug 13 12:33 hobby.txt
-rw-r--r--   2 joe    users     3316 Aug 20 15:14 chemistry.txt
```

In this example the content of the current directory is written both to the `list` file and the screen. (The `list` file does not show up in the `ls` output because it is only created afterwards by `tee`.)

Exercises

7.6 [!2] How would you write the same intermediate result to several files at the same time?

Table 7.2: Options for `cat` (selection)

Option	Result
`-b`	(engl. *number non-blank lines*) Numbers all non-blank lines in the output, starting at 1.
`-E`	(engl. *end-of-line*) Displays a `$` at the end of each line (useful to detect otherwise invisible space characters).
`-n`	(engl. *number*) Numbers all lines in the output, starting at 1.
`-s`	(engl. *squeeze*) Replaces sequences of empty lines by a single empty line.
`-T`	(engl. *tabs*) Displays tab characters as "`^I`".
`-v`	(engl. *visible*) Makes control characters *c* visible as "`^`*c*", characters α with character codes greater than 127 as "`M-`α".
`-A`	(engl. *show all*) Same as `-vET`.

7.2 Filter Commands

toolkit principle

One of the basic ideas of Unix—and, consequently, Linux—is the "toolkit principle". The system comes with a great number of system programs, each of which performs a (conceptually) simple task. These programs can be used as "building blocks" to construct other programs, to save the authors of those programs from having to develop the requisite functions themselves. For example, not every program contains its own sorting routines, but many programs avail themselves of the `sort` command provided by Linux. This modular structure has several advantages:

- It makes life easier for programmers, who do not need to develop (or incorporate) new sorting routines all the time.
- If `sort` receives a bug fix or performance improvement, all programs using `sort` benefit from it, too—and in most cases do not even need to be changed.

Tools that take their input from standard input and write their output to standard output are called "filter commands" or "filters" for short. Without input redirection, a filter will read its input from the keyboard. To finish off keyboard input for such a program, you must enter the key sequence Ctrl+d, which is interpreted as "end of file" by the terminal driver.

Note that the last applies to keyboard input *only*. Files on the disk may of course contain the Ctrl+d character (ASCII 4), without the system believing that the file ended at that point. This as opposed to a certain very popular operating system, which traditionally has a somewhat quaint notion of the meaning of the Control-Z (ASCII 26) character even in text files …

Many "normal" commands, such as the aforementioned `grep`, operate like filters if you do not specify input file names for them to work on.

In the remainder of the chapter you will become familiar with a selection of the most important such commands. Some commands have crept in that are not technically genuine filter commands, but all of them form important building blocks for pipelines.

7.3 Reading and Writing Files

7.3.1 Outputting and Concatenating Text Files—`cat` and `tac`

concatenating files

The `cat` ("concatenate") command is really intended to join several files named on the command line into one. If you pass just a single file name, the content of that

Table 7.3: Options for `tac` (selection)

Option	Result
`-b`	(engl. *before*) The separator is considered to occur (and be output) *in front of* a part, not behind it.
`-r`	(engl. *regular expression*) The separator is interpreted as a regular expression.
`-s` *s*	(engl. *separator*) Defines a different separator *s* (in place of `\n`) an. The separator may be several characters long.

file will be written to standard output. If you do not pass a file name at all, `cat` reads its standard input—this may seem useless, but `cat` offers options to number lines, make line ends and special characters visible or compress runs of blank lines into one (Table 7.2).

It goes without saying that only text files lead to sensible screen output with `cat`. If you apply the command to other types of files (such as the binary file `/bin/cat`), it is more than probable—on a text terminal at least—that the shell prompt will consist of unreadable characters once the output is done. In this case you can restore the normal character set by (blindly) typing `reset`. If you redirect `cat` output to a file this is of course not a problem.

text files

The "Useless Use of `cat` Award" goes to people using `cat` where it is extraneous. In most cases, commands do accept filenames and don't just read their standard input, so `cat` is not required to pass a single file to them on standard input. A command like "`cat data.txt | grep foo`" is unnecessary if you can just as well write "`grep foo data.txt`". Even if `grep` could only read its standard input, "`grep foo <data.txt`" would be shorter and would not involve an additional `cat` process.However, the whole issue is a bit more subtle; see Exercise 7.21.

Output a file's lines in reverse order

The `tac` command's name is "`cat` backwards", and it works like that, too: It reads a number of named files or its standard input and outputs the lines it has read in *reverse order*:

```
$ tac <<END
Alpha
Beta
Gamma
END
Gamma
Beta
Alpha
```

However, this is where the similarity ends already: `tac` does not support the same options as `cat` but features its own (Table 7.3). For example, you can use the `-s` option to set up an alternative separator which the program will use when reversing the input—normally the separator is a newline character, so the input is reversed line by line. Consider, for example

separator

```
$ echo A:B:C:D | tac -s :
D
C:B:A:$ _
```

(where the new shell prompt is appended directly to the last output line). This output, which at first glance looks totally weird, can be explained as follows: The input consists of the four parts "`A:`", "`B:`", "`C:`", and "`D\n`" (the separator, here "`:`" is considered to belong to the immediately preceding part, and the final newline

character is contributed by `echo`). These parts are output in reverse order, i. e., "`D\n`" comes first and then the other three, with no other intervening separators (since every part contains a perfectly workable separator already); the next shell prompt is appended immediately (without a new line) to the output. The `-b` option considers the separator to belong to the following part rather than the preceding one; with "`tac -s : -b`", our example would produce the following output:

```
:D
:C:BA$ _
```

(think it through!).

Exercises

7.7 [2] How can you check whether a directory contains files with "weird" names (e. g., ones with spaces at the end or invisible control characters in the middle)?

7.3.2 Beginning and End—`head` and `tail`

Sometimes you are only interested in part of a file: The first few lines to check whether it is the right file, or, in particular with log files, the last few entries. The `head` and `tail` commands deliver exactly that—by default, the first ten and the last ten lines of every file passed as an argument, respectively (or else as usual the first or last ten lines of their standard input). The `-n` option lets you specify a different number of lines: "`head -n 20`" returns the first 20 lines of its standard input, "`tail -n 5 data.txt`" the last 5 lines of file `data.txt`.

Tradition dictates that you can specify the number *n* of desired lines directly as "*-n*". Officially this is no longer allowed, but the Linux versions of `head` and `tail` still support it.

You can use the `-c` option to specify that the count should be in bytes, not lines: "`head -c 20`" displays the first 20 bytes of standard input, no matter how many lines they occupy. If you append a "`b`", "`k`", or "`m`" (for "blocks", "kibibytes", and "mebibytes", respectively) to the count, the count will be multiplied by 512, 1024, or 1048576, respectively.

`head` also lets you use a minus sign: "`head -c -20`" displays all of its standard input *but* the last 20 bytes.

By way of revenge, `tail` can do something that `head` does not support: If the number of lines starts with "+", it displays everything *starting with* the given line:

```
$ tail -n +3 file                                   Everything from line 3
```

The `tail` command also supports the important `-f` option. This makes `tail` wait after outputting the current end of file, to also output data that is appended later on. This is very useful if you want to keep an eye on some log files. If you pass several file names to `tail -f`, it puts a header line in front of each block of output lines telling what file the new data was written to.

Exercises

7.8 [!2] How would you output just the 13th line of the standard input?

7.9 [3] Check out "`tail -f`": Create a file and invoke "`tail -f`" on it. Then, from another window or virtual console, append something to the file using, e. g., "`echo >>…`", and observe the output of `tail`. What does it look like when `tail` is watching several files simultaneously?

Table 7.4: Options for `od` (excerpt)

Option	Result
`-A` *r*	Base of the offset at the beginning of the line. Valid values are: `d` (decimal), `o` (octal), `x` (hexadecimal), `n` (no offset at all).
`-j` *o*	Skip *o* bytes at the beginning of the input, then start writing output.
`-N` *n*	Output at most *n* bytes.
`-t` *t*	Use type specification *t*. Several `-t` options may occur, and one line will be output for each of them in the requisite format. Possible values for *t*: `a` (named character), `c` (ASCII character), `d` (signed decimal number), `f` (floating-point number), `o` (octal number), `u` (unsigned decimal number), `x` (hexadecimal number). You can append a digit to all options except `a` and `c`. This specifies how many bytes of the input should be interpreted as a unit. Details for this and for letter-based width specifiers can be found in `od`(1). If you append a `z` to an option, the printable characters of that line will be displayed to the right.
`-v`	Outputs all duplicate lines as well.
`-w` *w*	Writes *w* bytes per line; default value is 16.

7.10 [3] What happens to "`tail -f`" if the file being observed shrinks?

7.11 [3] Explain the output of the following commands:

```
$ echo Hello >/tmp/hello
$ echo "Hiya World" >/tmp/hello
```

when you have started the command

```
$ tail -f /tmp/hello
```

in a different window after the first `echo` above.

7.3.3 Just the Facts, Ma'am—`od` and `hexdump`

`cat`, `tac`, `head`, and `tail` work best with text files: Arbitrary binary files can in principle be processed, but the last three programs in particular prefer dealing with files that consist of noticeable lines. Even so, it is often useful to be able to check exactly what is in a file. A suitable tool is the `od` ("octal dump") command, which can display arbitrary data in different formats. Binary data can be displayed byte by byte or word by word in octal, hexadecimal, decimal or ASCII coding. The standard display style of `od` is as follows:

`od`

```
$ od /etc/passwd | head -3
0000000 067562 072157 074072 030072 030072 071072 067557 035164
0000020 071057 067557 035164 061057 067151 061057 071541 005150
0000040 060563 064163 067562 072157 074072 030072 030072 071072
```

At the very left there is the (octal) offset in the file where the output line starts. The eight following numbers each correspond to two bytes from the file, printed in octal. This is only useful in very specific circumstances.

Line format

Fortunately `od` supports options that let you change the output format in very many ways (Table 7.4). Most important is the `-t` option, which describes the format of the data lines. For byte-by-byte hexadecimal output, you could use, for example,

`-t`

```
$ od -txC /etc/passwd
0000000 72 6f 6f 74 3a 78 3a 30 3a 30 3a 72 6f 6f 74 3a
0000020 2f 72 6f 6f 74 3a 2f 62 69 6e 2f 62 61 73 68 0a
0000040 73 61 73 68 72 6f 6f 74 3a 78 3a 30 3a 30 3a 72
◁◁◁◁◁
```

(the offset remains octal). Here, `x` specifies "hexadecimal", and `C` specifies "bytewise". If you want to see the characters themselves in addition to the hexadecimal numbers, you can append a `z`:

```
$ od -txCz /etc/passwd
0000000 72 6f 6f 74 3a 78 3a 30 3a 30 3a 72 6f 6f 74 3a  >root:x:0:0:root:<
0000020 2f 72 6f 6f 74 3a 2f 62 69 6e 2f 62 61 73 68 0a  >/root:/bin/bash.<
0000040 73 61 73 68 72 6f 6f 74 3a 78 3a 30 3a 30 3a 72  >sashroot:x:0:0:r<
◁◁◁◁◁
```

Non-printable characters (here the `0a`—a newline character—at the end of the second line) are replaced by ".".

several type specifiers

You can also concatenate several type specifiers or put them into separate `-t` options. This gives you one line per type specifier:

```
$ od -txCc /etc/passwd
0000000 72 6f 6f 74 3a 78 3a 30 3a 30 3a 72 6f 6f 74 3a
          r   o   o   t   :   x   :   0   :   0   :   r   o   o   t   :
0000020 2f 72 6f 6f 74 3a 2f 62 69 6e 2f 62 61 73 68 0a
          /   r   o   o   t   :   /   b   i   n   /   b   a   s   h  \n
0000040 73 61 73 68 72 6f 6f 74 3a 78 3a 30 3a 30 3a 72
          s   a   s   h   r   o   o   t   :   x   :   0   :   0   :   r
◁◁◁◁◁
```

(which is identical to »`od -txC -tc /etc/passwd`«).

identical output lines

A sequence of lines that would be equal to the last previously-output line is replaced by an asterisk ("*") at the left margin:

```
$ od -tx -N 64 /dev/zero
0000000 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
*
0000100
```

(`/dev/zero` produces an unlimited supply of null bytes, and the `-N` option to `od` limits the output to 64 of them.) The `-v` option suppresses the abbreviation:

```
$ od -tx -N 64 -v /dev/zero
0000000 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0000020 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0000040 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0000060 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00
0000100
```

hexdump

The `hexdump` (or `hd`) program does a very similar job. It supports output formats that are very like those of `od`, even though the corresponding options are completely different. For example, the

```
$ hexdump -o -s 446 -n 64 /etc/passwd
```

is mostly equivalent to the first `od` example above. Most `od` options have fairly similar counterparts in `hexdump`

A major difference between `hexdump` and `od` is `hexdump`'s support for output formats. These let you specify in much more detail than is possible with `od` what the output should look like. Consider the following example: output formats

```
$ cat hexdump.txt
0123456789ABC◁◁◁◁◁ XYZabc◁◁◁◁◁ xyz
$ hexdump -e '"%x-"' hexdump.txt
33323130-37363534-◁◁◁◁◁-a7a79-$
```

The following points are notable:

- The "`"%x"`" output format writes 4 bytes' worth of the input in a hexadecimal representation—"`30`" is the hexadecimal equivalent of 48, the numerical value of the "`0`" character according to the ASCII. The "`-`" suffix is output as-is.
- The 4 bytes are output in reverse order. This is an artefact of the Intel processor architecture.
- The double quotes are part of the syntax of `hexdump` and need to be protected using single quotes (or equivalent) lest the shell remove them.
- The $ at the end is the next command prompt; `hexdump` does not output newline characters of its own.

Conveniently for programmers, the possible output formats derive from those used by the `printf`(3) function found in programming languages like C, Perl, `awk`, and so on (even `bash` supports a `printf` command). Check the documentation for details!

`hexdump` output formats are much more sophisticated than the simple example shown above. As usual with `printf`, you get to specify a "field width" for the output:

```
$ hexdump -e '"%10x-"' hexdump.txt
  33323130-  37363534-  ◁◁◁◁◁ a7a79-$
```

(In this case every sequence of hexadecimal digits—eight characters in length—appears flush-right in a ten-character field.)

You can also specify how often a format will be "executed": repeat count

```
$ hexdump -e '4 "%x-" "\n"' hexdump.txt
33323130-37363534-42413938-46454443-
4a494847-4e4d4c4b-5251504f-56555453-
5a595857-64636261-68676665-6c6b6a69-
706f6e6d-74737271-78777675-a7a79-
```

The `4` preceding the commands in this section says that the "`"%x"`" format is to be applied four times. After that, we continue with the next format—"`"\n"`"—, which produces a newline character. After that, `hexdump` starts again from the front. newline character

In addition, you can determine how many bytes a format should process (with the numerical formats you usually have a choice of 1, 2, and 4): byte count

```
$ hexdump -e '/2 "%x-" "\n"' hexdump.txt
3130-
3332-
◁◁◁◁◁
7a79-
a-
```

("`/2`" is an abbreviation for "`1/2`", which is why every `%x` format appears just once per line.) Repeat count and byte count may be combined:

Table 7.5: Options for `tr`

Option	Result
`-c` (*complement*)	Replaces all characters *not* in $\langle s_1 \rangle$ by characters from $\langle s_2 \rangle$
`-d` (*delete*)	Removes all characters in $\langle s_1 \rangle$ without substitution
`-s` (*squeeze*)	Runs of identical characters from $\langle s_2 \rangle$ are replaced by a single character

```
$ hexdump -e '4/2 "%x-" "\n"' hexdump.txt
3130-3332-3534-3736-
3938-4241-4443-4645-
◁◁◁◁◁
7675-7877-7a79-a-
```

And you may also mix different output formats:

```
$ hexdump -e '"%2_ad" "%2.2s" 3/2 " %x" " %1.1s" "\n"'▷
 ◁  hexdump.txt
0 01 3332 3534 3736 8
9 9A 4342 4544 4746 H
◁◁◁◁◁
```

In this case we output the first two characters from the file as characters (rather than numerical codes) (“`"%2.2s"`”), then three times the codes of two characters in hexadecimal form (“`3/2 " %x"`”) followed by another character as a character (“`"%1.1s"`”) and a newline character. Then we start again from the front. The “`"%2_ad"`” at the beginning of the line outputs the current offset in the file (counted in bytes from the start of the file) in decimal form in a 2-character field.

Exercises

7.12 [2] What is the difference between the “`a`” and “`c`” type specifiers of `od`?

7.13 [3] The `/dev/random` “device” returns random bytes (see Section 9.3). Use `od` with `/dev/random` to assign a decimal random number from 0 to 65535 to the shell variable `r`.

7.4 Text Processing

7.4.1 Character by Character—`tr`, `expand` and `unexpand`

The `tr` command is used to replace single characters by different ones inside a text, or to delete them outright. `tr` is strictly a filter command, it does not take filename arguments but works with the standard channels only.

substitutions

For substitutions, the command syntax is “`tr` $\langle s_1 \rangle$ $\langle s_2 \rangle$”. The two parameters are character strings describing the substitution: In the simplest case the first character in $\langle s_1 \rangle$ will be substituted by the first character in $\langle s_2 \rangle$, the second character in $\langle s_1 \rangle$ by the second in $\langle s_2 \rangle$, and so on. If $\langle s_1 \rangle$ is longer than $\langle s_2 \rangle$, the “excess” characters in $\langle s_1 \rangle$ are replaced by the final character in $\langle s_2 \rangle$; if $\langle s_2 \rangle$ is longer than $\langle s_1 \rangle$, the extra characters in $\langle s_2 \rangle$ are ignored.

A little example by way of illustration:

```
$ tr AEiu aey <example.txt >new1.txt
```

Table 7.6: Characters and character classes for `tr`

Class	Meaning
`\a`	Control-G (ASCII 7), audible alert
`\b`	Control-H (ASCII 8), backspace
`\f`	Control-L (ASCII 12), form feed
`\n`	Control-J (ASCII 10), line feed
`\r`	Control-M (ASCII 13), carriage return
`\t`	Control-I (ASCII 9), tabulator character
`\v`	Control-K (ASCII 11), vertical tabulator
`\`*kkk*	the character with octal code *kkk*
`\\`	a backslash
`[`*c*`*`*n*`]`	in $\langle s_2 \rangle$: *n* times character *c*
`[`*c*`*]`	in $\langle s_2 \rangle$: character *c* as often as needed to make $\langle s_2 \rangle$ as long as $\langle s_1 \rangle$
`[:alnum:]`	all letters and digits
`[:alpha:]`	all letters
`[:blank:]`	all horizontal whitespace characters
`[:cntrl:]`	all control characters
`[:digit:]`	all digits
`[:graph:]`	all printable characters (excluding space)
`[:lower:]`	all lowercase letters
`[:print:]`	all printable characters (including space)
`[:punct:]`	all punctuation characters
`[:space:]`	all horizontal or vertical whitespace characters
`[:upper:]`	all capital letters
`[:xdigit:]`	alle hexadecimal letters (`0`–`9`, `A`–`F`, `a`–`f`)
`[:`*c*`:]`	alle characters equivalent to *c* (at this point only *c* itself)

This command reads file `example.txt` and replaces all "A" characters by "a", all "E" characters by "e", and all "i" and "u" characters by "y". The result is stored in file `new1.txt`.

It is permissible to express sequences of characters by ranges of the form "*m*`-`*n*", where *m* must precede *n* in the character collating order. With the `-c` option, `tr` does not replace the content of $\langle s_1 \rangle$ but its "complement", all characters *not* contained in $\langle s_1 \rangle$. The command

ranges

```
$ tr -c A-Za-z ' ' <example.txt >new1.txt
```

replaces all non-letters in `example.txt` by spaces.

It is also possible to use character classes of the form `[:`*k*`:]` (the valid class names are shown in Table 7.6); in many cases this makes sense in order to construct commands that work in different language environments. In a German-language environment, the character class "`[:alpha:]`", for example, contains the umlauts, a "home-cooked" class like "`A-Za-z`", which works for English, doesn't. There are some other restrictions on character classes which you can look up in the `tr` documentation (see "`info tr`").

character classes

To delete characters, you need only specify $\langle s_1 \rangle$: The

Deleting characters

```
$ tr -d a-z <example.txt >new2.txt
```

command removes all lowercase letters from `example.txt`. Furthermore, you can replace runs of equivalent input characters by a single output character: The

```
$ tr -s '\n' <example.txt >new3.txt
```

command removes empty lines by replacing sequences of newline characters by a single one.

The `-s` option ("squeeze") also makes it possible to substitute two different input characters by two identical ones, and to replace them by a single one (as with `-s` with a single argument). The following turns all "A" and "E" characters (and sequences of those) into a single "X" in `new3.txt`:

```
$ tr -s AE X <example.txt >new3.txt
```

tabulator

The "tabulator"—a good old typewriter feature—is a convenient way of producing indentation when programming (or entering text in general). By convention, "tabulator stops" are set in certain columns (usually every 8 columns, i. e., at positions 8, 16, 24, …), and common editors move to the next tabulator stop to the right when the Tab key is pressed—if you press Tab when the cursor is at column 11 on the screen, the cursor goes to column 16. In spite of this, the resulting "tabulator characters" (or "tabs") will be written to the file verbatim, and many programs cannot interpret them correctly. The `expand` command helps here: It reads the files named as its parameters (or else—you knew it—its standard input) and writes them to its standard output with all tabs removed by the appropriate number of spaces to keep the tabulator stops every 8 columns. With the `-t` you can define a different "scale factor" for the tabulator stops; a common value is, e. g., "`-t 4`", which sets up tabulator stops at columns 4, 8, 12, 16, etc.

Expanding tabs

If you give several comma-separated numbers with `-t`, tabulator stops will be set at the named columns exactly: "`expand -t 4,12,32`" sets tabulator stops at columns 4, 12 and 32. Additional tabs in an input line will be replaced by spaces.

The `-i` ("initial") option causes only tabs at the beginning of the line to be expanded to spaces.

Introducing tabs

The `unexpand` more or less reverses the effect of `expand`: All runs of tabs and spaces at the beginning of the input lines (as usual taken from named files or standard input) are replaced by the shortest sequence of tabs and spaces resulting in the same indentation. A line starting with a tab, two spaces, another tab and nine spaces will, for example—assuming standard tabulator stops every eight columns—be replaced by a line starting with three tabs and a space. The `-a` ("all") option causes *all* sequences of two or more tabs and spaces to be "optimized", not just those at the beginning of a line.

Exercises

7.14 [!2] The famous Roman general Julius Caesar supposedly used the following cipher to transmit secret messages: The letter "A" was replaced by "D", "B" by "E" and so on; "X" was replaced by "A", "Y" by "B" and "Z" by "C" (if we start from today's 26-letter alphabet, disregarding the fact that the ancient Romans did not use J, K, W, or Y). Imagine you are are programmer in Caesar's legion. Which `tr` commands would you use to encrypt the general's messages and to decrypt them again?

7.15 [3] What `tr` command would you use to replace all vowels in a text by a single one? Consider the (German) children's game:

```
DREI CHINESEN MIT DEM KONTRABASS
DRAA CHANASAN MAT DAM KANTRABASS
```

7.16 [3] How would you transform a text file such that all punctuation is removed and every word appears on a line on its own?

7.17 [2] Give a `tr` command to remove the characters "`a`", "`z`", and "`-`" from the standard input.

7.18 [1] How would you convince yourself that `unexpand` really replaces spaces and tabulator characters by an "optimal" sequence?

7.4.2 Line by Line—`fmt`, `pr` and so on

While the commands from the previous section considered their input characters singly or in small groups, Linux also contains many commands that deal with whole input lines. Some of them are introduced in this and the subsequent sections.

The `fmt` program wraps the input lines (as usual taken from the files mentioned on the command line, or the standard input) such that they have a given maximal line—75 characters, unless otherwise specified using the `-w` option. It is quite concerned with producing pleasant-looking output. Line wrapping

Let us consider some examples of `fmt` (the `frog0.txt` file is equivalent to `frog.txt`, except that the first line of each paragraph is indented by two spaces):

```
$ head frog0.txt
The Frog King, or Iron Henry

  In olden times when wishing still helped one, there lived a king
whose daughters were all beautiful, but the youngest was so beautiful
that the sun itself, which has seen so much, was astonished whenever
it shone in her face.

  Close by the king's castle lay a great dark forest, and under an old
lime-tree in the forest was a well, and when the day was very warm,
the king's child went out into the forest and sat down by the side of
```

In the first example we reduce the line length to 40 characters:

```
$ fmt -w 40 frog0.txt
The Frog King, or Iron Henry

  In olden times when wishing still
  helped one, there lived a king
whose daughters were all beautiful,
but the youngest was so beautiful that
the sun itself, which has seen so much,
was astonished whenever it shone in
⊲⊲⊲⊲⊲
```

Note that the second line of the first paragraph is indented by spaces for no apparent reason. This is due to the fact that `fmt` usually only considers those ranges of lines for wrapping that are indented the same. The indented first line of the first paragraph of the example file is therefore considered its own paragraph, and all resulting lines are indented like the input paragraph's first (and only) line. The second and subsequent input lines are considered an independent, additional "paragraph", and wrapped accordingly (using the indentation of the second line).

`fmt` tries to keep empty lines, the word spacing, and the indentation from the input. It prefers line breaks at the end of a sentence and tries to avoid them after the first and before the last word of a sentence. The "end of a sentence" according to `fmt` is either the end of a paragraph or a word ending with "`.`", "`?`", or "`!`", followed by two (!) spaces.

There is more information about the way `fmt` works in the info page of the program (Hint to find it: `fmt` is part of the GNU "coreutils" collection.)

Table 7.7: Options for `pr` (selection)

Option	Result
`-`*n*	Creates *n*-column output (any positive integer value is permissible, but only 2 to 5 usually make sense)
`-h` *t*	(engl. *header*) Outputs *t* instead of the source file name at the top of each page
`-l` *n*	(engl. *length*) Sets the number of lines per page, default value is 66
`-n`	(engl. *number*) Labels each line with a five-digit line number separated from the rest of the line by a tab character
`-o` *n*	(engl. *offset*) Indents the text *n* characters from the left margin
`-t`	(engl. *omit*) Suppresses the header and footer lines (5 each)
`-w` *n*	(engl. *width*) Sets the number of characters per line, default value is 72

In the next example we use the `-c` ("crown-margin mode") option to avoid the phenomenon we just explained:

```
$ fmt -c -w 40 frog0.txt
The Frog King, or Iron Henry

  In olden times when wishing still
helped one, there lived a king whose
daughters were all beautiful, but the
youngest was so beautiful that the
sun itself, which has seen so much,
was astonished whenever it shone in
◁◁◁◁◁
```

Here the indentation of the (complete) paragraph is taken from the first *two* lines of the input; their indentation is kept, and the subsequent input lines follow the indentation of the second.

Finally, an example featuring long lines:

```
$ fmt -w 100 frog0.txt
The Frog King, or Iron Henry

  In olden times when wishing still helped one, there lived a king
whose daughters were all beautiful, but the youngest was so beautiful that the sun itself,
which has seen so much, was astonished whenever it shone in her face.

  Close by the king's castle lay a great dark forest, and under an old
lime-tree in the forest was a well, and when the day was very warm, the king's child went out
into the forest and sat down by the side of the cool fountain, and when she was bored she took
a golden ball, and threw it up on high and caught it, and this ball was her favourite plaything.
◁◁◁◁◁
```

We could have used `-c` here as well to avoid the "short" first lines of the paragraphs. Without this option, the first line is once more considered a paragraph of its own, and not amalgamated with the subsequent lines.

The name of the `pr` ("print") command may be misleading at first. It does not, as might be surmised, output files to the printer—this is the domain of the `lpr` command. Instead, `pr` manages formatting a text for printed output, including page breaks, indentation and header and footer lines. You can either specify input files on the command line or have `pr` process its standard input (Table 7.7).

Here is a somewhat more complex example to illustrate `pr`'s workings:

```
$ fmt -w 34 frog.txt | pr -h "Grimm Fairy-Tales" -2
```

Table 7.8: Options for `nl` (selection)

Option		Result
`-b` *s*	(*body style*)	Numbers the body lines according to *s*. Possible values for *s* are `a` (number all lines), `t` (number only non-blank lines), `n` (number no lines at all), and `p`⟨*regex*⟩ (number only the lines matching regular expression ⟨*regex*⟩). The default value is `t`.
`-d` *p*[*q*]	(*delimiter*)	Use the two characters *pq* instead of "`\:`" in delimiter lines. If only *p* is given, *q* remains set to "`:`".
`-f` *s*	(*footer style*)	Formats the footer lines according to *s*. The possible values of *s* correspond to those of `-b`. The default value is `n`.
`-h` *s*	(*header style*)	Similar to `-f`, for header lines.
`-i` *n*	(*increment*)	Increments the line number by *n* for every line.
`-n` *f*	(*number format*)	Determines the line number format. Possible values for *f*: `ln` (flush-left with no leading zeroes), `rn` (flush-right with no leading zeroes), `rz` (flush-right with leading zeroes).
`-p`	(*page*)	Does *not* reset the line number to its original value between logical pages.
`-v` *n*		Starts numbering at line number *n*.
`-w` *n*	(*width*)	Output a *n*-character line number (according to `-n`).

```
2004-09-13 08:42               Grimm Fairy-Tales               Page 1


The Frog King, or Iron Henry        >>Whatever you will have, dear
                                    frog,« said she, >>My clothes, my
In olden times when wishing         pearls and jewels, and even the
still helped one, there lived a     golden crown which I am wearing.«
king whose daughters were all
beautiful, but the youngest         The frog answered, >>I do not care
was so beautiful that the sun       for your clothes, your pearls
itself, which has seen so much,     and jewels, nor for your golden
was astonished whenever it shone    crown, but if you will love me
in her face.                        and let me be your companion and
⊲⊲⊲⊲⊲
```

Here we use `fmt` to format the text of the *Frog King* in a long narrow column, and `pr` to display the text in two columns.

The `nl` command specialises in line numbering. If nothing else is specified, it numbers the non-blank lines of its input (which as usual will be taken from named files or else standard input) in sequence:

line numbering

```
$ nl frog.txt
     1  The Frog King, or Iron Henry

     2  In olden times when wishing still helped one, there lived a king whose
     3  daughters were all beautiful, but the youngest was so beautiful that
     4  the sun itself, which has seen so much, was astonished whenever it
     5  shone in her face.

     6  Close by the king's castle lay a great dark forest, and under an old
⊲⊲⊲⊲⊲
```

This by itself is nothing you would not manage using "`cat -b`". For one, though, `nl` allows for much closer control of the line numbering process:

```
$ nl -b a -n rz -w 5 -v 1000 -i 10 frog.txt
01000   The Frog King, or Iron Henry
01010
01020   In olden times when wishing still helped one, there lived a king whose
01030   daughters were all beautiful, but the youngest was so beautiful that
01040   the sun itself, which has seen so much, was astonished whenever it
01050   shone in her face.
01060
01070   Close by the king's castle lay a great dark forest, and under an old
01080   lime-tree in the forest was a well, and when the day was very warm,
01090   the king's child went out into the forest and sat down by the side of
◁◁◁◁◁
```

Taken one by one, the options imply the following (see also Table 7.8): "`-b a`" causes all lines to be numbered, not just—as in the previous example—the non-blank ones. "`-n rz`" formats line numbers flush-right with leading zeroes, "`-w 5`" caters for a five-column line number, and "`-i 10`" increments the line number by 10 per line (not, as usual, 1).

Per-page line numbers

In addition, `nl` can also handle per-page line numbers. This is organized using the "magical" strings "`\:\:\:`", "`\:\:`" und "`\:`", as shown in the previous example:

```
$ cat nl-test
\:\:\:
Header of first page
\:\:
First line of first page
Second line of first page
Last line of first page
\:
Footer of first page
\:\:\:
Footer of second page
(Two lines high)
\:\:
First line of second page
Second line of second page
Second-to-last line of second page
Last line of second page
\:
Header of second page
(Two lines high)
```

header and footer

Each (logical) page has a header and footer as well as a "body" containing the text proper. The header is introduced using "`\:\:\:`", and separated from the body using "`\:\:`". The body, in turn, ends at a "`\:`" line. Header and footer may also be omitted.

By default, `nl` numbers the lines on each page starting at 1; header and footer lines are not numbered:

```
$ nl nl-test

       Header of first page

     1  First line of first page
     2  Second line of first page
     3  Last line of first page

       Footer of first page
```

Table 7.9: Options for `wc` (selection)

Option	Wirkung
`-l` (*lines*)	outputs line count
`-w` (*words*)	outputs word count
`-c` (*characters*)	outputs character count

```
    Footer of second page
    (Two lines high)

1   First line of second page
2   Second line of second page
3   Second-to-last line of second page
4   Last line of second page

    Header of second page
    (Two lines high)
```

The "`\:…`" separator lines are replaced by blank lines in the output.

The name of the `wc` command is an abbreviation of "word count". In spite of this moniker, not just a word count can be determined, but also a count of total characters and lines in the input (files, standard input). This is done using the options in Table 7.9. A "word", from `wc`'s point of view, is a sequence of one or more letters. Without an option, all three values are output in the order given in Table 7.9:

Count lines, words, characters

```
$ wc frog.txt
 144 1397 7210 frog.txt
```

With the options in Table 7.9, you can limit `wc`'s output to only some of the values:

```
$ ls | wc -l
     13
```

The example shows how to use `wc` to determine the number of entries in the current directory by counting the lines in the output of the `ls` command.

Exercises

7.19 [1] Number the lines of file `frog.txt` with an increment of 2 per line starting at 100.

7.20 [3] How can you number the lines of a file in *reverse* order, similar to

```
144  The Frog King, or Iron Henry
143
142  In olden times when wishing still helped one, there lived a king whose
141  daughters were all beautiful, but the youngest was so beautiful that
```

(*Hint:* Two reversals give the original)?

7.21 [!2] How does the output of the "`wc a.txt b.txt c.txt`" command differ from that of the "`cat a.txt b.txt c.txt | wc`" command?

7.5 Data Management

7.5.1 Sorted Files—`sort` and `uniq`

default setting

The `sort` command lets you sort the lines of text files according to predetermined criteria. The default setting is ascending (from A to Z) according to the ASCII values[1] of the first few characters of each line. This is why special characters such as German umlauts are frequently sorted incorrectly. For example, the character code of "Ä" is 143, so that character ends up far beyond "Z" with its character code of 91. Even the lowercase latter "a" is considered "greater than" the uppercase letter "Z".

Of course, `sort` can adjust itself to different languages and cultures. To sort according to German conventions, set one of the environment variables `LANG`, `LC_ALL`, or `LC_COLLATE` to a value such as "`de`", "`de_DE`", or "`de_DE@UTF-8`" (the actual value depends on your distribution). If you want to set this up for a single `sort` invocation only, do

```
$ … | LC_COLLATE=de_DE.UTF-8 sort
```

The value of `LC_ALL` has precedence over the value of `LC_COLLATE` and that, again, has precedence over the value of `LANG`. As a side effect, German sort order causes the case of letters to be ignored when sorting.

Sorting by fields

Unless you specify otherwise, the sort proceeds "lexicographically" considering all of the input line. That is, if the initial characters of two lines compare equal, the first differing character within the line governs their relative positioning. Of course `sort` can sort not just according to the whole line, but more specifically according to the values of certain "columns" or fields of a (conceptual) table. Fields are numbered starting at 1; with the "`-k 2`" option, the first field would be ignored and the second field of each line considered for sorting. If the values of two lines are equal in the second field, the rest of the line will be looked at, unless you specify the last field to be considered using something like "`-k 2,3`". Incidentally, it is permissible to specify several `-k` options with the same `sort` command.

In addition, `sort` supports an obsolete form of position specification: Here fields are numbered starting at 0, the initial field is specified as "+*m*" and the final field as "-*n*". To complete the differences to the modern form, the final field is specified "exclusively"—you give the first field that should *not* be taken into account for sorting. The examples above would, respectively, be "`+1`", "`+1 -3`", and "`+1 -2`".

separator

The space character serves as the separator between fields. If several spaces occur in sequence, only the first is considered a separator; the others are considered part of the value of the following field. Here is a little example, namely the list of participants for the annual marathon run of the Lameborough Track & Field Club. To start, we ensure that we use the system's standard language environment ("`POSIX`") by resetting the corresponding environment variables. (Incidentally, the fourth column gives a runner's bib number.)

```
$ unset LANG LC_ALL LC_COLLATE
$ cat participants.dat
Smith      Herbert  Pantington AC         123 Men
Prowler    Desmond  Lameborough TFC       13  Men
Fleetman   Fred     Rundale Sportsters    217 Men
Jumpabout  Mike     Fairing Track Society 154 Men
```

[1] Of course ASCII only goes up to 127. What is really meant here is ASCII together with whatever extension for the characters with codes from 128 up is currently used, for example ISO-8859-1, also known as ISO-Latin-1.

```
de Leaping Gwen     Fairing Track Society 26  Ladies
Runnington Vivian   Lameborough TFC       117 Ladies
Sweat      Susan    Rundale Sportsters    93  Ladies
Runnington Kathleen Lameborough TFC       119 Ladies
Longshanks Loretta  Pantington AC         55  Ladies
O'Finnan   Jack     Fairing Track Society 45  Men
Oblomovsky Katie    Rundale Sportsters    57  Ladies
```

Let's try a list sorted by last name first. This is easy in principle, since the last names are at the front of each line:

```
$ sort participants.dat
Fleetman   Fred     Rundale Sportsters    217 Men
Jumpabout  Mike     Fairing Track Society 154 Men
Longshanks Loretta  Pantington AC         55  Ladies
O'Finnan   Jack     Fairing Track Society 45  Men
Oblomovsky Katie    Rundale Sportsters    57  Ladies
Prowler    Desmond  Lameborough TFC       13  Men
Runnington Kathleen Lameborough TFC       119 Ladies
Runnington Vivian   Lameborough TFC       117 Ladies
Smith      Herbert  Pantington AC         123 Men
Sweat      Susan    Rundale Sportsters    93  Ladies
de Leaping Gwen     Fairing Track Society 26  Ladies
```

You will surely notice the two small problems with this list: "Oblomovsky" should really be in front of "O'Finnan", and "de Leaping" should end up at the front of the list, not the end. These will disappear if we specify "English" sorting rules:

```
$ LC_COLLATE=en_GB sort participants.dat
de Leaping Gwen     Fairing Track Society 26  Ladies
Fleetman   Fred     Rundale Sportsters    217 Men
Jumpabout  Mike     Fairing Track Society 154 Men
Longshanks Loretta  Pantington AC         55  Ladies
Oblomovsky Katie    Rundale Sportsters    57  Ladies
O'Finnan   Jack     Fairing Track Society 45  Men
Prowler    Desmond  Lameborough TFC       13  Men
Runnington Kathleen Lameborough TFC       119 Ladies
Runnington Vivian   Lameborough TFC       117 Ladies
Smith      Herbert  Pantington AC         123 Men
Sweat      Susan    Rundale Sportsters    93  Ladies
```

(`en_GB` is short for "British English"; `en_US`, for "American English", would also work here.) Let's sort according to the first name next:

```
$ sort -k 2,2 participants.dat
Smith      Herbert  Pantington AC         123 Men
Sweat      Susan    Rundale Sportsters    93  Ladies
Prowler    Desmond  Lameborough TFC       13  Men
Fleetman   Fred     Rundale Sportsters    217 Men
O'Finnan   Jack     Fairing Track Society 45  Men
Jumpabout  Mike     Fairing Track Society 154 Men
Runnington Kathleen Lameborough TFC       119 Ladies
Oblomovsky Katie    Rundale Sportsters    57  Ladies
de Leaping Gwen     Fairing Track Society 26  Ladies
Longshanks Loretta  Pantington AC         55  Ladies
Runnington Vivian   Lameborough TFC       117 Ladies
```

This illustrates the property of `sort` mentioned above: The first of a sequence of spaces is considered the separator, the others are made part of the following field's

Table 7.10: Options for `sort` (selection)

Option		Result
`-b`	(*blank*)	Ignores leading blanks in field contents
`-d`	(*dictionary*)	Sorts in "dictionary order", i. e., only letters, digits and spaces are taken into account
`-f`	(*fold*)	Makes uppercase and lowercase letters equivalent
`-i`	(*ignore*)	Ignores non-printing characters
`-k` ⟨*field*⟩[,⟨*field'*⟩]	(*key*)	Sort according to ⟨*field*⟩ (up to and including ⟨*field'*⟩)
`-n`	(*numeric*)	Considers field value as a number and sorts according to its numeric value; leading blanks will be ignored
`-o datei`	(*output*)	Writes results to a file, whose name may match the original input file
`-r`	(*reverse*)	Sorts in descending order, i. e., Z to A
`-t`⟨*char*⟩	(*terminate*)	The ⟨*char*⟩ character is used as the field separator
`-u`	(*unique*)	Writes only the first of a sequence of equal output lines

value. As you can see, the first names are listed alphabetically but only within the same length of last name. This can be fixed using the `-b` option, which treats runs of space characters like a single space:

```
$ sort -b -k 2,2 participants.dat
Prowler    Desmond  Lameborough TFC       13  Men
Fleetman   Fred     Rundale Sportsters    217 Men
Smith      Herbert  Pantington AC         123 Men
O'Finnan   Jack     Fairing Track Society 45  Men
Runnington Kathleen Lameborough TFC       119 Ladies
Oblomovsky Katie    Rundale Sportsters    57  Ladies
de Leaping Gwen     Fairing Track Society 26  Ladies
Longshanks Loretta  Pantington AC         55  Ladies
Jumpabout  Mike     Fairing Track Society 154 Men
Sweat      Susan    Rundale Sportsters    93  Ladies
Runnington Vivian   Lameborough TFC       117 Ladies
```

This sorted list still has a little blemish; see Exercise 7.24.

More detailed field specification

The sort field can be specified in even more detail, as the following example shows:

```
$ sort -br -k 2.2 participants.dat
Sweat      Susan    Rundale Sportsters    93  Ladies
Fleetman   Fred     Rundale Sportsters    217 Men
Longshanks Loretta  Pantington AC         55  Ladies
Runnington Vivian   Lameborough TFC       117 Ladies
Jumpabout  Mike     Fairing Track Society 154 Men
Prowler    Desmond  Lameborough TFC       13  Men
Smith      Herbert  Pantington AC         123 Men
de Leaping Gwen     Fairing Track Society 26  Ladies
Oblomovsky Katie    Rundale Sportsters    57  Ladies
Runnington Kathleen Lameborough TFC       119 Ladies
O'Finnan   Jack     Fairing Track Society 45  Men
```

Here, the `participants.dat` file is sorted in descending order (`-r`) according to the second character of the second table field, i. e., the second character of the first name (very meaningful!). In this case as well it is necessary to ignore leading spaces using the `-b` option. (The blemish from Exercise 7.24 still manifests itself here.)

field separator

With the `-t` ("terminate") option you can select an arbitrary character in place of the field separator. This is a good idea in principle, since the fields then may

contain spaces. Here is a more usable (if less readable) version of our example file:

```
Smith:Herbert:Pantington AC:123:Men
Prowler:Desmond:Lameborough TFC:13:Men
Fleetman:Fred:Rundale Sportsters:217:Men
Jumpabout:Mike:Fairing Track Society:154:Men
de Leaping:Gwen:Fairing Track Society:26:Ladies
Runnington:Vivian:Lameborough TFC:117:Ladies
Sweat:Susan:Rundale Sportsters:93:Ladies
Runnington:Kathleen:Lameborough TFC:119:Ladies
Longshanks:Loretta: Pantington AC:55:Ladies
O'Finnan:Jack:Fairing Track Society:45:Men
Oblomovsky:Katie:Rundale Sportsters:57:Ladies
```

Sorting by first name now leads to correct results using "`LC_COLLATE=en_GB sort -t: -k2,2`". It is also a lot easier to sort, e. g., by a participant's number (now field 4, no matter how many spaces occur in their club's name:

```
$ sort -t: -k4 participants0.dat
Runnington:Vivian:Lameborough TFC:117:Ladies
Runnington:Kathleen:Lameborough TFC:119:Ladies
Smith:Herbert:Pantington AC:123:Men
Prowler:Desmond:Lameborough TFC:13:Men
Jumpabout:Mike:Fairing Track Society:154:Men
Fleetman:Fred:Rundale Sportsters:217:Men
de Leaping:Gwen:Fairing Track Society:26:Ladies
O'Finnan:Jack:Fairing Track Society:45:Men
Longshanks:Loretta: Pantington AC:55:Ladies
Oblomovsky:Katie:Rundale Sportsters:57:Ladies
Sweat:Susan:Rundale Sportsters:93:Ladies
```

Of course the "number" sort is done lexicographically, unless otherwise specified—"117" and "123" are put before "13", and that in turn before "154". This can be fixed by giving the `-n` option to force a numeric comparison:

numeric comparison

```
$ sort -t: -k4 -n participants0.dat
Prowler:Desmond:Lameborough TFC:13:Men
de Leaping:Gwen:Fairing Track Society:26:Ladies
O'Finnan:Jack:Fairing Track Society:45:Men
Longshanks:Loretta: Pantington AC:55:Ladies
Oblomovsky:Katie:Rundale Sportsters:57:Ladies
Sweat:Susan:Rundale Sportsters:93:Ladies
Runnington:Vivian:Lameborough TFC:117:Ladies
Runnington:Kathleen:Lameborough TFC:119:Ladies
Smith:Herbert:Pantington AC:123:Men
Jumpabout:Mike:Fairing Track Society:154:Men
Fleetman:Fred:Rundale Sportsters:217:Men
```

These and some more important options for `sort` are shown in Table 7.10; studying the program's documentation is well worthwhile. `sort` is a versatile and powerful command which will save you a lot of work.

The `uniq` command does the important job of letting through only the first of a sequence of equal lines in the input (or the last, just as you prefer). What is considered "equal" can, as usual, be specified using options. `uniq` differs from most of the programs we have seen so far in that it does not accept an arbitrary number of named input files but just one; a second file name, if it is given, is considered the name of the desired output file (if not, standard output is assumed). If no file is named in the `uniq` call, `uniq` reads standard input (as it ought).

`uniq` command

`uniq` works best if the input lines are sorted such that *all* equal lines occur one after another. If that is not the case, it is not guaranteed that each line occurs only once in the output:

```
$ cat uniq-test
Hipp
Hopp
Hopp
Hipp
Hipp
Hopp
$ uniq uniq-test
Hipp
Hopp
Hipp
Hopp
```

Compare this to the output of "`sort -u`":

```
$ sort -u uniq-test
Hipp
Hopp
```

Exercises

7.22 [!2] Sort the list of participants in `participants0.dat` (the file with colon separators) according to the club's name and, within clubs, the last and first names of the runners (in that order).

7.23 [3] How can you sort the list of participants by club name in ascending order and, within clubs, by number in descending order? (*Hint:* Read the documentation!)

7.24 [!2] What is the "blemish" alluded to in the examples and why does it occur?

7.25 [2] A directory contains files with the following names:

```
01-2002.txt  01-2003.txt  02-2002.txt  02-2003.txt
03-2002.txt  03-2003.txt  04-2002.txt  04-2003.txt
⋖⋖⋖⋖
11-2002.txt  11-2003.txt  12-2002.txt  12-2003.txt
```

Give a `sort` command to sort the output of `ls` into "chronologically correct" order:

```
01-2002.txt
02-2002.txt
⋖⋖⋖⋖
12-2002.txt
01-2003.txt
⋖⋖⋖⋖
12-2003.txt
```

7.26 [3] How can you produce a sorted list of all words in a text file? Each word should occur only once in the list. (*Hint:* Exercise 7.16)

7.5.2 Columns and Fields—`cut`, `paste` etc.

Cutting columns

While you can locate and "cut out" lines of a text file using `grep`, the `cut` command works through a text file "by column". This works in one of two ways:

Absolute columns

One possibility is the absolute treatment of columns. These columns correspond to single characters in a line. To cut out such columns, the column number must be given after the `-c` option ("column"). To cut several columns in one step, these can be specified as a comma-separated list. Even column ranges may be specified.

```
$ cut -c 12,1-5 participants.dat
SmithH
ProwlD
FleetF
JumpaM
de LeG
```

In this example, the first letter of the first name and the first five letters of the last name are extracted. It also illustrates the notable fact that the output always contains the columns in the same order as in input. Even if the selected column ranges overlap, every input character is output at most once:

```
$ cut -c 1-5,2-6,3-7 participants.dat
Smith
Prowler
Fleetma
Jumpabo
de Leap
```

Relative fields

The second method is to cut relative fields, which are delimited by separator characters. If you want to cut delimited fields, `cut` needs the `-f` ("field") option and the desired field number. The same rules as for columns apply. The `-c` and `-f` options are mutually exclusive.

separators

The default separator is the tab character; other separators may be specified with the `-d` option ("delimiter"):

```
$ cut -d: -f 1,4 participants0.dat
Smith:123
Prowler:13
Fleetman:217
Jumpabout:154
de Leaping:26
```

In this way, the participants' last names (column 1) and numbers (column 4) are taken from the list. For readability, only the first few lines are displayed.

Incidentally, using the `--output-delimiter` option you can specify a different separator character for the output fields than is used for the input fields:

```
$ cut -d: --output-delimiter=': ' -f 1,4 participants0.dat
Smith: 123
Prowler: 13
Fleetman: 217
Jumpabout: 154
de Leaping: 26
```

If you really want to change the order of columns and fields, you have to bring in the big guns, such as `awk` or `perl`; you could do it using the `paste` command, which will be introduced presently, but that is rather tedious.

Suppressing no-field lines

When files are treated by fields (rather than columns), the `-s` option ("separator") is helpful. If "`cut -f`" encounters lines that do not contain the separator character, these are normally output in their entirety; `-s` suppresses these lines.

Joining lines of files

The `paste` command joins the lines of the specified files. It is thus frequently used together with `cut`. As you will have noticed immediately, `paste` is not a filter command. You may however give a minus sign in place of one of the input filenames for `paste` to read its standard input at that point. Its output always goes to standard output.

Join files "in parallel"

As we said, `paste` works by lines. If two file names are specified, the first line of the first file and the first of the second are joined (using a tab character as the separator) to form the first line of the output. The same is done with all other lines in the files. To specify a different separator, use the `-d` option.

separator

By way of an example, we can construct a version of the list of marathon runners with the participants' numbers in front:

```
$ cut -d: -f4 participants0.dat >number.dat
$ cut -d: -f1-3,5 participants0.dat \
>   | paste -d: number.dat - >p-number.dat
$ cat p-number.dat
123:Smith:Herbert:Pantington AC:Men
13:Prowler:Desmond:Lameborough TFC:Men
217:Fleetman:Fred:Rundale Sportsters:Men
154:Jumpabout:Mike:Fairing Track Society:Men
26:de Leaping:Gwen:Fairing Track Society:Ladies
117:Runnington:Vivian:Lameborough TFC:Ladies
93:Sweat:Susan:Rundale Sportsters:Ladies
119:Runnington:Kathleen:Lameborough TFC:Ladies
55:Longshanks:Loretta: Pantington AC:Ladies
45:O'Finnan:Jack:Fairing Track Society:Men
57:Oblomovsky:Katie:Rundale Sportsters:Ladies
```

This file may now conveniently be sorted by number using "`sort -n p-number.dat`".

Join files serially

With `-s` ("serial"), the given files are processed in sequence. First, all the lines of the first file are joined into one single line (using the separator character), then all lines from the second file make up the second line of the output etc.

```
$ cat list1
Wood
Bell
Potter
$ cat list2
Keeper
Chaser
Seeker
$ paste -s list*
Wood    Bell    Potter
Keeper  Chaser  Seeker
```

All files matching the `list*` wildcard pattern—in this case, `list1` and `list2`—are joined using `paste`. The `-s` option causes every line of these files to make up one column of the output.

"Relational" joining of files

The `join` command joins the lines of files, too, but in a much more sophisticated manner. Instead of just joining the first lines, second lines, …, it considers one designated field per line and joins two lines only if the values in these fields are equal. Hence, `join` implements the eponymous operator from relational algebra,

Table 7.11: Options for `join` (selection)

Option		Result
`-j1` *n*		Uses field *n* of the first file as the "join field" ($n \geqslant 1$). Synonym: `-1` *n*.
`-j2` *n*		Uses field *n* of the second file as the "join field" ($n \geqslant 1$). Synonym: `-2` *n*.
`-j` *n*	(*join*)	Abbreviation for "`-j1` *n* `-j2` *n*"
`-o` *f*	(*output*)	Output line specification. *f* is a comma-separated sequence of field specifications, where each field specification is either the digit "`0`" or a field number *m.n*. "`0`" is the "join field", *m* is 1 or 2, and *n* is a field number in the first or second file.
`-t` *c*		The *c* character will be used as the field separator for input and output.

as seen in SQL databases—even though the actual operation is a lot cruder and more inefficient than with a "real" database.

Example

Even so, Examplethe `join` command does come in useful. Imagine that the big day has arrived and the Lameborough TFC's marathon has been run. The umpires have been diligent and not only have timed how long everybody took, but also entered them into a file `times.dat`. The first columns is always a participant's number, the second the time achieved (in whole seconds, for simplicity):

```
$ cat times.dat
45:8445
123:8517
217:8533
93:8641
154:8772
119:8830
13:8832
117:8954
57:9111
26:9129
```

Now we want to join this file with the list of participants, in order to assign each time to the corresponding participant. To do so, we must first sort the result file by participant number:

```
$ sort -n times.dat >times-s.dat
```

Next we can use `join` to join the lines of file `times-s.dat` to the corresponding lines of the modified list of participants from the `paste` example—`join` presumes by default that the input files are sorted by the value of the "join field", and that the "join field" is the first field of each line.

```
$ cat p-number.dat
123:Smith:Herbert:Pantington AC:Men
13:Prowler:Desmond:Lameborough TFC:Men
217:Fleetman:Fred:Rundale Sportsters:Men
154:Jumpabout:Mike:Fairing Track Society:Men
26:de Leaping:Gwen:Fairing Track Society:Ladies
117:Runnington:Vivian:Lameborough TFC:Ladies
93:Sweat:Susan:Rundale Sportsters:Ladies
119:Runnington:Kathleen:Lameborough TFC:Ladies
55:Longshanks:Loretta: Pantington AC:Ladies
45:O'Finnan:Jack:Fairing Track Society:Men
57:Oblomovsky:Katie:Rundale Sportsters:Ladies
$ sort -n p-number.dat \
>  | join -t: times-s.dat - >p-times.dat
```

```
$ cat p-times.dat
13:8832:Prowler:Desmond:Lameborough TFC:Men
26:9129:de Leaping:Gwen:Fairing Track Society:Ladies
45:8445:O'Finnan:Jack:Fairing Track Society:Men
57:9111:Oblomovsky:Katie:Rundale Sportsters:Ladies
93:8641:Sweat:Susan:Rundale Sportsters:Ladies
117:8954:Runnington:Vivian:Lameborough TFC:Ladies
119:8830:Runnington:Kathleen:Lameborough TFC:Ladies
123:8517:Smith:Herbert:Pantington AC:Men
154:8772:Jumpabout:Mike:Fairing Track Society:Men
217:8533:Fleetman:Fred:Rundale Sportsters:Men
```

The resulting file `p-times.dat` now just needs to be sorted by time:

```
$ sort -t: -k2,2 p-times.dat
45:8445:O'Finnan:Jack:Fairing Track Society:Men
123:8517:Smith:Herbert:Pantington AC:Men
217:8533:Fleetman:Fred:Rundale Sportsters:Men
93:8641:Sweat:Susan:Rundale Sportsters:Ladies
154:8772:Jumpabout:Mike:Fairing Track Society:Men
119:8830:Runnington:Kathleen:Lameborough TFC:Ladies
13:8832:Prowler:Desmond:Lameborough TFC:Men
117:8954:Runnington:Vivian:Lameborough TFC:Ladies
57:9111:Oblomovsky:Katie:Rundale Sportsters:Ladies
26:9129:de Leaping:Gwen:Fairing Track Society:Ladies
```

This is a nice example of how Linux's standard tools make even fairly complicated text and data processing possible. In "real life", one would use shell scripts to prepare these processing steps and automate them as far as possible.

Exercises

7.27 [!2] Generate a new version of the `participants.dat` file (the one with fixed-width columns) in which the participant numbers and club affiliations do not occur.

7.28 [!2] Generate a new version of the `participants0.dat` file (the one with fields separated using colons) in which the participant numbers and club affiliations do not occur.

7.29 [3] Generate a version of `participants0.dat` in which the fields are not separated by colons but by the string "`,␣`" (a comma followed by a space character).

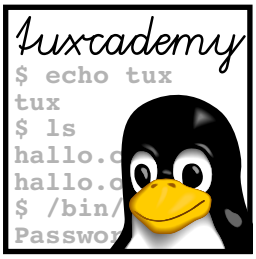
7.30 [3] How many groups are used as primary groups by users on your system? (The primary group of a user is the fourth field in `/etc/passwd`.)

Commands in this Chapter

cat	Concatenates files (among other things)	cat(1)	94
cut	Extracts fields or columns from its input	cut(1)	112
expand	Replaces tab characters in its input by an equivalent number of spaces	expand(1)	102
fmt	Wraps the lines of its input to a given width	fmt(1)	103
hd	Abbreviation for hexdump	hexdump(1)	98
head	Displays the beginning of a file	head(1)	96
hexdump	Displays file contents in hexadecimal (octal, …) form	hexdump(1)	98
join	Joins the lines of two files according to relational algebra	join(1)	114
od	Displays binary data in decimal, octal, hexadecimal, … formats	od(1)	97
paste	Joins lines from different input files	paste(1)	114
pr	Prepares its input for printing—with headers, footers, etc.	pr(1)	104
reset	Resets a terminal's character set to a "reasonable" value	tset(1)	95
sort	Sorts its input by line	sort(1)	107
tac	Displays a file back to front	tac(1)	95
tail	Displays a file's end	tail(1)	96
tr	Substitutes or deletes characters on its standard input	tr(1)	100
unexpand	"Optimises" tabs and spaces in its input lines	unexpand(1)	102
uniq	Replaces sequences of identical lines in its input by single specimens	uniq(1)	111
wc	Counts the characters, words and lines of its input	wc(1)	107

Summary

- Every Linux program supports the standard I/O channels `stdin`, `stdout`, and `stderr`.
- Standard output and standard error output can be redirected using operators `>` and `>>`, standard input using operator `<`.
- Pipelines can be used to connect the standard output and input of programs directly (without intermediate files).
- Using the `tee` command, intermediate results of a pipeline can be stored to files.
- Filter commands (or "filters") read their standard input, manipulate it, and write the results to standard output.
- The `tr` command substitutes or deletes single characters. `expand` and `unexpand` convert tabs to spaces and vice-versa.
- With `pr`, you can prepare data for printing—not actually print it.
- `wc` can be used to count the lines, words and characters of the standard input (or a number of named files).
- `sort` is a versatile program for sorting.
- The `cut` command cuts specified ranges of columns or fields from every line of its input.
- With `paste`, the lines of files can be joined.



8

More About The Shell

Contents

Goals

- Knowing about shell variables and evironment variables
- Handling foreground and background processes

Prerequisites

- Basic shell knowledge (Chapter 3)
- File management and simple filter commands (Chapter 6, Chapter 7)
- Use of a text editor (Chapter 5)

8.1 Simple Commands: `sleep`, `echo`, and `date`

To give you some tools for experiments, we shall now explain some very simple commands:

sleep This command does nothing for the number of seconds specified as the argument. You can use it if you want your shell to take a little break:

```
$ sleep 10
                                        Nothing happens for approximately 10 seconds
$ _
```

Output arguments

echo The command `echo` outputs its arguments (and nothing else), separated by spaces. It is still interesting and useful, since the shell replaces variable references (see Section 8.2) and similar things first:

```
$ p=Planet
$ echo Hello $p
Hello Planet
$ echo Hello ${p}oid
Hello Planetoid
```

(The second `echo` illustrates what to do if you want to append something directly to the value of a variable.)

If `echo` is called with the `-n` option, it does not write a line terminator at the end of its output:

```
$ echo -n Hello
Hello_
```

date and time

date The `date` command displays the current date and time. You have considerable leeway in determining the format of the output—call "`date --help`", or read the online documentation using "`man date`".

(When reading through this manual for the second time:) In particular, `date` serves as a world clock, if you first set the `TZ` environment variable to the name of a time zone or important city (usually capital):

```
$ date
Thu Oct  5 14:26:07 CEST 2006
$ export TZ=Asia/Tokyo
$ date
Tue Oct  5 21:26:19 JST 2006
$ unset TZ
```

You can find out about valid time zone and city names by rooting around in `/usr/share/zoneinfo`.

Set the system time

While every user is allowed to read the system time, only the system administrator `root` may change the system time using the `date` command and an argument of the form `MMDDhhmm`, where `MM` is the calendar month, `DD` the calendar day, `hh` the hour, and `mm` the minute. You can optionally add two digits the year (plus possibly another two for the century) and the seconds (separated with a dot), which should, however, prove necessary only in very rare cases.

```
$ date
Thu Oct  5 14:28:13 CEST 2006
$ date 08181715
date: cannot set date: Operation not permitted
Fri Aug 18 17:15:00 CEST 2006
```

The `date` command only changes the internal time of the Linux system. This time will not necessarily be transferred to the CMOS clock on the computer's mainboard, so a special command may be required to do so. Many distributions will do this automatically when the system is shut down.

Exercises

8.1 [!3] Assume now is 22 October 2003, 12:34 hours and 56 seconds. Study the `date` documentation and state formatting instructions to achieve the following output:

1. `22-10-2003`
2. `03-294 (WK43)` (Two-digit year, number of day within year, calendar week)
3. `12h34m56s`

8.2 [!2] What time is it now in Los Angeles?

8.2 Shell Variables and The Environment

Like most common shells, `bash` has features otherwise found in programming languages. For example, it is possible to store pieces of text or numbers in variables and retrieve them later. Variables also control various aspects of the operation of the shell itself.

Within the shell, a variable is set by means of a command like "`foo=bar`" (this command sets the `foo` variable to the textual value `bar`). Take care *not* to insert spaces in front of or behind the equals sign! You can retrieve the value of the variable by using the variable name with a dollar sign in front:

Setting variables

```
$ foo=bar
$ echo foo
foo
$ echo $foo
bar
```

(note the difference).

We distinguish **environment variables** from **shell variables**. Shell variables are only visible in the shell in which they have been defined. On the other hand, environment variables are passed to the child process when an external command is started and can be used there. (The child process does not have to be a shell; every Linux process has environment variables). All the environment variables of a shell are also shell variables but not vice versa.

environment variables
shell variables

Using the `export` command, you can declare an existing shell variable an environment variable:

`export`

```
$ foo=bar                          foo is now a shell variable
$ export foo                       foo is now an environment variable
```

Or you define a new variable as a shell and environment variable at the same time:

Table 8.1: Important Shell Variables

Variable	Meaning
PWD	Name of the current directory
EDITOR	Name of the user's favourite editor
PS1	Shell command prompt template
UID	Current user's user name
HOME	Current user's home directory
PATH	List of directories containing executable programs that are eligible as external commands
LOGNAME	Current user's user name (again)

```
$ export foo=bar
```

The same works for several variables simultaneously:

```
$ export foo baz
$ export foo=bar baz=quux
```

You can display all environment variables using the `export` command (with no parameters). The `env` command (also with no parameters) also displays the current environment. All shell variables (including those which are also environment variables) can be displayed using the `set` command. The most common variables and their meanings are shown in Table 8.1.

The `set` command also does many other strange and wonderful things. You will encounter it again in the Linup Front training manual *Advanced Linux*, which covers shell programming.

`env`, too, is actually intended to manipulate the process environment rather than just display it. Consider the following example:

```
$ env foo=bar bash                          Launch child shell with foo
$ echo $foo
bar
$ exit                                      Back to the parent shell
$ echo $foo
                                                          Not defined
$ _
```

At least with `bash` (and relations) you don't really need `env` to execute commands with an extended environment – a simple

```
$ foo=bar bash
```

does the same thing. However, `env` also allows you to remove variables from the environment temporarily (how?).

Delete a variable

If you have had enough of a shell variable, you can delete it using the `unset` command. This also removes it from the environment. If you want to remove a variable from the environment but keep it on as a shell variable, use "`export -n`":

```
$ export foo=bar                        foo is an environment variable
$ export -n foo                         foo is a shell variable (only)
$ unset foo                             foo is gone and lost forever
```

8.3 Command Types—Reloaded

Controlling the shell

One application of shell variables is controlling the shell itself. Here's another example: As we discussed in Chapter 3, the shell distinguishes internal and external commands. External commands correspond to executable programs, which the shell looks for in the directories that make up the value of the PATH environment variable. Here is a typical value for PATH:

```
$ echo $PATH
/home/joe/bin:/usr/local/bin:/usr/bin:/bin:/usr/games
```

Individual directories are separated in the list by colons, therefore the list in the example consists of five directories. If you enter a command like

```
$ ls
```

the shell knows that this isn't an internal command (it knows its internal commands) and thus begins to search the directories in PATH, starting with the leftmost directory. In particular, it checks whether the following files exist:

```
/home/joe/bin/ls                                   Nope …
/usr/local/bin/ls                                  Still no luck …
/usr/bin/ls                                        Again no luck …
/bin/ls                                            Gotcha!
                                   The directory /usr/games is not checked.
```

This implies that the /bin/ls file will be used to execute the ls command.

Of course this search is a fairly involved process, which is why the shell prepares for the future: If it has once identified the /bin/ls file as the implementation of the ls command, it remembers this correspondence for the time being. This process is called "hashing", and you can see that it did take place by applying type to the ls command.

```
$ type ls
ls is hashed (/bin/ls)
```

The hash command tells you which commands your bash has "hashed" and how often they have been invoked in the meantime. With "hash -r" you can delete the shell's complete hashing memory. There are a few other options which you can look up in the bash manual or find out about using "help hash".

Strictly speaking, the PATH variable does not even need to be an environment variable—for the current shell a shell variable would do just fine (see Exercise 8.5). However it is convenient to define it as an environment variable so the shell's child processes (often also shells) use the desired value.

If you want to find out exactly which program the shell uses for a given external command, you can use the which command:

```
$ which grep
/bin/grep
```

which uses the same method as the shell—it starts at the first directory in PATH and checks whether the directory in question contains an executable file with the same name as the desired command.

`which` knows nothing about the shell's internal commands; even though something like "`which test`" returns "`/usr/bin/test`", this does not imply that this program will, in fact, be executed, since internal commands have precedence. If you want to know for sure, you need to use the "`type`" shell command.

The `whereis` command not only returns the names of executable programs, but also documentation (man pages), source code and other interesting files pertaining to the command(s) in question. For example:

```
$ whereis passwd
passwd: /usr/bin/passwd /etc/passwd /etc/passwd.org /usr/share/passwd▷
 ◁ /usr/share/man/man1/passwd.1.gz /usr/share/man/man1/passwd.1ssl.gz▷
 ◁ /usr/share/man/man5/passwd.5.gz
```

This uses a hard-coded method which is explained (sketchily) in `whereis`(1).

Exercises

8.3 [!2] Convince yourself that passing (or not passing) environment and shell variables to child processes works as advertised, by working through the following command sequence:

```
$ foo=bar                                   foo is a shell variable
$ bash                                      New shell (child process)
$ echo $foo

                                            foo is not defined
$ exit                                      Back to the parent shell
$ export foo                                foo is an environment variable
$ bash                                      New shell (child process)
$ echo $foo
bar                                         Environment variable was passed along
$ exit                                      Back to the parent shell
```

8.4 [!2] What happens if you change an environment variable in the child process? Consider the following command sequence:

```
$ foo=bar                                   foo is a shell variable
$ bash                                      New shell (child process)
$ echo $foo
bar                                         Environment variable was passed along
$ foo=baz                                   New value
$ exit                                      Back to the parent shell
$ echo $foo                                 What do we get??
```

8.5 [2] Make sure that the shell's command line search works even if `PATH` is a "only" simple shell variable rather than an environment variable. What happens if you remove `PATH` completely?

8.6 [!1] Which executable programs are used to handle the following commands: `fgrep`, `sort`, `mount`, `xterm`

8.7 [!1] Which files on your system contain the documentation for the "`crontab`" command?

8.4 The Shell As A Convenient Tool

Since the shell is the tool many Linux users use most often, its developers have spared no trouble to make its use convenient. Here are some more useful trifles:

Command Editor You can edit command lines like in a simple text editor. Hence, you can move the cursor around in the input line and delete or add characters arbitrarily before finishing the input using the return key. The behaviour of this editor can be adapted to that of the most popular editors on Linux (Chapter 5) using the "`set -o vi`" and "`set -o emacs`" commands.

Aborting Commands With so many Linux commands around, it is easy to confuse a name or pass a wrong parameter. Therefore you can abort a command while it is being executed. You simply need to press the Ctrl+c keys at the same time.

The History The shell remembers ever so many of your most recent commands as part of the "history", and you can move through this list using the ↑ and ↓ cursor keys. If you find a previous command that you like you can either re-execute it unchanged using ↩, or else edit it as described above. You can search the list "incrementally" using Ctrl+r—simply type a sequence of characters, and the shell shows you the most recently executed command containing this sequence. The longer your sequence, the more precise the search.

When you log out of the system, the shell stores the history in the hidden file `~/.bash_history` and makes it available again after your next login. (You may use a different file name by setting the `HISTFILE` variable to the name in question.)

A consequence of the fact that the history is stored in a "plain" file is that you can edit it using a text editor (Chapter 5 tells you how). So in case you accidentally enter your password on the command line, you can (and should!) remove it from the history manually—in particular, if your system is one of the more freewheeling ones where home directories are visible to anybody.

By default, the shell remembers the last 500 commands; you can change this by putting the desired number into the `HISTSIZE` variable. The `HISTFILESIZE` command specifies how many commands to write to the `HISTFILE` file – usually 500 as well.

Besides the arrow keys you can access the history also via "magical" character sequences in new commands. The shell replaces these character sequences first, immediately after the command line has been read. Replacement proceeds in two stages:

- At first the shell determines which command from the history to use for the replacement. The `!!` sequence stands for the immediately preceding command, `!-`*n* refers to the *n*th command before the current one (`!-2`, for example, to the penultimate one), and `!`*n* to the command with number *n* in the history. (The `history` command outputs the whole history including numbers for the commands.) `!xyz` selects the most recent command starting with `xyz`, and `!?xyz` the most recent command *containing* `xyz`.
- After that, the shell decides which part of the selected command will be "recycled" and how. If you do not specify anything else, the complete command will be inserted; otherwise there are various selection methods. All these selection methods are separated from the command selection character sequence by a colon ("`:`").

  n Selects the *n*-th word. Word 0 is the command itself.

  `^` Selects the first word (immediately after the command).

  `$` Selects the final word.

  m`-`*n* Selects words *m* through *n*.

n`*` Selects all words starting at word *n*.

n`-` Selects all words starting at word *n* except for the final one.

Some examples for clarity:

`!-2:$` Picks the final word of the penultimate command.

`!!:0-` Picks the complete immediately preceding command except for the final word.

`!333^` Picks the first word from command 333.

The final example, incidentally, is not a typo; if the first character from the intra-command selection is from the list `^$*-%` you may leave out the colon.—If you like, look at the `bash` documentation (section HISTORY) to find out what else the shell has in store. As far as we (and the LPI) are concerned you do not need to learn all of this off by heart.

The history is one of the things that `bash` took over from the C shell, and whoever did not use Unix during the 1980s may have some trouble imagining what the world looked like before interactive command line editing was invented. (For Windows users, this time doesn't even go *that* far back.) During that time, the history with all its `!` selectors and transformations was widely considered the best idea since sliced bread; today its documentation exudes the sort of morbid fascination one would otherwise associate with the user manual for a Victorian steam engine.

Some more remarks concerning the `history` command: An invocation like

```
$ history 33
```

(with a number as the parameter) only outputs that many history lines. "`history -c`" empties the history completely. There are some more options; check the `bash` documentation or try "`help history`".

Completing command and file names

Autocompletion A massive convenience is `bash`'s ability to automatically complete command and file names. If you hit the Tab key, the shell completes an incomplete input if the continuation can be identified uniquely. For the first word of a command, `bash` considers all executable programs, within the rest of the command line all the files in the current or specified directory. If several commands or files exist whose names start out equal, the shell completes the name as far as possible and then signals acoustically that the command or file name may still be incomplete. Another Tab press then lists the remaining possibilities.

It is possible to adapt the shell's completion mechanism to specific programs. For example, on the command line of a FTP client it might offer the names of recently visited FTP servers in place of file names. Check the `bash` documentation for details.

Table 8.2 gives an overview of the most important key strokes within `bash`.

Multiple Commands On One Line You are perfectly free to enter several commands on the same input line. You merely need to separate them using a semicolon:

```
$ echo Today is; date
Today is
Fri  5 Dec 12:12:47 CET 2008
```

In this instance the second command will be executed once the first is done.

Table 8.2: Key Strokes within `bash`

Key Stroke	Function
↑ or ↓	Scroll through most recent commands
Ctrl + r	Search command history
← bzw. →	Move cursor within current command line
Home oder Ctrl + a	Jump to the beginning of the command line
End oder Ctrl + e	Jump to the end of the command line
⇐ bzw. Del	Delete character in front of/under the cursor, respectively
Ctrl + t	Swap the two characters in front of and under the cursor
Ctrl + l	Clear the screen
Ctrl + c	Interrupt a command
Ctrl + d	End the input (for login shells: log off)

Conditional Execution Sometimes it is useful to make the execution of the second command depend on whether the first was executed correctly or not. Every Unix process yields a **return value** which states whether it was executed correctly or whether errors of whatever kind have occurred. In the former case, the return value is 0; in the latter, it is different from 0.

return value

You can find the return value of a child process of your shell by looking at the `$?` variable:

```
$ bash                                          Start a child shell …
$ exit 33                                       … and exit again immediately
exit
$ echo $?
33                                              The value from our exit above
$ _
```

But this really has no bearing on the following.

With `&&` as the "separator" between two commands (where there would otherwise be the semicolon), the second command is only executed when the first has exited successfully. To demonstrate this, we use the shell's `-c` option, with which you can pass a command to the child shell on the command line (impressive, isn't it?):

```
$ bash -c "exit 0" && echo "Successful"
Successful
$ bash -c "exit 33" && echo "Successful"
                                                Nothing -- 33 isn't success!
```

Conversely, with `||` as the "separator", the second command is only executed if the first did *not* finish successfully:

```
$ bash -c "exit 0" || echo "Unsuccessful"
$ bash -c "exit 33" || echo "Unsuccessful"
Unsuccessful
```

Exercises

8.8 [3] What is wrong about the command "`echo "Hello!"`"? (*Hint:* Experiment with commands of the form "`!-2`" or "`!ls`".)

8.5 Commands From A File

You can store shell commands in a file and execute them *en bloc*. (Chapter 5 explains how to conveniently create files.) You just need to invoke the shell and pass the file name as a parameter:

```
$ bash my-commands
```

shell script Such a file is also called a **shell script**, and the shell has extensive programming features that we can only outline very briefly here. (The Linup Front training manual *Advanced Linux* explains shell programming in great detail.)

You can avoid having to prepend the `bash` command by inserting the magical incantation

```
#!/bin/bash
```

as the first line of your file and making the file "executable":

```
$ chmod +x my-commands
```

(You will find out more about `chmod` and access rights in Chapter 12.) After this, the

```
$ ./my-commands
```

command will suffice.

subshell If you invoke a shell script as above, whether with a prepended `bash` or as an executable file, it is executed in a subshell, a shell that is a child process of the current shell. This means that changes to, e. g., shell or environment variables do not influence the current shell. For example, assume that the file `assignment` contains the line

```
foo=bar
```

Consider the following command sequence:

```
$ foo=quux
$ bash assignment                                   Contains foo=bar
$ echo $foo
quux                                   No change; assignment was only in subshell
```

This is generally considered a feature, but every now and then it would be quite desirable to have commands from a file affect the *current* shell. That works, too: The `source` command reads the lines in a file exactly as if you would type them directly into the current shell—all changes to variables (among other things) hence take effect in your current shell:

```
$ foo=quux
$ source assignment                                 Contains foo=bar
$ echo $foo
bar                                                 Variable was changed!
```

A different name for the `source` command, by the way, is ".". (You read correctly – dot!) Hence

```
$ source assignment
```

is equivalent to

```
$ . assignment
```


Like program files for external commands, the files to be read using `source` or `.` are searched in the directories given by the `PATH` variable.

8.6 The Shell As A Programming Language

Being able to execute shell commands from a file is a good thing, to be sure. However, it is even better to be able to structure these shell commands such that they do not have to do the same thing every time, but—for example—can obtain command-line parameters. The advantages are obvious: In often-used procedures you save a lot of tedious typing, and in seldom-used procedures you can avoid mistakes that might creep in because you accidentally leave out some important step. We do not have space here for a full explanation of the shell als a programming language, but fortunately there is enough room for a few brief examples.

Command-line parameters When you pass command-line parameters to a shell script, the shell makes them available in the variables `$1`, `$2`, …. Consider the following example:

Single parameters

```
$ cat hello
#!/bin/bash
echo Hello $1, are you free $2?
$ ./hello Joe today
Hello Joe, are you free today?
$ ./hello Sue tomorrow
Hello Sue, are you free tomorrow?
```

The `$*` contains all parameters at once, and the number of parameters is in `$#`:

All parameters

```
$ cat parameter
#!/bin/bash
echo $# parameters: $*
$ ./parameter
0 parameters:
$ ./parameter dog
1 parameters: dog
$ ./parameter dog cat mouse tree
4 parameters: dog cat mouse tree
```

Loops The `for` command lets you construct loops that iterate over a list of words (separated by white space):

```
$ for i in 1 2 3
> do
>   echo And $i!
> done
And 1!
And 2!
And 3!
```

Here, the `i` variable assumes each of the listed values in turn as the commands between `do` and `done` are executed.

This is even more fun if the words are taken from a variable:

```
$ list='4 5 6'
$ for i in $list
> do
>   echo And $i!
> done
And 4!
And 5!
And 6!
```

Loop over parameters

If you omit the "`in` …", the loop iterates over the command line parameters:

```
$ cat sort-wc
#!/bin/bash
# Sort files according to their line count
for f
do
    echo `wc -l <"$f» lines in $f
done | sort -n
$ ./sort-wc /etc/passwd /etc/fstab /etc/motd
```

(The "`wc -l`" command counts the lines of its standard input or the file(s) passed on the command line.) Do note that you can redirect the standard output of a *loop* to `sort` using a pipe line!

Alternatives You can use the aforementioned `&&` and `||` operators to execute certain commands only under specific circumstances. The

```
#!/bin/bash
# grepcp REGEX
rm -rf backup; mkdir backup
for f in *.txt
do
    grep $1 "$f" && cp "$f" backup
done
```

script, for example, copies a file to the `backup` directory only if its name ends with `.txt` (the `for` loop ensures this) and which contain at least one line matching the regular expression that is passed as a parameter.

`test` A useful tool for alternatives is the `test` command, which can check a large variety of conditions. It returns an exit code of 0 (success), if the condition holds, else a non-zero exit code (failure). For example, consider

```
#!/bin/bash
# filetest NAME1 NAME2 ...
for name
do
   test -d "$name" && echo $name: directory
   test -f "$name" && echo $name: file
   test -L "$name" && echo $name: symbolic link
done
```

This script looks at a number of file names passed as parameters and outputs for each one whether it refers to a directory, a (plain) file, or a symbolic link.

The `test` command exists both as a free-standing program in `/bin/test` and as a built-in command in `bash` and other shells. These variants can differ subtly especially as far as more outlandish tests are concerned. If in doubt, read the documentation.

You can use the `if` command to make more than one command depend on a condition (in a convenient and readable fashion). You may write "`[ …]`" instead of "`test …`": `if`

```
#!/bin/bash
# filetest2 NAME1 NAME2 ...
for name
do
    if [ -L "$name" ]
    then
        echo $name: symbolic link
    elif [ -d "$name" ]
        echo $name: directory
    elif [ -f "$name" ]
        echo $name: file
    else
        echo $name: no idea
    fi
done
```

If the command after the `if` signals "success" (exit code 0), the commands after `then` will be executed, up to the next `elif`, `else`, or `fi`. If on the other hand it signals "failure", the command after the next `elif` will be evaluated next and its exit code will be considered. The shell continues the pattern until the matching `fi` is reached. Commands after the `else` are executed if none of the `if` or `elif` commands resulted in "success". The `elif` and `else` branches may be omitted if they are not required.

More loops With the `for` loop, the number of trips through the loop is fixed at the beginning (the number of words in the list). However, we often need to deal with situations where it is not clear at the beginning how often a loop should be executed. To handle this, the shell offers the `while` loop, which (like `if`) executes a command whose success or failure determines what to do about the loop: On success, the "dependent" commands will be executed, on failure execution will continue after the loop. `while`

The following script reads a file like

```
Aunt Maggie:maggie@example.net:the delightful tea cosy
Uncle Bob:bob@example.com:the great football
```

(whose name is passed on the command line) and constructs a thank-you e-mail message from each line (Linux *is* very useful in daily life):

```
#!/bin/bash
# birthday FILE
IFS=:
while read name email present
do
    (echo $name
     echo ""
     echo "Thank you very much for $present!"
     echo "I enjoyed it very much."
     echo ""
     echo "Best wishes"
     echo "Tim") | mail -s "Many thanks!" $email
done <$1
```

The `read` command reads the input file line by line and splits each line at the colons `read`

(variable IFS) into the three fields name, email, and present which are then made available as variables inside the loop. Somewhat counterintuitively, the input redirection for the loop can be found at the very end.

Please test this script with innocuous e-mail addresses only, lest your relations become confused!

Exercises

8.9 [1] What is the difference (as far as loop execution is concerned) between

```
for f; do …; done
```

and

```
for f in $*; do …; done
```

? (Try it, if necessary)

8.10 [2] In the sort-wc script, why do we use the

```
wc -l <$f
```

instead of

```
wc -l $f
```

8.11 [2] Alter the grepcp such that the list of files to be considered is also taken from the command line. (*Hint:* The shift shell command removes the first command line parameter from $ and pulls all others up to close the gap. After a shift, the previous $2 is now $1, $3 is $2 and so on.)

8.12 [2] Why does the filetest script output

```
$ ./filetest foo
foo: file
foo: symbolic link
```

for symbolic links (instead of just »foo: symbolic link«)?

8.6.1 Foreground and Background Processes

child process

After a command has been entered, it is processed by the shell. The shell executes internal commands directly; for external commands, the shell generates a **child process**, which is used to execute the command and terminates itself afterwards. In Unix, a process is a running programm; the same program can be executed several times simultaneously (e. g., by different users) and corresponds with several processes. Every process can generate child processes (even if most of them—unlike shells—don't).

Usually, the shell waits until the child process has done its work and terminates. You can tell by the fact that no new shell prompt is displayed while the child process is running. After the child process has exited, the shell reads and processes its return value, and only after that it displays a new shell prompt. The execution of the shell and the child process is, so to speak, synchronised. This "synchronous" manner of processing commands is displayed in Figure 8.1; from the user's point of view it looks like the following:

```
$ sleep 10
                                    Nothing happens for approximately 10 seconds
$ _
```

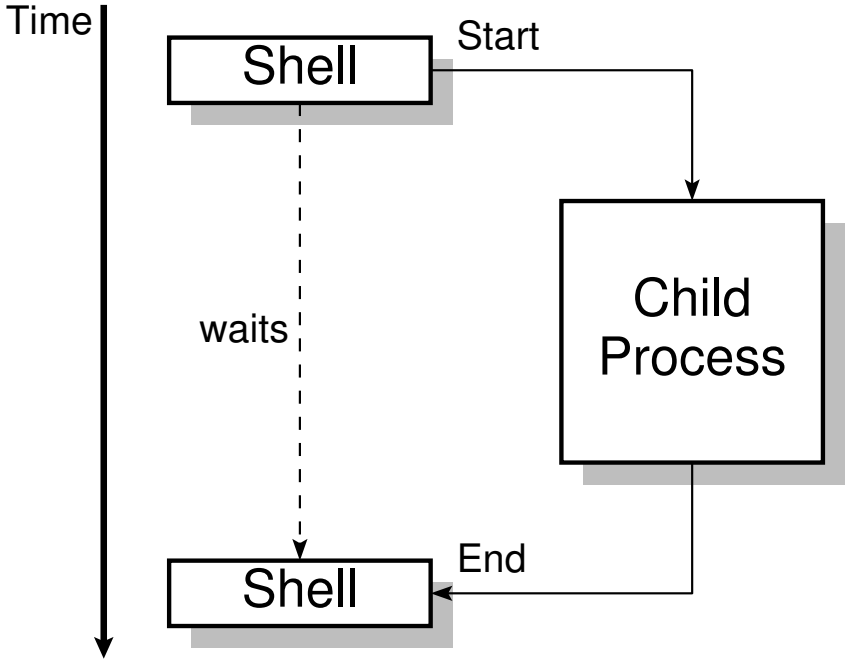


Figure 8.1: Synchronous command execution in the shell

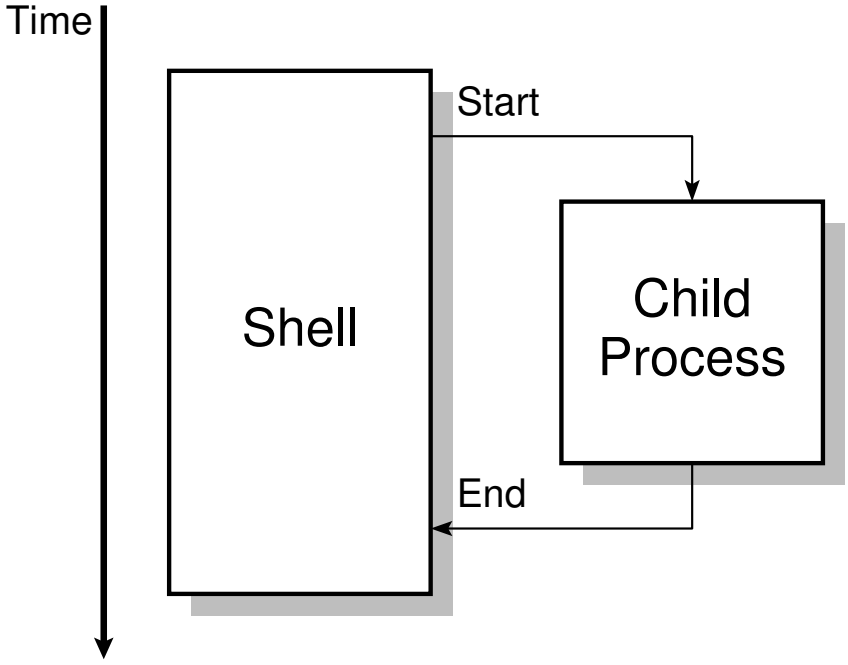


Figure 8.2: Asynchronous command execution in the shell

Table 8.3: Options for `jobs`

Option	Meaning
`-l` (long)	Adds PIDs to the output
`-n` (notify)	Displays only processes that have been terminated since the last invocation of `jobs`
`-p` (process)	Displays only PIDs

If you do not want the shell to wait until the child process has finished, you have to append an ampersand (`&`) to the command line. Then, while the child process is executed in the background, a short message appears on the terminal, immediately followed by the shell's command prompt:

```
$ sleep 10 &
[2] 6210
                                                    And then immediately:
$ _
```

This mode of operation is called "asynchronous", since the shell does not wait idly for the child process to finish (qv. Figure 8.2).

The "`[2] 6210`" means that the system has created the process with the number (or "process ID") 6210 as "job" number 2. These numbers will probably differ on your system.

Syntactically, the `&` really acts like a semicolon, and can therefore serve as a separator between commands. See Exercise 8.14.

Here are some hints for successful background process operation:

- The background process should not expect keyboard input, since the shell cannot determine to which process—foreground or background—any keyboard input should be assigned. If necessary, input can be taken from a file. This is covered more extensively in Chapter 7.
- The background process should not direct output to the terminal, since these may be mixed up with the output of foreground processes or discarded altogether. Again, there is more about this in Chapter 7.
- If the parent process (the shell) is aborted, all its children (and consequently their children etc.) will in many cases be terminated as well. Only processes that completely disawov their parents are exempted from this; this applies, e. g., to processes that perform system services in the background.

Job control

When several processes are executed in the background from the same shell, it is easy to lose track. Therefore the shell makes available an (internal) command that you can use to find out about the state of background processes—`jobs`. If `jobs` is invoked without options, its output consists of a list of job numbers, process states and command lines. This looks approximately like the following:

```
$ jobs
[1]   Done                    sleep
$ _
```

In this case, job number 1 has already finished ("Done"), otherwise the message "`Running`" would have appeared. The `jobs` command supports various options, the most important of which are shown in Table 8.3.

The shell makes it possible to stop a foreground process using Ctrl+z. This process is displayed by `jobs` with a "`Stopped`" status and can be continued as a background process using the `bg` command. (Otherwise, processes stay stopped until

hell freezes over, or the next system restart, whichever occurs earlier.) For example, "`bg %5`" will send job 5 to the background, where it will continue to run.

Conversely, you can select one of a number of background processes and fetch it back to the foreground using the `fg` command. The syntax of the `fg` command is equivalent to that of the `bg` command.

You can terminate a foreground process from the shell with the Ctrl+c key sequence. A background process can be terminated directly using the `kill` command followed by a job number with a leading percent character (similar to `bg`).

Exercises

8.13 [2] Use a suitably spectacular program (such as the OpenGL demo `gears` under X11 in the SUSE distributions, alternatively, for example, "`xclock -update 1`") to experiment with background processes and job control. Make sure that you are able to start background processes, to stop foreground processes using Ctrl+z and send them to the background using `bg`, to list background processes using `jobs` and so on.

8.14 [3] Describe (and explain) the differences between the following three command lines:

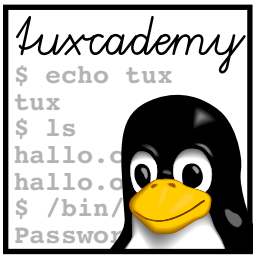
```
$  sleep 5 ; sleep 5
$  sleep 5 ; sleep 5 &
$  sleep 5 & sleep 5 &
```

Commands in this Chapter

`.`	Reads a file containing shell commands as if they had been entered on the command line	`bash`(1)	128
`bg`	Continues a (stopped) process in the background	`bash`(1)	134
`date`	Displays the date and time	`date`(1)	120
`env`	Outputs the process environment, or starts programs with an adjusted environment	`env`(1)	122
`export`	Defines and manages environment variables	`bash`(1)	121
`fg`	Fetches a background process back to the foreground	`bash`(1)	134
`gears`	Displays turning gears on X11	`gears`(1)	135
`hash`	Shows and manages "'seen"' commands in `bash`	`bash`(1)	123
`history`	Displays recently used `bash` command lines	`bash`(1)	125
`jobs`	Reports on background jobs	`bash`(1)	134
`kill`	Terminates a background process	`bash`(1), `kill`(1)	135
`set`	Manages shell variables and options	`bash`(1)	122
`source`	Reads a file containing shell commands as if they had been entered on the command line	`bash`(1)	128
`test`	Evaluates logical expressions on the command line	`test`(1), `bash`(1)	130
`unset`	Deletes shell or environment variables	`bash`(1)	122
`whereis`	Searches executable programs, manual pages, and source code for given programs	`whereis`(1)	123
`which`	Searches programs along `PATH`	`which`(1)	123
`xclock`	Displays a graphical clock	`xclock`(1x)	135

Summary

- The `sleep` command waits for the number of seconds specified as the argument.
- The `echo` command outputs its arguments.
- The date and time may be determined using `date`
- Various `bash` features support interactive use, such as command and file name autocompletion, command line editing, alias names and variables.
- External programs can be started asynchronously in the background. The shell then immediately prints another command prompt.



9

The File System

Contents

Goals

- Understanding the terms “file” and “file system”
- Recognising the different file types
- Knowing your way around the directory tree of a Linux system
- Knowing how external file systems are integrated into the directory tree

Prerequisites

- Basic Linux knowledge (from the previous chapters)
- Handling files and directories (Chapter 6)

Table 9.1: Linux file types

Type	`ls -l`	`ls -F`	Create using …
plain file	`-`	`name`	diverse programs
directory	`d`	`name/`	`mkdir`
symbolic link	`l`	`name@`	`ln -s`
device file	`b` or `c`	`name`	`mknod`
FIFO (*named pipe*)	`p`	`name|`	`mkfifo`
Unix-domain socket	`s`	`name=`	no command

9.1 Terms

file Generally speaking, a **file** is a self-contained collection of data. There is no restriction on the type of the data within the file; a file can be a text of a few letters or a multi-megabyte archive containing a user's complete life works. Files do not need to contain plain text. Images, sounds, executable programs and lots of other things can be placed on a storage medium as files. To guess at the type of data
file contained in a file you can use the `file` command:

```
$ file /bin/ls /usr/bin/groups /etc/passwd
/bin/ls:         ELF 32-bit LSB executable, Intel 80386,▷
 ◁ version 1 (SYSV), for GNU/Linux 2.4.1,▷
 ◁ dynamically linked (uses shared libs), for GNU/Linux 2.4.1, stripped
/usr/bin/groups: Bourne shell script text executable
/etc/passwd:     ASCII text
```

`file` guesses the type of a file based on rules in the `/usr/share/file` directory. `/usr/share/file/magic` contains a clear-text version of the rules. You can define your own rules by putting them into the `/etc/magic` file. Check `magic`(5) for details.

To function properly, a Linux system normally requires several thousand different files. Added to that are the many files created and owned by the system's various users.

file system A **file system** determines the method of arranging and managing data on a storage medium. A hard disk basically stores bytes that the system must be able to find again somehow—and as efficiently and flexibly as possible at that, even for very huge files. The details of file system operation may differ (Linux knows lots of different file systems, such as `ext2`, `ext3`, `ext4`, ReiserFS, XFS, JFS, btrfs, …) but what is presented to the user is largely the same: a tree-structured hierarchy of file and directory names with files of different types. (See also Chapter 6.)

In the Linux community, the term "file system" carries several meanings. In addition to the meaning presented here—"method of arranging bytes on a medium"—, a file system is often considered what we have been calling a "directory tree". In addition, a specific medium (hard disk partition, USB key, …) together with the data on it is often called a "file system"—in the sense that we say, for example, that hard links (Section 6.4.2) do not work "across file system boundaries", that is, between two different partitions on hard disk or between the hard disk and a USB key.

9.2 File Types

Linux systems subscribe to the basic premise "Everything is a file". This may seem confusing at first, but is a very useful concept. Six file types may be distinguished in principle:

Plain files This group includes texts, graphics, sound files, etc., but also executable programs. Plain files can be generated using the usual tools like editors, `cat`, shell output redirection, and so on.

Directories Also called "folders"; their function, as we have mentioned, is to help structure storage. A directory is basically a table giving file names and associated inode numbers. Directories are created using the `mkdir` command.

Symbolic links Contain a path specification redirecting accesses to the link to a different file (similar to "shortcuts" in Windows). See also Section 6.4.2. Symbolic links are created using `ln -s`.

Device files These files serve as interfaces to arbitrary devices such as disk drives. For example, the file `/dev/fd0` represents the first floppy drive. Every write or read access to such a file is redirected to the corresponding device. Device files are created using the `mknod` command; this is usually the system administrator's prerogative and is thus not explained in more detail in this manual.

FIFOs Often called "named pipes". Like the shell's pipes, they allow the direct communication between processes without using intermediate files. A process opens the FIFO for writing and another one for reading. Unlike the pipes that the shell uses for its pipelines, which behave like files from a program's point of view but are "anonymous"—they do not exist within the file system but only between related processes—, FIFOs have file names and can thus be opened like files by arbitrary programs. Besides, FIFOs may have access rights (pipes may not). FIFOs are created using the `mkfifo` command.

Unix-domain sockets Like FIFOs, Unix-domain sockets are a method of interprocess communication. They use essentially the same programming interface as "real" network communications across TCP/IP, but only work for communication peers on the same computer. On the other hand, Unix-domain sockets are considerably more efficient than TCP/IP. Unlike FIFOs, Unix-domain sockets allow bi-directional communications—both participating processes can send as well as receive data. Unix-domain sockets are used, e. g., by the X11 graphic system, if the X server and clients run on the same computer. There is no special program to create Unix-domain sockets.

Exercises

9.1 [3] Check your system for examples of the various file types. (Table 9.1 shows you how to recognise the files in question.)

9.3 The Linux Directory Tree

A Linux system consists of hundreds of thousands of files. In order to keep track, there are certain conventions for the directory structure and the files comprising a Linux system, the *Filesystem Hierarchy Standard* (**FHS**). Most distributions adhere to this standard (possibly with small deviations). The FHS describes all directories immediately below the file system's root as well as a second level below `/usr`. FHS

The file system tree starts at the **root directory**, "`/`" (not to be confused with `/root`, the home directory of user `root`). The root directory contains either just subdirectories or else additionally, if no `/boot` directory exists, the operating system kernel. root directory

You can use the "`ls -la /`" command to list the root directory's subdirectories. The result should look similar to Figure 9.1. The individual subdirectories follow FHS and therefore contain approximately the same files on every distribution. We shall now take a closer look at some of the directories:

```
$ cd /
$ ls -l
insgesamt 125
drwxr-xr-x    2 root  root    4096 Dez 20 12:37 bin
drwxr-xr-x    2 root  root    4096 Jan 27 13:19 boot
lrwxrwxrwx    1 root  root      17 Dez 20 12:51 cdrecorder▷
                                                                    ◁ -> /media/cdrecorder
lrwxrwxrwx    1 root  root      12 Dez 20 12:51 cdrom -> /media/cdrom
drwxr-xr-x   27 root  root   49152 Mär  4 07:49 dev
drwxr-xr-x   40 root  root    4096 Mär  4 09:16 etc
lrwxrwxrwx    1 root  root      13 Dez 20 12:51 floppy -> /media/floppy
drwxr-xr-x    6 root  root    4096 Dez 20 16:28 home
drwxr-xr-x    6 root  root    4096 Dez 20 12:36 lib
drwxr-xr-x    6 root  root    4096 Feb  2 12:43 media
drwxr-xr-x    2 root  root    4096 Mär 21  2002 mnt
drwxr-xr-x   14 root  root    4096 Mär  3 12:54 opt
dr-xr-xr-x   95 root  root       0 Mär  4 08:49 proc
drwx------   11 root  root    4096 Mär  3 16:09 root
drwxr-xr-x    4 root  root    4096 Dez 20 13:09 sbin
drwxr-xr-x    6 root  root    4096 Dez 20 12:36 srv
drwxrwxrwt   23 root  root    4096 Mär  4 10:45 tmp
drwxr-xr-x   13 root  root    4096 Dez 20 12:55 usr
drwxr-xr-x   17 root  root    4096 Dez 20 13:02 var
```

Figure 9.1: Content of the root directory (SUSE)

There is considerable consensus about the FHS, but it is just as "binding" as anything on Linux, i. e., not that much. On the one hand, there certainly are Linux systems (for example the one on your broadband router or PVR) that are mostly touched only by the manufacturer and where conforming to every nook and cranny of the FHS does not gain anything. On the other hand, you may do whatever you like on your own system, but must be prepared to bear the consequences—your distributor assures you to keep to his side of the FHS bargain, but also expects you not to complain if you are not playing completely by the rules and problems do occur. For example, if you install a program in `/usr/bin` and the file in question gets overwritten during the next system upgrade, this is your own fault since, according to the FHS, you are not supposed to put your own programs into `/usr/bin` (`/usr/local/bin` would have been correct).

The Operating System Kernel—`/boot` The `/boot` directory contains the actual operating system: `vmlinuz` is the Linux kernel. In the `/boot` directory there are also other files required for the boot loader (usually GRUB).

On some systems, `/boot` is placed on its own separate partition. This can be necessary if the actual file system is encrypted or otherwise difficult to reach for the boot loader, possibly because special drivers are required to access a hardware RAID system.

General Utilities—`/bin` In `/bin` there are the most important executable programs (mostly system programs) which are necessary for the system to boot. This includes, for example, `mount` and `mkdir`. Many of these programs are so essential that they are needed not just during system startup, but also when the system is running—like `ls` and `grep`. `/bin` also contains programs that are necessary to get a damaged system running again if only the file system containing the root directory is available. Additional programs that are not required on boot or for system

repair can be found in /usr/bin.

Special System Programs—/sbin Like /bin, /sbin contains programs that are necessary to boot or repair the system. However, for the most part these are system configuration tools that can really be used only by root. "Normal" users can use some of these programs to query the system, but can't change anything. As with /bin, there is a directory called /usr/sbin containing more system programs.

System Libraries—/lib This is where the "shared libraries" used by programs in /bin and /sbin reside, as files and (symbolic) links. Shared libraries are pieces of code that are used by various programs. Such libraries save a lot of resources, since many processes use the same basic parts, and these basic parts must then be loaded into memory only once; in addition, it is easier to fix bugs in such libraries when they are in the system just once and all programs fetch the code in question from one central file. Incidentally, below /lib/modules there are **kernel modules**, i. e., kernel code which is not necessarily in use—device drivers, file systems, or network protocols. These modules can be loaded by the kernel when they are needed, and in many cases also be removed after use.

kernel modules

Device Files—/dev This directory and its subdirectories contain a plethora of entries for device files. **Device files** form the interface between the shell (or, generally, the part of the system that is accessible to command-line users or programmers) to the device drivers inside the kernel. They have no "content" like other files, but refer to a driver within the kernel via "device numbers".

Device files

In former times it was common for Linux distributors to include an entry in /dev for every conceivable device. So even a laptop Linux system included the device files required for ten hard disks with 63 partitions each, eight ISDN adapters, sixteen serial and four parallel interfaces, and so on. Today the trend is away from overfull /dev directories with one entry for every imaginable device and towards systems more closely tied to the running kernel, which only contain entries for devices that actually exist. The magic word in this context is udev (short for *userspace /dev*) and will be discussed in more detail in *Linux Administration I*.

Linux distinguishes between **character devices** and **block devices**. A character device is, for instance, a terminal, a mouse or a modem—a device that provides or processes single characters. A block device treats data in blocks—this includes hard disks or floppy disks, where bytes cannot be read singly but only in groups of 512 (or some such). Depending on their flavour, device files are labelled in "ls -l" output with a "c" or "b":

character devices
block devices

```
crw-rw-rw-  1  root  root  10,  4 Oct 16 11:11 amigamouse
brw-rw----  1  root  disk   8,  1 Oct 16 11:11 sda1
brw-rw----  1  root  disk   8,  2 Oct 16 11:11 sda2
crw-rw-rw-  1  root  root   1,  3 Oct 16 11:11 null
```

Instead of the file length, the list contains two numbers. The first is the "major device number" specifying the device's type and governing which kernel driver is in charge of this device. For example, all SCSI hard disks have major device number 8. The second number is the "minor device number". This is used by the driver to distinguish between different similar or related devices or to denote the various partitions of a disk.

There are several notable **pseudo devices**. The *null device*, /dev/null, is like a "dust bin" for program output that is not actually required, but must be directed somewhere. With a command like

pseudo devices

```
$ program >/dev/null
```

the program's standard output, which would otherwise be displayed on the terminal, is discarded. If `/dev/null` is read, it pretends to be an empty file and returns end-of-file at once. `/dev/null` must be accessible to all users for reading and writing.

The "devices" `/dev/random` and `/dev/urandom` return random bytes of "cryptographic quality" that are created from "noise" in the system—such as the intervals between unpredictable events like key presses. Data from `/dev/random` is suitable for creating keys for common cryptographic algorithms. The `/dev/zero` file returns an unlimited supply of null bytes; you can use these, for example, to create or overwrite files with the `dd` command.

Configuration Files—`/etc` The `/etc` directory is very important; it contains the configuration files for most programs. Files `/etc/inittab` and `/etc/init.d/*`, for example, contain most of the system-specific data required to start system services. Here is a more detailed descriptionof the most important files—except for a few of them, only user `root` has write permission but everyone may read them.

`/etc/fstab` This describes all mountable file systems and their properties (type, access method, "mount point").

`/etc/hosts` This file is one of the configuration files of the TCP/IP network. It maps the names of network hosts to their IP addresses. In small networks and on freestanding hosts this can replace a name server.

`/etc/inittab` The `/etc/inittab` file is the configuration file for the `init` program and thus for the system start.

`/etc/init.d/*` This directory contains the "init scripts" for various system services. These are used to start up or shut down system services when the system is booted or switched off.

On Red Hat distributions, this directory is called `/etc/rc.d/init.d`.

`/etc/issue` This file contains the greeting that is output before a user is asked to log in. After the installation of a new system this frequently contains the name of the vendor.

`/etc/motd` This file contains the "message of the day" that appears after a user has successfully logged in. The system administrator can use this file to notify users of important facts and events[1].

`/etc/mtab` This is a list of all mounted file systems including their mount points. `/etc/mtab` differs from `/etc/fstab` in that it contains all currently mounted file systems, while `/etc/fstab` contains only settings and options for file systems that *might* be mounted—typically on system boot but also later. Even that list is not exhaustive, since you can mount file systems via the command line where and how you like.

We're really not supposed to put that kind of information in a file within `/etc`, where files ought to be static. Apparently, tradition has carried the day here.

`/etc/passwd` In `/etc/passwd` there is a list of all users that are known to the system, together with various items of user-specific information. In spite of the name of the file, on modern systems the passwords are not stored in this file but in another one called `/etc/shadow`. Unlike `/etc/passwd`, that file is not readable by normal users.

[1] There is a well-known claim that the only thing all Unix systems in the world have in common is the "message of the day" asking users to remove unwanted files since all the disks are 98% full.

Accessories—/opt This directory is really intended for third-party software—complete packages prepared by vendors that are supposed to be installable without conflicting with distribution files or locally-installed files. Such software packages occupy a subdirectory `/opt/`⟨*package*⟩. By rights, the `/opt` directory should be completely empty after a distribution has been installed on an empty disk.

"Unchanging Files"—/usr In `/usr` there are various subdirectories containing programs and data files that are not essential for booting or repairing the system or otherwise indispensable. The most important directories include:

/usr/bin System programs that are not essential for booting or otherwise important

/usr/sbin More system programs for `root`

/usr/lib Further libraries (not used for programs in `/bin` or `/sbin`

/usr/local Directory for files installed by the local system administrator. Corresponds to the `/opt` directory—the distribution may not put anything here

/usr/share Architecture-independent data. In principle, a Linux network consisting, e. g., of Intel, SPARC and PowerPC hosts could share a single copy of `/usr/share` on a central server. However, today disk space is so cheap that no distribution takes the trouble of actually implementing this.

/usr/share/doc Documentation, e. g., HOWTOs

/usr/share/info Info pages

/usr/share/man Manual pages (in subdirectories)

/usr/src Source code for the kernel and other programs (if available)

The name `/usr` is often erroneously considered an acronym of "Unix system resources". Originally this directory derives from the time when computers often had a small, fast hard disk and another one that was bigger but slower. All the frequently-used programs and files went to the small disk, while the big disk (mounted as `/usr`) served as a repository for files and programs that were either less frequently used or too big. Today this separation can be exploited in another way: With care, you can put `/usr` on its own partition and mount that partition "read-only". It is even possible to import `/usr` from a remote server, even though the falling prices for disk storage no longer make this necessary (the common Linux distributions do not support this, anyway).

Read-only `/usr`

A Window into the Kernel—/proc This is one of the most interesting and important directories. `/proc` is really a "pseudo file system": It does not occupy space on disk, but its subdirectories and files are created by the kernel if and when someone is interested in their content. You will find lots of data about running processes as well as other information the kernel possesses about the computer's hardware. For instance, in some files you will find a complete hardware analysis. The most important files include:

pseudo file system

/proc/cpuinfo This contains information about the CPU's type and clock frequency.

/proc/devices This is a complete list of devices supported by the kernel including their major device numbers. This list is consulted when device files are created.

/proc/dma A list of DMA channels in use. On today's PCI-based systems this is neither very interesting nor important.

/proc/interrupts A list of all hardware interrupts in use. This contains the interrupt number, number of interrupts triggered and the drivers handling that particular interrupt. (An interrupt occurs in this list only if there is a driver in the kernel claiming it.)

/proc/ioports Like /proc/interrupts, but for I/O ports.

/proc/kcore This file is conspicuous for its size. It makes available the computer's complete RAM and is required for debugging the kernel. This file requires root privileges for reading. You do well to stay away from it!

/proc/loadavg This file contains three numbers measuring the CPU load during the last 1, 5 and 15 minutes. These values are usually output by the uptime program

/proc/meminfo Displays the memory and swap usage. This file is used by the free program

/proc/mounts Another list of all currently mounted file systems, mostly identical to /etc/mtab

/proc/scsi In this directory there is a file called scsi listing the available SCSI devices. There is another subdirectory for every type of SCSI host adapter in the system containing a file 0 (1, 2, …, for multiple adapters of the same type) giving information about the SCSI adapter.

/proc/version Contains the version number and compilation date of the current kernel.

Back when /proc had not been invented, programs like the process status display tool, ps, which had to access kernel information, needed to include considerable knowledge about internal kernel data structures as well as the appropriate access rights to read the data in question from the running kernel. Since these data structures used to change fairly rapidly, it was often necessary to install a new version of these programs along with a new version of the kernel. The /proc file system serves as an abstraction layer between these internal data structures and the utilities: Today you just need to ensure that after an internal change the data formats in /proc remain the same—and ps and friends continue working as usual.

Hardware Control—/sys The Linux kernel has featured this directory since version 2.6. Like /proc, it is made available on demand by the kernel itself and allows, in an extensive hierarchy of subdirectories, a consistent view on the available hardware. It also supports management operations on the hardware via various special files.

Theoretically, all entries in /proc that have nothing to do with individual processes should slowly migrate to /sys. When this strategic goal is going to be achieved, however, is anybody's guess.

Dynamically Changing Files—/var This directory contains dynamically changing files, distributed across different directories. When executing various programs, the user often creates data (frequently without being aware of the fact). For example, the man command causes compressed manual page sources to be uncompressed, while formatted man pages may be kept around for a while in case they are required again soon. Similarly, when a document is printed, the print data must be stored before being sent to the printer, e. g., in /var/spool/cups. Files in log files /var/log record login and logout times and other system events (the "log files"), /var/spool/cron contains information about regular automatic command invocations, and users' unread electronic mail is kept in /var/mail.


Just so you heard about it once (it might be on the exam): On Linux, the system log files are generally handled by the "syslog" service. A program called `syslogd` accepts messages from other programs and sorts these according to their origin and priority (from "debugging help" to "error" and "emergency, system is crashing right now") into files below `/var/log`, where you can find them later on. Other than to files, the syslog service can also write its messages elsewhere, such as to the console or via the network to another computer serving as a central "management station" that consolidates all log messages from your data center.


Besides the `syslogd`, some Linux distributions also contain a `klogd` service. Its job is to accept messages from the operating system kernel and to pass them on to `syslogd`. Other distributions do not need a separate `klogd` since their `syslogd` can do that job itself.


The Linux kernel emits all sorts of messages even before the system is booted far enough to run `syslogd` (and possibly `klogd`) to accept them. Since the messages might still be important, the Linux kernel stores them internally, and you can access them using the `dmesg` command.

Transient Files—`/tmp` Many utilities require temporary file space, for example some editors or `sort`. In `/tmp`, all programs can deposit temporary data. Many distributions can be set up to clean out `/tmp` when the system is booted; thus you should not put anything of lasting importance there.


According to tradition, `/tmp` is emptied during system startup but `/var/tmp` isn't. You should check what your distribution does.

Server Files—`/srv` Here you will find files offered by various server programs, such as

```
drwxr-xr-x    2 root     root         4096 Sep 13 01:14 ftp
drwxr-xr-x    5 root     root         4096 Sep  9 23:00 www
```

This directory is a relatively new invention, and it is quite possible that it does not yet exist on your system. Unfortunately there is no other obvious place for web pages, an FTP server's documents, etc., that the FHS authors could agree on (the actual reason for the introduction of `/srv`), so that on a system without `/srv`, these files could end up somewhere completely different, e. g., in subdirectories of `/usr/local` or `/var`.

Access to CD-ROM or Floppies—`/media` This directory is often generated automatically; it contains additional empty directories, like `/media/cdrom` and `/media/floppy`, that can serve as mount points for CD-ROMs and floppies. Depending on your hardware setup you should feel free to add further directories such as `/media/dvd`, if these make sense as mount points and have not been preinstalled by your distribution vendor.

Access to Other Storage Media—`/mnt` This directory (also empty) serves as a mount point for short-term mounting of additional storage media. With some distributions, such as those by Red Hat, media mountpoints for CD-ROM, floppy, … might show up here instead of below `/media`.

User Home Directories—`/home` This directory contains the home directories of all users except `root` (whose home directory is located elsewhere).


If you have more than a few hundred users, it is sensible, for privacy protection and efficiency, not to keep all home directories as immediate children of `/home`. You could, for example, use the users' primary group as a criterion for further subdivision:

Table 9.2: Directory division according to the FHS

	static	dynamic
local	`/etc`, `/bin`, `/sbin`, `/lib`	`/dev`, `/var/log`
remote	`/usr`, `/opt`	`/home`, `/var/mail`

```
/home/support/jim
/home/develop/bob
◁◁◁◁◁
```

Administrator's Home Directory—`/root` The system administrator's home directory is located in `/root`. This is a completely normal home directory similar to that of the other users, with the marked difference that it is not located below `/home` but immediately below the root directory (`/`).

The reason for this is that `/home` is often located on a file system on a separate partition or hard disk. However, `root` must be able to access their own user environment even if the separate `/home` file system is not accessible for some reason.

Lost property—`lost+found` (`ext` file systems only; not mandated by FHS.) This directory is used for files that look reasonable but do not seem to belong to any directory. The file system consistency checker creates liks to such files in the `lost+found` directory on the same file system, so the system administrator can figure out where the file really belongs; `lost+found` is created "on the off-chance" for the file system consistency checker to find in a fixed place (by convention, on the `ext` file systems, it always uses inode number 11).

Another motivation for the directory arrangement is as follows: The FHS divides files and directories roughly according to two criteria—do they need to be available locally or can they reside on another computer and be accessed via the network, and are their contents static (do files only change by explicit administrator action) or do they change while the system is running? (Table 9.2)

The idea behind this division is to simplify system administration: Directories can be moved to file servers and maintained centrally. Directories that do not contain dynamic data can be mounted read-only and are more resilient to crashes.

Exercises

9.2 [1] How many programs does your system contain in the "usual" places?

9.3 [I]f `grep` is called with more than one file name on the command line, it outputs the name of the file in question in front of every matching line. This is possibly a problem if you invoke `grep` with a shell wildcard pattern (such as "`*.txt`"), since the exact format of the `grep` output cannot be foreseen, which may mess up programs further down the pipeline. How can you enforce output of the file name, even if the search pattern expands to a single file name only? (*Hint:* There is a very useful "file" in `/dev`.)

9.4 [T]he "`cp foo.txt /dev/null`" command does basically nothing, but the "`mv foo.txt /dev/null`"—assuming suitable access permissions—replaces `/dev/null` by `foo.txt`. Why?

9.5 [2] On your system, which (if any) software packages are installed below `/opt`? Which ones are supplied by the distribution and which ones are third-party products? Should a distribution install a "teaser version" of a third-party product below `/opt` or elsewhere? What do you think?

9.6 [1] Why is it inadvisable to make backup copies of the directory tree rooted at `/proc`?

9.4 Directory Tree and File Systems

A Linux system's directory tree usually extends over more than one partition on disk, and removable media like CD-ROM disks, USB keys as well as portable MP3 players, digital cameras and so on must be taken into account. If you know your way around Microsoft Windows, you are probably aware that this problem is solved there by means of identifying different "drives" by means of letters—on Linux, all available disk partitions and media are integrated in the directory tree starting at "/".

In general, nothing prevents you from installing a complete Linux system on a single hard disk partition. However, it is common to put at least the `/home` directory—where users' home directories reside—on its own partition. The advantage of this approach is that you can re-install the actual operating system, your Linux distribution, completely from scratch without having to worry about the safety of your own data (you simply need to pay attention at the correct moment, namely when you pick the target partition(s) for the installation in your distribution's installer.) This also simplifies the creation of backup copies.

partitioning

On larger server systems it is also quite usual to assign other directories, typically `/tmp`, `/var/tmp`, or `/var/spool`, their own partitions. The goal is to prevent users from disturbing system operations by filling important partitions completely. For example, if `/var` is full, no protocol messages can be written to disk, so we want to keep users from filling up the file system with large amounts of unread mail, unprinted print jobs, or giant files in `/var/tmp`. On the other hand, all these partitions tend to clutter up the system.

server systems

More information and strategies for partitioning are presented in the Linup Front training manual, *Linux Administration I*.

The `/etc/fstab` file describes how the system is assembled from various disk partitions. During startup, the system arranges for the various file systems to be made available—the Linux insider says "mounted"—in the correct places, which you as a normal user do not need to worry about. What you may in fact be interested in, though, is how to access your CD-ROM disks and USB keys, and these need to be mounted, too. Hence we do well to cover this topic briefly even though it is really administrator country.

`/etc/fstab`

To mount a medium, you require both the name of the device file for the medium (usually a block device such as `/dev/sda1`) and a directory somewhere in the directory tree where the content of the medium should appear—the so-called *mount point*. This can be any directory.

The directory doesn't even have to be empty, although you cannot access the original content once you have mounted another medium "over" it. (The content reappears after you unmount the medium.)

In principile, somebody could mount a removable medium over an important system directory such as `/etc` (ideally with a file called `passwd` containing a `root` entry without a password). This is why mounting of file systems in arbitrary places within the directory tree is restricted to the system administrator, who will have no need for shenanigans like these, as they are already `root`.

Earlier on, we called the "device file for the medium" `/dev/sda1`. This is really the first partition on the first SCSI disk drive in the system—the real name may be completely different depending on the type of medium you are using. Still it is an obvious name for USB keys, which for technical reasons are treated by the system as if they were SCSI devices.

With this information—device name and mount point—a system administrator can mount the medium as follows:

```
# mount /dev/sda1 /media/usb
```

This means that a file called `file` on the medium would appear as `/media/usb/file` in the directory tree. With a command such as

```
# umount /media/usb                                    Note: no ''n''
```

the administrator can also unmount the medium again.

9.5 Removable Media

The explict mounting of removable media is a tedious business, and the explicit unmounting before removing a medium even more so—but especially the latter can lead to problems if you remove the medium physically before Linux is completely finished with it. Linux does try to speed up the system by not executing slow operations like writing to media immediately but later, when the "right moment" has arrived, and if you pull out your USB key before the data have actually been written there, you have in the best case gained nothing, and in the worst case the data on there have descended into chaos.

As a user of a graphical desktop interface on a modern Linux system, you have it easy: If you insert or plug in a medium—no matter whether it is an audio CD, USB key, or digital camera—, a dialog appears suggesting various interesting actions that you can perform on the medium. "Mounting" is usually one of those, and the system also figures out a nice mount point for you. It is just as easy to remove the medium later by means of an icon on the desktop background or the desktop environment's control panel. We don't need to cover this in detail here.

Things look different on the command line, though, where you must mount and unmount removable media explicitly as discussed in the previous section. As we said, as a normal user you are not allowed to do this for arbitrary media in arbitrary places, but only for media that your system administrator has prepared for this and then only at "pre-cooked" mount points. You can recognise these because they have been marked with the `user` or `users` options:

```
$ grep user /etc/fstab
/dev/hdb        /media/cdrom0   udf,iso9660 ro,user,noauto 0 0
/dev/sda1       /media/usb      auto    user,noauto        0 0
/dev/mmcblk0p1  /media/sd       auto    user,noauto        0 0
```

For the details of `/etc/fstab` entries we need to refer you to the Linup Front training manual, *Linux Administration I* (O. K., `fstab`(5) also works, but our manual is nicer); here and now we shall restrict ourselves to pointing out that in our example three types of removable media are available, namely CD-ROM disks (the first entry), USB-based media such as USB keys, digital cameras or MP3 players (the second entry), and SD cards (the third entry). As a "normal user", you have to stick to the given mount points and can (after inserting the medium in question) say things like

```
$ mount /dev/hdb                                       for the CD-ROM
$ mount /media/cdrom0                                  ditto
```

```
$ mount /dev/sda1                                   for the USB key
$ mount /media/sd                                   for the SD card
```

That is, Linux expects *either* the device name *or* the mount point; the matching counterpart always derives from the `/etc/fstab` entry. Unmounting using `umount` works similarly.

The `user` option in `/etc/fstab` makes this work (it also produces some other effects that we shall not be treating in detail here). The `users` option is roughly the same; the difference between the two—and you may want to remember this, as it may occur on the exam—is that, with `user`, only the user who mounted the file system originally may *unmount* it again. With `users`, any user may do so (!). (And `root` can do it all the time, anyway.)

Exercises

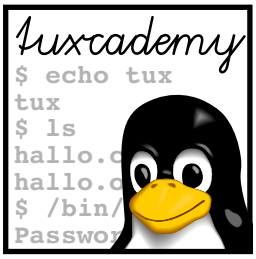
9.7 [1] Insert a floppy in the drive, mount it, copy a file (like `/etc/passwd`) to the floppy, and unmount the floppy again. (If your system is "legacy-free" and no longer sports a floppy disk drive, then do the same with a USB key or a similar suitable removable medium.)

Commands in this Chapter

dmesg	Outputs the content of the kernel message buffer	dmesg(8)	145
file	Guesses the type of a file's content, according to rules	file(1)	138
free	Displays main memory and swap space usage	free(1)	144
klogd	Accepts kernel log messages	klogd(8)	145
mkfifo	Creates FIFOs (named pipes)	mkfifo(1)	139
mknod	Creates device files	mknod(1)	139
syslogd	Handles system log messages	syslogd(8)	145
uptime	Outputs the time since the last system boot as well as the system load averages	uptime(1)	144

Summary

- Files are self-contained collections of data stored under a name. Linux uses the "file" abstraction also for devices and other objects.
- The method of arranging data and administrative information on a disk is called a file system. The same term covers the complete tree-structured hierarchy of directories and files in the system or a specific storage medium together with the data on it.
- Linux file systems contain plain files, directories, symbolic links, device files (two kinds), FIFOs, and Unix-domain sockets.
- The *Filesystem Hierarchy Standard* (FHS) describes the meaning of the most important directories in a Linux system and is adhered to by most Linux distributions.
- Removable media must be mounted into the Linux directory tree to be accessible, and be unmounted after use. The `mount` and `umount` commands are used to do this. Graphical desktop enviroments usually offer more convenient methods.



10

System Administration

Contents

Goals

- Reviewing a system administrator's tasks
- Being able to log on as the system administrator
- Being able to assess the advantages and disadvantage of (graphical) administration tools

Prerequisites

- Basic Linux skills
- Administration skills for other operating systems are helpful

10.1 Introductory Remarks

As a mere user of a Linux system, you are well off: You sit down in front of your computer, everything is configured correctly, all the hardware is supported and works. You have no care in the world since you can call upon a system administrator who will handle all administrative tasks for you promptly and thoroughly (that's what we wish your environment is like, anyway).

Should you be (or strive to be) the system administrator yourself—within your company or the privacy of your home—then you have your work cut out for you: You must install and configure the system and connect any peripherals. Having done that, you need to keep the system running, for example by checking the system logs for unusual events, regularly getting rid of old log files, making backup copies, installing new software and updating existing programs, and so on.

Today, in the age of Linux distributions with luxurious installation tools, system installation is no longer rocket science. However, an ambitious administrator can spend lots of time mobilising every last resource on their system. In general, system administration mostly takes place when a noticeable change occurs, for example when new hardware or software is to be integrated, new users arrive or existing ones disappear, or hardware problems arise.

changes

Tools

Many Linux distributions these days contain specialised tools to facilitate system administration. These tools perform different tasks ranging from user management and creating file systems to complete system updates. Utilities like these can make these tasks a lot easier but sometimes a lot more difficult. Standard procedures are simplified but for specialised settings you should know the exact relationships between system components. Furthermore, most of these tools are only available for certain distributions.

The administration of a Linux system, as of any other computer system, requires a considerable amount of responsibility and care. You should not see yourself as a demigod (at least) but as a service provider. No matter whether you are the only system administrator—say, on your own computer—or working in a team of colleagues to support a company network: communication is paramount. You should get used to documenting configuration changes and other administrative decisions in order to be able to retrace them later. The Linux way of directly editing text files makes this convenient, since you can comment configuration settings right where they are made (a luxury not usually enjoyed with graphical administration tools). Do so.

responsibility

communication

10.2 The Privileged `root` Account

For many tasks, the system administrator needs special privileges. Accordingly, he can make use of a special user account called `root`. As `root`, a user is the so-called **super user**. In brief: He may do anything.

super user

The normal file permissions and security precautions do not apply to `root`. He has allowing him nearly unbounded access to all data, devices and system components. He can institute system changes that all other users are prohibited from by the Linux kernel's security mechanisms. This means that, as `root`, you can change every file on the system no matter who it belongs to. While normal users cannot wreak damage (e. g., by destroying file systems or manipulating other users' files), `root` is not thus constrained.

unlimited privileges

In many cases, these extensive system administrator privileges are really a liability. For example, when making backup copies it is necessary to be able to read all files on the system. However, this by no means implies that the person making the backup (possibly an intern) should be empowered to open all files on the system with a text editor, to read them or change them—or start a network service which might be accessible from anywhere in the

world. There are various ways of giving out administrator privileges only in controlled circumstances (such as sudo, a system which lets normal users execute certain commands using administrator privileges), of selectively giving particular privileges to individual process rather than operating on an "all or nothing" principle (cue POSIX capabilities), or of doing away with the idea of an "omnipotent" system administrator completely (for instance, SELinux—"security-enhanced Linux"—a freely available software package by the American intelligence agency, NSA, contains a "role-based" access control system that can get by without an omnipotent system administrator).

sudo

POSIX capabilities

SELinux

Why Security?

Why does Linux contain security precautions in the first place? The most important reason is for users to be able to determine the access privileges that apply to their own files. By setting permission bits (using the chmod command), users can ascertain that certain files may be read, written to or executed by certain others (or no) users. This helps safeguard the privacy and integrity of their data. You would certainly not approve of other users being able to read your private e-mail or change the source code of an important program behind your back.

Access control for devices

The security mechanisms are also supposed to keep users from damaging the system. Access to many of the device files in /dev corresponding to hardware components such as hard disks is constrained by the system. If normal users could access disk storage directly, all sorts of mayhem might occur (a user might overwrite the complete content of a disk or, having obtained information about the layout of the filesystem on the disk, access files that are none of his business). Instead, the system forces normal users to access the disks via the file system and protects their data in that way.

It is important to stress that damage is seldom caused on purpose. The system's security mechanisms serve mostly to save users from unintentional mistakes and misunderstandings; only in the second instance are they meant to protect the privacy of users and data.

groups

On the system, users can be pooled into **groups** to which you may assign their own access privileges. For example, a team of software developers could have read and write permission to a number of files, while other users are not allowed to change these files. Every user can determine for their own files how permissive or restrictive access to them should be.

Privileged system calls

The security mechanisms also prevent normal users from performing certain actions such as the invocation of specific system calls from a program. For example, there is a system call that will halt the system, which is executed by programs such as shutdown when the system is to be powered down or rebooted. If normal users were allowed to invoke this routine from their own programs, they could inadvertently (or intentionally) stop the system at any time.

The administrator frequently needs to circumvent these security mechanisms in order to maintain the system or install updated software versions. The root account is meant to allow exactly this. A good administrator can do his work without regard for the usual access permissions and other constraints, since these do not apply to root. The root account is not better than a normal user account because it has more privileges; the restriction of these privileges to root is a security measure. Since the operating system's reasonable and helpful protection and security mechanisms do not apply to the system administrator, working as root is very risky. You should therefore use root to execute only those commands that really require the privileges.

Many of the security problems of other popular operating systems can be traced back to the fact that normal users generally enjoy administrator privileges. Thus, programs such as "worms" or "Trojan horses", which users often execute by accident, find it easy to establish themselves on the system. With a Linux system that is correctly installed and operated, this is hardly possible since users read their e-mail without administrator privi-

leges, but administrator privileges are required for all system-wide configuration changes.

Of course, Linux is not magically immune against malicious pests like "mail worms"; somebody could write and make popular a mail program that would execute "active content" such as scripts or binary programs within messages like some such programs do on other operating systems. On Linux, such a "malicious" program from elsewhere could remove all the caller's files or try to introduce "Trojan" code to his environment, but it could not harm other users nor the system itself—unless it exploited a security vulnerability in Linux that would let a local user gain administrator privileges "through the back door" (such vulnerabilities are detected now and again, and patches are promptly published which you should install in a timely manner).

Exercises

10.1 [2] What is the difference between a user and an administrator? Name examples for tasks and actions (and suitable commands) that are typically performed from a user account and the `root` account, respectively.

10.2 [!1] Why should you, as a normal user, not use the `root` account for your daily work?

10.3 [W]hat about access control on your computer at home? Do you work from an administrator account?

10.3 Obtaining Administrator Privileges

There are two ways of obtaining administrator privileges:

1. You can log in as user `root` directly. After entering the correct `root` password you will obtain a shell with administrator privileges. However, you should avoid logging in to the GUI as `root`, since then all graphical applications including the X server would run with `root` privileges, which is not necessary and can lead to security problems. Nor should direct `root` logins be allowed across the network.

   You can determine which terminals are eligible for direct `root` login by listing them in the `/etc/securetty` file. The default setting is usually "all virtual consoles and `/dev/ttyS0`" (the latter for users of the "serial console").

2. You can, from a normal shell, use the `su` command to obtain a new shell with administrator privileges. `su`, like `login`, asks for a password and opens the `root` shell only after the correct `root` password has been input. In GUIs like KDE there are similar methods.

(See also *Introduction to Linux for Users and Administrators*.)

Single-user systems, too!

Even if a Linux system is used by a single person only, it makes sense to create a normal account for this user. During everyday work on the system as `root`, most of the kernel's normal security precautions are circumvented. That way errors can occur that impact on the whole system. You can avoid this danger by logging into your normal account and starting a `root` shell via "`/bin/su -`" if and when required.

Using `su`, you can also assume the identity of arbitrary other users (here `hugo`) by invoking it like

```
$ /bin/su - hugo
```

You need to know the target user's password unless you are calling `su` as user `root`.

The second method is preferable to the first for another reason, too: If you use the `su` command to become `root` after logging in to your own account, `su` creates a message like

```
Apr  1 08:18:21 HOST su: (to root) user1 on /dev/tty2
```

in the system log (such as `/var/log/messages`). This entry means that user `user1` successfully executed `su` to become `root` on terminal 2. If you log in as `root` directly, no such message is logged; there is no way of figuring out which user has fooled around with the `root` account. On a system with several administrators it is often important to retrace who entered the `su` command when. system log

Ubuntu is one of the "newfangled" distributions that deprecate–and, in the default setup, even disable—logging in as `root`. Instead, particular users may use the `sudo` mechanism to execute individual commands with administrator privileges. Upon installation, you are asked to create a "normal" user account, and that user account is automatically endowed with "indirect" administrator privileges.

When installing Debian GNU/Linux, you can choose between assigning a password to the `root` account and thereby enabling direct administrator logins, and declining this and, as on Ubuntu, giving `sudo`-based administrator privileges to the first unprivileged user account created as part of the installation process.

On many systems, the shell prompt differs between `root` and the other users. The classic `root` prompt contains a hash mark (`#`), while other users see a prompt containing a dollar sign (`$`) or greater-than sign (`>`). The `#` prompt is supposed to remind you that you are `root` with all ensuing privileges. However, the shell prompt is easily changed, and it is your call whether to follow this convention or not. shell prompt

Of course, if you are using `sudo`, you never get to see a prompt for `root`.

Like all powerful tools, the `root` account can be abused. Therefore it is important for you as the system administrator too keep the `root` password secret. It should only be passed on to users who are trusted both professionally and personally (or who can be held responsible for their actions). If you are the sole user of the system this problem does not apply to you. Misuse of `root`

Too many cooks spoil the broth! This principle also applies to system administration. The main benefit of "private" use of the `root` account is not that the possibility of misuse is minimised (even though this is surely a consequence). More importantly, `root` as the sole user of the `root` account knows the complete system configuration. If somebody besides the administrator can, for example, change important system files, then the system configuration could be changed without the administrator's knowledge. In a commercial environment, it is necessary to have several suitably privileged employees for various reasons—for example, safeguarding system operation during holidays or sudden severe illness of the administrator—; this requires close cooperation and communication. Administration: alone or by many

If there is only one system administrator who is responsible for system configuration, you can be sure that one person really knows what is going on on the system (at least in theory), and the question of accountability also has an obvious asnwer. The more users have access to `root`, the greater is the probability that somebody will commit an error as `root` at some stage. Even if all users with `root` access possess suitable administration skills, mistakes can happen to anybody. Prudence and thorough training are the only precautions against accidents. accountability

There are a few other useful tools for team-based system administration. For example, Debian GNU/Linux and Ubuntu support a package called `etckeeper`, which allows storing the complete content of the `/etc` directory in a revision control system such as Git or Mercurial. Revision control systems (which we cannot cover in detail here) make it possible to track changes to files in a directory hierarchy in a very detailed manner, to comment them and, if necessary, to undo them. With Git or Mercurial it is even possible to store a copy of the `/etc` directory on a completely different computer and to keep it in sync automatically—great protection from accidents.

Exercises

10.4 [2] What methods exist to obtain administrator rights? Which method is better? Why?

10.5 [!2] On a conventionally configured system, how can you recognise whether you are working as `root`?

10.6 [2] Log in as a normal user (e. g., `test`). Change over to `root` and back to `test`. How do you work best if you frequently need to change between both these accounts (for example, to check on the results of a new configuration)?

10.7 [!2] Log in as a normal user and change to `root` using `su`. Where do you find a log entry documenting this change? Look at that message.

10.4 Distribution-specific Administrative Tools

Many Linux distributions try to stand out in the crowd by providing more or less ingenious tools that are supposed to simplify system administration. These tools are usually tailored to the distributions in question. Here are a few comments about typical specimens:

A familiar sight to SUSE administrators is "YaST", the graphical administration interface of the SUSE distributions (it also runs on a text screen). It allows the extensive configuration of many aspects of the system either by directly changing the configuration files concerned or by manipulating abstract configuration files below `/etc/sysconfig` which are then used to adapt the real configuration files by means of the `SuSEconfig` tool. For some tasks such as network configuration, the files below `/etc/sysconfig` *are* the actual configuration files.

Unfortunately, YaST is not a silver bullet for all problems of system administration. Even though many aspects of the system are amenable to YaST-based administration, important settings may not be accessible via YaST, or the YaST modules in question simply do not work correctly. The danger zone starts where you try to administer the computer partly through YaST and partly through changing configuration files manually: Yast does exercise some care not to overwrite your changes (which wasn't the case in the past—up till SuSe 6 or so, YaST and SuSEconfig used to be quite reckless), but will then not perform its own changes such that they really take effect in the system. In other places, manual changes to the configuration files will actually show up in YaST. Hence you have to have some "insider knowledge" and experience in order to assess which configuration files you may change directly and which your grubby fingers had better not touch.

Some time ago, Novell released the YaST source code under the GPL (in SUSE's time it used to be available but not under a "free" licence). However, so far no other distribution of consequence has adapted YaST to its purposes, let alone made it a standard tool (SUSE fashion).

The Webmin package by Jamie Cameron (`http://www.webmin.com/`) allows the convenient administration of various Linux distributions (or Unix versions) via a web-based interface. Webmin is very extensive and offers special facilities for administering "virtual" servers (for web hosters and their customers). However you may have to install it yourself, since most distributions do not provide it. Webmin manages its own users, which means that you can extend administrator privileges to users who do not have interactive system access. (Whether that is a smart idea is a completely different question.)

Most administration tools like YaST and Webmin share the same disadvantages:

- They are not extensive enough to take over all aspects of system administrations, and as an administrator you have to have detailed knowledge of their limits in order to be able to decide where to intervene manually.
- They make system administration possible for people whose expertise is not adequate to assess the possible consequences of their actions or to find and correct mistakes. Creating a user account using an administration tool is certainly not a critical job and surely more convenient than editing four different system files using `vi`, but other tasks such as configuring a firewall or mail server are not suitable for laypeople even using a convenient administration tool. The danger is that inexperienced administrators will use an administration tool to attempt tasks which do not look more complicated than others but which, without adequate background knowledge, may endanger the safety and/or reliability of the system.
- They usually do not offer a facility to version control or document any changes made, and thus complicate teamwork and auditing by requiring logs to be kept externally.
- They are often intransparent, i. e., they do not provide documentation about the actual steps they take on the system to perform administrative tasks. This keeps the knowledge about the necessary procedures buried in the programs; as the administrator you have no direct way of "learning" from the programs like you could by observing an experienced administrator. Thus the adminstration tools keep you artificially stupid.
- As an extension of the previous point: If you need to administer several computers, common administration tools force you to execute the same steps repeatedly on every single machine. Many times it would be more convenient to write a shell script automating the required procedure, and to execute it automatically on every computer using, e. g., the "secure shell", but the administration tool does not tell you what to put into this shell script. Therefore, viewed in a larger context, their use is inefficient.

From various practical considerations like these we would like to recommend against relying too much on the "convenient" administration tools provided by the distributions. They are very much like training wheels on a bicycle: They work effectively against falling over too early and provide a very large sense of achievement very quickly, but the longer the little ones zoom about with them, the more difficult it becomes to get them used to "proper" bike-riding (here: doing administration in the actual configuration files, including all advantages such as documentation, transparency, auditing, team capability, transportability, …).

Excessive dependence on an administration tool also leads to excessive dependence on the distribution featuring that tool. This may not seem like a real liability, but on the other hand one of the more important *advantages* of Linux is the fact that there are multiple independent vendors. So, if one day you should be fed up with the SUSE distributions (for whatever reason) and want to move over to Red Hat or Debian GNU/Linux, it would be very inconvenient if your administrators

knew only YaST and had to relearn Linux administration from scratch. (Third-party administration tools like Webmin do not exhibit this problem to the same degree.)

Exercises

10.8 [!2] Does your distribution provide an administration tool (such as YaST)? What can you do with it?

10.9 [3] (Continuation of the previous exercise—when working through the manual for the second time.) Find out how your administration tool works. Can you change the system configuration manually so the administration tool will notice your changes? Only under some circumstances?

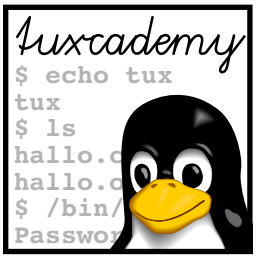
10.10 [!1] Administration tools like Webmin are potentially accessible to everybody with a browser. Which advantages and disadvantages result from this?

Commands in this Chapter

su	Starts a shell using a different user's identity	su(1) 154
sudo	Allows normal users to execute certain commands with administrator privileges	sudo(8) 152

Summary

- Every computer installation needs a certain amount of system administration. In big companies, universities and similar institutions these services are provided by (teams of) full-time administrators; in smaller companies or private households, (some) users usually serve as administrators.
- Linux systems are, on the whole, straightforward to administer. Work arises mostly during the initial installation and, during normal operation, when the configuration changes noticeably.
- On Linux systems, there usually is a privileged user account called `root`, to which the normal security mechanisms do not apply.
- As an administrator, one should not work as `root` exclusively, but use a normal user account and assume `root` privileges only if necessary.
- Administration tools such as YaST or Webmin can help perform some administrative duties, but are no substitute for administrator expertise and may have other disadvantages as well.



11

User Administration

Contents

Goals

- Understanding the user and group concepts of Linux
- Knowing how user and group information is stored on Linux
- Being able to use the user and group administration commands

Prerequisites

- Knowledge about handling configuration files

11.1 Basics

11.1.1 Why Users?

Computers used to be large and expensive, but today an office workplace without its own PC ("personal computer") is nearly inconceivable, and a computer is likely to be encountered in most domestic "dens" as well. And while it may be sufficient for a family to agree that Dad, Mom and the kids will put their files into different directories, this will no longer do in companies or universities—once shared disk space or other facilities are provided by central servers accessible to many users, the computer system must be able to distinguish between different users and to assign different access rights to them. After all, Ms Jones from the Development Division has as little business looking at the company's payroll data as Mr Smith from Human Resources has accessing the detailed plans for next year's products. And a measure of privacy may be desired even at home—the Christmas present list or teenage daughter's diary (erstwhile fitted with a lock) should not be open to prying eyes as a matter of course.

We shall be discounting the fact that teenage daughter's diary may be visible to the entire world on Facebook (or some such); and even if that is the case, the entire world should surely not be allowed to *write* to teenage daughter's dairy. (Which is why even Facebook supports the notion of different users.)

The second reason for distinguishing between different users follows from the fact that various aspects of the system should not be visible, much less changeable, without special privileges. Therefore Linux manages a separate user identity (`root`) for the system administrator, which makes it possible to keep information such as users' passwords hidden from "common" users. The bane of older Windows systems—programs obtained by e-mail or indiscriminate web surfing that then wreak havoc on the entire system—will not plague you on Linux, since anything you can execute as a common user will not be in a position to wreak system-wide havoc.

Unfortunately this is not entirely correct: Every now and then a bug comes to light that enables a "normal user" to do things otherwise restricted to administrators. This sort of error is extremely nasty and usually corrected very quickly after having been found, but there is a considerable chance that such a bug has remained undetected in the system for an extended period of time. Therefore, on Linux (as on all other operating systems) you should strive to run the most current version of critical system parts like the kernel that your distributor supports.

Even the fact that Linux safeguards the system configuration from unauthorised access by normal users should not entice you to shut down your brain. We do give you some advice (such as not to log in to the graphical user interface as `root`), but you should keep thinking along. E-mail messages asking you to view web site *X* and enter your credit card number and PIN there can reach you even on Linux, and you should disregard them in the same way as everywhere else.

user accounts

Linux distinguishes between different users by means of different **user accounts**. The common distributions typically create two user accounts during installation, namely `root` for administrative tasks and another account for a "normal" user. You (as the administrator) may add more accounts later, or, on a client PC in a larger network, they may show up automatically from a user account database stored elsewhere.

Linux distinguishes between *user accounts*, not users. For example, no one keeps you from using a separate user account for reading e-mail and surfing the web, if you want to be 100% sure that things you download from the

Net have no access to your important data (which might otherwise happen in spite of the user/administrator divide). With a little cunning you can even display a browser and e-mail program running under your "surfing account" among your "normal" programs[1].

Under Linux, every user account is assigned a unique number, the so-called *user ID* (or **UID**, for short). Every user account also features a textual **user name** (such as `root` or `joe`) which is easier to remember for humans. In most places where it counts—e. g., when logging in, or in a list of files and their owners—Linux will use the textual name whenever possible.

UID
user name

The Linux kernel does not know anything about textual user names; process data and the ownership data in the filesystem use the UID exclusively. This may lead to difficulties if a user is deleted while he still owns files on the system, and the UID is reassigned to a different user. That user "inherits" the previous UID owner's files.

There is no technical problem with assigning the same (numerical) UID to different user names. These users have equal access to all files owned by that UID, but every user can have his own password. You should not actually use this (or if you do, use it only with great circumspection).

11.1.2 Users and Groups

To work with a Linux computer you need to log in first. This allows the system to recognise you and to assign you the correct access rights (of which more later). Everything you do during your session (from logging in to logging out) happens under your user account. In addition, every user has a **home directory**, where only they can store and manage their own files, and where other users often have no read permission and very emphatically no write permission. (Only the system administrator—`root`—may read and write all files.)

home directory

Depending on which Linux distribution you use (cue: Ubuntu) it may be possible that you do not have to log into the system explicitly. This is because the computer "knows" that it will usually be you and simply assumes that this is going to be the case. You are trading security for convenience; this particular deal probably makes sense only where you can stipulate with reasonable certainty that nobody except you will switch on your computer—and hence should be restricted *by rights* to the computer in your single-person household without a cleaner. We told you so.

Several users who want to share access to certain system resources or files can form a **group**. Linux identifies group members either fixedly by name or transiently by a login procedure similar to that for users. Groups have no "home directories" like users do, but as the administrator you can of course create arbitrary directories meant for certain groups and having appropriate access rights.

group

Groups, too, are identified internally using numerical identifiers ("group IDs" or GIDs).

Group names relate to GIDs as user names to UIDs: The Linux kernel only knows about the former and stores only the former in process data or the file system.

Every user belongs to a *primary group* and possibly several *secondary* or *additional groups*. In a corporate setting it would, for example, be possible to introduce project-specific groups and to assign the people collaborating on those projects to the appropriate group in order to allow them to manage common data in a directory only accessible to group members.

[1] Which of course is slightly more dangerous again, since programs runninig on the same screen can communicate with one another

For the purposes of access control, all groups carry equivalent weight—every user always enjoys all rights deriving from all the groups that he is a member of. The only difference between the primary and secondary groups is that files newly created by a user are usually[2] assigned to his primary group.


Up to (and including) version 2.4 of the Linux kernel, a user could be a member of at most 32 additional groups; since Linux 2.6 the number of secondary groups is unlimited.

You can find out a user account's UID, the primary and secondary groups and the corresponding GIDs by means of the `id` program:

```
$ id
uid=1000(joe) gid=1000(joe) groups=24(cdrom),29(audio),44(video),▷
 ◁ 1000(joe)
$ id root
uid=0(root) gid=0(root) groups=0(root)
```


With the options `-u`, `-g`, and `-G`, `id` lets itself be persuaded to output just the account's UID, the GID of the primary group, or the GIDs of the secondary groups. (These options cannot be combined.) With the additional option `-n` you get names instead of numbers:

```
$ id -G
1000 24 29 44
$ id -Gn
joe cdrom audio video
```


The `groups` command yields the same result as the "'`id -Gn`"' command.

`last` You can use the `last` command to find who logged into your computer and when (and, in the case of logins via the network, from where):

```
$ last
joe      pts/1        pcjoe.example.c  Wed Feb 29 10:51   still logged in
bigboss  pts/0        pc01.example.c   Wed Feb 29 08:44   still logged in
joe      pts/2        pcjoe.example.c  Wed Feb 29 01:17 - 08:44  (07:27)
sue      pts/0        :0               Tue Feb 28 17:28 - 18:11  (00:43)
◁◁◁◁◁
reboot   system boot 3.2.0-1-amd64    Fri Feb  3 17:43 - 13:25 (4+19:42)
◁◁◁◁◁
```

For network-based sessions, the third column specifies the name of the `ssh` client computer. "`:0`" denotes the graphical screen (the first X server, to be exact—there might be more than one).


Do also note the `reboot` entry, which tells you that the computer was started. The third column contains the version number of the Linux operating system kernel as provided by "`uname -r`".

With a user name, `last` provides information about a particular user:

```
$ last
joe      pts/1        pcjoe.example.c  Wed Feb 29 10:51   still logged in
joe      pts/2        pcjoe.example.c  Wed Feb 29 01:17 - 08:44  (07:27)
◁◁◁◁◁
```

[2] The exception occurs where the owner of a directory has decreed that new files and subdirectories within this directory are to be assigned to the same group as the directory itself. We mention this strictly for completeness.


You might be bothered (and rightfully so!) by the fact that this somewhat sensitive information is apparently made available on a casual basis to arbitrary system users. If you (as the administrator) want to protect your users' privacy somewhat better than you Linux distribution does by default, you can use the

```
# chmod o-r /var/log/wtmp
```

command to remove general read permissions from the file that `last` consults for the telltale data. Users without administrator privileges then get to see something like

```
$ last
last: /var/log/wtmp: Permission denied
```

11.1.3 People and Pseudo-Users

Besides "natural" persons—the system's human users—the user and group concept is also used to allocate access rights to certain parts of the system. This means that, in addition to the personal accounts of the "real" users like you, there are further accounts that do not correspond to actual human users but are assigned to administrative functions internally. They define functional "roles" with their own accounts and groups.

pseudo-users

After installing Linux, you will find several such pseudo-users and groups in the `/etc/passwd` and `/etc/group` files. The most important role is that of the `root` user (which you know) and its eponymous group. The UID and GID of `root` are 0 (zero).


`root`'s privileges are tied to UID 0; GID 0 does not confer any additional access privileges.

Further pseudo-users belong to certain software systems (e. g., `news` for Usenet news using INN, or `postfix` for the Postfix mail server) or certain components or devices (such as printers, tape or floppy drives). You can access these accounts, if necessary, like other user accounts via the `su` command. These pseudo-users are helpful as file or directory owners, in order to fit the access rights tied to file ownership to special requirements without having to use the `root` account. The same appkies to groups; the members of the `disk` group, for example, have block-level access to the system's disks.

pseudo-users for privileges

Exercises


11.1 [1] How does the operating system kernel differentiate between various users and groups?


11.2 [2] What happens if a UID is assigned to two different user names? Is that allowed?


11.3 [1] What is a pseudo-user? Give examples!


11.4 [2] (On the second reading.) Is it acceptable to assign a user to group `disk` who you would not want to trust with the `root` password? Why (not)?

11.2 User and Group Information

11.2.1 The `/etc/passwd` File

The `/etc/passwd` file is the system user database. There is an entry in this file for every user on the system—a line consisting of attributes like the Linux user name,

"real" name, etc. After the system is first installed, the file contains entries for most pseudo-users.

The entries in `/etc/passwd` have the following format:

⟨*user name*⟩:⟨*password*⟩:⟨*UID*⟩:⟨*GID*⟩:⟨*GECOS*⟩:⟨*home directory*⟩:⟨*shell*⟩

⟨*user name*⟩ This name should consist of lowercase letters and digits; the first character should be a letter. Unix systems often consider only the first eight characters—Linux does not have this limitation but in heterogeneous networks you should take it into account.

Resist the temptation to use umlauts, punctuation and similar special characters in user names, even if the system lets you do so—not all tools that create new user accounts are picky, and you could of course edit `/etc/passwd` by hand. What seems to work splendidly at first glance may lead to problems elsewhere later.

You should also stay away from user names consisting of only uppercase letters or only digits. The former may give their owners trouble logging in (see Exercise 11.6), the latter can lead to confusion, especially if the numerical user name does not equal the account's numerical UID. Commands such as "`ls -l`" will display the UID if there is no corresponding entry for it in `/etc/passwd`, and it is not exactly straightforward to tell UIDs from purely numerical user names in `ls` output.

⟨*password*⟩ Traditionally, this field contains the user's encrypted password. Today, most Linux distributions use "shadow passwords"; instead of storing the password in the publically readable `/etc/passwd` file, it is stored in `/etc/shadow` which can only be accessed by the administrator and some privileged programs. In `/etc/passwd`, a "`x`" calls attention to this circumstance. Every user can avail himself of the `passwd` program to change his password.

⟨*UID*⟩ The numerical user identifier—a number between 0 and $2^{32} - 1$. By convention, UIDs from 0 to 99 (inclusive) are reserved for the system, UIDs from 100 to 499 are for use by software packages if they need pseudo-user accounts. With most popular distributions, "real" users' UIDs start from 500 (or 1000).

Precisely because the system differentiates between users not by name but by UID, the kernel treats two accounts as completely identical if they contain different user names but the same UID—at least as far as the access privileges are concerned. Commands that display a user name (e. g., "`ls -l`" or `id`) show the one used when the user logged in.

primary group ⟨*GID*⟩ The GID of the user's **primary group** after logging in.

The Novell/SUSE distributions (among others) assign a single group such as `users` as the shared primary group of all users. This method is quite established as well as easy to understand.

Many distributions, such as those by Red Hat or Debian GNU/Linux, create a new group whenever a new account is created, with the GID equalling the account's UID. The idea behind this is to allow more sophisticated assignments of rights than with the approach that puts all users into the same group `users`. Consider the following situation: Jim (user name `jim`) is the personal assistant of CEO Sue (user name `sue`). In this capacity he sometimes needs to access files stored inside Sue's home directory that other users should not be able to get at. The method used by Red Hat, Debian & co., "one group per user", makes it straightforward to put user `jim` into group `sue` and to arrange for Sue's

files to be readable for all group members (the default case) but not others. With the "one group for everyone" approach it would have been necessary to introduce a new group completely from scratch, and to reconfigure the `jim` and `sue` accounts accordingly.

By virtue of the assignment in `/etc/passwd`, every user must be a member of at least one group.


The user's secondary groups (if applicable) are determined from entries in the `/etc/group` file.

⟨*GECOS*⟩ This is the comment field, also known as the "GECOS field".


GECOS stands for "General Electric Comprehensive Operating System" and has nothing whatever to do with Linux, except that in the early days of Unix this field was added to `/etc/passwd` in order to keep compatibility data for a GECOS remote job entry service.

This field contains various bits of information about the user, in particular his "real" name and optional data such as the office number or telephone number. This information is used by programs such as `mail` or `finger`. The full name is often included in the sender's address by news and mail software.


Theoretically there is a program called `chfn` that lets you (as a user) change the content of your GECOS field. Whether that works in any particular case is a different question, since at least in a corporate setting one does not necessarily want to allow people to change their names at a whim.

⟨*home directory*⟩ This directory is that user's personal area for storing his own files. A newly created home directory is by no means empty, since a new user normally receives a number of "profile" files as his basic equipment. When a user logs in, his shell uses his home directory as its current directory, i. e., immediately after logging in the user is deposited there.

⟨*shell*⟩ The name of the program to be started by `login` after successful authentication—this is usually a shell. The seventh field extends through the end of the line.


The user can change this entry by means of the `chsh` program. The eligible programs (shells) are listed in the `/etc/shells` file. If a user is not supposed to have an interactive shell, an arbitrary program, with arguments, can be entered here (a common candidate is `/bin/true`). This field may also remain empty, in which case the standard shell `/bin/sh` will be started.


If you log in to a graphical environment, various programs will be started on your behalf, but not necessarily an interactive shell. The shell entry in `/etc/passwd` comes into its own, however, when you invoke a terminal emulator such as `xterm` or `konsole`, since these programs usually check it to identify your preferred shell.

Some of the fields shown here may be empty. Absolutely necessary are only the user name, UID, GID and home directory. For most user accounts, all the fields will be filled in, but pseudo-users might use only part of the fields.

home directories

The home directories are usually located below `/home` and take their name from their owner's user name. In general this is a fairly sensible convention which makes a given user's home directory easy to find. In theory, a home directory might be placed anywhere in the file system under a completely arbitrary name.


On large systems it is common to introduce one or more additional levels of directories between `/home` and the "user name" directory, such as

`/home/hr/joe`	*Joe from Human Resources*
`/home/devel/sue`	*Sue from Development*
`/home/exec/bob`	*Bob the CEO*

There are several reasons for this. On the one hand this makes it easier to keep one department's home directory on a server within that department, while still making it available to other client computers. On the other hand, Unix (and some Linux) file systems used to be slow dealing with directories containing very many files, which would have had an unfortunate impact on a `/home` with several thousand entries. However, with current Linux file systems (`ext3` with `dir_index` and similar) this is no longer an issue.

tools

Note that as an administrator you should not really be editing `/etc/passwd` by hand. There is a number of programs that will help you create and maintain user accounts.

In principle it is also possible to store the user database elsewhere than in `/etc/passwd`. On systems with very many users (thousands), storing user data in a relational database is preferable, while in heterogeneous networks a shared multi-platform user database, e. g., based on an LDAP directory, might recommend itself. The details of this, however, are beyond the scope of this course.

11.2.2 The `/etc/shadow` File

For security, nearly all current Linux distributions store encrypted user passwords in the `/etc/shadow` file ("shadow passwords"). This file is unreadable for normal users; only `root` may write to it, while members of the `shadow` group may read it in addition to `root`. If you try to display the file as a normal user an error occurs.

Use of `/etc/shadow` is not mandatory but highly recommended. However there may be system configurations where the additional security afforded by shadow passwords is nullified, for example if NIS is used to export user data to other hosts (especially in heterogeneous Unix environments).

format

Again, this file contains one line for each user, with the following format:

⟨*user name*⟩:⟨*password*⟩:⟨*change*⟩:⟨*min*⟩:⟨*max*⟩▷
◁:⟨*warn*⟩:⟨*grace*⟩:⟨*lock*⟩:⟨*reserved*⟩

For example:

```
root:gaY2Ll9jxzHj5:10816:0:10000::::
daemon:*:8902:0:10000::::
joe:GodY6c5pZk1xs:10816:0:10000::::
```

Here is the meaning of the individual fields:

⟨*user name*⟩ This must correspond to an entry in the `/etc/passwd` file. This field "joins" the two files.

⟨*password*⟩ The user's encrypted password. An empty field generally means that the user can log in without a password. An asterisk or an exclamation point prevent the user in question from logging in. It is common to lock user's accounts without deleting them entirely by placing an asterisk or exclamation point at the beginning of the corresponding password.

⟨*change*⟩ The date of the last password change, in days since 1 January 1970.

⟨*min*⟩ The minimal number of days that must have passed since the last password change before the password may be changed again.

⟨*max*⟩ The maximal number of days that a password remains valid without having to be changed. After this time has elapsed the user must change his password.

⟨*warn*⟩ The number of days before the expiry of the ⟨*max*⟩ period that the user will be warned about having to change his password. Generally, the warning appears when logging in.

⟨*grace*⟩ The number of days, counting from the expiry of the ⟨*max*⟩ period, after which the account will be locked if the user does not change his password. (During the time from the expiry of the ⟨*max*⟩ period and the expiry of this grace period the user may log in but must immediately change his password.)

⟨*lock*⟩ The date on which the account will be definitively locked, again in days since 1 January 1970.

password encryption

Some brief remarks concerning password encryption are in order. You might think that if passwords are encrypted they can also be *decrypted* again. This would open all of the system's accounts to a clever cracker who manages to obtain a copy of `/etc/shadow`. However, in reality this is not the case, since password "encryption" is a one-way street. It is impossible to recover the decrypted representation of a Linux password from the "encrypted" form because the method used for encryption prevents this. The only way to "crack" the encryption is by encrypting likely passwords and checking whether they match what is in `/etc/shadow`.

Let's assume you select the characters of your password from the 95 visible ASCII characters (uppercase and lowercase letters are distinguished). This means that there are 95 different one-character passwords, $95^2 = 9025$ two-character passwords, and so on. With eight characters you are already up to 6.6 quadrillion ($6.6 \cdot 10^{15}$) possibilities. Stipulating that you can trial-encrypt 10 million passwords per second (not entirely unrealistic on current hardware), this means you would require approximately 21 years to work through all possible passwords. If you are in the fortunate position of owning a modern graphics card, another acceleration by a factor of 50–100 is quite feasible, which makes that about two months. And then of course there are handy services like Amazon's EC2, which will provide you (or random crackers) with almost arbitrary CPU power, or the friendly neighbourhood Russian bot net … so don't feel too safe.

There are a few other problems. The traditional method (usually called "crypt" or "DES"—the latter because it is based on, but not identical to, the eponymous encryption method[3]) should no longer be used if you can avoid it. It has the unpleasant property of only looking at the first eight characters of the entered password, and clever crackers can nowadays buy enough disk space to build a pre-encrypted cache of the 50 million (or so) most common passwords. To "crack" a password they only need to search their cache for the encrypted password, which can be done extremely quickly, and read off the corresponding clear-text password.

To make things even more laborious, when a newly entered password is encrypted the system traditionally adds a random element (the so-called

[3] If you must know exactly: The clear-text password is used as the key (!) to encrypt a constant string (typically a sequence of zero bytes). A DES key is 56 bits, which just happens to be 8 characters of 7 bits each (as the leftmost bit in each character is ignored). This process is repeated for a total of 25 rounds, with the previous round's output serving as the new input. Strictly speaking the encryption scheme used isn't quite DES but changed in a few places, to make it less feasible to construct a special password-cracking computer from commercially available DES encryption chips.

"salt") which selects one of 4096 different possibilities for the encrypted password. The main purpose of the salt is to avoid random hits resulting from user *X*, for some reason or other, getting a peek at the content of `/etc/shadow` and noting that his encrypted password looks just like that of user *Y* (hence letting him log into user *Y*'s account using his own *cleartext* password). For a pleasant side effect, the disk space required for the cracker's pre-encrypted dictionary from the previous paragraph is blown up by a factor of 4096.

Nowadays, password encryption is commonly based on the MD5 algorithm, allows for passwords of arbitrary length and uses a 48-bit salt instead of the traditional 12 bits. Kindly enough, the encryption works much more slowly than "crypt", which is irrelevant for the usual purpose (checking a password upon login—you can still encrypt several hundred passwords per second) but does encumber clever crackers to a certain extent. (You should not let yourself be bothered by the fact that cryptographers poo-poo the MD5 scheme as such due to its insecurity. As far as password encryption is concerned, this is fairly meaningless.)

You should not expect too much of the various password administration parameters. They are being used by the text console login process, but whether other parts of the system (such as the graphical login screen) pay them any notice depends on your setup. Nor is there usually an advantage in forcing new passwords on users at short intervals—this usually results in a sequence like `bob1`, `bob2`, `bob3`, …, or users alternate between two passwords. A *minimal interval* that must pass before a user is allowed to change their password again is outright dangerous, since it may give a cracker a "window" for illicit access even though the user knows their password has been compromised.

The problem you need to cope with as a system administrator is usually not people trying to crack your system's passwords by "brute force". It is much more promising, as a rule, to use "social engineering". To guess your password, the clever cracker does not start at `a`, `b`, and so on, but with your spouse's first name, your kids' first names, your car's plate number, your dog's birthday et cetera. (We do not in any way mean to imply that *you* would use such a stupid password. No, no, not *you* by any means. However, we are not quite so positive about your boss …) And then there is of course the time-honoured phone call approach: "Hi, this is the IT department. We're doing a security systems test and urgently require your user name and password."

There are diverse ways of making Linux passwords more secure. Apart from the improved encryption scheme mentioned above, which by now is used by default by most Linux distributions, these include complaining about (too) weak passwords when they are first set up, or proactively running software that will try to identify weak encrypted passwords, just like clever crackers would (*Caution:* Do this in your workplace only with written (!) pre-approval from your boss!). Other methods avoid passwords completely in favour of constantly changing magic numbers (as in SecurID) or smart cards. All of this is beyond the scope of this manual, and therefore we refer you to the Linup Front manual *Linux Security*.

11.2.3 The `/etc/group` File

group database

By default, Linux keeps group information in the `/etc/group` file. This file contains one-line entry for each group in the system, which like the entries in `/etc/passwd` consists of fields separated by colons (`:`). More precisely, `/etc/group` contains four fields per line.

⟨*group name*⟩:⟨*password*⟩:⟨*GID*⟩:⟨*members*⟩

Their meaning is as follows:

⟨*group name*⟩ The name of the group, for use in directory listings, etc.

⟨*password*⟩ An optional password for this group. This lets users who are not members of the group via `/etc/shadow` or `/etc/group` assume membership of the group using `newgrp`. A "`*`" as an invalid character prevents normal users from changing to the group in question. A "`x`" refers to the separate password file `/etc/gshadow`.

⟨*GID*⟩ The group's numerical group identifier.

⟨*Members*⟩ A comma-separated list of user names. This list contains all users who have this group as a secondary group, i. e., who are members of this group but have a different value in the GID field of their `/etc/passwd` entry. (Users with this group as their primary group may also be listed here but that is unnecessary.)

A `/etc/group` file could, for example, look like this:

```
root:x:0:root
bin:x:1:root,daemon
users:x:100:
project1:x:101:joe,sue
project2:x:102:bob
```

The entries for the `root` and `bin` groups are entries for administrative groups, similar to the system's pseudo-user accounts. Many files are assigned to groups like this. The other groups contain user accounts. administrative groups

Like UIDs, GIDs are counted from a specific value, typically 100. For a valid entry, at least the first and third field (group name and GID) must be filled in. Such an entry assigns a GID (which might occur in a user's primary GID field in `/etc/passwd`) a textual name. GID values

The password and/or membership fields must only be filled in for groups that are assigned to users as secondary groups. The users listed in the membership list are not asked for a password when they want to change GIDs using the `newgrp` command. If an encrypted password is given, users without an entry in the membership list can authenticate using the password to assume membership of the group. membership list group password

In practice, group passwords are hardly if ever used, as the administrative overhead barely justifies the benefits to be derived from them. On the one hand it is more convenient to assign the group directly to the users in question (since, from version 2.6 of the Linux kernel on, there is no limit to the number of secondary groups a user can join), and on the other hand a *single* password that must be known by *all* group members does not exactly make for bullet-proof security.

If you want to be safe, ensure that there is an asterisk ("`*`") in every group password slot.

11.2.4 The `/etc/gshadow` File

As for the user database, there is a shadow password extension for the group database. The group passwords, which would otherwise be encrypted but readable for anyone in `/etc/group` (similar to `/etc/passwd`), are stored in the separate file `/etc/gshadow`. This also contains additional information about the group, for example the names of the group administrators who are entitled to add or remove members from the group.

11.2.5 The `getent` Command

Of course you can read and process the `/etc/passwd`, `/etc/shadow`, and `/etc/group` files, like all other text files, using programs such as `cat`, `less` or `grep` (OK, OK, you need to be `root` to get at `/etc/shadow`). There are, however, some practical problems:

- You may not be able to see the whole truth: Your user database (or parts of it) might be stored on an LDAP server, SQL database, or a Windows domain controller, and there really may not be much of interest in `/etc/passwd`.
- If you want to look for a specific user's entry, it is slightly inconvenient to type this using `grep` if you want to avoid "false positives".

The `getent` command makes it possible to query the various databases for user and group information directly. With

```
$ getent passwd
```

you will be shown something that looks like `/etc/passwd`, but has been assembled from all sources of user information that are currently configured on your computer. With

```
$ getent passwd hugo
```

you can obtain user `hugo`'s entry, no matter where it is actually stored. Instead of `passwd`, you may also specify `shadow`, `group`, or `gshadow` to consult the respective database. (Naturally, even with `getent` you can only access `shadow` and `gshadow` as user `root`.)

The term "database" is understood as "totality of all sources from where the C library can obtain information on that topic (such as users)". If you want to know exactly where that information comes from (or might come from), then read `nsswitch.conf`(5) and examine the `/etc/nsswitch.conf` file on your system.

You may also specify several user or group names. In that case, information on all the named users or groups will be output:

```
$ getent passwd hugo susie fritz
```

Exercises

11.5 [1] Which value will you find in the second column of the `/etc/passwd` file? Why do you find that value there?

11.6 [2] Switch to a text console (using, e. g., Alt + F1) and try logging in but enter your user name in uppercase letters. What happens?

11.7 [2] How can you check that there is an entry in the `shadow` database for every entry in the `passwd` database? (`pwconv` only considers the `/etc/passwd` and `/etc/shadow` *files*, and also rewrites the `/etc/shadow` file, which we don't want.

11.3 Managing User Accounts and Group Information

After a new Linux distribution has been installed, there is often just the `root` account for the system administrator and the pseudo-users' accounts. Any other user accounts must be created first (and most distributions today will gently but firmly nudge the installing person to create at least *one* "normal" user account).

tools for user management

As the administrator, it is your job to create and manage the accounts for all required users (real and pseudo). To facilitate this, Linux comes with several tools for user management. With them, this is mostly a straightforward task, but it is important that you understand the background.

11.3.1 Creating User Accounts

The procedure for creating a new user account is always the same (in principle) and consists of the following steps:

1. You must create entries in the `/etc/passwd` (and possibly `/etc/shadow`) files.
2. If necessary, an entry (or several) in the `/etc/group` file is necessary.
3. You must create the home directory, copy a basic set of files into it, and transfer ownership of the lot to the new user.
4. If necessary, you must enter the user in further databases, e. g., for disk quotas, database access privilege tables and special applications.

All files involved in adding a new account are plain text files. You can perform each step manually using a text editor. However, as this is a job that is as tedious as it is elaborate, it behooves you to let the system help you, by means of the `useradd` program.

`useradd`

In the simplest case, you pass `useradd` merely the new user's user name. Optionally, you can enter various other user parameters; for unspecified parameters (typically the UID), "reasonable" default values will be chosen automatically. On request, the user's home directory will be created and endowed with a basic set of files that the program takes from the `/etc/skel` directory. The `useradd` command's syntax is:

```
useradd [⟨options⟩] ⟨user name⟩
```

The following options (among others) are available:

`-c` ⟨*comment*⟩ GECOS field entry

`-d` ⟨*home directory*⟩ If this option is missing, `/home/`⟨*user name*⟩ is assumed

`-e` ⟨*date*⟩ On this date the account will be deactivated automatically (format "YYYY-MM-DD")

`-g` ⟨*group*⟩ The new user's primary group (name or GID). This group must exist.

`-G` ⟨*group*⟩[**,**⟨*group*⟩]**...** Supplementary groups (names or GIDs). These groups must also exist.

`-s` ⟨*shell*⟩ The new user's login shell

`-u` ⟨*UID*⟩ The new user's numerical UID. This UID must not be already in use, unless the "`-o`" option is given

`-m` Creates the home directory and copies the basic set of files to it. These files come from `/etc/skel`, unless a different directory was named using "`-k` ⟨*directory*⟩".

For instance, the

```
# useradd -c "Joe Smith" -m -d /home/joe -g devel \
>    -k /etc/skel.devel
```

command creates an account by the name of `joe` for a user called Joe Smith, and assigns it to the `devel` group. `joe`'s home directory is created as `/home/joe`, and the files from `/etc/skel.devel` are being copied into it.

With the `-D` option (on SUSE distributions, `--show-defaults`) you may set default values for some of the properties of new user accounts. Without additional options, the default values are displayed:

```
# useradd -D
GROUP=100
HOME=/home
INACTIVE=-1
EXPIRE=
SHELL=/bin/sh
SKEL=/etc/skel
CREATE_MAIL_SPOOL=no
```

You can change these values using the `-g`, `-b`, `-f`, `-e`, and `-s` options, respectively:

```
# useradd -D -s /usr/bin/zsh                    zsh as the default shell
```

The final two values in the list cannot be changed.

`useradd` is a fairly low-level tool. In real life, you as an experienced administrator will likely not be adding new user accounts by means of `useradd`, but through a shell script that incorporates your local policies (just so you don't have to remember them all the time). Unfortunately you will have to come up with this shell script by yourself—at least unless you are using Debian GNU/Linux or one of its derivatives (see below).

Watch out: Even though every serious Linux distribution comes with a program called `useradd`, the implementations differ in their details.

The Red Hat distributions include a fairly run-of-the-mill version of `useradd`, without bells and whistles, which provides the features discussed above.

The SUSE distributions' `useradd` is geared towards optionally adding users to a LDAP directory rather than the `/etc/passwd` file. (This is why the `-D` option cannot be used to query or set default values like it can elsewhere—it is already spoken for to do LDAPy things.) The details are beyond the scope of this manual.

On Debian GNU/Linux and Ubuntu, `useradd` does exist but the recommended method to create new user accounts is a program called `adduser` (thankfully this is not confusing). The advantage of `adduser` is that it plays according to Debian GNU Linux's rules, and furthermore makes it possible to execute arbitrary other actions for a new account besides creating the actual account. For example, one might create a directory in a web server's document tree so that the new user (and nobody else) can publish files there, or the user could automatically be authorised to access a database server. You can find the details in `adduser`(8) and `adduser.conf`(5).

After it has been created using `useradd`, the new account is not yet accessible;
password the system administrator must first set up a password. We shall be explaining this presently.

11.3.2 The `passwd` Command

The `passwd` command is used to set up passwords for users. If you are logged in as `root`, then

```
# passwd joe
```

asks for a new password for user `john` (You must enter it twice as it will not be echoed to the screen).

The `passwd` command is also available to normal users, to let them change their own passwords (changing other users' passwords is `root`'s prerogative):

```
$ passwd
Changing password for joe.
(current) UNIX password: secret123
Enter new UNIX password: 321terces
Retype new UNIX password: 321terces
passwd: password updated successfully
```

Normal users must enter their own password correctly once before being allowed to set a new one. This is supposed to make life difficult for practical jokers that play around on your computer if you had to step out very urgently and didn't have time to engage the screen lock.

On the side, `passwd` serves to manage various settings in `/etc/shadow`. For example, you can look at a user's "password state" by calling the `passwd` command with the `-S` option:

```
# passwd -S bob
bob LK 10/15/99 0 99999 7 0
```

The first field in the output is (once more) the user name, followed by the password state: "`PS`" or "`P`" if a password is set, "`LK`" or "`L`" for a locked account, and "`NP`" for an account with no password at all. The other fields are, respectively, the date of the last password change, the minimum and maximum interval for changing the password, the expiry warning interval and the "grace period" before the account is locked completely after the password has expired. (See also Section 11.2.2.)

You can change some of these settings by means of `passwd` options. Here are a few examples:

```
# passwd -l joe                    Lock the account
# passwd -u joe                    Unlock the account
# passwd -n 7 joe                  Password change at most every 7 days
# passwd -x 30 joe                 Password change at least every 30 days
# passwd -w 3 joe                  3 days grace period before password expires
```

Locking and unlocking accounts by means of `-l` and `-u` works by putting a "`!`" in front of the encrypted password in `/etc/shadow`. Since "`!`" cannot result from password encryption, it is impossible to enter something upon login that matches the "encrypted password" in the user database—hence access via the usual login procedure is prevented. Once the "`!`" is removed, the original password is back in force. (Astute, innit?) However, you should keep in mind that users may be able to gain access to the system by other means that do not refer to the encrypted password in the user database, such as the secure shell with public-key authentication.

Changing the remaining settings in `/etc/shadow` requires the `chage` command:

```
# chage -E 2009-12-01 joe          Lock account from 1 Dec 2009
# chage -E -1 joe                  Cancel expiry date
# chage -I 7 joe                   Grace period 1 week from password expiry
# chage -m 7 joe                   Like passwd -n (Grr.)
# chage -M 7 joe                   Like passwd -x (Grr, grr.)
# chage -W 3 joe                   Like passwd -w (Grr, grr, grr.)
```

(`chage` can change all settings that `passwd` can change, and then some.)

If you cannot remember the option names, invoke `chage` with the name of a user account only. The program will present you with a sequence of the current values to change or confirm.

You cannot retrieve a clear-text password even if you are the administrator. Even checking `/etc/shadow` doesn't help, since this file stores all passwords already encrypted. If a user forgets their password, it is usually sufficient to reset their password using the `passwd` command.

Should you have forgotten the `root` password and not be logged in as `root` by any chance, your last option is to boot Linux to a shell, or boot from a rescue disk or CD. (See Chapter 16.) After that, you can use an editor to clear the ⟨*password*⟩ field of the `root` entry in `/etc/passwd`.

Exercises

11.8 [3] Change user `joe`'s password. How does the `/etc/shadow` file change? Query that account's password state.

11.9 [!2] The user `dumbo` has forgotten his password. How can you help him?

11.10 [!3] Adjust the settings for user `joe`'s password such that he can change his password after at least a week, and must change it after at most two weeks. There should be a warning two days before the two weeks are up. Check the settings afterwards.

11.3.3 Deleting User Accounts

To delete a user account, you need to remove the user's entries from `/etc/passwd` and `/etc/shadow`, delete all references to that user in `/etc/group`, and remove the user's home directory as well as all other files created or owned by that user. If the user has, e. g., a mail box for incoming messages in `/var/mail`, that should also be removed.

`userdel` Again there is a suitable command to automate these steps. The `userdel` command removes a user account completely. Its syntax:

```
userdel [-r] ⟨user name⟩
```

The `-r` option ensures that the user's home directory (including its content) and his mail box in `/var/mail` will be removed; other files belonging to the user—e. g., `crontab` files—must be delete manually. A quick way to locate and remove files belonging to a certain user is the

```
find / -uid ⟨UID⟩ -delete
```

command. Without the `-r`option, only the user information is removed from the user database; the home directory remains in place.

11.3.4 Changing User Accounts and Group Assignment

User accounts and group assignments are traditionally changed by editing the `/etc/passwd` and `/etc/group` files. However, many systems contain commands like `usermod` and `groupmod` for the same purpose, and you should prefer these since they are safer and—mostly—more convenient to use.

`usermod` The `usermod` program accepts mostly the same options as `useradd`, but changes existing user accounts instead of creating new ones. For example, with

```
usermod -g ⟨group⟩ ⟨user name⟩
```

you could change a user's primary group.

Changing UIDs Caution! If you want to change an existing user account's UID, you could edit the ⟨*UID*⟩ field in `/etc/passwd` directly. However, you should at the same time transfer that user's files to the new UID using `chown`: "`chown -R tux /home/tux`" re-confers

ownership of all files below user tux's home directory to user tux, after you have changed the UID for that account. If "ls -l" displays a numerical UID instead of a textual name, this implies that there is no user name for the UID of these files. You can fix this using chown.

11.3.5 Changing User Information Directly—vipw

The vipw command invokes an editor (vi or a different one) to edit /etc/passwd directly. At the same time, the file in question is locked in order to keep other users from simultaneously changing the file using, e. g., passwd (which changes would be lost). With the -s option, /etc/shadow can be edited.


The actual editor that is invoked is determined by the value of the VISUAL environment variable, alternatively that of the EDITOR environment variable; if neither exists, vi will be launched.

Exercises


11.11 [!2] Create a user called test. Change to the test account and create a few files using touch, including a few in a different directory than the home directory (say, /tmp). Change back to root and change test's UID. What do you see when listing user test's files?


11.12 [!2] Create a user called test1 using your distribution's graphical tool (if available), test2 by means of the useradd command, and another, test3, manually. Look at the configuration files. Can you work without problems using any of these three accounts? Create a file using each of the new accounts.


11.13 [!2] Delete user test2's account and ensure that there are no files left on the system that belong to that user.


11.14 [2] Change user test1's UID. What else do you need to do?


11.15 [2] Change user test1's home directory from /home/test1 to /home/user/test1.

11.3.6 Creating, Changing and Deleting Groups

Like user accounts, you can create groups using any of several methods. The "manual" method is much less tedious here than when creating new user accounts: Since groups do not have home directories, it is usually sufficient to edit the /etc/group file using any text editor, and to add a suitable new line (see below for vigr). When group passwords are used, another entry must be added to /etc/gshadow.

Incidentally, there is nothing wrong with creating directories for groups. Group members can place the fruits of their collective labour there. The approach is similar to creating user home directories, although no basic set of configuration files needs to be copied.

For group management, there are, by analogy to useradd, usermod, and userdel, the groupadd, groupmod, and groupdel programs that you should use in favour of editing /etc/group and /etc/gshadow directly. With groupadd you can create new groups simply by giving the correct command parameters: groupadd

```
groupadd [-g ⟨GID⟩] ⟨group name⟩
```

The -g option allows you to specify a given group number. As mentioned before, this is a positive integer. The values up to 99 are usually reserved for system groups. If -g is not specified, the next free GID is used.

You can edit existing groups with groupmod without having to write to /etc/group directly: groupmod

```
groupmod [-g ⟨GID⟩] [-n ⟨name⟩] ⟨group name⟩
```

The "`-g` ⟨*GID*⟩" option changes the group's GID. Unresolved file group assignments must be adjusted manually. The "`-n` ⟨*name*⟩" option sets a new name for the group without changing the GID; manual adjustments are not necessary.

There is also a tool to remove group entries. This is unsurprisingly called `groupdel`:

groupdel

```
groupdel ⟨group name⟩
```

Here, too, it makes sense to check the file system and adjust "orphaned" group assignments for files with the `chgrp` command. Users' primary groups may not be removed—the users in question must either be removed beforehand, or they must be reassigned to a different primary group.

gpasswd

The `gpasswd` command is mainly used to manipulate group passwords in a way similar to the `passwd` command. The system administrator can, however, delegate the administration of a group's membership list to one or more group administrators. Group administrators also use the `gpasswd` command:

group administrator

```
gpasswd -a ⟨user⟩ ⟨group⟩
```

adds the ⟨*user*⟩ to the ⟨*group*⟩, and

```
gpasswd -d ⟨user⟩ ⟨group⟩
```

removes him again. With

```
gpasswd -A ⟨user⟩,… ⟨group⟩
```

the system administrator can nominate users who are to serve as group administrators.

The SUSE distributions haven't included `gpasswd` for some time. Instead there are modified versions of the user and group administration tools that can handle an LDAP directory.

As the system administrator, you can change the group database directly using the `vigr` command. It works like `vipw`, by invoking an editor for "exclusive" access to `/etc/group`. Similarly, "`vigr -s`" gives you access to `/etc/gshadow`.

vigr

Exercises

11.16 [2] What are groups needed for? Give possible examples.

11.17 [1] Can you create a directory that all members of a group can access?

11.18 [!2] Create a supplementary group `test`. Only user `test1` should be a member of that group. Set a group password. Log in as user `test1` or `test2` and try to change over to the new group.

Commands in this Chapter

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chfn Allows users to change the GECOS field in the user database chfn(1) 165
getent Gets entries from administrative databases getent(1) 170
gpasswd Allows a group administrator to change a group's membership and update the group password gpasswd(1) 176
groupadd Adds user groups to the system group database groupadd(8) 175
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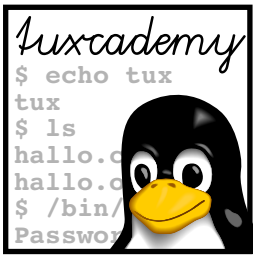
vigr Allows editing /etc/group or /etc/gshadow with "file locking", to avoid conflicts vipw(8) 176

Summary

- Access to the system is governed by user accounts.
- A user account has a numerical UID and (at least) one textual user name.
- Users can form groups. Groups have names and numerical GIDs.
- "Pseudo-users" and "pseudo-groups" serve to further refine access rights.
- The central user database is (normally) stored in the /etc/passwd file.
- The users' encrypted passwords are stored—together with other password parameters—in the /etc/shadow file, which is unreadable for normal users.
- Group information is stored in the /etc/group and /etc/gshadow files.
- Passwords are managed using the passwd program.
- The chage program is used to manage password parameters in /etc/shadow.
- User information is changed using vipw or—better—using the specialised tools useradd, usermod, and userdel.
- Group information can be manipulated using the groupadd, groupmod, groupdel and gpasswd programs.



12

Access Control

Contents

Goals

- Understanding the Linux access control/privilege mechanisms
- Being able to assign access permissions to files and directories
- Knowing about the “umask”, SUID, SGID and the “sticky bit”
- Knowing about file attributes in the ext file systems

Prerequisites

- Knowledge of Linux user and group concepts (see Chapter 11)
- Knowledge of Linux files and directories

12.1 The Linux Access Control System

access control system

Whenever several users have access to the same computer system there must be an access control system for processes, files and directories in order to ensure that user *A* cannot access user *B*'s private files just like that. To this end, Linux implements the standard system of Unix privileges.

separate privileges

In the Unix tradition, every file and directory is assigned to exactly one user (its owner) and one group. Every file supports separate privileges for its owner, the members of the group it is assigned to ("the group", for short), and all other users ("others"). Read, write and execute privileges can be enabled individually for these three sets of users. The owner may determine a file's access privileges. The group and others may only access a file if the owner confers suitable privileges to them. The sum total of a file's access permissions is also called its **access mode**.

access mode

access control

In a multi-user system which stores private or group-internal data on a generally accessible medium, the owner of a file can keep others from reading or modifying his files by instituting suitable access control. The rights to a file can be determined separately and independently for its owner, its group and the others. Access permissions allow users to map the responsibilities of a group collaborative process to the files that the group is working with.

12.2 Access Control For Files And Directories

12.2.1 The Basics

For each file and each directory in the system, Linux allows separate access rights for each of the three classes of users—owner, members of the file's group, others. These rights include read permission, write permission, and execute permission.

file permissions

As far as files are concerned, these permissions control approximately what their names suggest: Whoever has read permission may look at the file's content, whoever has write permission is allowed to change its content. Execute permission is necessary to launch the file as a process.

Executing a binary "machine-language program" requires only execute permission. For files containing shell scripts or other types of "interpreted" programs, you also need read permission.

directory permissions

For directories, things look somewhat different: Read permission is required to look at a directory's content—for example, by executing the `ls` command. You need write permission to create, delete, or rename files in the directory. "Execute" permission stands for the possibility to "use" the directory in the sense that you can change into it using `cd`, or use its name in path names referring to files farther down in the directory tree.

In directories where you have only read permission, you may read the file names but cannot find out anything else about the files. If you have only "execute permission" for a directory, you can access files as long as you know their names.

Usually it makes little sense to assign write and execute permission to a directory separately; however, it may be useful in certain special cases.

It is important to emphasise that write permission on a *file* is completely immaterial if the file is to be *deleted*—you need write permission to the *directory* that the file is in and nothing else! Since "deleting" a file only removes a reference to the actual file information (the inode) from the directory, this is purely a directory operation. The `rm` command does warn you if you're trying to delete a file that you do not have write permission for, but if you confirm the operation and have write permission to the directory involved, nothing will stand in the way of the operation's success. (Like any other

Unix-like system, Linux has no way of "deleting" a file outright; you can only remove all references to a file, in which case the Linux kernel decides on its own that no one will be able to access the file any longer, and gets rid of its content.)

If you do have write permission to the file but not its directory, you cannot remove the file completely. You can, however, truncate it down to 0 bytes and thereby remove its *content*, even though the file itself still exists in principle.

For each user, Linux determines the "most appropriate" access rights. For example, if the members of a file's group do not have read permission for the file but "others" do, then the group members may not read the file. The (admittedly enticing) rationale that, if all others may look at the file, then the group members, who are in some sense also part of "all others", should be allowed to read it as well, does not apply.

12.2.2 Inspecting and Changing Access Permissions

information

You can obtain information about the rights, user and group assignment that apply to a file using "`ls -l`":

```
$ ls -l
-rw-r--r--  1  joe  users   4711  Oct 4 11:11 datei.txt
drwxr-x---  2  joe  group2  4096  Oct 4 11:12 testdir
```

The string of characters in the first column of the table details the access permissions for the owner, the file's group, and others (the very first character is just the file type and has nothing to do with permissions). The third column gives the owner's user name, and the fourth that of the file's group.

In the permissions string, "`r`", "`w`", and "`x`" signify existing read, write, and execute permission, respectively. If there is just a "`-`" in the list, then the corresponding category does not enjoy the corresponding privilege. Thus, "`rw-r--r--`" stands for "read and write permission for the owner, but read permission only for group members and others".

`chmod` command

As the file owner, you may set access permissions for a file using the `chmod` command (from "change mode"). You can specify the three categories by means of the abbreviations "`u`" (user) for the owner (yourself), "`g`" (group) for the file's group's members, and "`o`" (others) for everyone else. The permissions themselves are given by the already-mentioned abbreviations "`r`", "`w`", and "`x`". Using "`+`", "`-`", and "`=`", you can specify whether the permissions in question should be added to any existing permissions, "subtracted" from the existing permissions, or used to replace whatever was set before. For example:

```
$ chmod u+x file                    Execute permission for owner
$ chmod go+w file                   sets write permission for group and others
$ chmod g+rw file                   sets read and write permission for group
$ chmod g=rw,o=r file               sets read and write permission,
                                    removes group execute permission;
                                    sets just read permission for others
$ chmod a+w file                    equivalent to ugo+w
```

In fact, permission specifications can be considerably more complex. Consult the `info` documentation for `chmod` to find out all the details.

A file's owner is the single user (apart from `root`) who is allowed to change a file's or directory's access permissions. This privilege is independent of the actual permissions; the owner may take away all their own permissions, but that does not keep them from giving them back later.

The general syntax of the `chmod` command is

```
chmod [⟨options⟩] ⟨permissions⟩ ⟨name⟩ …
```

You can give as many file or directory names as desired. The most important options include:

-R If a directory name is given, the permissions of files and directories inside this directory will also be changed (and so on all the way down the tree).

--reference=⟨*name*⟩ Uses the access permissions of file ⟨*name*⟩. In this case no ⟨*permissions*⟩ must be given with the command.

You may also specify a file's access mode "numerically" instead of "symbolically" (what we just discussed). In practice this is very common for setting all permissions of a file or directory at once, and works like this: The three permission triples are represented as a three-digit octal number—the first digit describes the owner's rights, the second those of the file's group, and the third those that apply to "others". Each of these digits derives from the sum of the individual permissions, where read permission has value 4, write permission 2, and execute permission 1. Here are a few examples for common access modes in "`ls -l`" and octal form:

```
rw-r--r--  644
r--------  400
rwxr-xr-x  755
```

Using numerical access modes, you can only set all permissions at once—there is no way of setting or removing individual rights while leaving the others alone, like you can do with the "+" and "-" operators of the symbolic representation. Hence, the command

```
$ chmod 644 file
```

is equivalent to the symbolic

```
$ chmod u=rw,go=r file
```

12.2.3 Specifying File Owners and Groups—`chown` and `chgrp`

The `chown` command lets you set the owner and group of a file or directory. This command takes the desired owner's user name and/or group name and the file or directory name the change should apply to. It is called like

```
chown ⟨user name⟩[:][⟨group name⟩] ⟨name⟩ …
chown :⟨group name⟩ ⟨name⟩ …
```

If both a user and group name are given, both are changed; if just a user name is given, the group remains as it was; if a user name followed by a colon is given, then the file is assigned to the user's primary group. If just a group name is given (with the colon in front), the owner remains unchanged. For example:

```
# chown joe:devel letter.txt
# chown www-data foo.html                    new user www-data
# chown :devel /home/devel                   new group devel
```

`chown` also supports an obsolete syntax where a dot is used in place of the colon.

To "give away" files to other users or arbitrary groups you need to be `root`. The main reason for this is that normal users could otherwise annoy one another if the system uses quotas (i.e., every user can only use a certain amount of storage space).

Using the `chgrp` command, you can change a file's group even as a normal user—as long as you own the file and are a member of the *new* group:

`chgrp` ⟨*group name*⟩ ⟨*name*⟩ …


Changing a file's owner or group does not change the access permissions for the various categories.

`chown` and `chgrp` also support the `-R` option to apply changes recursively to part of the directory hierarchy.


Of course you can also change a file's permissions, group, and owner using most of the popular file browsers (such as Konqueror or Nautilus).

Exercises


12.1 [!2] Create a new file. What is that file's group? Use `chgrp` to assign the file to one of your secondary groups. What happens if you try to assign the file to a group that you are not a member of?


12.2 [4] Compare the mechanisms that various file browsers (like Konqueror, Nautilus, …) offer for setting a file's permissions, owner, group, … Are there notable differences?

12.2.4 The umask

New files are usually created using the (octal) access mode 666 (read and write permission for everyone). New directories are assigned the access mode 777. Since this is not always what is desired, Linux offers a mechanism to remove certain rights from these access modes. This is called "umask".


Nobody knows exactly where this name comes from—even though there are a few theories that all sound fairly implausible.

The umask is an octal number whose complement is ANDed bitwise to the standard access mode—666 or 777—to arrive at the new file's or directory's actual access mode. In other words: You can consider the umask an access mode containing exactly those rights that the new file should *not* have. Here's an example—let the umask be 027:

umask interpretation

1.	Umask value:	027	`----w-rwx`
2.	Complement of umask value:	750	`rwxr-x---`
3.	A new file's access mode:	666	`rw-rw-rw-`
4.	Result (2 and 3 ANDed together):	640	`rw-r-----`

The third column shows the octal value, the fourth a symbolic representation. The AND operation in step 4 can also be read off the fourth column of the second and third lines: In the fourth line ther e is a letter in each position that had a letter in the second *and* the third line—if there is just one dash ("`-`"), the result will be a dash.


If you'd rather not bother with the complement and AND, you can simply imagine that each digit of the umask is subtracted from the corresponding digit of the actual access mode and negative results are considered as zero (so no "borrowing" from the place to the left). For our example—access mode 666 and umask 027—this means something like

$$666 \ominus 027 = 640,$$

since $6 \ominus 0 = 6$, $6 \ominus 4 = 2$, and $6 \ominus 7 = 0$.

umask shell command

The umask is set using the umask shell command, either by invoking it directly or via a shell startup file—typically `~/.profile`, `~/.bash_profile`, or `~/.bashrc`.

process attribute

The umask is a process attribute similar to the current directory or the process environment, i. e., it is passed to child processes, but changes in a child process do not modify the parent process's settings.

syntax

The `umask` command takes a parameter specifying the desired umask:

```
umask [-S|⟨umask⟩]
```

symbolic representation

The umask may be given as an octal number or in a symbolic representation similar to that used by `chmod`—deviously enough, the symbolic form contains the permissions that should be *left* (rather than those to be taken away):

```
$ umask 027                                          … is equivalent to …
$ umask u=rwx,g=rx,o=
```

This means that in the symbolic form you must give the exact complement of the value that you would specify in the octal form—exactly those rights that do *not* occur in the octal specification.

If you specify no value at all, the current umask is displayed. If the `-S` option is given, the current umask is displayed in symbolic form (where, again, the remaining permissions are set):

```
$ umask
0027
$ umask -S
u=rwx,g=rx,o=
```

execute permission?

Note that you can only *remove* permissions using the umask. There is no way of making files executable by default.

umask and `chmod`

Incidentally, the umask also influences the `chmod` command. If you invoke `chmod` with a "+" mode (e. g., "`chmod +w file`") without referring to the owner, group or others, this is treated like "`a+`", but the permissions set in the umask are not modified. Consider the following example:

```
$ umask 027
$ touch file
$ chmod +x file
$ ls -l file
-rwxr-x---   1 tux   users        0 May 25 14:30 file
```

The "`chmod +x`" sets execute permission for the user and group, but not the others, since the umask contains the execute bit for "others". Thus with the umask you can take precautions against giving overly excessive permissions to files.

Theoretically, this also works for the `chmod` operators "`-`" and "`=`", but this does not make a lot of sense in practice.

Exercises

12.3 [!1] State a numerical umask that leaves the user all permissions, but removes all permissions from group members and others? What is the corresponding symbolic umask?

12.4 [2] Convince yourself that the "`chmod +x`" and "`chmod a+x`" commands indeed differ from each other as advertised.

12.3 Access Control Lists (ACLs)

As mentioned above, Linux allows you to assign permissions for a file's owner, group, and all others separately. For some applications, though, this three-tier system is too simple-minded, or the more sophisticated permission schemes of other operating systems must be mapped to Linux. Access control lists (ACLs) can be used for this.

On most file systems, Linux supports "POSIX ACLs" according to IEEE 1003.1e (draft 17) with some Linux-specific extensions. This lets you specify additional groups and users for files and directories, who then can be assigned read, write, and execute permissions that differ from those of the file's group and "others". Other rights, such as that to assign permissions, are still restricted to a file's owner (or `root`) and cannot be delegated even wiht ACLs. The `setfacl` and `getfacl` commands are used to set and query ACLs.

ACLs are a fairly new and rarely-used addition to Linux, and their use is subject to certain restrictions. The kernel does oversee compliance with them, but, for instance, not every program is able to copy ACLs along with a file's content—you may have to use a specially-adapted `tar` (`star`) for backups of a file system using ACLs. ACLs are supported by Samba, so Windows clients get to see the correct permissions, but if you export file systems to other (proprietary) Unix systems, it may be possible that your ACLs are ignored by Unix clients that do not support ACLs.


You can read up on ACLs on Linux on `http://acl.bestbits.at/` and in `acl`(5) as well as `getfacl`(1) and `setfacl`(1).

Detailed knowledge of ACLs is not required for the LPIC-1 exams.

12.4 Process Ownership

Linux considers not only the data on a storage medium as objects that can be owned. The processes on the system have owners, too.

Many commands create a process in the system's memory. During normal use, there are always several processes that the system protects from each other. Every process together with all data within its virtual address space is assigned to a user, its owner. This is most often the user who started the process—but processes created using administrator privileges may change their ownership, and the SUID mechanism (Section 12.5) can also have a hand in this.

Processes have owners

The owners of processes are displayed by the `ps` program if it is invoked using the `-u` option.

```
# ps -u
USER   PID %CPU  %MEM SIZE      RSS TTY STAT  START  TIME COMMAND
bin     89  0.0   1.0  788      328   ?    S  13:27  0:00 rpc.portmap
test1  190  0.0   2.0 1100       28   3    S  13:27  0:00 bash
test1  613  0.0   1.3  968       24   3    S  15:05  0:00 vi XF86.tex
nobody 167  0.0   1.4  932       44   ?    S  13:27  0:00 httpd
root     1  0.0   1.0  776       16   ?    S  13:27  0:03 init [3]
root     2  0.0   0.0    0        0   ?   SW  13:27  0:00 (kflushd)
```

12.5 Special Permissions for Executable Files

When listing files using the "`ls -l`" command, you may sometimes encounter permission sets that differ from the usual `rwx`, such as

```
-rwsr-xr-x   1 root shadow  32916 Dec 11 20:47 /usr/bin/passwd
```

What does that mean? We have to digress here for a bit:

Assume that the `passwd` program carries the usual access mode:

```
-rwxr-xr-x   1 root shadow  32916 Dec 11 20:47 /usr/bin/passwd
```

A normal (unprivileged) user, say `joe`, wants to change his password and invokes the `passwd` program. Next, he receives the message "permission denied". What is the reason? The `passwd` process (which uses `joe`'s privileges) tries to open the `/etc/shadow` file for writing and fails, since only `root` may write to that file—this cannot be different since otherwise, everybody would be able to manipulate passwords arbitrarily and, for example, change the `root` password.

SUID bit

By means of the **set-UID bit** (frequently called "SUID bit", for short) a program can be caused to run not with the invoker's privileges but those of the file owner—here, `root`. In the case of `passwd`, the *process* executing `passwd` has write permission to `/etc/shadow`, even though the invoking user, not being a system administrator, generally doesn't. It is the responsibility of the author of the `passwd` program to ensure that no monkey business goes on, e. g., by exploiting programming errors to change arbitrary files except `/etc/shadow`, or entries in `/etc/shadow` except the password field of the invoking user. On Linux, by the way, the set-UID mechanism works only for binary programs, not shell or other interpreter scripts.

Bell Labs used to hold a patent on the SUID mechanism, which was invented by Dennis Ritchie [SUID]. Originally, AT&T distributed Unix with the caveat that license fees would be levied after the patent had been granted; however, due to the logistical difficulties of charging hundreds of Unix installations small amounts of money retroactively, the patent was released into the public domain.

SGID bit

By analogy to the set-UID bit there is a SGID bit, which causes a process to be executed with the program file's group and the corresponding privileges (usually to access other files assigned to that group) rather than the invoker's group setting.

`chmod` syntax

The SUID and SGID modes, like all other access modes, can be changed using the `chmod` program, by giving symbolic permissions such as `u+s` (sets the SUID bit) or `g-s` (deletes the SGID bit). You can also set these bits in octal access modes by adding a fourth digit at the very left: The SUID bit has the value 4, the SGID bit the value 2—thus you can assign the access mode 4755 to a file to make it readable and executable to all users (the owner may also write to it) and to set the SUID bit.

`ls` output

You can recognise set-UID and set-GID programs in the output of "`ls -l`" by the symbolic abbreviations "`s`" in place of "`x`" for executable files.

12.6 Special Permissions for Directories

There is another exception from the principle of assigning file ownership according to the identity of its creator: a directory's owner can decree that files created in that directory should belong to the same group as the directory itself. This can be specified by setting the SGID bit on the directory. (As directories cannot be executed, the SGID bit is available to be used for such things.)

SGID for directories

A directory's access permissions are not changed via the SGID bit. To create a file in such a directory, a user must have write permission in the category (owner, group, others) that applies to him. If, for example, a user is neither the owner of a directory nor a member of the directory's group, the directory must be writable for "others" for him to be able to create files there. A file created in a SGID directory then belongs to that directory's group, even if the user is not a member of that group at all.

The typical application for the SGID bit on a directory is a directory that is used as file storage for a "project group". (Only) the members of the project group are supposed to be able to read and write all files in the directory, and

to create new files. This means that you need to put all users collaborating on the project into a project group (a secondary group will suffice):

```
# groupadd project                                    Create new group
# usermod -a -G project joe                           joe into the group
# usermod -a -G project sue                                    sue too
◁◁◁◁◁
```

Now you can create the directory and assign it to the new group. The owner and group are given all permissions, the others none; you also set the SGID bit:

```
# cd /home/project
# chgrp project /home/project
# chmod u=rwx,g=srwx /home/project
```

Now, if user `hugo` creates a file in `/home/project`, that file should be assigned to group `project`:

```
$ id
uid=1000(joe) gid=1000(joe) groups=101(project),1000(joe)
$ touch /tmp/joe.txt                                  Test: standard directory
$ ls -l /tmp/joe.txt
-rw-r--r-- 1 joe joe 0 Jan  6 17:23 /tmp/joe.txt
$ touch /home/project/joe.txt                                 project directory
$ ls -l /home/project/joe.txt
-rw-r--r-- 1 joe project 0 Jan  6 17:24 /home/project/joe.txt
```

There is just a little fly in the ointment, which you will be able to discern by looking closely at the final line in the example: The file does belong to the correct group, but other members of group `project` may nevertheless only read it. If you want all members of group `project` to be able to write to it as well, you must either apply `chmod` after the fact (a nuisance) or else set the umask such that group write permission is retained (see Exercise 12.6).

The SGID mode only changes the system's behaviour when new files are created. Existing files work just the same as everywhere else. This means, for instance, that a file created outside the SGID directory keeps its existing group assignment when moved into it (whereas on copying, the new copy would be put into the directory's group).

The `chgrp` program works as always in SGID directories, too: the owner of a file can assign it to any group he is a member of. Is the owner not a member of the directory's group, he cannot put the file into that group using `chgrp`—he must create it afresh within the directory.


It is possible to set the SUID bit on a directory—this permission does not signify anything, though.

Linux supports another special mode for directories, where only a file's owner may delete or remove files within that directory:

```
drwxrwxrwt   7 root   root   1024 Apr  7 10:07 /tmp
```

This `t` mode, the "sticky bit", can be used to counter a problem which arises when public directories are in shared use: Write permission to a directory lets a user delete other users' files, regardless of their access mode and owner! For example, the `/tmp` directories are common ground, and many programs create their temporary files there. To do so, all users have write permission to that directory. This implies that any user has permission to delete files there.

Table 12.1: The most important file attributes

Attribute	Meaning
`A`	*atime* is not updated (interesting for mobile computers)
`a`	(*append-only*) The file can only be appended to
`c`	The file's content is compressed transparently (not implemented)
`d`	The file will not be backed up by `dump`
`i`	(*immutable*) The file cannot be changed at all
`j`	Write operations to the file's content are passed through the journal (`ext3` only)
`s`	File data will be overwritten with zeroes on deletion (not implemented)
`S`	Write operations to the file are performed "synchronously", i. e., without buffering them internally
`u`	The file may be "undeleted" after deletion (not implemented)

Usually, when deleting or renaming a file, the system does not consider that file's access permissions. If the "sticky bit" is set on a directory, a file in that directory can subsequently be deleted only by its owner, the directory's owner, or `root`. The "sticky bit" can be set or removed by specifying the symbolic `+t` and `-t` modes; in the octal representation it has value 1 in the same digit as SUID and SGID.

The "sticky bit" derives its name from an additional meaning it used to have in earlier Unix systems: At that time, programs were copied to swap space in their entirety when started, and removed completely after having terminated. Program files with the sticky bit set would be left in swap space instead of being removed. This would accelerate subsequent invocations of those programs since no copy would have to be done. Like most current Unix systems, Linux uses demand paging, i. e., it fetches only those parts of the code from the program's executable file that are really required, and does not copy anything to swap space at all; on Linux, the sticky bit never had its original meaning.

Exercises

12.5 [2] What does the special "`s`" privilege mean? Where do you find it? Can you set this privilege on a file that you created yourself?

12.6 [!1] Which `umask` invocation can be used to set up a umask that would, in the project directory example above, allow all members of the `project` group to read *and* write files in the project directory?

12.7 [2] What does the special "`t`" privilege mean? Where do you find it?

12.8 [4] (For programmers.) Write a C program that invokes a suitable command (such as `id`). Set this program SUID `root` (or SGID `root`) and observe what happens when you execute it.

12.9 [I]f you leave them alone for a few minutes with a `root` shell, clever users might try to stash a SUID `root` shell somewhere in the system, in order to assume administrator privileges when desired. Does that work with `bash`? With other shells?

12.7 File Attributes

file attributes

Besides the access permissions, the `ext2` and `ext3` file systems support further **file**

attributes enabling access to special file system features. The most important file attributes are summarised in Table 12.1.

Most interesting are perhaps the "append-only" and "immutable" attributes, which you can use to protect log files and configuration files from modification; only `root` may set or reset these attributes, and once set they also apply to processes running as `root`.

`a` and `i` attributes

In principle, an attacker who has gained `root` privileges may reset these attributes. However, attackers do not necessarily consider that they might be set.

The `A` attribute may also be useful; you can use it on mobile computers to ensure that the disk isn't always running, in order to save power. Usually, whenever a file is read, its "atime"—the time of last access—is updated, which of course entails an inode write operation. Certain files are very frequently looked at in the background, such that the disk never gets to rest, and you can help here by judiciously applying the `A` attribute.

`A` attribute

The `c`, `s` and `u` attributes sound very nice in theory, but are not (yet) supported by "normal" kernels. There are some more or less experimental enhancements making use of these attributes, and in part they are still pipe dreams.

You can set or reset attributes using the `chattr` command. This works rather like `chmod`: A preceding "`+`" sets one or more attributes, "`-`" deletes one or more attributes, and "`=`" causes the named attributes to be the only enabled ones. The `-R` option, as in `chmod`, lets `chattr` operate on all files in any subdirectories passed as arguments and their nested subdirectories. Symbolic links are ignored in the process.

`chattr`

```
# chattr +a /var/log/messages                    Append only
# chattr -R +j /data/important                   Data journaling …
# chattr -j /data/important/notso                … with exception
```

With the `lsattr` command, you can review the attributes set on a file. The program behaves similar to "`ls -l`":

`lsattr`

```
# lsattr /var/log/messages
-----a---------- /var/log/messages
```

Every dash stands for a possible attribute. `lsattr` supports various options such as `-R`, `-a`, and `-d`, which generally behave like the eponymous options to `ls`.

Exercises

12.10 [!2] Convince yourself that the `a` and `i` attributes work as advertised.

12.11 [2] Can you make *all* dashes disappear in the `lsattr` output for a given file?

Commands in this Chapter

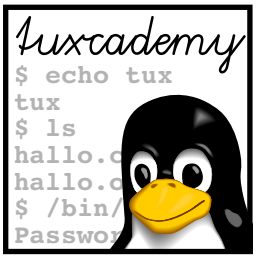
chattr	Sets file attributes for ext2 and ext3 file systems	chattr(1)	189
chgrp	Sets the assigned group of a file or directory	chgrp(1)	182
chmod	Sets access modes for files and directories	chmod(1)	181
chown	Sets the owner and/or assigned group of a file or directory	chown(1)	182
getfacl	Displays ACL data	getfacl(1)	185
lsattr	Displays file attributes on ext2 and ext3 file systems	lsattr(1)	189
setfacl	Enables ACL manipulation	setfacl(1)	185
star	POSIX-compatible tape archive with ACL support	star(1)	185

Summary

- Linux supports file read, write and execute permissions, where these permissions can be set separately for a file's owner, the members of the file's group and "all others".
- The sum total of a file's permissions is also called its access mode.
- Every file (and directory) has an owner and a group. Access rights—read, write, and execute permission—are assigned to these two categories and "others" separately. Only the owner is allowed to set access rights.
- Access rights do not apply to the system administrator (root). He may read or write all files.
- File permissions can be manipulated using the chmod command.
- Using chown, the system administrator can change the user and group assignment of arbitrary files.
- Normal users can use chgrp to assign their files to different groups.
- The umask can be used to limit the standard permissions when files and directories are being created.
- The SUID and SGID bits allow the execution of programs with the privileges of the file owner or file group instead of those of the invoker.
- The SGID bit on a directory causes new files in that directory to be assigned the directory's group (instead of the primary group of the creating user).
- The "sticky bit" on a directory lets only the owner (and the system administrator) delete files.
- The ext file systems support special additional file attributes.

Bibliography

SUID Dennis M. Ritchie. "Protection of data file contents". US patent 4,135,240.



13

Process Management

Contents

Goals

- Knowing the Linux process concept
- Using the most important commands to query process information
- Knowing how to signal and stop processes
- Being able to influence process priorities

Prerequisites

- Linux commands

13.1 What Is A Process?

A process is, in effect, a "running program". Processes have code that is executed, and data on which the code operates, but also various attributes the operating uses to manage them, such as:

process number

- The unique process number (PID or "process identity") serves to identify the process and can only be assigned to a single process at a time.

parent process number

- All processes know their parent process number, or PPID. Every process can spawn others ("children") that then contain a reference to their procreator. The only process that does not have a parent process is the "pseudo" process with PID 0, which is generated during system startup and creates the "init" process with a PID of 1, which in turn is the ancestor of all other processes in the system.

user groups

- Every process is assigned to a user and a set of groups. These are important to determine the access the process has to files, devices, etc. (See Section 12.4.) Besides, the user the process is assigned to may stop, terminate, or otherwise influence the process. The owner and group assignments are passed on to child processes.

priority

- The system splits the CPU time into little chunks ("time slices"), each of which lasts only for a fraction of a second. The current process is entitled to such a time slice, and afterwards the system decides which process should be allowed to execute during the next time slice. This decision is made by the appropriate "scheduler" based on the priority of a process.

  
  In multi-processor systems, Linux also takes into account the particular topology of the computer in question when assigning CPU time to processes—it is simple to run a process on any of the different cores of a multi-core CPU which share the same memory, while the "migration" of a process to a different processor with separate memory entails a noticeable administrative overhead and is therefore less often worthwhile.

other attributes

- A process has other attributes—a current directory, a process environment, …—which are also passed on to child processes.

process file system

You can consult the `/proc` file system for this type of information. This process file system is used to make available data from the system kernel which is collected at run time and presented by means of directories and files. In particular, there are various directories using numbers as names; every such directory corresponds to one process and its name to the PID of that process. For example:

```
dr-xr-xr-x  3   root  root      0  Oct 16 11:11 1
dr-xr-xr-x  3   root  root      0  Oct 16 11:11 125
dr-xr-xr-x  3   root  root      0  Oct 16 11:11 80
```

In the directory of a process, there are various "files" containing process information. Details may be found in the `proc`(5) man page.

job control


The job control available in many shells is also a form of process management—a "job" is a process whose parent process is a shell. From the corresponding shell, its jobs can be controlled using commands like `jobs`, `bg`, and `fg`, as well as the key combinations Ctrl+z and Ctrl+c (among others). More information is available from the manual page of the shell in question, or from the Linup Front training manual, *Introduction to Linux for Users and Administrators*.

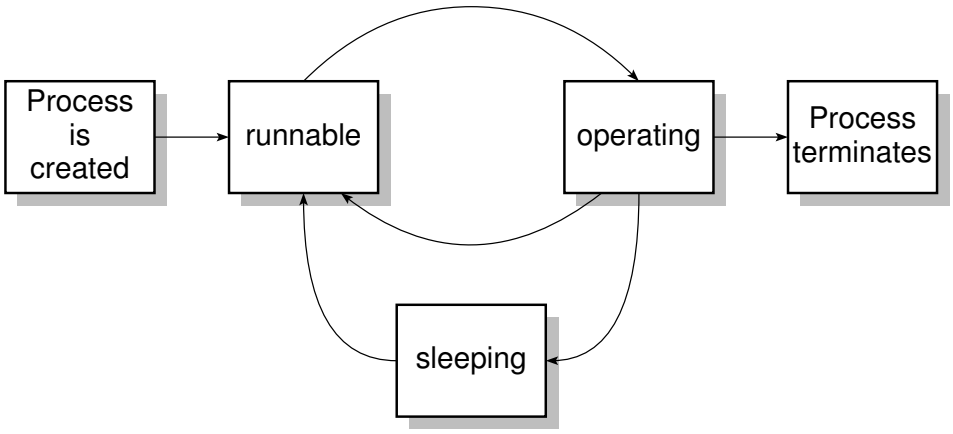


Figure 13.1: The relationship between various process states

Exercises

13.1 [3] How can you view the environment variables of any of your processes? (*Hint:* `/proc` file system.)

13.2 [2] (For programmers.) What is the maximum possible PID? What happens when this limit is reached? (*Hint:* Look for the string "`PID_MAX`" in the files below `/usr/include/linux`.)

13.2 Process States

Another important property of a process is its **process state**. A process in memory waits to be executed by the CPU. This state is called "runnable". Linux uses **pre-emptive multitasking**, i. e., a scheduler distributes the available CPU time to waiting processes in pieces called "time slices". If a process is actually executing on the CPU, this state is called "operating", and after its time slice is over the process reverts to the "runnable" state.

process state

pre-emptive multitasking

From an external point of view, Linux does not distinguish between these two process states; the process in question is always marked "runnable".

It is quite possible that a process requires further input or needs to wait for peripheral device operations to complete; such a process cannot be assigned CPU time, and its state is considered to be "sleeping". Processes that have been stopped by means of Ctrl+Z using the shell's job control facility are in state "stopped". Once the execution of a process is over, it terminates itself and makes a **return code** available, which it can use to signal, for example, whether it completed successfully or not (for a suitable definition of "success").

return code

Once in a while processes appear who are marked as **zombies** using the "Z" state. These "living dead" usually exist only for a brief instant. A process becomes a zombie when it finishes and dies for good once its parent process has queried its return code. If a zombie does not disappear from the process table this means that its parent should really have picked up the zombie's return code but didn't. A zombie cannot be removed from the process table. Because the original process no longer exists and cannot take up neither RAM nor CPU time, a zombie has no impact on the system except for an unattractive entry in the system state. Persistent or very numerous zombies usually indicate programming errors in the parent process; when the parent process terminates they should do so as well.

zombies

Zombies disappear when their parent process disappears because "orphaned" processes are "adopted" by the init process. Since the init process

spends most of its time waiting for other processes to terminate so that it can collect their return code, the zombies are then disposed of fairly quickly.


Of course, zombies take up room in the process table that might be required for other processes. If that proves a problem, look at the parent process.

Exercises


13.3 [2] Start a `xclock` process in the background. In the `$!` shell variable you will find the PID of that process (it always contains the PID of the most recently launched background process). Check the state of that process by means of the "`grep ^State: /proc/$!/status`" command. Stop the `xclock` by moving it to the foreground and stopping it using Ctrl+Z. What is the process state now? (Alternatively, you may use any other long-running program in place of `xclock`.)


13.4 [4] (When going over this manual for the second time.) Can you create a zombie process on purpose?

13.3 Process Information—`ps`

You would normally not access the process information in `/proc` directly but use the appropriate commands to query it.

The `ps` ("process status") command is available on every Unix-like system. Without any otions, all processes running on the current terminal are output. The resulting list contains the process number `PID`, the terminal `TTY`, the process state `STAT`, the CPU time used so far `TIME` and the command being executed.

```
$ ps
  PID TTY STAT TIME COMMAND
  997   1 S    0:00 -bash
 1005   1 R    0:00 ps
$ _
```

There are two processes currently executing on the `tty1` terminal: Apart from the `bash` with PID 997, which is currently sleeping (state "`S`"), a `ps` command is executed using PID 1005 (state "`R`"). The "operating" state mentioned above is not being displayed in `ps` output.

The syntax of `ps` is fairly confusing. Besides Unix98-style options (like `-l`) and GNU-style long options (such as `--help`), it also allows BSD-style options without a leading dash. Here is a selection out of all possible parameters:

`a` ("all") displays all processes with a terminal

`--forest` displays the process hierarchy

`l` ("long") outputs extra information such as the priority

`r` ("running") displays only runnable processes

`T` ("terminal") displays all processes on the current terminal

`U` ⟨*name*⟩ ("user") displays processes owned by user ⟨*name*⟩

`x` also displays processes without a terminal


The unusual syntax of `ps` derives from the fact that AT&T's `ps` traditionally used leading dashes on options while BSD's didn't (and the same option can have quite different results in both flavours). When the big reunification came in System V Release 4, one could hang on to most options with their customary meaning.

If you give ps a PID, only information pertaining to the process in question will be displayed (if it exists):

```
$ ps 1
  PID TTY      STAT   TIME COMMAND
    1 ?        Ss     0:00 init [2]
```

With the -C option, ps displays information about the process (or processes) based on a particular command:

```
$ ps -C konsole
    PID TTY          TIME CMD
   4472 ?        00:00:10 konsole
  13720 ?        00:00:00 konsole
  14045 ?        00:00:14 konsole
```

(Alternatively, grep would help here as well.)

Exercises

13.5 [!2] What does the information obtainable with the ps command mean? Invoke ps without an option, then with the a option, and finally with the ax option. What does the x option do?

13.6 [3] The ps command allows you to determine the output format yourself by means of the -o option. Study the ps(1) manual page and specify a ps command line that will output the PID, PPID, the process state and the command.

13.4 Processes in a Tree—pstree

If you do not want to obtain every bit of information about a process but are rather interested in the relationships between processes, the pstree command is helpful. pstree displays a process tree in which the child processes are shown as depending on their parent process. The processes are displayed by name:

pstree

```
$ pstree
init-+-apache---7*[apache]
     |-apmd
     |-atd
     |-cannaserver
     |-cardmgr
     |-chronyd
     |-cron
     |-cupsd
     |-dbus-daemon-1
     |-events/0-+-aio/0
     |          |-kblockd/0
     |          `-2*[pdflush]
     |-6*[getty]
     |-ifd
     |-inetd
     |-kapmd
     |-kdeinit-+-6*[kdeinit]
     |         |-kdeinit-+-bash---bash
     |         |         |-2*[bash]
     |         |         |-bash---less
```

```
     |         |         |-bash-+-pstree
     |         |         |      `-xdvi---xdvi.bin---gs
     |         |         `-bash---emacs---emacsserver
     |         |-kdeinit---3*[bash]
     |         |-kteatime
     |         `-tclsh
     |-10*[kdeinit]
     |-kdeinit---kdeinit
◁◁◁◁◁
```

Identical processes are collected in brackets and a count and "*" are displayed. The most important options of `pstree` include:

`-p` displays PIDs along with process names

`-u` displays process owners' user name

`-G` makes the display prettier by using terminal graphics characters—whether this is in fact an improvement depends on your terminal

You can also obtain an approximated tree structure using "`ps --forest`". The tree structure is part of the `COMMAND` column in the output.

13.5 Controlling Processes—`kill` and `killall`

signals

The `kill` command sends **signals** to selected processes. The desired signal can be specified either numerically or by name; you must also pass the process number in question, which you can find out using `ps`:

```
$ kill -15 4711          Send signal SIGTERM to process 4711
$ kill -TERM 4711                                Same thing
$ kill -SIGTERM 4711                        Same thing again
$ kill -s TERM 4711                         Same thing again
$ kill -s SIGTERM 4711                      Same thing again
$ kill -s 15 4711                              Guess what
```

Here are the most important signals with their numbers and meaning:

`SIGHUP` (1, "hang up") causes the shell to terminate all of its child processes that use the same controlling terminal as itself. For background processes without a controlling terminal, this is frequently used to cause them to re-read their configuration files (see below).

`SIGINT` (2, "interrupt") Interrupts the process; equivalent to the Ctrl+c key combination.

`SIGKILL` (9, "kill") Terminates the process and cannot be ignored; the "emergency brake".

`SIGTERM` (15, "terminate") Default for `kill` and `killall`; terminates the process.

`SIGCONT` (18, "continue") Lets a process that was stopped using `SIGSTOP` continue.

`SIGSTOP` (19, "stop") Stops a process temporarily.

`SIGTSTP` (20, "terminal stop") Equivalent to the Ctrl+z key combination.

You shouldn't get hung up on the signal numbers, which are not all guaranteed to be the same on all Unix versions (or even Linux platforms). You're usually safe as far as 1, 9, or 15 are concerned, but for everything else you should rather be using the names.

Unless otherwise specified, the signal SIGTERM ("terminate") will be sent, which (usually) ends the process. Programs can be written such that they "trap" signals (handle them internally) or ignore them altogether. Signals that a process neither traps nor ignores usually cause it to crash hard. Some (few) signals are ignored by default.

The SIGKILL and SIGSTOP signals are not handled by the process but by the kernel and hence cannot be trapped or ignored. SIGKILL terminates a process without giving it a chance to object (as SIGTERM would), and SIGSTOP stops the process such that it is no longer given CPU time.

kill does not always stop processes. Background processes which provide system services without a controlling terminal—daemons—usually reread their configuration files without a restart if they are sent SIGHUP ("hang up"). daemons

You can apply kill, like many other Linux commands, only to processes that you actually own. Only root is not subject to this restriction.

Sometimes a process will not even react to SIGKILL. The reason for this is either that it is a zombie (which is already dead and cannot be killed again) or else blocked in a system call. The latter situation occurs, for example, if a process waits for a write or read operation on a slow device to finish.

An alternative to the kill command is the killall command. killall acts just like kill—it sends a signal to the process. The difference is that the process must be named instead of addressed by its PID, and that all processes of the same name are signalled. If no signal is specified, it sends SIGTERM by default (like kill). killall outputs a warning if there was nothing to signal to under the specified name. killall

The most important options for killall include:

-i killall will query you whether it is actually supposed to signal the process in question.

-l outputs a list of all available signals.

-w waits whether the process that was signalled actually terminates. killall checks every second whether the process still exists, and only terminates once it is gone.

Be careful with killall if you get to use Solaris or BSD every now and then. On these systems, the command does exactly what its name suggests—it kills *all* processes.

Exercises

13.7 [2] Which signals are being ignored by default? (*Hint:* signal(7))

13.6 pgrep and pkill

As useful as ps and kill are, as difficult can it be sometimes to identify exactly the right processes of interest. Of course you can look through the output of ps using grep, but to make this "foolproof" and without allowing too many false positives is at least inconvenient, if not tricky. Nicely enough, Kjetil Torgrim Homme has taken this burden off us and developed the pgrep program, which enables us to search the process list conveniently. A command like

```
$ pgrep -u root sshd
```

will, for example, list the PIDs of all sshd processes belonging to root.

By default, pgrep restricts itself to outputting PIDs. Use the -l option to get it to show the command name, too. With -a it will list the full command line.

The -d option allows you to specify a separator (the default is "\n"):

```
$ pgrep -d, -u hugo bash
4261,11043,11601,12289
```

You can obtain more detailed information on the processes by feeding the PIDs to `ps`:

```
$ ps up $(pgrep -d, -u hugo bash)
```

(The `p` option lets you give `ps` a comma-separated list of PIDs of interest.)

`pgrep`'s parameter is really an (extended) regular expression (consider `egrep`) which is used to examine the process names. Hence something like

```
$ pgrep '^([bd]a|t?c|k|z|)sh$'
```

will look for the common shells.

Normally `pgrep` considers only the process name (the first 15 characters of the process name, to be exact). Use the `-f` option to search the whole command line.

You can add search criteria by means of options. Here is a small selection:

`-G` Consider only processes belonging to the given group(s). (Groups can be specified using names or GIDs.)

`-n` Only display the newest (most recently started) of the found processes.

`-o` Only display the oldest (least recently started) of the found processes.

`-P` Consider only processes whose parent processes have one of the given PIDs.

`-t` Consider only processes whose controlling terminal is listed. (Terminal names should be given without the leading "`/dev/`".)

`-u` Consider only processes with the given (effective) UIDs.

If you specify search criteria but no regular expression for the process name, all processes matching the search criteria will be listed. If you omit both you will get an error message.

The `pkill` command behaves like `pgrep`, except that it does not list the found processes' PIDs but sends them a signal directly (by default, `SIGTERM`). As in `kill` you can specify another signal:

```
# pkill -HUP syslogd
```

The `--signal` option would also work:

```
# pkill --signal HUP syslogd
```

The advantage of `pkill` compared to `killall` is that `pkill` can be much more specific.

Exercises

13.8 [!1] Use `pgrep` to determine the PIDs of all processes belonging to user `hugo`. (If you don't have a user `hugo`, then specify some other user instead.)

13.9 [2] Use two separate terminal windows (or text consoles) to start one "`sleep 60`" command each. Use `pkill` to terminate (a) the first command started, (b) the second command started, (c) the command started in one of the two terminal windows.

13.7 Process Priorities—nice and renice

In a multi-tasking operating system such as Linux, CPU time must be shared among various processes. This is the scheduler's job. There is normally more than one runnable process, and the scheduler must allot CPU time to runnable processes according to certain rules. The deciding factor for this is the **priority** of a process. The priority of a process changes dynamically according to its prior behaviour—"interactive" processes, i. e, ones that do I/O, are favoured over those that just consume CPU time. priority

As a user (or administrator) you cannot set process priorities directly. You can merely ask the kernel to prefer or penalise processes. The "nice value" quantifies the degree of favouritism exhibited towards a process, and is passed along to child processes.

A new process's nice value can be specified with the `nice` command. Its syntax is nice

```
nice [-⟨nice value⟩] ⟨command⟩ ⟨parameter⟩ …
```

(`nice` is used as a "prefix" for another command).

The possible nice values are numbers between −20 and +19. A negative nice value increases the priority, a positive value decreases it (the higher the value, the "nicer" you are towards the system's other users by giving your own processes a lower priority). If no nice value is specified, the default value of +10 is assumed. Only `root` may start processes with a negative nice value (negative nice value are not generally nice for other users). possible nice values

The priority of a running process can be influenced using the `renice` command. You call `renice` with the desired new nice value and the PID (or PIDs) of the process(es) in question: renice

```
renice [-⟨nice value⟩] ⟨PID⟩ …
```

Again, only the system administrator may assign arbitrary nice values. Normal users may only increase the nice value of their own processes using `renice`—for example, it is impossible to revert a process started with nice value 5 back to nice value 0, while it is absolutely all right to change its nice value to 10. (Think of a ratchet.)

Exercises

13.10 [2] Try to give a process a higher priority. This may possibly not work—why? Check the process priority using `ps`.

13.8 Further Process Management Commands—nohup and top

When you invoke a command using `nohup`, that command will ignore a `SIGHUP` signal and thus survive the demise of its parent process: Ignoring SIGHUP

```
nohup ⟨command⟩ …
```

The process is not automatically put into the background but must be placed there by appending a `&` to the command line. If the program's standard output is a terminal and the user has not specified anything else, the program's output together with its standard error output will be redirected to the `nohup.out` file. If the current directory is not writable for the user, the file is created in the user's home directory instead.

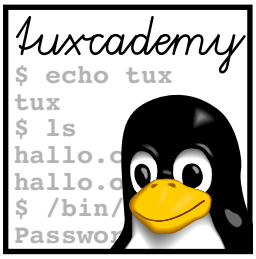
`top` `top` unifies the functions of many process management commands in a single program. It also provides a process table which is constantly being updated. You can interactively execute various operations; an overview is available using h. For example, it is possible to sort the list according to several criteria, send signals to processes (k), or change the nice value of a process (r).

Commands in this Chapter

kill	Terminates a background process	bash(1), kill(1)	196
killall	Sends a signal to all processes matching the given name	killall(1)	197
nice	Starts programs with a different *nice* value	nice(1)	199
nohup	Starts a program such that it is immune to SIGHUP signals	nohup(1)	199
pgrep	Searches processes according to their name or other criteria	pgrep(1)	197
pkill	Signals to processes according to their name or other criteria	pkill(1)	198
ps	Outputs process status information	ps(1)	194
pstree	Outputs the process tree	pstree(1)	195
renice	Changes the *nice* value of running processes	renice(8)	199
top	Screen-oriented tool for process monitoring and control	top(1)	199

Summary

- A process is a program that is being executed.
- Besides a program text and the corresponding data, a process has attributes such as a process number (PID), parent process number (PPID), owner, groups, priority, environment, current directory, …
- All processes derive from the `init` process (PID 1).
- `ps` can be used to query process information.
- The `pstree` command shows the process hierarchy as a tree.
- Processes can be controlled using signals.
- The `kill` and `killall` commands send signals to processes.
- The `nice` and `renice` commands are used to influence process priorities. `ulimit` limits the resource usage of a process.
- `top` is a convenient user interface for process management.



14

Hard Disks (and Other Secondary Storage)

Contents

Goals

- Understanding how Linux deals with secondary storage devices based on ATA, SATA, and SCSI.
- Understanding MBR-based and GPT-based partitioning
- Knowing about Linux partitioning tools and how to use them
- Being able to use loop devices

Prerequisites

- Basic Linux knowledge
- Knowledge about Linux hardware support

14.1 Fundamentals

RAM is fairly cheap these days, but even so not many computers can get by without the permanent storage of programs and data on mass storage devices. These include (among others):

- Hard disks with rotating magnetic platters
- "Solid-state disks" (SSDs) that look like hard disks from the computer's point of view, but use flash memory internally
- USB thumb drives, SD cards, CF cards, and other interchangeable media based on flash memory
- RAID systems that aggregate hard disks and present them as one big storage medium
- SAN devices which provide "virtual" disk drives on the network
- File servers that offer file access at an abstract level (CIFS, NFS, …)

In this chapter we shall explain the basics of Linux support for the first three entries in the list—hard disks, SSDs and flash-based portable media like USB thumb drives. RAID sstems and SAN are discussed in the Linup Front training manual, *Linux Storage and File Systems*, file servers are discussed in *Linux Infrastructure Services*.

14.2 Bus Systems for Mass Storage

IDE, ATA and SATA Until not so long ago, hard disks and optical drives such as CD-ROM and DVD readers and writers used to be connected via a "IDE controller", of which self-respecting PCs had at least two (with two "channels" each).

IDE

"IDE" is really an abbreviation of "Integrated Drive Electronics". The "integrated drive electronics" alluded to here lets the computer see the disk as a sequence of numbered blocks without having to know anything about sectors, cylinders, and read/write heads, even though this elaborate charade is still kept up between the BIOS, disk controller, and disks. However, for a long time this description has applied to *all* hard disks, not just those with the well-known "IDE" interface, which by now is officially called "ATA", short for "AT Attachment"[1].

Computers bought new these days usually still contain IDE interfaces, but the method of choice to connect hard disks and optical drives today is a serial version of the ATA standard, imaginatively named "Serial ATA" (SATA, for short). Since SATA (i. e., approximately 2003), traditional ATA (or "IDE") is commonly called "P-ATA", an abbreviation of "parallel ATA". The difference applies to the cable, which for traditional ATA is an inconvenient-to-place and electrically not 100% fortunate 40- or 80-lead ribbon cable which can transfer 16 data bits in parallel, and which links several devices at once to the controller. SATA, on the other hand, utilises narrow flat seven-lead cables for serial transmission, one per device (usually produced in a cheerful orange colour).

Serial ATA

SATA cables and connectors are much more sensitive mechanically than the corresponding P-ATA hardware, but they make up for that through other advantages: They are less of an impediment to air flow in a PC case, cannot be installed wrongly due to their different connectors on each end, which furthermore cannot be plugged in the wrong way round. In addition, the illogical separation between 2.5-inch and 3.5-inch diskdrives, which required different connectors for P-ATA, goes away.

[1] Anyone remember the IBM PC/AT?


Interestingly, serial ATA allows considerably faster data transfers than traditional ATA, even though with the former all bits are transferred in "single file" rather than 16 at a go in parallel. This is due to the electrical properties of the interface, which uses differential transmission and a signalling voltage of only 0.5 V instead of 5 V. (This is why cables may be longer, too—1 m instead of formerly 45 cm.) Current SATA interfaces can theoretically transfer up to 16 GiBit/s (SATA 3.2) which due to encoding and other impediments comes out as approximately 2 MiB/s—rather more than single disk drives can keep up with at sustained rates, but useful for RAID systems that access multiple disk drives at the same time, and for fast SSDs. It is unlikely that SATA speeds will evolve further, since the trend with SSDs is towards connecting them directly via PCIe[2].


Besides the higher speed and more convenient cabling, SATA also offers the advantage of "hot-swapping": It is possible to disconnect a SATA disk drive and connect another one in its place, without having to shut down the computer. This of course presupposes that the computer can do without the data on the drive in question—typically because it is part of a RAID-1 or RAID-5, where the the data on the new drive can be reconstructed based on other drives in the system. With traditional ATA, this was impossible (or only possible by jumping through hoops).


External SATA ("eSATA") is a derivative of SATA for use with external drives. It has different connectors and electrical specifications, which are much more robust mechanically and better suited for hot-swapping. In the meantime, it has been almost completely ousted from the market by USB 3.*x*, but can still be found in older hardware.

eSATA

SCSI and SAS The "Small Computer System Interface" or SCSI (customary pronunciation: "SCUZ-zy") has served for more than 25 years to connect hard disks, tape drives and other mass storage devices, but also peripherals such as scanners, to "small" computers[3]. SCSI buses and connectors exist in a confusing variety, beginning with the "traditional" 8-bit bus and ranging from the fast 16-bit varieties to new, even faster serial implementations (see below). They also differ in the maximum number of devices per bus, and in physical parameters such as the maximum cable length and the allowable distances between devices on the cable. Nicely enough, most of the variants are compatible or can be made compatible (possibly with loss of efficiency!). Varieties such as *FireWire* (IEEE-1394) or *FiberChannel* are treated like SCSI by Linux.


Nowadays, most work goes into the serial SCSI implementations, most notably "Serial Attached SCSI" (SAS). As with SATA, data transfer is potentially faster (at the moment, SAS is slightly slower than the fastest parallel SCSI version, Ultra-640 SCSI) and electrically much less intricate. In particular, the fast parallel SCSI versions are plagued by clocking problems that derive from the electrical properties of the cables and termination, and that do not exist with SAS (where the pesky termination is no longer necessary at all).


SAS and SATA are fairly closely related; the most notable differences are that SAS allows things like accessing a drive via several cable paths for redundancy ("multipath I/O"; SATA requires jumping through hoops for this), supports more extensive diagnosis and logging functions, and is based on a higher signalling voltage, which allows for longer cables (up to 8 m) and physically larger servers.

[2]SATA in a strict sense allows speeds up to 6 GiBit/s; the higher speed of SATA 3.2 is already achieved by means of PCIe. This "SATA Express" specification defines an interface that can carry SATA signals as well as PCIe, such that compatible devices can be connected not only to SATA Express controllers, but also to older hosts which support "only" SATA with up to 6 GiBit/s.

[3]Nobody has ever defined the meaning of "small" in this context, but it must be something like "can be bodily lifted by at most two people"

Table 14.1: Different SCSI variants

Name	Width	Transfer rate	Devices	Explanation
SCSI-1	8 bit	$\leqslant$ 5 MiB/s	8	"Ancestor"
SCSI-2 »Fast«	8 bit	10 MiB/s	8	
SCSI-2 »Wide«	16 bit	20 MiB/s	16	
SCSI-3 »Ultra«	8 bit	20 MiB/s	8	
SCSI-3 »Ultrawide«	16 bit	40 MiB/s	16	
Ultra2 SCSI	16 bit	80 MiB/s	16	LVD bus[a]
Ultra-160 SCSI[b]	16 bit	160 MiB/s	16	LVD bus
Ultra-320 SCSI[c]	16 Bit	320 MiB/s	16	LVD bus
Ultra-640 SCSI	16 Bit	640 MiB/s	16	LVD bus

SATA and SAS are compatible to an extent where you can use SATA disk drives on a SAS backplane (but not vice-versa).

Vorkommen

"Pure-bred" SCSI, as far as PCs are concerned, is found mostly in servers; work stations and "consumer PCs" tend to use IDE or SATA for mass storage and USB for other devices. Devices based on IDE and USB are much cheaper to manufacture than SCSI-based devices—IDE disks, for example, cost about a third or a fourth of the price of comparatively large SCSI disks.

We do need to mention that SCSI disks are usually designed especially for use in servers, and are therefore optimised for high speed and longevity. SATA disks for workplace PCs do not come with the same warranties, are not supposed to rival a jet fighter for noise, and should support fairly frequent starting and stopping.

As a Linux administrator, you should know about SCSI even if you do not run any SCSI-based systems, since from the point of view of the Linux kernel, in addition to SATA many USB or FireWire devices are accessed like SCSI devices and use the same infrastrucure.

SCSI ID

Every device on a SCSI bus requires a unique "SCSI ID". This number between 0 and 7 (15 on the wide buses) is used to address the device. Most "true" SCSI devices sport jumpers or a switch to select it; with Fibre-Channel, USB, or SATA devices that are accessed via the SCSI infrastructure, the system arranges for suitable unique SCSI IDs to be assigned.

host adapter
SCSI BIOS

To use SCSI, a PC needs at least one host adapter (or "host"). Motherboard-based and better expansion card host adapters contain a SCSI BIOS which lets the system boot from a SCSI device. You can also use this to check which SCSI IDs are available and which are used, and which SCSI device, if any, should be used for booting.

The host adapter counts as a device on the SCSI bus—apart from itself you can connect 7 (or 15) other devices.

boot order

If your BIOS can boot from SCSI devices, you can also select in the boot order whether the ATA disk `C:` should be preferred to any (potentially) bootable SCSI devices.

termination

Most important for the correct function of a parallel SCSI system is appropriate **termination** of the SCSI bus. This can either be ensured via a special plug ("terminator") or switched on or off on individual devices. Erroneous termination is the possible origin of all sorts of SCSI problems. If you do experience difficulties with SCSI, always check first that termination is in order. SAS does not require termination.

USB With the new fast USB variants, few if any compromises will be needed when connecting mass storage devices—reading and writing speeds are bounded by the storage device, not (as with USB 1.1 and USB 2.0) by the bus. Linux manages USB-based storage devices exactly like SCSI devices.

Exercises

14.1 [1] How many hard disks or SSDs does your computer contain? What is their capacity? How are they connected to the computer (SATA, …)?

14.3 Partitioning

14.3.1 Fundamentals

Mass storage devices such as hard disks or SSDs are commonly "partitioned", i. e., subdivided into several logical storage devices that the operating system can then access independently. This does not only make it easier to use data structures that are appropriate to the intended use—sometimes partitioning is the only way to make a very large storage medium fully accessible, if limits within the operating system preclude the use of the medium "as a whole" (even though this sort of problem tends to be rare today).

Advantages of partitioning include the following:

- Logically separate parts of the system may be separated. For example, you could put your users' data on a different partition from that used by the operating system itself. This makes it possible to reinstall the operating system from scratch without endangering your users' data. Given the often rudimentary "upgrade" functionality of even current distributions this is very important. Furthermore, if inconsistencies occur in a file system then only one partition may be impacted at first.

- The structure of the file system may be adapted to the data to be stored. Most file systems keep track of data by means of fixed-size "blocks", where every file, no matter how small, occupies at least a single block. With a 4 KiB block size this implies that a 500-byte file only occupies 1/8 of its block—the rest goes to waste. If you know that a directory will contain mostly small files (cue: mail server), it may make sense to put this directory on a partition using smaller blocks (1 or 2 KiB). This can reduce waste considerably. Some database servers, on the other hand, like to work on "raw" partitions (without any file system) that they manage themselves. An operating system must make that possible, too.

- "Runaway" processes or incautious users can use up all the space available on a file system. At least on important server systems it makes sense to allow user data (including print jobs, unread e-mail, etc.) only on partitions that may get filled up without getting the system itself in trouble, e.g., by making it impossible to append information to important log files.

There are currently two competing methods to partition hard disks for PCs. The traditional method goes back to the 1980s when the first hard disks (with awesome sizes like 5 or 10 MB) appeared. Recently a more modern method was introduced; this does away with various limitations of the traditional approach, but in some cases requires special tools.

Hard disks are virtually always partitioned, even though at times only one partition will be created. With USB thumb drives, one sometimes eschews partitioning altogether.

Table 14.2: Partition types for Linux (hexadecimal)

Type	Description
81	Linux data
82	Linux swap space
86	RAID super block (old style)
8E	Linux LVM
E8	LUKS (encrypted partition)
EE	"Protective partition" for GPT-partitioned disk
FD	RAID super block with autodetection
FE	Linux LVM (old style)

14.3.2 The Traditional Method (MBR)

The traditional method stores partitioning information inside the "master boot record" (MBR), the first sector (number 0) of a hard disk. (Traditionally, PC hard disk sectors are 512 bytes long, but see below.) The space there—64 bytes starting at offset 446—is sufficient for four **primary partitions**. If you want to create more than four partitions, you must use one of these primary partitions as an **extended partition**. An extended partition may contain further **logical partitions**.

primary partitions
extended partition
logical partitions

The details about logical partitions are not stored inside the MBR, but at the start of the partition (extended or logical) in question, i. e., they are scattered around the hard disk.

Partition entries today usually store the starting sector number of the partition on the disk as well as the length of the partition in question in sectors[4]. Since these values are 32-bit numbers, given the common 512-byte sectors this results in a maximum partition size of 2 TiB.

There are hard disks available today which are larger than 2 TiB. Such disks cannot be made fully accessible using MBR partitioning. One common ruse consists in using disks whose sectors are 4096 bytes long instead of 512. This will let you have 16-TiB disks even with MBR, but not every operating system supports such "4Kn" drives (Linux from kernel 2.6.31, Windows from 8.1 or Server 2012).

4-KiB sectors are useful on hard disks even without considering partitions. The larger sectors are more efficient for storing larger files and allow better error correction. Therefore the market offers "512e" disks which use 4-KiB sectors internally but pretend to the outside that they really have 512-byte sectors. This means that if a single 512-byte sector needs to be rewritten, the adjoining 7 sectors must be read and also rewritten (a certain, but usually bearable, loss of efficiency, since data is most often written in larger chunks). When partitioning, you will have to pay attention that the 4-KiB blocks that Linux uses internally for hard disk access coincide with the disk's internal 4-KiB sectors—if that is not the case, then to write one 4-KiB Linux block *two* 4-KiB disk sectors might have to be read *and* rewritten, and that would not be good. (Fortunately, the partitioning tools help you watch out for this.)

partition type

Besides the starting address and length of the (primary) partitions, the partition table contains a partition type which loosely describe the type of data management structure that might appear on the partition. A selection of Linux partition types appears in Table 14.2.

[4] In former times, partitions used to be described in terms of the cylinder, head, and sector addresses of the sectors in question, but this has been deprecated for a very long time.

14.3.3 The Modern Method (GPT)

In the late 1990s, Intel developed a new partitioning method that should do away with the limitations of the MBR approach, namely "GUID Partition Table" or GPT.

GPT was developed hand-in-hand with UEFI and is part of the UEFI specification today. You can, however, use a BIOS-based Linux system to access GPT-partitioned disks and vice-versa.

GPT uses 64-bit sector addresses and thus allows a maximum disk size of 8 ZiB—zebibyte, in case you haven't run into that prefix. 1 ZiB are 2^{70} bytes, or, roughly speaking, about one million million tebibytes. This should last even the NSA for a while. (Disk manufactures, who prefer to talk powers of ten rather than powers of two, will naturally sell you an 8-ZiB disk as a 9.4 zettabyte disk.)

With GPT, the first sector of the disk remains reserved as a "protective MBR" which designates the whole disk as partitioned from a MBR point of view. This avoids problems if a GPT-partitioned disk is connected to a computer that can't handle GPT.

The second sector (address 1) contains the "GPT header" which stores management information for the whole disk. Partitioning information is usually contained in the third and subsequent sectors.

The GPT header points to the partitioning information, and therefore they could be stored anywhere on the disk. It is, however, reasonable to place them immediately after the GPT header. The UEFI header stipulates a minimum of 16 KiB for partitioning information (regardless of the disk's sector size).

On a disk with 512-byte sectors, with a 16 KiB space for partitioning information the first otherwise usable sector on the disk is the one at address 34. You should, however, avoid placing the disk's first partition at that address because that will get you in trouble with 512e disks. The next correctly-aligned sector is the one at address 40.

For safety reasons, GPT replicates the partitioning information at the end of the disk.

Traditionally, partition boundaries are placed at the start of a new "track" on the disk. Tracks, of course, are a relic from the hard disk paleolithic, since contemporary disks are addressed linearly (in other words, the sectors are numbered consecutively from the start of the disk to the end)—but the idea of describing a disk by means of a combination of a number of read/write heads, a number of "cylinders", and a number of sectors per "track" (a track is the concentric circle a single head describes on a given cylinder) has continued to be used for a remarkably long time. Since the maximum number of sectors per track is 63, this means that the first partition would start at block 63, and that is, of course, disastrous for 512e disks.

Since Windows Vista it is common to have the first partition start 1 MiB after the start of the disk (with 512-byte sectors, at sector 2048). This isn't a bad idea for Linux, either, since the ample free space between the partition table and the first partition can be used to store the GRUB boot loader. (The space between the MBR and sector 63 was quite sufficient earlier, too.)

Partition table entries are at least 128 bytes long and, apart from 16-byte GUIDs for the partition type and the partition itself and 8 bytes each for a starting and ending block number, contains 8 bytes for "attributes" and 72 bytes for a partition name. It is debatable whether 16-byte GUIDs are required for partition types, but on the one hand the scheme is called "GUID partition table" after all, and on the other hand this ensures that we won't run out of partition types anytime soon. A selection is displayed in Table 14.3.

GUID	Description
00000000-0000-0000-0000-000000000000	Unused entry
C12A7328-F81F-11D2-BA4B-00A0C93EC93B	EFI system partition (ESP)
21686148-6449-6E6F-744E-656564454649	BIOS boot partition
0FC63DAF-8483-4772-8E79-3D69D8477DE4	Linux file system
A19D880F-05FC-4D3B-A006-743F0F84911E	Linux RAID partition
0657FD6D-A4AB-43C4-84E5-0933C84B4F4F	Linux swap space
E6D6D379-F507-44C2-A23C-238F2A3DF928	Linux LVM
933AC7E1-2EB4-4F13-B844-0E14E2AEF915	/home partition
3B8F8425-20E0-4F3B-907F-1A25A76F98E8	/srv partition
7FFEC5C9-2D00-49B7-8941-3EA10A5586B7	dm-crypt partition
CA7D7CCB-63ED-4C53-861C-1742536059CC	LUKS partition

Table 14.3: Partition type GUIDs for GPT (excerpt)

Linux can use GPT-partitioned media. This needs the "EFI GUID Partition support" option enabled in the kernel, but with current distributions this is the case. Whether the installation procedure allows you to create GPT-partitioned disks is a different question, just like the question of whether the boot loader will be able to deal with them. But that is neither here nor there.

14.4 Linux and Mass Storage

If a mass storage device is connected to a Linux computer, the Linux kernel tries to locate any partitions. It then creates block-oriented device files in /dev for the device itself and its partitions. You can subsequently access the partitions' device files and make the directory hierarchies there available as part of the computer's file system.

A new mass storage device may have no partitions at all. In this case you can use suitable tools to create partitions. This will be explained later in this chapter. The next step after partitioning consists of generating file systems on the partitions. This is explained in detail in Chapter 15.

The device names for mass storage are usually /dev/sda, /dev/sdb, …, in the order the devices are recognised. Partitions are numbered, the /dev/sda device therefore contains partitions like /dev7sda1, /dev/sda2, … A maximum of 15 partitions per device is possible. If /dev/sda is partitioned according to the MBR scheme, /dev/sda1 to /dev/sda4 correspond to the primary partitions (possibly including an extended partition), while any logical partitions are numbered starting with /dev/sda5 (regardless of whether there are four primary partitions on the disk or fewer).

The "s" in /dev/sda derives from "SCSI". Today, almost all mass storage devices in Linux are managed as SCSI devices.

For P-ATA disks there is another, more specific mechanism. This accesses the IDE controllers inside the computer directly—the two drives connected to the first controller are called /dev/hda and /dev/hdb, the ones connected to the second /dev/hdc and /dev/hdd. (These names are used independently of whether the drives actually exist or not—if you have a single hard disk and a CD-ROM drive on your system, you do well to connect the one to one controller and the other to the other so they will not be in each other's way. Therefore you will have /dev/hda for the disk and /dev/hdc for the CD-ROM drive.) Partitions on P-ATA disks are, again, called /dev/hda1, /dev/hda2 and so on. In this scheme, 63 (!) partitions are allowed.


If you still use a computer with P-ATA disks, you will notice that in the vast majority of cases the SCSI infrastructure is used for those, too (note the `/dev/sda` style device names). This is useful for convenience and consistency. Some very few P-ATA controllers are not supported by the SCSI infrastructure, and must use the old P-ATA specific infrastructure.


The migration of an existing Linux system from "traditional" P-ATA drivers to the SCSI infrastructure should be well-considered and involve changing the configuration in `/etc/fstab` such that file systems are not mounted via their device files but via volume labels or UUIDs that are independent of the partitions' device file names. (See Section 15.2.3.)

The Linux kernel's mass storage subsystem uses a three-tier architecture. At the bottom there are drivers for the individual SCSI host adapters, SATA or USB controllers and so on, then there is a generic "middle layer", on top of which there are drivers for the various devices (disks, tape drives, …) that you might encounter on a SCSI bus. This includes a "generic" driver which is used to access devices without a specialised driver such as scanners or CD-ROM recorders. (If you can still find any of those anywhere.)

architecture


Every SCSI host adapter supports one or more buses ("channels"). Up to 7 (or 15) other devices can be connected to each bus, and every device can support several "local unit numbers" (or LUNs), such as the individual CDs in a CD-ROM changer (rarely used). Every SCSI device in the system can thus be describe by a quadrupel (⟨*host*⟩, ⟨*channel*⟩, ⟨*ID*⟩, ⟨*LUN*⟩). Usually (⟨*host*⟩, ⟨*channel*⟩, ⟨*ID*⟩) are sufficient.

LUNs


In former times you could find information on SCSI devices within the `/proc/scsi/scsi` directory. This is no longer available on current systems unless the kernel was compiled using "Legacy `/proc/scsi` support".


Nowadays, information about "SCSI controllers" is available in `/sys/class/scsi_host` (one directory per controller). This is unfortunately not quite as accessible as it used to be. You can still snoop around:

```
# cd /sys/class/scsi_host/host0/device
# ls
power  scsi_host  subsystem  target0:0:0  uevent
# cd target0:0:0; ls
0:0:0:0  power  subsystem  uevent
# ls 0:0:0:0/block
sda
```

A peek into `/sys/bus/scsi/devices` will also be instructive:

```
# ls /sys/bus/scsi/devices
0:0:0:0  10:0:0:0  host1   host2  host4  target0:0:0  target10:0:0
1:0:0:0  host0     host10  host3  host5  target1:0:0
```

Device names such as `/dev/sda`, `/dev/sdb`, etc. have the disadvantage of not being very illuminating. In addition, they are assigned to devices in the order of their appearance. So if today you connect first your MP3 player and then your digital camera, they might be assigned the device files `/dev/sdb` and `/dev/sdc`; if tomorrow you start with the digital camera and continue with the MP3 player, the names might be the other way round. This is of course a nuisance. Fortunately, `udev` assigns some symbolic names on top of the traditional device names. These can be found in `/dev/block`:

```
# ls -l /dev/block/8:0
lrwxrwxrwx 1 root root 6 Jul 12 14:02 /dev/block/8:0 -> ../sda
# ls -l /dev/block/8:1
lrwxrwxrwx 1 root root 6 Jul 12 14:02 /dev/block/8:1 -> ../sda1
# ls -l /dev/disk/by-id/ata-ST9320423AS_5VH5TBTC
lrwxrwxrwx 1 root root 6 Jul 12 14:02 /dev/disk/by-id/▷
 ◁ ata-ST9320423AS_5VH5TBTC -> ../../sda
# ls -l /dev/disk/by-id/ata-ST9320423AS_5VH5TBTC-part1
lrwxrwxrwx 1 root root 6 Jul 12 14:02 /dev/disk/by-id/▷
 ◁ ata-ST9320423AS_5VH5TBTC-part1 -> ../../sda1
# ls -l /dev/disk/by-path/pci-0000:00:1d.0-usb-▷
 ◁ 0:1.4:1.0-scsi-0:0:0:0
lrwxrwxrwx 1 root root 6 Jul 12 14:02 /dev/disk/by-path/▷
 ◁ pci-0000:00:1d.0-usb-0:1.4:1.0-scsi-0:0:0:0  -> ../../sdb
# ls -l /dev/disk/by-uuid/c59fbbac-9838-4f3c-830d-b47498d1cd77
lrwxrwxrwx 1 root root 10 Jul 12 14:02 /dev/disk/by-uuid/▷
 ◁ c59fbbac-9838-4f3c-830d-b47498d1cd77 -> ../../sda1
# ls -l /dev/disk/by-label/root
lrwxrwxrwx 1 root root 10 Jul 12 14:02 /dev/disk/by-label/root ◁
▷ -> ../../sda1
```

These device names are derived from data such as the (unique) serial number of the disk drive, its position on the PCIe bus, or the UUID or name of the file system, and are independent of the name of the actual device file.

Exercises

14.2 [!2] On your ssytem there are two SATA hard disks. The first disk has two primary and two logical partitions. The second disk has one primary and three logical partitions. Which are the device names for these partitions on Linux?

14.3 [!1] Examine the `/dev` directory on your system. Which storage media are available and what are the corresponding device files called? (Also check `/dev/block` and `/dev/disk`.)

14.4 [1] Plug a USB thumb drive into your computer. Check whether new device files have been added to `/dev`. If so, which ones?

14.5 Partitioning Disks

14.5.1 Fundamentals

Before you partition the (possibly sole) disk on a Linux system, you should briefly consider what a suitable partitioning scheme might look like and how big the partitions ought to be. Changes after the fact are tedious and inconvenient at best and may at worst necessitate a complete re-install of the system (which would be exceedingly tedious and inconvenient). (See Section 14.7 for an alternative, much less painful approach.)

Here are a few basic suggestions for partitioning:

- Apart from the partition with the root directory `/`, you should provide at least one spearate partition for the file system containing the `/home` directory. This lets you cleanly separate the operating system from your own data, and facilitates distribution upgrades or even switching from one Linux distribution to a completely different one.


If you follow this approach, you should probably also use symbolic links to move the `/usr/local` and `/opt` directories to (for example) `/home/usr-local` and `/home/opt`. This way, these directories, which also contain data provided by you, are on "your" partition and can more easily be included in regular backups.

- It is absolutely possible to fit a basic Linux system into a 2 GiB partition, but, considering today's (low) costs per gigabyte for hard disk storage, there is little point in scrimping and saving. With something like 30 GiB, you're sure to be on the safe side and will have enough room for log files, downloaded distribution packages during a larger update, and so on.

- On server systems, it may make sense to provide separate partitions for `/tmp`, `/var`, and possibly `/srv`. The general idea is that arbitrary users can put data into these directories (besides outright files, this could include unread or unsent e-mail, queued print jobs, and so on). If these directories are on separate partitions, users cannot fill up the system in general and thereby create problems.

- You should provide swap space of approximately the same size as the computer's RAM, up to a maximum of 8 GiB or thereabouts. Much more is pointless, but on workstations and mobile computers you may want to avail yourself of the possibility to "suspend" your computer instead of shutting it down, in order to speed up a restart and end up exactly where you were before—and the infrastructures enabling this like to use the swap space to save the RAM content.

  
  There used to be a rule of thumb saying that the swap space should be about twice or three times the available RAM size. This rule of thumb comes from traditional Unix systems, where RAM works as "cache" for the swap space. Linux doesn't work that way, instead RAM and swap space are added—on a computer with 4 GiB of RAM and 2 GiB of swap space, you get to run processes to the tune of 6 GiB or so. With 8 GiB of RAM, providing 16 to 24 GiB of swap space would be absurd.

  
  You should dimension the RAM of a computer (especially a server) to be big enough that practically no swap space is necessary during normal operations.; on an 8-GiB server, you won't usually need 16 GiB of swap space, but a gigabyte or two to be on the safe side will certainly not hurt (especially considering today's prices for disk storage). That way, if RAM gets tight, the computer will slow down before processes crash outright because they cannot get memory from the operating system.

- If you have several (physical) hard disks, it can be useful to spread the system across the available disks in order to increase the access speeed to individual components.

  
  Traditionally, one would place the root file system (`/` with the essential subdirectories `/bin`, `/lib`, `/etc`, and so on) on one disk and the `/usr` directory with its subdirectories on a separate file system on another disk. However, the trend on Linux is decisively away from the (artificial) separation between `/bin` and `/usr/bin` or `/lib` and `/usr/lib` and towards a root file system which is created as a RAM disk on boot. Whether the traditional separation of `/` and `/usr` will gain us a lot in the future is up for debate.

  
  What will certainly pay off is to spread swap space across several disks. Linux always uses the least-used disk for swapping.

Provided that there is enough empty space on the medium, new partitions can be created and included (even while the system is running). This procedure consists of the following steps:

1. Backup the current boot sectors and data on the hard disk in question
2. Partition the disk using `fdisk` (or a similar program)
3. Possibly create file systems on the new partitions ("formatting")
4. Making the new file systems accessible using `mount` or `/etc/fstab`


Items 3 and 4 on this list will be considered in more detail in Chapter 15.

Data and boot-sector contents can be saved using the `dd` program (among others).

```
# dd if=/dev/sda of=/dev/st0
```

will, for example, save all of the `sda` hard disk to magnetic tape.

You should be aware that the partitioning of a storage medium has nothing to do with the data stored on it. The partition table simply specifies where on the disk the Linux kernel can find the partitions and hence the file structures. Once the Linux kernel has located a partition, the content of the partition table is irrelevant until it searches again, possibly during the next system boot. This gives you—if you are courageous (or foolhardy)—far-reaching opportunities to tweak your system while it is running. For example, you can by all means enlarge partitions (if after the end of the partition there is unused space or a partition whose contents you can do without) or make them smaller (and possibly place another partition in the space thus freed up). As long as you exercise appropriate care this will be reasonably safe.


This should of course in no way discourage you from making appropriate backup copies before doing this kind of open-heart surgery.


In addition, the file systems on the disks must play along with such shenanigans (many Linux file systems can be enlarged without loss of data, and some of them even be made smaller), or you must be prepared to move the data out of the way, generate a new file system, and then fetch the data back.

14.5.2 Partitioning Disks Using `fdisk`

`fdisk` `fdisk` is an interactive program for manipulating disk partition tables. It can also create "foreign" partition types such as DOS partitions. Drives are addressed using the corresponding device files (such as `/dev/sda` for the first disk).


`fdisk` confines itself to entering a partition into the partition table and setting the correct partition type. If you create a DOS or NTFS partition using `fdisk`, this means just that the partition exists in the partition table, not that you can boot DOS or Windows NT now and write files to that partition. Before doing that, you must create a file system, i. e., write the appropriate management data structures to the disk. Using Linux-based tools you can do this for many but not all non-Linux file systems.

After invoking "`fdisk` ⟨*device*⟩", the program comes back with a succinct prompt of

Neue (leere) Platte

```
# fdisk /dev/sdb
Welcome to fdisk (util-linux 2.25.2).
Changes will remain in memory only, until you decide to write them.
Be careful before using the write command.

Device does not contain a recognized partition table.
```

```
Created a new DOS disklabel with disk identifier 0x68d97339.

Command (m for help): _
```

The m command will display a list of the available commands.

`fdisk` lets you partition hard disks according to the MBR or GPT schemes. It recognises an existing partition table and adjusts itself accordingly. On an empty (unpartitioned) disk `fdisk` will by default create an MBR partition table, but you can change this afterwards (we'll show you how in a little while).

You can create a new partition using the "`n`" command:

```
Command (m for help): n
Partition type
   p   primary (0 primary, 0 extended, 4 free)
   e   extended (container for logical partitions)
Select (default p): p
Partition number (1-4, default 1): 1
First sector (2048-2097151, default 2048): ↩
Last sector, +sectors or +sizeK,M,G,T,P (2048-2097151,▷
 ◁ default 2097151): +500M

Created a new partition 1 of type 'Linux' and of size 500 MiB.

Command (m for help): _
```

The `p` command displays the current partition table. This could look like this:

```
Command (m for help): p
Disk /dev/sdb: 1 GiB, 1073741824 bytes, 2097152 sectors
Units: sectors of 1 * 512 = 512 bytes
Sector size (logical/physical): 512 bytes / 512 bytes
I/O size (minimum/optimal): 512 bytes / 512 bytes
Disklabel type: dos
Disk identifier: 0x68d97339

Device     Boot Start     End Sectors  Size Id Type
/dev/sdb1        2048 1026047 1024000  500M 83 Linux
```

You can change the partition type using the `t` command. You must select the desired partition and can then enter the code (as a hexadecimal number). `L` displays the whole list.

You can delete a partition you no longer want by means of the `d` command. When you're done, you can write the partition table to disk and quit the program using `w`. With `q`, you can quit the program without rewriting the partition table.

After storing the partition table, `fdisk` tries to get the Linux kernel to reread the new partition table; this works well with new or unused disks, but fails if a partition on the disk is currently in use (as a mounted file system, active swap space, …). This lets you repartition the disk with the / file system only with a system reboot. One of the rare occasions when a Linux system needs to be rebooted …

Options

Like all Linux commands, `fdisk` supports a number of command-line options. The most important of those include:

-l displays the partition table of the selected disk and then terminates the program.

-u ("units") lets you select the units of measure used when displaying partition tables. The default is "sectors"; if you specify "`-u=cylinders`", cylinders will be used instead (but there is no good reason for that today).

If you use `fdisk` in MBR mode, it tries to observe the usual conventions and arrange the partitions such that they work properly on 4Kn and 512e hard disks. You should follow the program's suggestions wherever possible, and not deviate from them unless there are very compelling reasons.

If you partition a hard disk according to the GPT standard and there is no GPT-style partition table on the disk yet, you can generate one using the `g` command (*Warning:* A possibly existing MBR partition table will be overwritten in the process):

```
Command (m for help): g
Created a new GPT disklabel (GUID: C2A556FD-7C39-474A-B383-963E09AA7269)
```

(The GUID shown here applies to the disk as a whole.) Afterwards you can use the `n` command to create partitions in the usual way, even if the dialog looks slightly different:

```
Command (m for help): n
Partition number (1-128, default 1): 1
First sector (2048-2097118, default 2048): ↩
Last sector, +sectors or +sizeK,M,G,T,P (2048-2097118, default▷
 ◁ 2097118): +32M

Created a new partition 1 of type 'Linux filesystem' and of size 32 MiB.
```

The partition type selection is different, too, because it is about GUIDs rather than two-digit hexadecimal numbers:

```
Command (m for help): t
Selected partition 1
Partition type (type L to list all types): L
  1 EFI System                     C12A7328-F81F-11D2-BA4B-00A0C93EC93B
◁◁◁◁◁
 14 Linux swap                     0657FD6D-A4AB-43C4-84E5-0933C84B4F4F
 15 Linux filesystem               0FC63DAF-8483-4772-8E79-3D69D8477DE4
 16 Linux server data              3B8F8425-20E0-4F3B-907F-1A25A76F98E8
 17 Linux root (x86)               44479540-F297-41B2-9AF7-D131D5F0458A
 18 Linux root (x86-64)            4F68BCE3-E8CD-4DB1-96E7-FBCAF984B709
◁◁◁◁◁
Partition type (type L to list all types): _
```

Exercises

14.5 [!2] Create an empty 1 GiB file using the

```
# dd if=/dev/zero of=$HOME/test.img bs=1M count=1024
```

command. Use `fdisk` to "partition" the file according to the MBR scheme: Create two Linux partitions of 256 MiB and 512 MiB, respectively, and create a swap space partitions using the balance.

14.6 [!2] Repeat the following exercise, but create a GPT partition table instead. Assume that the 512-MiB partition will contain a `/home` directory.

14.5.3 Formatting Disks using GNU `parted`

Another popular program for partitioning storage media is the GNU project's `parted`. Featurewise, it is roughly comparable with `fdisk`, but it has a few useful features.


Unlike `fdisk`, `parted` does not come pre-installed with most distributions, but can generally be added after the fact from the distribution's servers.

Similar to `fdisk`, `parted` must be started with the name of the medium to be partitioned as a parameter.

```
# parted /dev/sdb
GNU Parted 3.2
Using /dev/sdb
Welcome to GNU Parted! Type 'help' to view a list of commands.
(parted) _
```

You can create a new partition using `mkpart`. This works either interactively …

```
(parted) mkpart
Partition name?  []? Test
File system type?  [ext2]? ext4
Start? 211MB
End? 316MB
```

… or directly when the command is invoked:

```
(parted) mkpart primary ext4 211MB 316MB
```


You can abbreviate the commands down to an unambiguous prefix. Hence, `mkp` will work instead of `mkpart` (`mk` would collide with the `mklabel` command).


The file system type will only be used to guess a partition type. You will still need to manually create a file system on the partition later on.

You can examine the partition table using the `print` command:

```
(parted) p
Model: ATA VBOX HARDDISK (scsi)
Disk /dev/sdb: 1074MB
Sector size (logical/physical): 512B/512B
Partition Table: gpt
Disk Flags:

Number  Start   End    Size   File system  Name     Flags
 1      1049kB  106MB  105MB
 2      106MB   211MB  105MB
 3      211MB   316MB  105MB  ext4         primary

(parted) _
```

(This also shows you where the magic numbers "`211MB`" and "`316MB`" came from, earlier on.)


`print` has a few interesting subcommands: "`print devices`" lists all available block devices, "`print free`" displays free (unallocated) space, and "`print all`" outputs the partition tables of all block devices.

You can get rid of unwanted partitions using `rm`. Use `name` to give a name to a partition (only for GPT). The `quit` command stops the program.

Important: While `fdisk` updates the partition table on the disk only once you leave the program, `parted` does it on an ongoing basis. This means that the addition or removal of a partition takes effect on the disk immediately.

If you use `parted` on a new (unpartitioned) disk, you must first create a partition table.

```
(parted) mklabel gpt
```

creates a GPT-style partition table, and

```
(parted) mklabel msdos
```

one according to the MBR standard. There is no default value; without a partition table, `parted` will refuse to execute the `mkpart` command.

If you inadvertently delete a partition that you would rather have kept, `parted` can help you find it again. You will just need to tell it approximately where on the disk the partition used to be:

```
(parted) rm 3                                                    Oops.
(parted) rescue 200MB 350MB
Information: A ext4 primary partition was found at 211MB -> 316MB.
Do you want to add it to the partition table?

Yes/No/Cancel? yes
```

For this to work, there must be a file system on the partition, because `parted` looks for data blocks that appear to be the start of a file system.

In addition to the interactive mode, `parted` allows you to pass commands immediately on the Linux command line, like this:

```
# parted /dev/sdb mkpart primary ext4 316MB 421MB
Information: You may need to update /etc/fstab.
```

Exercises

14.7 [!2] Repeat Exercise 14.5 using `parted` rather than `fdisk`, for the MBR as well as the GPT scheme.

14.8 [2] (If you have worked through Chapter 15 already.) Generate Linux file systems on the partitions on the "disk" from the earlier exercises. Remove these partitions. Can you restore them using `parted`'s `rescue` command?

14.5.4 `gdisk`

The `gdisk` program specialises in GPT-partitioned disks and can do a few useful things the previously explained programs can't. You may however have to install it specially.

The elementary functions of `gdisk` correspond to those of `fdisk` and `parted`, and we will not reiterate those (read the documentation and do a few experiments). A few features of `gdisk`, however, are of independent interest:

- You can use `gdisk` to convert an MBR-partitioned medium to a GPT-partitioned medium. This presupposes that there is enough space at the start and the end of the medium for GPT partition tables. With media where, according to current conventions, the first partition starts at sector 2048, the former is not a problem, but the latter may be. You will possibly have to ensure that the last 33 sectors on the medium are not assigned to a partition.

For the conversion it is usually sufficient to start gdisk with the device file name of the medium in question as a parameter. You will either receive a warning that no GPT partition table was found and disk used the MPT partition table instead (at this point you can quit the program using w and you're done), or that an intact MBR, but a damaged GPT partition table was found (then you tell gdisk to follow the MBR, and can then quit the program using w and you're done).

- The other direction is also possible. To do this, you must use the r command in gdisk to change to the menu for "recovery/transformation commands", and select the g command there ("convert GPT into MBR and exit"). Afterwards you can quit the program using w and convert the storage medium this way.

Exercises

14.9 [!2] Repeat Exercise 14.5 using gdisk rather than fdisk and generate a GPT partition table.

14.10 [2] Create (e. g., using fdisk) an MBR-partitioned "disk" and use gdisk to convert it to GPT partitioning. Make sure that a correct "protective MBR" was created.

14.5.5 More Partitioning Tools

Most distributions come with alternative ways of partitioning disks. Most of them offer the cfdisk program as an alternative to fdisk. This is screen-oriented and thus somewhat more convenient to use. Even easier to use are graphical programs, such as SUSE's YaST or "DiskDruid" on Red Hat distributions.

distributions

Also worth mentioning is sfdisk, a completely non-interactive partitioning program. sfdisk takes partitioning information from an input file and is therefore useful for unattended partitioning, e. g., as part of an automated installation procedure. Besides, you can use sfdisk to create a backup copy of your partitioning information and either print it as a table or else store it on a disk or CD as a file. If the worst happens, this copy can then be restored using sfdisk.

sfdisk only works for MBR-partitioned disks. There is a corresponding program called sgdisk which does an equivalent job for GPT-partitioned disks. However, sfdisk and sgdisk are not compatible—their option structures are completely different.

14.6 Loop Devices and kpartx

Linux has the useful property of being able to treat files like storage media. This means that if you have a file you can partition it, generate file systems, and generally treat the "partitions" on that file as if they were partitions on a "real" hard disk. In real life, this can be useful if you want to access CD-ROMs or DVDs without having a suitable drive in your computer (it is also faster). For learning purposes, it means that you can perform various experiments without having to obtain extra hard disks or mess with your computer.

A CD-ROM image can be created straightforwardly from an existing CD-ROM using dd:

CD-ROM image

```
# dd if=/dev/cdrom of=cdrom.iso bs=1M
```

You can subsequently make the image directly accessible:

```
# mount -o loop,ro cdrom.iso /mnt
```

In this example, the content of the CD-ROM will appear within the `/mnt` directory.

You can also use the `dd` command to create an empty file:

```
# dd if=/dev/zero of=disk.img bs=1M count=1024
```

That file can then be "partitioned" using one of the common partitioning tools:

```
# fdisk disk.img
```

Before you can do anything with the result, you will have to ensure that there are device files available for the partitions (unlike with "real" storage media, this is not automatic for simulated storage media in files). To do so, you will first need a device file for the file as a whole. This—a so-called "loop device"—can be created using the `losetup` command:

```
# losetup -f disk.img
# losetup -a
/dev/loop0: [2050]:93 (/tmp/disk.img)
```

`losetup` uses device file names of the form "`/dev/loop`*n*". The "`-f`" option makes the program search for the first free name. "`losetup -a`" outputs a list of the currently active loop devices.

Once you have assigned your disk image to a loop device, you can create device files for its partitions. This is done using the `kpartx` command.

You may have to install `kpartx` first. On Debian and Ubuntu, the package is called `kpartx`.

The command to create device files for the partitions on `/dev/loop0` is

```
# kpartx -av /dev/loop0
add map loop0p1 (254:0): 0 20480 linear /dev/loop0 2048
add map loop0p2 (254:1): 0 102400 linear /dev/loop0 22528
```

(without the "`-v`" command, `kpartx` keeps quiet). The device files then appear in the `/dev/mapper` directory:

```
# ls /dev/mapper
control  loop0p1  loop0p2
```

Now nothing prevents you from, e. g., creating file systems on these "partitions" and mounting them into your computer's directory structure. See Chapter 15.

When you no longer need the device files for the partitions, you can remove them again using the

```
# kpartx -dv /dev/loop0
del devmap : loop0p2
del devmap : loop0p1
```

command. An unused loop device can be released using

```
# losetup -d /dev/loop0
```

The

```
# losetup -D
```

command releases all loop devices.

Exercises

14.11 [!2] Use the test "disk" from Exercise 14.5. Assign it a loop device using `losetup` and make its partitions accessible with `kpartx`. Convince yourself that the correct device files show up in `/dev/mapper`. Then release the partitions and the loop device again.

14.7 The Logical Volume Manager (LVM)

Partitioning a disk and creating file systems on it seems like a simple and obvious thing to do. On the other hand, you are committing yourself: The partition scheme of a hard disk can only be changed with great difficulty and, if the disk in question contains the root file system, may even involve the use of a "rescue system". In addition, there is no compelling reason why you should be constrained in your system architecture by trivialities such as the limited capacity of hard disks and the fact that file system can be at most as large as the partitions they are sitting on.

One method to transcend these limitations is the use of the "Logical Volume Manager" (LVM). LVM provides an abstraction layer between disks (and disk partitions) and file systems—instead of creating file systems directly on partitions, you can contribute partitions (or whole disks) to a "pool" of disk space and then allocate space from that pool to create file systems. Single file systems can freely use space which is located on more than one physical disk.

In LVM terminology, disks and disk partitions are considered "physical volumes" (PV) which are made part of a "volume group" (VG). There may be more than one VG on the same computer. The space within a VG is available for creating "logical volumes" (LV), which can then hold arbitrary file systems or swap space.

When creating LVs, you can cause their storage space to be spread deviously across several physical disks ("striping") or multiple copies of their data to be stored in several places within the VG at the same time ("mirroring"). The former is supposed to decrease retrieval time (even if there is a danger of losing data whenever *any* of the disks in the volume group fail), the latter is supposed to reduce the risk of losing data (even if you are paying for this with increased access times). In real life, you will probably prefer to rely on (hardware or software) RAID instead of using LVM's features.

One of the nicer properties of LVM is that LVs can be changed in size while the system is running. If a file system is running out of space, you can first enlarge the underlying LV (as long as your VG has unused space available—otherwise you would first need to install another disk and add it to the VG). Afterwards you can enlarge the file system on the LV in question.

This presumes that the file system in question enables size changes after the fact. With the popular file systems, e. g., `ext3` or `ext4`, this is the case. They even allow their size to be increased while the file system is mounted. (You will need to unmount the file system to reduce the size.)

If you use a file system that does not let itself be enlarged, you will have to bite the bullet, copy the data elsewhere, recreate the file system with the new size, and copy the data back.

If a disk within your VG should start acting up, you can migrate the LVs from that disk to another within the VG (if you still have or can make enough space). After that, you can withdraw the flaky disk from the VG, install a new disk, add that to the VG and migrate the LVs back.

You can do that, too, while the system is running and with your users none the wiser—at least as long as you have invested enough loose change into making your hard disks "hot-swappable".

"snapshots" Also nice are "snapshots", which you can use for backup copies without having to take your system offline for hours (which would otherwise be necessary to ensure that nothing changes while the backup is being performed). You can "freeze" the current state of an LV on another (new) LV—which takes a couple of seconds at most—and then make a copy of that new LV in your own time while normal operations continue on the old LV.

The "snapshot" LV only needs to be big enough to hold the amount of changes to the original LV you expect while the backup is being made (plus a sensible safety margin), since only the changes are being stored inside the new LV. Hence, nobody prevents you from making a snapshot of your 10 TB file system even if you don't have another 10 TB of free disk space: If you only expect 10 GB of data to be changed while you're writing the copy to tape, a snapshot LV of 20–30 GB should be fairly safe.

As a matter of fact it is now possible to create writable snapshots. This is useful, for example, if you are working with "virtual machines" that share a basic OS installation but differ in details. Writable snapshots make it possible to make the basic installation in one LV for all virtual machines and then store the configuration specific to each virtual machine in one LV with a writable snapshot each. (You shouldn't overstretch this approach, though; if you change the LV with the basic installation the virtual machines won't notice.)

On Linux, LVM is a special application of the "device mapper", a system component enabling the flexible use of block devices. The device mapper also provides other useful features such as encrypted disks or space-saving storage provisioning for "virtual servers". Unfortunately we do not have room in this training manual to do LVM and the device mapper justice, and refer you to the manual, *Linux Storage and File Systems* (STOR).

Commands in this Chapter

cfdisk	Character-screen based disk partitioner	cfdisk(8)	217
gdisk	Partitioning tool for GPT disks	gdisk(8)	216
kpartx	Creates block device maps from partition tables	kpartx(8)	218
losetup	Creates and maintains loop devices	losetup(8)	218
sfdisk	Non-interactive hard disk partitioner	sfdisk(8)	217
sgdisk	Non-interactive hard disk partitioning tool for GPT disks	sgdisk(8)	217

Summary

- Linux supports all notable types of mass storage device—magnetic hard disks (SATA, P-ATA, SCSI, SAS, Fibre Channel, USB, …), SSDs, USB thumb drives, SD cards, …
- Storage media such as hard disks may be partitioned. Partitions allow the independent management of parts of a hard disk, e. g., with different file systems or operating systems.
- Linux can deal with storage media partitioned according to the MBR and GPT schemes.
- Linux manages most storage media like SCSI devices. There is an older infrastructure for P-ATA disks which is only rarely used.
- Linux offers various tools for partitioning such as `fdisk`, `parted`, `gdisk`, `cfdisk`, or `sfdisk`. Various distributions also provide their own tools.
- Loop devices make block-oriented devices from files. Partitions on loop devices can be made accessible using `kpartx`.
- The Logical Volume Manager (LVM) decouples physical storage space on media from logical storage structures. It enables the flexible management of mass storage, e. g., to create file systems which are larger than a single physical storage medium. Snapshots help create backup copies and provision storage space for virtual machines.

Bibliography

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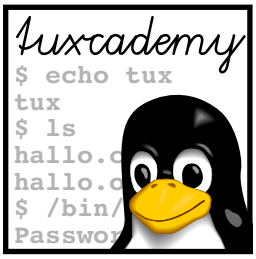

15

File Systems: Care and Feeding

Contents

Goals

- Knowing the most important file systems for Linux and their properties
- Being able to generate file systems on partitions and storage media
- Knowing about file system maintenance tools
- Being able to manage swap space
- Being able to mount local file systems
- Knowing how to set up disk quotas for users and groups

Prerequisites

- Competent use of the commands to handle files and directories
- Knowledge of mass storage on Linux and partitioning (Chapter 14)
- Existing knowledge about the structure of PC disk storage and file systems is helpful

15.1 Creating a Linux File System

15.1.1 Overview

After having created a new partition, you must "format" that partition, i. e., write the data structures necessary to manage files and directories onto it. What these data structures look like in detail depends on the "file system" in question.

Unfortunately, the term "file system" is overloaded on Linux. It means, for example:

1. A method to arrange data and management information on a medium ("the `ext3` file system")
2. Part of the file hierarchy of a Linux system which sits on a particular medium or partition ("the root file system", "the `/var` file system")
3. All of the file hierarchy, across media boundaries

The file systems (meaning 1 above) common on Linux may differ considerably. On the one hand, there are file systems that were developed specifically for Linux, such as the "`ext` filesystems" or the Reiser file system, and on the other hand there are file systems that originally belonged to other operating systems but that Linux supports (to a greater or lesser degree) for compatibility. This includes the file systems of DOS, Windows, OS X, and various Unix variants as well as "network file systems" such as NFS or SMB which allow access to file servers via the local network.

Many file systems "native" to Linux are part of the tradition of file systems common on Unix, like the Berkeley Fast Filesystem (FFS), and their data structures are based on those. However, development did not stop there; more modern influences are constantly being integrated in order to keep Linux current with the state of the art.

Btrfs (pronounced "butter eff ess") by Chris Mason (Fusion-IO) is widely considered the answer to the famous ZFS of Solaris. (The source code for ZFS is available but cannot be integrated in the Linux directly, due to licensing considerations.) Its focus is on "fault tolerance, repairs and simple administration". By now it seems to be mostly usable, at least some distributions rely on it.

superblock

With Linux file systems it is common to have a **superblock** at the beginning of the file system. This contains information pertaining to the file system as a whole—such as when it was last mounted or unmounted, whether it was unmounted "cleanly" or because of a system crash, and so on. The superblock normally also points to other parts of the management data structures, like where the inodes or free/occupied block lists are to be found and which parts of the medium are available for data.

It is usual to keep spare copies of the superblock elsewhere on the file system, in case something happens to the original. This is what the `ext` file systems do.

On disk, there is usually a "boot sector" in front of the superblock, into which you can theoretically put a boot loader (Chapter 16). This makes it possible to, e. g., install Linux on a computer alongside Windows and use the Windows boot manager to start the system.

`mkfs`

On Linux, file systems (meaning 2 above) are created using the `mkfs` command. `mkfs` is independent of the actual file system (meaning 1) desired; it invokes the real routine specific to the file system (meaning 1) in question, `mkfs.`⟨*file system name*⟩. You can select a file system type by means of the `-t` option—with "`mkfs -t ext2`", for example, the `mkfs.ext2` program would be started (another name for `mke2fs`).

When the computer has been switched off inadvertently or crashed, you have to consider that the file system might be in an inconsistent state (even though this happens very rarely in real life, even on crashes). File system errors can occur because write operations are cached inside the computer's RAM and may be lost if the system is switched off before they could be written to disk. Other errors can come up when the system gives up the ghost in the middle of an unbuffered write operation. inconsistent state

Besides data loss, problems can include errors within the file system management structure. These can be located and repaired using suitable programs and include structural errors

- Erroneous directory entries
- Erroneous inode entries
- Files that do not occur in any directory
- Data blocks belonging to several different files

Most but not all such problems can be repaired automatically without loss of data; generally, the file system can be brought back to a consistent state.

On boot, the system will find out whether it has not been shut down correctly by checking a file system's state. During a regular shutdown, the file systems are unmounted and the "valid flag" in every file system's super block will be set. On boot, this super block information may be used to automatically check these possibly-erroneous file systems and repair them if necessary—before the system tries to mount a file system whose valid flag is not set, it tries to do a file system check. valid flag

With all current Linux distributions, the system initialisation scripts executed by `init` after booting contain all necessary commands to perform a file system check.

If you want to check the consistency of a file system you do not need to wait for the next reboot. You can launch a file system check at any time. Should a file contain errors, however, it can only be repaired if it is not currently mounted. This restriction is necessary so that the kernel and the repair program do not "collide". This is another argument in favour of the automatic file system checks during booting. file system check

Actual consistency checks are performed using the `fsck` command. Like `mkfs`, depending on the type of the file system to be checked this command uses a specific sub-command called `fsck.`⟨*type*⟩—e.g., `fsck.ext2` for `ext2`. `fsck` identifies the required sub-command by examining the file system in question. Using the

```
# fsck /dev/sdb1
```

command, for example, you can check the file system on `/dev/sdb1`.

The simple command

```
# fsck
```

checks all file systems listed in `/etc/fstab` with a non-zero value in the sixth (last) column in sequence. (If several different values exist, the file systems are checked in ascending order.) `/etc/fstab` is explained in more detail in Section 15.2.2.

`fsck` supports a `-t` option which at first sight resembles `mkfs` but has a different meaning: A command like

```
# fsck -t ext3
```

checks all file systems in `/etc/fstab` that are marked as type `ext3` there.

options The most important options of `fsck` include:

-A (All) causes `fsck` to check all file systems mentioned in `/etc/fstab`.

This obeys the checking order in the sixth column of the file. If several file systems share the same value in that column, they are checked in parallel if they are located on different physical disks.

-R With `-A`, the root file system is not checked (which is useful if it is already mounted for writing).

-V Outputs verbose messages about the check run.

-N Displays what `fsck` would do without actually doing it.

-s Inhibits parallel checking of multiple file systems. The "`fsck`" command without any parameters is equivalent to "`fsck -A -s`".

Besides its own options, you can pass additional options to `fsck` which it will forward to the specific checking program. These must occur after the name of the file system(s) to be checked and possibly a "`--`" separator. The `-a`, `-f`, `-p` and `-v` options are supported by most such programs. Details may be found within the documentation for the respective programs. The

```
# fsck /dev/sdb1 /dev/sdb2 -pv
```

for example would check the file systems on the `/dev/sdb1` and `/dev/sdb2` partitions automatically, fix any errors without manual intervention and report verbosely on its progress.

At program termination, `fsck` passes information about the file system state to the shell:

0 No error was found in the file system

1 Errors were found and corrected

2 Severe errors were found and corrected. The system should be rebooted

4 Errors were found but not corrected

8 An error occurred while the program was executed

16 Usage error (e. g., bad command line)

128 Error in a shared library function

It is conceivable to analyse these return values in an init script and determine how to continue with the system boot. If several file systems are being checked (using the `-A` option), the return value of `fsck` is the logical OR of the return values of the individual checking programs.

15.1.2 The ext File Systems

History and Properties The original "extended file system" for Linux was implemented in April, 1992, by Rémy Card. It was the first file system designed specifically for Linux (although it did take a lot of inspiration from general Unix file systems) and did away with various limitations of the previously popular Minix file system.


The Minix file system had various nasty limits such as a maximum file system size of 64 MiB and file names of at most 14 characters. (To be fair, Minix was introduced when the IBM PC XT was considered a hot computer and 64 MiB, for PCs, amounted to an unimaginably vast amount of disk storage. By 1990, that assumption had begun to crumble.) `ext` allowed file systems of up to 2 GiB—quite useful at the time, but naturally somewhat ridiculous today.


The arrival of the `ext` file system marks another important improvement to the Linux kernel, namely the introduction of the "virtual file system switch", or VFS. The VFS abstracts file system operations such as the opening and closing of files or the reading and writing of data, and as such enables the coexistence of different file system implementations in Linux.


The original `ext` file system is no longer used today. From here on, when we talk about "the `ext` file systems", we refer to `ext2` and everything newer than that.

The subsequent version, `ext2` (the "second extended file system"), which was begun by Rémy Card in January, 1993, amounted to a considerable rework of the original "extended file system". The development of `ext2` made use of many ideas from the BSD "Berkeley Fast Filesystem". `ext2` is still being maintained and makes eminent sense for certain applications.


Compared to `ext`, `ext2` pushes various size limits—with the 4 KiB block size typical for Intel-based Linux systems, file systems can be 16 TiB and single files 2 TiB in size. Another important improvement in `ext2` was the introduction of separate timestamps for the last access, last content modification and last inode modification, which achieved compatibility to "traditional" Unix in this respect.


From the beginning, `ext2` was geared towards continued development and improvement: Most data structures contained surplus space which was later used for important extensions. These include ACLs and "extended attributes".

Since the end of the 1990s, Stephen Tweedie worked on a successor to `ext2`, which was made part of the Linux kernel at the end of 2001 under the name of `ext3`. (That was Linux 2.4.15.) The most important differences between `ext2` and `ext3` include:

- `ext3` supports Journaling.
- `ext3` allows enlarging file systems while they are mounted.
- `ext3` supports more efficient internal data structures for directories with many entries.

Even so it is largely compatible with `ext2`. It is usually possible to access `ext3` file systems as `ext2` file systems (which implies that the new features cannot be used) and vice-versa.


"Journaling" solves a problem that can be very tedious with the increasing size of file systems, namely that an unforeseen system crash makes it necessary to do a complete consistency check of the file system. The Linux kernel does not perform write operations immediately, but buffers the data in RAM and writes them to disk when that is convenient (e. g., when the read/write head of the disk drive is in the appropriate place). In addition, many write operations involve writing data to various places on the disk, e. g., one or more data blocks, the inode table, and the list of available blocks on the disk. If the power fails in the right (or wrong) moment, such an operation can remain only half-done—the file system is "inconsistent" in the sense that a data block can be assigned to a file in the inode, but not marked used in the free-block list. This can lead to serious problems later on.

A journaling file system like ext3 considers every write access to the disk as a "transaction" which must be performed completely or not at all. By definition, the file system is consistent before and after a transaction is performed. Every transaction is first written into a special area of the file system called the *journal*. If it has been entirely written, it is marked "complete" and, as such, it is official. The Linux kernel can do the actual write operations later.—If the system crashes, a journaling file system does not need to undergo a complete file system check, which with today's file system sizes could take hours or even days. Instead, the journal is considered and any transactions marked "complete" are transferred to the actual file system. Transactions not marked "complete" are thrown out.

Most journaling file systems use the journal to log changes to the file system's "metadata", i. e., directories, inodes, etc. For efficiency, the actual file data are normally not written to the journal. This means that after a crash and reboot you will have a consistent file system without having to spend hours or days on a complete consistency check. However, your file contents may have been scrambled—for example, a file might contain obsolete data blocks because the updated ones couldn't be written before the crash. This problem can be mitigated by writing the data blocks to disk first and then the metadata to the journal, but even that is not without risk. ext3 gives you the choice between three operating modes—writing everything to the journal (mount option data=journal), writing data blocks directly and then metadata to the journal (data=ordered), or no restrictions (data=writeback). The default is data=ordered.

Writing metadata or even file data twice—once to the journal, and then later to the actual file system—involves a certain loss of performance compared to file systems like ext2, which ignore the problem. One approach to fix this consists of *log-structured file systems*, in which the journal makes up the actual file system. Within the Linux community, this approach has so far not prevailed. Another approach is exemplified by "copy-on-write filesystems" like Btrfs.

Using a journaling file system like ext3 does not absolve you from having to perform complete consistency checks every so often. Errors in a file system's data structures might arise through disk hardware errors, cabling problems, or the dreaded cosmic rays (don't laugh) and might otherwise remain unnoticed until they wreak havoc. For this reason, the ext file systems force a file system check every so often when the system is booted (usually when you can least afford it). You will see how to tweak this later in this chapter.

With server systems that are rarely rebooted and that you cannot simply take offline for a few hours or days for a prophylactic file system check, you may have a big problem. We shall also come back to this.

The apex of ext file system evolution is currently represented by ext4, which has been developed since 2006 under the guidance of Theodore Ts'o. This has been considered stable since 2008 (Kernel version 2.6.28). Like ext3 and ext2, backward compatibility was an important goal: ext2 and ext3 file systems can be mounted as ext4 file systems and will profit from some internal improvements in ext4. On the other hand, the ext4 code introduces some changes that result in file systems no longer being accessible as ext2 and ext3. Here are the most important improvements in ext4 as compared to ext3:

- Instead of maintaining the data blocks of individual files as lists of block numbers, ext4 uses "extents", i. e., groups of physically contiguous blocks on disk. This leads to a considerable simplification of space management and to greater efficiency, but makes file systems using extents incompatible to ext3. It also avoids fragmentation, or the wild scattering of blocks belonging to the same file across the whole file system.

- When data is written, actual blocks on the disk are assigned as late as possible. This also helps prevent fragmentation.
- User programs can advise the operating system how large a file is going to be. Again, this can be used to assign contiguous file space and mitigate fragmentation.
- Ext4 uses checksums to safeguard the journal. This increases reliability and avoids some hairy problems when the journal is replayed after a system crash.
- Various optimisations of internal data structures increase the speed of consistency checks.
- Timestamps now carry nanosecond resolution and roll over in 2242 (rather than 2038).
- Some size limits have been increased—directories may now contain 64,000 or more subdirectories (previously 32,000), files can be as large as 16 TiB, and file systems as large as 1 EiB.

In spite of these useful improvements, according to Ted Ts'o ext4 is not to be considered an innovation, but rather a stopgap until even better file systems like Btrfs become available.

All ext file systems include powerful tools for consistency checks and file system repairs. This is very important for practical use.

Creating ext file systems To create a ext2 or ext3 file system, it is easiest to use the mkfs command with a suitable -t option:

```
# mkfs -t ext2 /dev/sdb1          ext2 file system
# mkfs -t ext3 /dev/sdb1          ext3 file system
# mkfs -t ext4 /dev/sdb1          ext4 file system
```

After the -t option and its parameter, you can specify further parameters which will be passed to the program performing the actual operation—in the case of the ext file systems, the mke2fs program. (In spite of the e2 in its name, it can also create ext3 and ext4 file systems.)

The following commands would also work:

```
# mkfs.ext2 /dev/sdb1          ext2 file system
# mkfs.ext3 /dev/sdb1          ext3 file system
# mkfs.ext4 /dev/sdb1          ext4 file system
```

These are exactly the commands that mkfs would invoke. All three commands are really symbolic links referring to mke2fs; mke2fs looks at the name used to call it and behaves accordingly.

You can even call the mke2fs command directly: mke2fs

```
# mke2fs /dev/sdb1
```

(Passing no options will get you a ext2 file system.)

The following options for mke2fs are useful (and possibly important for the exam):

-b ⟨*size*⟩ determines the block size. Typical values are 1024, 2048, or 4096. On partitions of interesting size, the default is 4096.

-c checks the partition for damaged blocks and marks them as unusable.

Current hard disks can notice "bad blocks" and replace them by blocks from a "secret reserve" without the operating system even noticing (at least as long as you don't ask the disk directly). While this is going on, "`mke2fs -c`") does not provide an advantage. The command will only find bad blocks when the secret reserve is exhausted, and at that point you would do well to replace the disk, anyway. (A completely new hard disk would at this point be a warranty case. Old chestnuts are only fit for the garbage.)

-i ⟨*count*⟩ determines the "inode density"; an inode is created for every ⟨*count*⟩ bytes of space on the disk. The value must be a multiple of the block size (option `b`); there is no point in selecting a ⟨*count*⟩ that is less than the block size. The minimum value is 1024, the default is the current block size.

-m ⟨*percentage*⟩ sets the percentage of data blocks reserved for `root` (default: 5%)

-S causes `mke2fs` to rewrite just the super blocks and group descriptors and leave the inodes intact

-j creates a journal and, hence, an `ext3` or `ext4` file system.

It is best to create an `ext4` file system using one of the precooked calls like "`mkfs -t ext4`", since `mke2fs` then knows what it is suppsed to do. If you must absolutely do it manually, use something like

```
# mke2fs -j -O extents,uninit_bg,dir_index /dev/sdb1
```

The `ext` file systems (still) need at least one complete data block for every file, no matter how small. Thus, if you create an `ext` file system on which you intend to store many small files (cue: mail or Usenet server), you may want to select a smaller block size in order to avoid internal fragmentation. (On the other hand, disk space is really quite cheap today.)

internal fragmentation

The inode density (`-i` option) determines how many files you can create on the file system—since every file requires an inode, there can be no more files than there are inodes. The default, creating an inode for every single data block on the disk, is very conservative, but from the point of view of the developers, the danger of not being able to create new files for lack of inodes seems to be more of a problem than wasted space due to unused inodes.

Various file system objects require inodes but no data blocks—such as device files, FIFOs or short symbolic links. Even if you create as many inodes as data blocks, you can still run out of inodes before running out of data blocks.

Using the `mke2fs -F` option, you can "format" file system objects that are not block device files. For example, you can create CD-ROMs containing an `ext2` file system by executing the command sequence

```
# dd if=/dev/zero of=cdrom.img bs=1M count=650
# mke2fs -F cdrom.img
# mount -o loop cdrom.img /mnt
#                                                  … copy stuff to /mnt …
# umount /mnt
# cdrecord -data cdrom.img
```

(`/dev/zero` is a "device" that produces arbitrarily many zero bytes.) The resulting CD-ROMs contain "genuine" `ext2` file systems with all permissions, attributes, ACLs etc., and can be mounted using

```
# mount -t ext2 -o ro /dev/scd0 /media/cdrom
```

(or some such command); you should replace `/dev/scd0` by the device name of your optical drive. (It is best to avoid using an `ext3` file system here, since the journal would be an utter waste of space. An `ext4` file system, though, can be created without a journal.)

Repairing `ext` file systems `e2fsck` is the consistency checker for `ext` file systems. `e2fsck` There are usually symbolic links such as `fsck.ext2` so it can be invoked from `fsck`.


Like `mke2fs`, `e2fsck` also works for `ext3` and `ext4` file systems.


You can of course invoke the program directly, which might save you a little typing when passing options. On the other hand, you can only specify the name of one single partition (strictly speaking, one single block device).

The most important options for `e2fsck` include: options

`-b` ⟨*number*⟩ reads the super block from block ⟨*number*⟩ of the partition (rather than the first super block)

`-B` ⟨*size*⟩ gives the size of a block group between two copies of the super block; with the `ext` file systems, backup copies of the super block are usually placed every 8192 blocks, on larger disks every 32768 blocks. (You can query this using the `tune2fs` command explained below; look for "blocks per group" in the output of "`tune2fs -l`".)

`-f` forces a file system to be checked even if its super block claims that it is clean

`-l` ⟨*file*⟩ reads the list of bad blocks from the ⟨*file*⟩ and marks these blocks as "used"

`-c` ("check") searches the file system for bad blocks

`-p` ("preen") causes errors to be repaired automatically with no further user interaction

`-v` ("verbose") outputs information about the program's execution status and the file system while the program is running

The device file specifies the partition whose file system is to be checked. If that partition does not contain an `ext` file system, the command aborts. `e2fsck` performs the following steps: steps

1. The command line arguments are checked
2. The program checks whether the file system in question is mounted
3. The file system is opened
4. The super block is checked for readability
5. The data blocks are checked for errors
6. The super block information on inodes, blocks and sizes are compared with the current system state
7. Directory entries are checked against inodes
8. Every data block that is marked "used" is checked for existence and whether it is referred to exactly once by some inode
9. The number of links within directories is checked with the inode link counters (must match)

10. The total number of blocks must equal the number of free blocks plus the number of used blocks

exit code

`e2fsck` returns an exit code with the same meaning as the standard `fsck` exit codes..

It is impossible to list all the file system errors that `e2fsck` can handle. Here are a few important examples:

- Files whose inodes are not referenced from any directory are placed in the file system's `lost+found` directory using the inode number as the file name and can be moved elsewhere from there. This type of error can occur, e. g., if the system crashes after a file has been created but before the directory entry could be written.
- An inode's link counter is greater than the number of links pointing to this inode from directories. `e2fsck` corrects the inode's link counter.
- `e2fsck` finds free blocks that are marked used (this can occur, e. g., when the system crashes after a file has been deleted but before the block count and bitmaps could be updated).
- The total number of blocks is incorrect (free and used blocks together are different from the total number of blocks).

complicated errors

Not all errors are straightforward to repair. What to do if the super block is unreadable? Then the file system can no longer be mounted, and `e2fsck` often fails as well. You can then use a copy of the super block, one of which is included with every block group on the partition. In this case you should boot a rescue system and invoke `fsck` from there. With the `-b` option, `e2fsck` can be forced to consider a particular block as the super block. The command in question then becomes, for example:

```
# e2fsck -f -b 8193 /dev/sda2
```

If the file system cannot be automatically repaired using `fsck`, it is possible to modify the file system directly. However, this requires very detailed knowledge of file system structures which is beyond the scope of this course.—There are two useful tools to aid with this. First, the `dumpe2fs` program makes visible the internal management data structures of a `ext` file system. The interpretation of its output requires the aforementioned detailed knowledge. An `ext` file system may be repaired using the `debugfs` file system debugger.

You should keep your hands off programs like `debugfs` unless you know exactly what you are doing. While `debugfs` enables you to manipulate the file system's data structures on a very low level, it is easy to damage a file system even more by using it injudiciously. Now that we have appropriately warned you, we may tell you that

```
# debugfs /dev/sda1
```

will open the `ext` file system on `/dev/sda1` for inspection (`debugfs`, reasonably, enables writing to the file system only if it was called with the `-w` option). `debugfs` displays a prompt; "`help`" gets you a list of available commands. These are also listed in the documentation, which is in `debugfs`(8).

Querying and Changing `ext` File System Parameters If you have created a partition and put an `ext` file system on it, you can change some formatting parameters after the fact. This is done using the `tune2fs` command, which should be used with utmost caution and should never be applied on a file system mounted for writing:

changing format parameters

```
tune2fs [⟨options⟩] ⟨device⟩
```

The following options are important:

`-c` ⟨*count*⟩ sets the maximum number of times the file system may be mounted between two routine file system checks. The default value set by `mke2fs` is a random number somewhere around 30 (so that not all file systems are preemptively checked at the same time). The value 0 means "infinitely many".

`-C` ⟨*count*⟩ sets the current "mount count". You can use this to cheat `fsck` or (by setting it to a larger value than the current maximum set up using `-c`) force a file system check during the next system boot.

`-e` ⟨*behaviour*⟩ determines the behaviour of the system in case of errors. The following possibilities exist:

`continue` Go on as normal

`remount-ro` Disallow further writing to the file system

`panic` Force a kernel panic

In every case, a file system consistency check will be performed during the next reboot.

`-i` ⟨*interval*⟩⟨*unit*⟩ sets the maximum time between two routine file system checks. ⟨*interval*⟩ is an integer; the ⟨*unit*⟩ is `d` for days, `w` for weeks and `m` for months. The value 0 means "infinitely long".

`-l` displays super block information.

`-m` ⟨*percent*⟩ sets the percentage of data blocks reserved for `root` (or the user specified using the `-u` option). The default value is 5%.

`-L` ⟨*name*⟩ sets a partition name (up to 16 characters). Commands like `mount` and `fsck` make it possible to refer to partitions by their names rather than the names of their device files.

To upgrade an existing `ext3` file system to an `ext4` file system, you need to execute the commands

```
# tune2fs -O extents,uninit_bg,dir_index /dev/sdb1
# e2fsck -fDp /dev/sdb1
```

(stipulating that the file system in question is on `/dev/sdb1`). Make sure to change `/etc/fstab` such that the file system is mounted as `ext4` later on (see Section 15.2).

Do note, though, that all existing files will still be using `ext3` structures—improvements like extents will only be used for files created later. The `e4defrag` defragmentation tool is supposed to convert older files but is not quite ready yet.

If you have the wherewithal, you should not upgrade a file system "in place" but instead backup its content, recreate the file system as `ext4`, and the restore the content. The performance of `ext4` is considerably better on "native" `ext4` file systems than on converted `ext3` file systems—this can amount to a factor of 2.

If you have ext2 file systems lying around that you would like to convert into ext3 file systems: This is easily done by creating a journal. tune2fs will do that for you, too:

```
# tune2fs -j /dev/sdb1
```

Again, you will have to adjust /etc/fstab if necessary.

Exercises

15.1 [!2] Generate an ext4 file system on a suitable medium (hard disk partition, USB thumb drive, file created using dd).

15.2 [2] Change the maximum mount count of the filesystem created in Exercise 15.1 to 30. In addition, 30% of the space available on the file system should be reserved for user test.

15.1.3 ReiserFS

Overview ReiserFS is a Linux file system meant for general use. It was developed by a team under the direction of Hans Reiser and debuted in Linux 2.4.1 (that was in 2001). This made it the first journaling file system available for Linux. ReiserFS also contained some other innovations that the most popular Linux file system at the time, ext2, did not offer:

- Using a special tool, ReiserFS file systems could be changed in size. Enlargement was even possible while the file system was mounted.
- Small files and the ends of larger files could be packed together to avoid "internal fragmentation" which arises in file systems like ext2 because space on disk is allocated based on the block size (usually 4 KiB). With ext2 and friends, even a 1-byte file requires a full 4-KiB block, which could be considered wasteful (a 4097-byte file requires two data blocks, and that is almost as bad). With ReiserFS, several such files could share one data block.

  

  There is nothing in principle that would keep the ext developers to add this "tail packing" feature to the ext file systems. This was discussed and the consensus was that by now, disk space is cheap enough that the added complexity would be worth the trouble.

- Inodes aren't pregenerated when the file system is created, but are allocated on demand. This avoids a pathological problem possible with the ext file systems, where there are blocks available in the file system but all inodes are occupied and no new files can be generated.

  

  The ext file systems mitigate this problem by allocating one inode per data block per default (the inode density corresponds to the block size). This makes it difficult to provoke the problem.

- ReiserFS uses trees instead of lists (like ext2) for its internal management data structures. This makes it more efficient for directories with many files.

  

  Ext3 and in particular ext4 can by now do that too.

  As a matter of fact, ReiserFS uses the same tree structure not just for directory entries, but also for inodes, file metadata and file block lists, which leads to a performance increase in places but to a decrease in others.

For a long time, ReiserFS used to be the default file system for the SUSE distributions (and SUSE contributed to the project's funding). Since 2006, Novell/SUSE has moved from ReiserFS to ext3; very new SLES versions use Btrfs for their root file system.

In real life you should give the Reiser file system (and its designated successor, Reiser4) a wide berth unless you need to manage older systems using it. This is less to do with the fact that Hans Reiser was convicted of his wife's murder (which of course does not speak in his favour as a human being, but things like these do happen not just among Linux kernel developers), but more with the fact that the Reiser file system does have its good points but is built on a fairly brittle base. For example, certain directory operations in ReiserFS break basic assumptions that are otherwise universally valid for Unix-like file systems. This means, for instance, that mail servers storing mailboxes on a ReiserFS file system are less resilient against system crashes than ones using different file systems. Another grave problem, which we will talk about briefly later on, is the existence of technical flaws in the file system repair program. Finally—and that may be the most serious problem—nobody seems to maintain the code any longer.

Creating ReiserFS file systems `mkreiserfs` serves to create a ReiserFS file system. The possible specification of a logical block size is currently ignored, the size is always 4 KiB. With `dumpreiserfs` you can determine information about ReiserFS file systems on your disk. `resize_reiserfs` makes it possible to change the size of currently-unused ReiserFS partitions. Mounted partitions may be resized using a command like "`mount -o remount,resize=`⟨*block count*⟩ ⟨*mount point*⟩".

`mkreiserfs`

`dumpreiserfs`

`resize_reiserfs`

Consistency Checks for ReiserFS For the Reiser file system, too, there is a checking and repair program, namely `reiserfsck`.

Reiser file system

`reiserfsck` performs a consistency check and tries to repair any errors found, much like `e2fsck`. This program is only necessary if the file system is really damaged. Should a Reiser file system merely have been unmounted uncleanly, the kernel will automatically try to restore it according to the journal.

`reiserfsck` has some serious issues. One is that when the tree structure needs to be reconstructed (which may happen in certain situations) it gets completely mixed up if data files (!) contain blocks that might be misconstrued as another ReiserFS file system's superblock. This will occur if you have an image of a ReiserFS file system in a file used as a ReiserFS-formatted "virtual" hard disk for a virtualisation environment such as VirtualBox or VMware. This effectively disqualifies the ReiserFS file system for serious work. You have been warned.

Exercises

15.3 [!1] What is the command to create a Reiser file system on the first logical partition of the second disk?

15.1.4 XFS

The XFS file system was donated to Linux by SGI (the erstwhile Silicon Graphics, Inc.); it is the file system used by SGI's Unix variant, IRIX, which is able to handle very large files efficiently. All Linux distributions of consequence offer XFS support, even though few deploy it by default; you may have to install the XFS tools separately.

XFS

In some circles, "XFS" is the abbreviation of "X11 Font Server". This can occur in distribution package names. Don't let yourself be confused.

You can create an XFS file system on an empty partition (or file) using the

```
# mkfs -t xfs /dev/sda2
```

command (insert the appropriate device name). Of course, the real work is done by a program called `mkfs.xfs`. You can control it using various options; consult the documentation (`xfs`(5) and `mkfs.xfs`(8)).

If performance is your goal, you can, for example, create the journal on another (physical) storge medium by using an option like "`-l logdev=/dev/sdb1,size=10000b`". (The actual file system should of course not be on `/dev/sdb`, and the partition for the journal should not otherwise be used.)

The XFS tools contain a `fsck.xfs` (which you can invoke using "`fsck -t xfs`"), but this program doesn't really do anything at all—it is merely there to give the system something to call when "all" file systems are to be checked (which is easier than putting a special exception for XFS into `fsck`). In actual fact, XFS file systems are checked automatically on mounting if they have not been unmounted cleanly. If you want to check the consistency of an XFS or have to repair one, use the `xfs_repair`(8) program—"`xfs_repair -n`" checks whether repairs are required; without the option, any repairs will be performed outright.

In extreme cases `xfs_repair` may not be able to repair the file system. In such a situation you can use `xfs_metadump` to create a dump of the filesystem's metadata and send that to the developers:

```
# xfs_metadump /dev/sdb1 sdb1.dump
```

(The file system must not be mounted when you do this.) The dump is a binary file that does not contain actual file data and where all file names have been obfuscated. Hence there is no risk of inadvertently passing along confidential data.

A dump that has been prepared using `xfs_metadump` can be written back to a file system (on a "real" storage medium or an image in a file) using `xfs_mdrestore`. This will not include file contents as these aren't part of the dump to begin with. Unless you are an XFS developer, this command will not be particularly interesting to you.

The `xfs_info` command outputs information about a (mounted) XFS file system:

```
# xfs_info /dev/sdb1
meta-data=/dev/sdb1              isize=256    agcount=4, agsize=16384 blks
         =                       sectsz=512   attr=2, projid32bit=1
         =                       crc=0        finobt=0
data     =                       bsize=4096   blocks=65536, imaxpct=25
         =                       sunit=0      swidth=0 blks
naming   =version 2              bsize=4096   ascii-ci=0 ftype=0
log      =Intern                 bsize=4096   blocks=853, version=2
         =                       sectsz=512   sunit=0 blks, lazy-count=1
realtime =keine                  extsz=4096   blocks=0, rtextents=0
```

You can see, for example, that the file system consists of 65536 blocks of 4 KiB each (`bsize` and `blocks` in the `data` section), while the journal occupies 853 4-KiB blocks in the same file system (`Intern`, `bsize` and `blocks` in the `log` section).

The same information is output by `mkfs.xfs` after creating a new XFS file system.

You should avoid copying XFS file systems using `dd` (or at least proceed very cautiously). This is because every XFS file system contains a unique UUID, and programs like `xfsdump` (which makes backup copies) can get confused if they run into two independent file systems using the same UUID. To copy XFS file systems, use `xfsdump` and `xfsrestore` or else `xfs_copy` instead.

15.1.5 Btrfs

Btrfs is considered the up-and-coming Linux file system for the future. It combines the properties traditionally associated with a Unix-like file system with some innovative ideas that are partly based on Solaris's ZFS. Besides some features otherwise provided by the Logical Volum Manager (LVM; Section 14.7)—such as the creation of file systems that span several physical storage media—or provided by the Linux kernel's RAID support—such as the redundant storage of data on several physical media—this includes transparent data compression, consistency checks on data blocks by means of checksums, and various others. The "killer feature" is probably snapshots that can provide views of different versions of files or complete file hierarchies simultaneously.

Btrfs is several years younger than ZFS, and its design therefore contains a few neat ideas that hadn't been invented yet when ZFS was first introduced. ZFS is currently considered the "state of the art" in file systems, but it is to be expected that some time in the not-too-distant future it will be overtaken by Btrfs.

Btrfs is based, in principle, on the idea of "copy on write". This means that if you create a snapshot of a Btrfs file system, nothing is copied at all; the system only notes that a copy exists. The data is accessible both from the original file system and the snapshot, and as long as data is just being read, the file systems can share the complete storage. Once write operations happen either in the original file system or the snapshot, only the data blocks being modified are copied. The data itself is stored in efficient data structures called B-trees.

Btrfs file systems are created with `mkfs`, as usual:

```
# mkfs -t btrfs /dev/sdb1
```

You can also mention several storage media, which will all be made part of the new file system. Btrfs stores metadata such as directory information redundantly on several media; by default, data is spread out across various disks ("striping") in order to accelerate access[1]. You can, however, request other storage arrangements:

```
# mkfs -t btrfs -L MyBtrfs -d raid1 /dev/sdb1 /dev/sdc1
```

This example generates a Btrfs file system which encompasses the `/dev/sdb1` and `/dev/sdc1` disks and is labeled "MyBtrfs". Data is stored redundantly on both disks ("`-d raid1`").

Within Btrfs file systems you can create "subvolumes", which serve as a type of partition at the file system level. Subvolumes are the units of which you will later be able to make snapshots. If your system uses Btrfs as its root file system, the command

```
# btrfs subvolume create /home
```

would, for instance, allow you to keep your own data within a separate subvolume. Subvolumes do not take a lot of space, so you should not hesitate to create more of them rather than fewer—in particular, one for every directory of which you might later want to create independent snapshots, since it is not possible to make directories into subvolumes after the fact.

[1] In other words, Btrfs uses RAID-1 for metadata and RAID-0 for data.

You can create a snapshot of a subvolume using

```
# btrfs subvolume snapshot /mnt/sub /mnt/sub-snap
```

The snapshot (here, `/mnt/sub-snap`) is at first indistinguishable from the original subvolume (here, `/mnt/sub`); both contain the same files and are writable. At first no extra storage space is being used—only if you change files in the original or snapshot or create new ones, the system copies whatever is required.

Btrfs makes on-the-fly consistency checks and tries to fix problems as they are detected. The "`btrfs scrub start`" command starts a house-cleaning operation that recalculates the checksums on all data and metadata on a Btrfs file system and repairs faulty blocks according to a different copy if required. This can, of course, take a long time; with "`btrfs scrub status`" you can query how it is getting on, with "`btrfs scrub cancel`" you can interrupt it, and restart it later with "`btrfs scrub resume`".

There is a `fsck.btrfs` program, but it does nothing beyond outputting a message that it doesn't do anything. The program is required because something needs to be there to execute when all file systems are checked for consistency during startup. To really check or repair Btrfs file systems there is the "`btrfs check`" command. By default this does only a consistency check, and if it is invoked with the "`--repair`" it tries to actually repair any problems it found.

Btrfs is very versatile and complex and we can only give you a small glimpse here. Consult the documentation (starting at `btrfs`(8)).

Exercises

15.4 [!1] Generate a Btrfs file system on an empty partition, using "`mkfs -t btrfs`".

15.5 [2] Within your Btrfs file system, create a subvolume called `sub0`. Create some files within `sub0`. Then create a snapshot called `snap0`. Convince yourself that `sub0` and `snap0` have the same content. Remove or change a few files in `sub0` and `snap0`, and make sure that the two subvolumes are independent of each other.

15.1.6 Even More File Systems

tmpfs

`tmpfs` is a flexible implementation of a "RAM disk file system", which stores files not on disk, but in the computer's virtual memory. They can thus be accessed more quickly, but seldom used files can still be moved to swap space. The size of a `tmpfs` is variable up to a set limit. There is no special program for generating a `tmpfs`, but you can create it simply by mounting it: For example, the

```
# mount -t tmpfs -o size=1G,mode=0700 tmpfs /scratch
```

command creates a `tmpfs` of at most 1 GiB under the name of `/scratch`, which can only be accessed by the owner of the `/scratch` directory. (We shall be coming back to mounting file systems in Section 15.2.)

VFAT

A popular file system for older Windows PCs, USB sticks, digital cameras, MP3 players and other "storage devices" without big ideas about efficiency and flexibility is Microsoft's venerable VFAT file system. Naturally, Linux can mount, read, and write media formatted thusly, and also create such file systems, for example by

```
# mkfs -t vfat /dev/mcblk0p1
```

(insert the appropriate device name again). At this point you will no longer be surprised to hear that `mkfs.vfat` is just another name for the `mkdosfs` program, which can create all sorts of MS-DOS and Windows file systems—including the file system used by the Atari ST of blessed memory. (As there are Linux variants running on Atari computers, this is not quite as far-fetched as it may sound.)

`mkdosfs` supports various options allowing you to determine the type of file system created. Most of these are of no practical consequence today, and `mkdosfs` will do the Right Thing in most cases, anyway. We do not want to disgress into a taxonomy of FAT file system variants and restrict ourselves to pointing out that the main difference between FAT and VFAT is that file systems of the latter persuasion allow file names that do not follow the older, strict 8 + 3 scheme. The "file allocation table", the data structure that remembers which data blocks belong to which file and that gave the file system its name, also exists invarious flavours, of which `mkdosfs` selects the one most suitable to the medium in question—floppy disks are endowed with a 12-bit FAT, and hard disk (partitions) or (today) USB sticks of considerable capacity get 32-bit FATs; in the latter case the resulting file system is called "VFAT32".

NTFS

NTFS, the file system used by Windows NT and its successors including Windows Vista, is a bit of an exasperating topic. Obviously there is considerable interest in enabling Linux to handle NTFS partitions—everywhere but on Microsoft's part, where so far one has not deigned to explain to the general public how NTFS actually works. (It is well-known that NTFS is based on BSD's "Berkeley Fast Filesystem", which is reasonably well understood, but in the meantime Microsoft butchered it into something barely recognisable.) In the Linux community there have been several attempts to provide NTFS support by trying to understand NTFS on Windows, but complete success is still some way off. At the moment there is a kernel-based driver with good support for reading, but questionable support for writing, and another driver running in user space which according to the grapevine works well for reading *and* writing. Finally, there are the "ntfsprogs", a package of tools for managing NTFS file systems, which also allow rudimentary access to data stored on them. Further information is available from `http://www.linux-ntfs.org/`.

15.1.7 Swap space

swap partition

In addition to the file system partitions, you should always create a **swap partition**. Linux can use this to store part of the content of system RAM; the effective amount of working memory available to you is thus greater than the amount of RAM in your computer.

Before you can use a swap partition you must "format" it using the `mkswap` command:

```
# mkswap /dev/sda4
```

This writes some administrative data to the partition.

When the system is started, it is necessary to "activate" a swap partition. This corresponds to mounting a partition with a file system and is done using the `swapon` command:

```
# swapon /dev/sda4
```

The partition should subsequently be mentioned in the `/proc/swaps` file:

```
# cat /proc/swaps
Filename                Type       Size    Used   Priority
/dev/sda4               partition  2144636 380    -1
```

After use the swap partition can be deactivated using `swapoff`:

```
# swapoff /dev/sda4
```


The system usually takes care of activating and deactivating swap partitions, as long as you put them into the `/etc/fstab` file. See Section 15.2.2.

You can operate up to 32 swap partitions (up to and including kernel version 2.4.10: 8) in parallel; the maximum size depends on your computer's architecture and isn't documented anywhere exactly, but "stupendously gigantic" is a reasonable approximation. It used to be just a little less than 2 GiB for most Linux platforms.


If you have several disks, you should spread your swap space across all of them, which should increase speed noticeably.


Linux can prioritise swap space. This is worth doing if the disks containing your swap space have different speeds, because Linux will prefer the faster disks. Read up on this in `swapon`(8).


Besides partitions, you can also use files as swap space. Since Linux 2.6 this isn't even any slower! This allows you to temporarily provide space for rare humongous workloads. You must initially create a swap file as a file full of zeros, for instance by using

```
# dd if=/dev/zero of=swapfile bs=1M count=256
```

before preparing it using the `mkswap` command and activating it with `swapon`. (Desist from tricks using `dd` or `cp`; a swap file may not contain "holes".)


You can find information about the currently active swap areas in the `/proc/swaps` file.

15.2 Mounting File Systems

15.2.1 Basics

To access data stored on a medium (hard disk, USB stick, floppy, …), it would in principle be possible to access the device files directly. This is in fact being done, for example when accessing tape drives. However, the well-known file management commands (`cp`, `mv`, and so on) can only access files via the directory tree. To use these commands, storage media must be made part of the directory tree ("mounted") using their device files. This is done using the `mount` command.

mount point

The place in the directory tree where a file system is to be mounted is called a **mount point**. This can be any directory; it does not even have to be empty, but you will not be able to access the original directory content while another file system is mounted "over" it.


The content reappears once the file system is unmounted using `umount`. Even so you should restrain yourself from mounting stuff on `/etc` and other important system directories …

15.2.2 The `mount` Command

The `mount` command mounts file systems into the directory tree. It can also be used to display the currently mounted file systems, simply by calling it without parameters:

```
proc       /proc         proc  defaults                  0 0
/dev/sda2  /             ext3  defaults,errors=remount-ro 0 1
/dev/sda1  none          swap  sw                        0 0
/dev/sda3  /home         ext3  defaults,relatime         0 1
/dev/sr0   /media/cdrom0 udf,iso9660 ro,user,exec,noauto  0 0
/dev/sdb1  /media/usb    auto  user,noauto               0 0
/dev/fd0   /media/floppy auto  user,noauto,sync          0 0
```

Figure 15.1: The `/etc/fstab` file (example)

```
$ mount
/dev/sda2 on / type ext3 (rw,relatime,errors=remount-ro)
tmpfs on /lib/init/rw type tmpfs (rw,nosuid,mode=0755)
proc on /proc type proc (rw,noexec,nosuid,nodev)
sysfs on /sys type sysfs (rw,noexec,nosuid,nodev)
◁◁◁◁◁
```

To mount a medium, for example a hard disk partition, you must specify its device file and the desired mount point:

```
# mount -t ext2 /dev/sda5 /home
```

It is not mandatory to specify the file system type using the `-t` option, since the kernel can generally figure it out for itself. If the partition is mentioned in `/etc/fstab`, it is sufficient to give either the mount point *or* the device file:

```
# mount /dev/sda5                                   One possibility …
# mount /home                                       … and another
```

Generally speaking, the `/etc/fstab` file describes the composition of the whole file system structure from various file systems that can be located on different partitions, disks etc. In addition to the device names and corresponding mount points, you can specify various options used to mount the file systems. The allowable options depend on the file system; many options are to be found in `mount`(8). `/etc/fstab`

A typical `/etc/fstab` file could look similar to Figure 15.1. The root partition usually occupies the first line. Besides the "normal" file systems, pseudo file systems such as `devpts` or `proc` and the swap areas are mentioned here.

The third field describes the type of the file system in question. Entries like `ext3` and `iso9660` speak for themselves (if `mount` cannot decide what to do with the type specification, it tries to delegate the job to a program called `/sbin/mount.`⟨*type*⟩), `swap` refers to swap space (which does not require mounting), and `auto` means that `mount` should try to determine the file system's type. type

To guess, `mount` utilises the content of the `/etc/filesystems` file, or, if that file does not exist, the `/proc/filesystems` file. (`/proc/filesystems` is also read if `/etc/filesystems` ends with a line containing just an asterisk.) In any case, `mount` processes only those lines that are not marked `nodev`. For your edification, here is a snippet from a typical `/proc/filesystems` file:

```
nodev   sysfs
nodev   rootfs
◁◁◁◁◁
nodev   usbfs
        ext3
nodev   nfs
        vfat
```

```
        xfs
◁◁◁◁◁
```

The kernel generates `/proc/filesystems` dynamically based on those file systems for which it actually contains drivers. `/etc/filesystems` is useful if you want to specify an order for `mount`'s guesswork that deviates from the one resulting from `/proc/filesystems` (which you cannot influence).

Before `mount` refers to `/etc/filesystems`, it tries its luck with the `libblkid` and `libvolume_id` libraries, both of which are (among other things) able to determine which type of file system exists on a medium. You can experiment with these libraries using the command line programs `blkid` and `vol_id`:

```
# blkid /dev/sdb1
/dev/sdb1: LABEL="TESTBTRFS" UUID="d38d6bd1-66c3-49c6-b272-eabdae▷
 ◁ 877368" UUID_SUB="3c093524-2a83-4af0-8290-c22f2ab44ef3" ▷
 ◁ TYPE="btrfs" PARTLABEL="Linux filesystem" ▷
 ◁ PARTUUID="ade1d2db-7412-4bc1-8eab-e42fdee9882b"
```

options The fourth field contains the options, including:

`defaults` Is not really an option, but merely a place holder for the standard options (see `mount`(8)).

`noauto` Opposite of `auto`, keeps a file system from being mounted automatically when the system is booted.

`user` In principle, only `root` can mount storage devices (normal users may only use the simple `mount` command to display information), unless the `user` option is set. In this case, normal users may say "`mount` ⟨*device*⟩" or "`mount` ⟨*mount point*⟩"; this will mount the named device on the designated mount point. The `user` option will allow the mounting user to unmount the device (`root`, too); there is a similar option `users` that allows any user to unmount the device.

`sync` Write operations are not buffered in RAM but written to the medium directly. The end of the write operation is only signaled to the application program once the data have actually been written to the medium. This is useful for floppies or USB thumb drives, which might otherwise be inadvertently removed from the drive while unwritten data is still buffered in RAM.

`ro` This file system is mounted for reading only, not writing (opposite of `rw`)

`exec` Executable files on this file system may be invoked. The opposite is `noexec`; `exec` is given here because the `user` option implies the `noexec` option (among others).

As you can see in the `/dev/sdb` entry, later options can overwrite earlier ones: `user` implies the `noexec` option, but the `exec` farther on the right of the line overwrites this default.

15.2.3 Labels and UUIDs

We showed you how to mount file systems using device names such as `/dev/hda1`. This has the disadvantage, though, that the correspondence between device files and actual devices is not necessarily fixed: As soon as you remove or repartition a disk or add another, the correspondence may change and you will have to adjust the configuration in `/etc/fstab`. With some device types, such as USB media, you cannot by design rely on anything. This is where labels and UUIDs come in.

label A **label** is a piece of arbitrary text of up to 16 characters that is placed in a file system's super block. If you have forgotten to assign a label when creating the

file system, you can add one (or modify an existing one) at any time using `e2label`. The command

```
# e2label /dev/sda3 home
```

(for example) lets you refer to `/dev/sda3` as `LABEL=home`, e. g., using

```
# mount -t ext2 LABEL=home /home
```

The system will then search all available partitions for a file system containing this label.

You can do the same using the `-L` option of `tune2fs`:

```
# tune2fs -L home /dev/sda3
```

The other file systems have their ways and means to set labels, too. With Btrfs, for example, you can either specify one when the file system is generated (option "`-L`") or use

```
# btrfs filesystem label /dev/sdb1 MYLABEL
```

If you have very many disks or computers and labels do not provide the required degree of uniqueness, you can fall back to a "universally unique identifier" or **UUID**. An UUID typically looks like

UUID

```
$ uuidgen
bea6383f-22a7-453f-8ef5-a5b895c8ccb0
```

and is generated automatically and randomly when a file system is created. This ensures that no two file systems share the same UUID. Other than that, UUIDs are used much like labels, except that you now need to use `UUID=bea6383f-22a7-453f-8ef5-a5b895c8ccb0` (Gulp.) You can also set UUIDs by means of `tune2fs`, or create completely new ones using

```
# tune2fs -U random /dev/hda3
```

This should seldom prove necessary, though, for example if you replace a disk or have cloned a file system.

Incidentally, you can determine a file system's UUID using

```
# tune2fs -l /dev/hda2 | grep UUID
Filesystem UUID:              4886d1a2-a40d-4b0e-ae3c-731dd4692a77
```

With other file systems (XFS, Btrfs) you can query a file system's UUID (`blkid` is your friend) but not necessarily change it.

The

```
# lsblk -o +UUID
```

command gives you an overview of all your block devices and their UUIDs.

You can also access swap partitions using labels or UUIDs:

```
# swapon -L swap1
# swapon -U 88e5f06d-66d9-4747-bb32-e159c4b3b247
```

You can find the UUID of a swap partition using `blkid` or `lsblk`, or check the `/dev/disk/by-uuid` directory. If your swap partition does not have a UUID nor a label, you can use `mkswap` to assign one.

You can also use labels and UUIDs in the `/etc/fstab` file (one might indeed claim that this is the whole point of the exercise). Simply put

```
LABEL=home
```

or

```
UUID=bea6383f-22a7-453f-8ef5-a5b895c8ccb0
```

into the first field instead of the device name. Of course this also works for swap space.

Exercises

15.6 [!2] Consider the entries in files `/etc/fstab` and `/etc/mtab`. How do they differ?

15.3 The `dd` Command

`dd` is a command for copying files "by block". It is used with particular preference to create "images", that is to say complete copies of file systems—for example, when preparing for the complete restoration of the system in case of a catastrophic disk failure.

`dd` (short for "copy and convert"[2]) reads data block by block from an input file and writes it unchanged to an output file. The data's type is of no consequence. Neither does it matter to `dd` whether the files in question are regular files or device files.

Using `dd`, you can create a quickly-restorable backup copy of your system partition as follows:

```
# dd if=/dev/sda2 of=/data/sda2.dump
```

This saves the second partition of the first SCSI disk to a file called `/data/sda2.dump`—this file should of course be located on another disk. If your first disk is damaged, you can easily and very quickly restore the original state after replacing it with an identical (!) drive:

```
# dd if=/data/sda2.dump of=/dev/sda2
```

(If `/dev/sda` is your system disk, you must of course have booted from a rescue or live system.)

partition table

For this to work, the new disk drive's geometry must match that of the old one. In addition, the new disk drive needs a partition table that is equivalent to the old one. You can save the partition table using `dd` as well (at least for MBR-partitioned disks):

```
# dd if=/dev/sda of=/media/floppy/mbr_sda.dump bs=512 count=1
```

Used like this, `dd` does not save all of the hard disk to floppy disk, but writes everything in chunks of 512 bytes (`bs=512`)—one chunk (`count=1`), to be exact. In effect, all of the MBR is written to the floppy. This kills two birds with the same stone: the boot loader's stage 1 also ends up back on the hard disk after the MBR is restored:

[2] Seriously! The `dd` command is inspired by a corresponding command on IBM mainframes (hence the parameter syntax, which according to Unix standards is quite quaint), which was called `CC` (as in "copy and convert"), but on Unix the `cc` name was already spoken for by the C compiler.

```
# dd if=/media/floppy/mbr_sda.dump of=/dev/sda
```

You do not need to specify a chunk size here; the file is just written once and is (hopefully) only 512 bytes in size.

Caution: The MBR does not contain partitioning information for logical partitions! IF you use logical partitions, you should use a program like `sfdisk` to save all of the partitioning scheme—see below.

To save partitioning information for GPT-partitioned disks, use, for example, `gdisk` (the `b` command).

`dd` can also be used to make the content of CD-ROMs or DVDs permanently accessible from hard disk. The "`dd if=/dev/cdrom of=/data/cdrom1.iso`" places the content of the CD-ROM on disk. Since the file is an ISO image, hence contains a file system that the Linux kernel can interpret, it can also be mounted. After "`mount -o loop,ro /data/cdrom.iso /mnt`" you can access the image's content. You can of course make this permanent using `/etc/fstab`.

Commands in this Chapter

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`dd` "*Copy and convert*", copies files or file systems block by block and does simple conversions `dd`(1) 244
`debugfs` File system debugger for fixing badly damaged file systems. For gurus only! `debugfs`(8) 232
`dumpe2fs` Displays internal management data of the `ext2` file system. For gurus only! `dumpe2fs`(8) 232
`dumpreiserfs` Displays internal management data of the Reiser file system. For gurus only! `dumpreiserfs`(8) 235
`e2fsck` Checks `ext2` and `ext3` file systems for consistency `e2fsck`(8) 231
`e2label` Changes the label on an ext2/3 file system `e2label`(8) 242
`fsck` Organises file system consistency checks `fsck`(8) 225
`lsblk` Lists available block devices `lsblk`(8) 243
`mkdosfs` Creates FAT-formatted file systems `mkfs.vfat`(8) 238
`mke2fs` Creates `ext2` or `ext3` file systems `mke2fs`(8) 229
`mkfs` Manages file system creation `mkfs`(8) 224
`mkfs.vfat` Creates FAT-formatted file systems `mkfs.vfat`(8) 238
`mkfs.xfs` Creates XFS-formatted file systems `mkfs.xfs`(8) 235
`mkreiserfs` Creates Reiser file systems `mkreiserfs`(8) 235
`mkswap` Initialises a swap partition or file `mkswap`(8) 239
`mount` Includes a file system in the directory tree `mount`(8), `mount`(2) 240
`reiserfsck` Checks a Reiser file system for consistency `reiserfsck`(8) 235
`resize_reiserfs` Changes the size of a Reiser file system `resize_reiserfs`(8) 235
`swapoff` Deactivates a swap partition or file `swapoff`(8) 239
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`tune2fs` Adjusts `ext2` and `ext3` file system parameters `tunefs`(8) 232, 243
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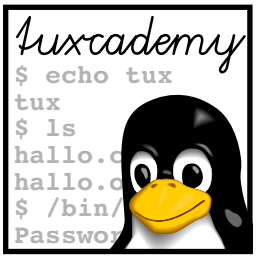
`xfs_mdrestore` Restores an XFS metadata dump to a filesystem image `xfs_mdrestore`(8) 236
`xfs_metadump` Produces metadata dumps from XFS file systems `xfs_metadump`(8) 236

Summary

- After partitioning, a file system must be created on a new partition before it can be used. To do so, Linux provides the `mkfs` command (with a number of file-system-specific auxiliary tools that do the actual work).
- Improperly unmounted file systems may exhibit inconsistencies. If Linux notes such file systems when it boots, these will be checked automatically and, if possible, repaired. These checks can also be triggered manually using programs such as `fsck` and `e2fsck`.
- The `mount` command serves to integrate file systems into the directory tree.
- With `dd`, partitions can be backed up at block level.



16

Booting Linux

Contents

Goals

- Knowing the GRUB Legacy and GRUB 2 boot loaders and how to configure them
- Being able to diagnose and fix system start problems

Prerequisites

- Basic knowledge of the PC startup procedure
- Handling of configuration files

16.1 Fundamentals

When you switch on a Linux computer, an interesting and intricate process takes place during which the computer initialises and tests itself before launching the actual operating system (Linux). In this chapter, we consider this process in some detail and explain how to adapt it to your requirements and to find and repair problems if necessary.


The word "to boot" is short for "to pull oneself up by one's bootstraps". While, as Newton tells us, this is a physical impossibility, it is a good image for what goes on, namely that the computer gets itself started from the most basic beginnings.

Immediately after the computer is switched on, its firmware—depending on the computer's age, either the "basic input/output system" (BIOS) or "unified extensible firmware interface" (UEFI) takes control. What happens next depends on the firmware.

BIOS startup On BIOS-based systems, the BIOS searches for an operating system on media like CD-ROM or hard disk, depending on the boot order specified in the BIOS setup. On disks (hard or floppy), the first 512 bytes of the boot medium will be read. These contain special information concerning the system start. Generally, this area is called the **boot sector**; a hard disk's boot sector is also called the **master boot record** (MBR).

boot sector
master boot record


We already came across the MBR when discussing the eponymous disk partitioning scheme in Chapter 14. We're now looking at the part of the MBR that does *not* contain partitioning information.

The first 446 bytes of the MBR contain a minimal startup program which in turn is responsible for starting the operating system—the **boot loader**. The rest is occupied by the partition table. 446 bytes are not enough for the complete boot loader, but they suffice for a small program which can fetch the rest of the boot loader from disk using the BIOS. In the space between the MBR and the start of the first partition—at least sector 63, today more likely sector 2048 there is enough room for the rest of the boot loader. (We shall come back to that topic presently.)

boot loader

Modern boot loaders for Linux (in particular, the "Grand Unified Boot loader" or **GRUB**) can read common Linux file systems and are therefore able to find the operating system kernel on a Linux partition, load it into RAM and start it there.

GRUB

boot manager


GRUB serves not just as a boot loader, but also as a **boot manager**. As such, it can, according to the user's preferences, launch various Linux kernels or even other operating systems.


Bootable CD-ROMs or DVDs play an important role for the installation or update of Linux systems, or as the basis of "live systems" that run directly from read-only media without having to be installed on disk. To boot a Linux computer from CD, you must in the simplest case ensure that the CD-ROM drive is ahead of the firmware's boot order than the hard disk, and start the computer while the desired CD is in the drive.


In the BIOS tradition, booting off CD-ROMs follows different rules than booting off hard disk (or floppy disk). The "El Torito" standard (which specifies these rules) basically defines two approaches: One method is to include an image of a bootable floppy disk on the CD-ROM (it may be as big as 2.88 MiB), which the BIOS finds and boots; the other method is to boot directly off the CD-ROM, which requires a specialised boot loader (such as `ISOLINUX` for Linux).


With suitable hardware and software (usually part of the firmware today), a PC can boot via the network. The kernel, root file system, and everything else can reside on a remote server, and the computer itself can be diskless and hence ear-friendly. The details would be a bit too involved and are irrelevant for LPIC-1 in any case; if necessary, look for keywords such as "PXE" or "Linux Terminal Server Project".

UEFI boot procedure UEFI-based systems do not use boot sectors. Instead, the UEFI firmware itself contains a boot manager which exploits information about the desired operating system which is held in non-volatile RAM (NVRAM). Boot loaders for the different operating systems on the computer are stored as regular files on an "EFI system partition" (ESP), where the firmware can read and start them. The system either finds the name of the desired boot loader in NVRAM, or else falls back to the default name, `/EFI/BOOT/BOOTX64.EFI`. (The `X64` here stands for "64-bit Intel-style PC". Theoretically, UEFI also works for 32-bit systems, but that doesn't mean it is a great idea.) The operating-system specific boot loader then takes care of the rest, as in the BIOS startup procedure.


The ESP must officially contain a FAT32 file system (there are Linux distributions that use FAT16, but that leads to problems with Windows 7, which requires FAT32). A size of 100 MiB is generally sufficient, but some UEFI implementations have trouble with FAT32 ESPs which are smaller than 512 MiB, and the Linux `mkfs` command will default to FAT16 for partitions of up to 520 MiB. With today's prices for hard disks, there is little reason not to play it safe and create an ESP of around 550 MiB.


In principle it is possible to simply write a complete Linux kernel as `BOOTX64.EFI` on the ESP and thus manage without any boot loader at all. PC-based Linux distributions don't usually do this, but this approach is interesting for embedded systems.


Many UEFI-based systems also allow BIOS-style booting from MBR-partitioned disks, i. e., with a boot sector. This is called "compatibility support module" or CSM. Sometimes this method is used automatically if a traditional MBR is found on the first recognised hard disk. This precludes an UEFI boot from an ESP on an MBR-partitioned disk and is not 100% ideologically pure.


UEFI-based systems boot from CD-ROM by looking for a file called `/EFI/BOOT/BOOTX64.EFI`—like they would for disks. (It is feasible to produce CD-ROMs that boot via UEFI on UEFI-based systems and via El Torito on BIOS-based systems.)

UEFI Secure Boot

"UEFI Secure Boot" is supposed to prevent computers being infected with "root kits" that usurp the startup procedure and take over the system before the actual operating system is being started. Here the firmware refuses to start boot loaders that have not been cryptographically signed using an appropriate key. Approved boot loaders, in turn, are responsible for only launching operating system kernels that have been cryptographically signed using an appropriate key, and approved operating system kernels are expected to insist on correct digital signatures for dynamically loadable drivers. The goal is for the system to run only "trusted" software, at least as far as the operating system is concerned.


A side effect is that this way one gets to handicap or exclude potentially undesirable operating systems. In principle, a company like Microsoft could exert pressure on the PC industry to only allow boot loaders and operating systems signed by Microsoft; since various anti-trust agencies would take a dim view to this, it is unlikely that such a step would become part of official company policy. It is more likely that the manufacturers of PC motherboards and UEFI implementations concentrate their testing and debugging

efforts on the "boot Windows" application, and that Linux boot loaders will be difficult or impossible to get to run simply due to inadvertent firmware bugs.

Shim

Linux supports UEFI Secure Boot in various ways. There is a boot loader called "Shim" (developed by Matthew Garrett) which a distributor can have signed by Microsoft. UEFI starts Shim and Shim then starts another boot loader or operating system kernel. These can be signed or unsigned; the security envisioned by UEFI Secure Boot is, of course, only obtainable with the signatures. You can install your own keys and then sign your own (self-compiled) kernels.

The details for this would be carrying things too far. Consult the Linup Front training manual *Linux System Customisation*

PreLoader

An alternative to Shim is "PreLoader" (by James Bottomley, distributed by the Linux Foundation). PreLoader is simpler than Shim and makes it possible to accredit a (possibly unsigned) subsequent boot loader with the system, and boot it later without further enquiries.

Hard disks: MBR vs. GPT The question of which partitioning scheme a hard disk is using and the question of whether the computer boots via the BIOS (or CSM) or UEFI really don't have a lot to do with each other. At least with Linux it is perfectly possible to boot a BIOS-based system from a GPT-partitioned disk or a UEFI-based system from an MBR-partitioned disk (the latter possibly via CSM).

To start a BIOS-based system from a GPT-partitioned disk it makes sense to create a "BIOS boot partition" to hold that part of the boot loader that does not fit into the MBR. The alternative—using the empty space between the MBR and the start of the first partition—is not reliable for GPT-partitioned disks, since the GPT partition table takes up at least part of this space and/or the first partition might start immediately after the GPT partition table. The BIOS boot partition does not need to be huge at all; 1 MiB is probably amply enough.

After the boot loader The boot loader loads the Linux operating system kernel and passes the control to it. With that, it is itself extraneous and can be removed from the system; the firmware, too, will be ignored from now on—the kernel is left to its own devices. In particular, it must be able to access all drivers required to initialise the storage medium containing the root file system, as well as that file system itself (the boot loader used the firmware to access the disk), typically at least a driver for an IDE, SATA, or SCSI controller and the file system in question. These drivers must be compiled into the kernel or—the preferred method today—will be taken from "early userspace", which can be configured without having to recompile the kernel. (As soon as the root file system is available, everything is peachy because all drivers can be read from there.) The boot loader's tasks also include reading the early-userspace data.

The "early userspace" used to be called an "initial RAM disk", because the data was read into memory *en bloc* as a (usually read-only) medium, and treated by the kernel like a block-oriented disk. There used to be special compressed file systems for this application. The method most commonly used today stipulates that the early-userspace data is available as a `cpio` archive which the kernel extracts directly into the disk block cache, as if you had read each file in the archive directly from a (hypothetical) storage medium. This makes it easier to get rid of the early userspace once it is no longer required.

The kernel uses `cpio` instead of `tar` because `cpio` archives in the format used by the kernel are better-standardised and easier to unpack than `tar` archives.

As soon as the "early userspace" is available, a program called `/init` is invoked. This is in charge of the remaining system initialisation, which includes tasks such as the identification of the storage medium that should be made available as the root file system, the loading of any required drivers to access that medium and the file system (these drivers, of course, also come from early userspace), possibly the (rudimentary) configuration of the network in case the root file system resides on a remote file server, and so on. Subsequently, the early userspace puts the desired root file system into place at "`/`" and transfers control to the actual init program—today most often either System-V init (Chapter 17) or systemd (Chapter 18), in each case under the name of `/sbin/init`. (You can juse the kernel command line option `init=` to pick a different program.)

If no early userspace exists, the operating system kernel makes the storage medium named on its command line using the `root=` option available as the root file system, and starts the program given by the `init=` option, by default `/sbin/init`.

Exercises

16.1 [2] Whereabouts on an MBR-partitioned hard disk may a boot loader reside? Why?

16.2 GRUB Legacy

16.2.1 GRUB Basics

Many distributions nowadays use GRUB as their standard boot loader. It has various advantages compared to LILO, most notably the fact that it can handle the common Linux file systems. This means that it can read the kernel directly from a file such as `/boot/vmlinuz`, and is thus immune against problems that can develop if you install a new kernel or make other changes to your system. Furthermore, on the whole GRUB is more convenient—for example offering an interactive GRUB shell featuring various commands and thus allowing changes to the boot setup for special purposes or in case of problems.

GRUB shell

The GRUB shell allows access to the file system without using the usual access control mechanism. It should therefore never be made available to unauthorised people, but be protected by a password (on important computers, at least). See also Section 16.2.5.

Right now there are two widespread versions of GRUB: The older version ("GRUB Legacy") is found in older Linux distributions—especially those with an "enterprise" flavour'—, while the newer distributions tend to rely on the more modern version GRUB 2 (Section 16.2.4).

The basic approach taken by GRUB Legacy follows the procedure outlined in Section 16.1. During a BIOS-based startup, the BIOS finds the first part ("stage 1") of the boot loader in the MBR of the boot disk (all 446 bytes of it). Stage 1 is able to find the next stage based on sector lists stored inside the program (as part of the 446 bytes) and the BIOS disk access functions[1].

The "next stage" is usually stage 1.5, which is stored in the otherwise unused space immediately after the MBR and before the start of the first partition. Stage 1.5 has rudimentary support for Linux file systems and can find GRUB's "stage 2" within the file system (normally below `/boot/grub`). Stage 2 may be anywhere on the disk. It can read file systems, too, and it fetches its configuration file, displays the menu, and finally loads and starts the desired operating system (in the case of Linux, possibly including the "early userspace").

[1] At least as long as the next stage can be found within the first 1024 "cylinders" of the disk. There are historical reasons for this and it can, if necessary, be enforced through appropriate partitioning.


Stage 1 could read stage 2 directly, but this would be subject to the same restrictions as reading stage 1.5 (no file system access and only within the first 1024 cylinders). This is why things aren't usually arranged that way.


GRUB can directly load and start most Unix-like operating systems for x86 computers, including Linux, Minix, NetBSD, GNU Hurd, Solaris, ReactOS, Xen, and VMware ESXi[2]. The relevant standard is called "multiboot". GRUB starts multiboot-incompatible systems (notably Windows) by invoking the boot loader of the operating system in question—a procedure called "chain loading".

To make GRUB Legacy work with GPT-partitioned disks, you need a BIOS boot partition to store its stage 1.5. There is a version of GRUB Legacy that can deal with UEFI systems, but for UEFI boot you are generally better off using a different boot loader.

16.2.2 GRUB Legacy Configuration

`/boot/grub/menu.lst`

The main configuration file for GRUB Legacy is usually stored as `/boot/grub/menu.lst`. It contains basic configuration as well as the settings for the operating systems to be booted. This file might look as follows:

```
default 1
timeout 10

title linux
   kernel (hd0,1)/boot/vmlinuz root=/dev/sda2
   initrd (hd0,1)/boot/initrd
title failsafe
   kernel (hd0,1)/boot/vmlinuz.bak root=/dev/sda2 apm=off acpi=off
   initrd (hd0,1)/initrd.bak
title someothersystem
   root (hd0,2)
   makeactive
   chainloader +1
title floppy
   root (fd0)
   chainloader +1
```

The individual parameters have the following meaning:

`default` Denotes the default system to be booted. Caution: GRUB counts from 0! Thus, by default, the configuration above launches the `failsafe` entry.

`timeout` This is how many seconds the GRUB menu will be displayed before the `default` entry will be booted.

`title` Opens an operating system entry and specifies its name, which will be displayed within the GRUB menu.

`kernel` Specifies the Linux kernel to be booted. `(hd0,1)/boot/vmlinuz`, for example, means that the kernel is to be found in `/boot/vmlinuz` on the first partition of the zeroth hard disk, thus in our example, for `linux`, on `/dev/hda2`. Caution: The zeroth hard disk is the first hard disk in the BIOS boot order! There is no distinction between IDE and SCSI! And: GRUB starts counting at 0 … Incidentally, GRUB takes the exact mapping of the individual drives from the `device.map` file.

After the kernel location, arbitrary kernel parameters can be passed. This includes the `boot=` entry.

[2] The "U" in GRUB must stand for something, after all.

initrd Denotes the location of the cpio archive used for the "early userspace".

root Determines the system partition for foreign operating systems. You can also specify media that only occasionally contain something bootable, such as the floppy disk drive—this will let you boot from floppy even though the floppy disk is disabled in the BIOS boot order.

chainloader +1 Denotes the boot loader to be loaded from the foreign system's system partition. Generally this is the content of that partition's boot loader.

makeactive Marks the specified partition temporarily as "bootable". Some operating systems (not Linux) require this in order to be able to boot off the partition in question. By the way: GRUB supports a few more such directives, for example map, which makes it possible to fool a system into believing it is installed on a different hard disk (than, e. g., the often disdained second disk) than it actually is.

16.2.3 GRUB Legacy Installation

Here "installation" does not refer to the installation of an RPM package but the installation of the GRUB boot sector, or stage 1 (and very likely the stage 1.5). This is very seldom required, for example during the original installation of the system (where the installation procedure of your distribution will do it for you).

The installation is done using the grub command, which invokes the GRUB shell. It is most convenient to use a "batch" file, since otherwise you would have to start from the very beginning after an erroneous input. Some distributions (e. g., those by SUSE/Novell) already come with a suitable file. In this case, the installation procedure might look like

```
# grub --batch --device-map=/boot/grub/device.map < /etc/grub.inst
```

The --device-map option creates a device.map file under the specified name, if none exists already.

The /etc/grub.inst file could have the following content: /etc/grub.inst

```
root (hd0,1)
setup (hd0)
quit
```

Here, root denotes the partition containing GRUB's "home directory" (usually /boot/grub—the other parts of GRUB necessary for the installation will be looked for in this directory).

The partition you specify using root here has nothing to do with the partition containing your Linux distribution's root directory, which you specify using root= in your Linux kernels' menu entries. At least not necessarily. See also Section 16.3.

setup installs GRUB on the specified device, here in hd0's MBR. GRUB's setup command is a simplified version of a more general command called install, which should work in most cases.

Alternatively, you may use the grub-install script to install the GRUB components. This comes with some distributions. grub-install

Inside the GRUB shell it is straightforward to figure out how to specify a hard disk in the root or kernel directives. The GRUB shell command find is useful here: disk specification

```
# grub
◁◁◁◁◁
grub> find /boot/vmlinuz
 (hd0,1)
```

16.2.4 GRUB 2

new implementation

GRUB 2 is a completely new implementation of the boot loader that did not make particular concessions to GRUB-Legacy compatibility. GRUB 2 was officially released in June 2012, even though various distributions used earlier versions by default.

The LPIC-1 certificate requires knowledge of GRUB 2 from version 3.5 of the exam (starting on 2 July 2012).

As before, GRUB 2 consists of several stages that build on each other:

- Stage 1 (`boot.img`) is placed inside the MBR (or a partition's boot sector) on BIOS-based systems. It can read the first sector of stage 1.5 by means of the BIOS, and that in turn will read the remainder of stage 1.5.
- Stage 1.5 (`core.img`) goes either between the MBR and the first partition (on MBR-partitioned disks) or else into the BIOS boot partition (on GPT-partitioned disks). Stage 1.5 consists of a first sector which is tailored to the boot medium (disk, CD-ROM, network, …) as well as a "kernel" that provides rudimentary functionality like device and file access, processing a command line, etc., and an arbitrary list of modules.

  This modular structure makes it easy to adapt stage 1.5 to size restrictions.

- GRUB 2 no longer includes an explicit stage 2; advanced functionality will be provided by modules and loaded on demand by stage 1.5. The modules can be found in `/boot/grub`, and the configuration file in `/boot/grub/grub.cfg`.

On UEFI-based systems, the boot loader sits on the ESP in a file called `EFI/`⟨*operating system*⟩`/grubx64.efi`, where ⟨*operating system*⟩ is something like `debian` or `fedora`. Have a look at the `/boot/efi/EFI` directory on your UEFI"=based Linux system.

Again, the "`x64`" in "`grubx64.efi`" stands for "64-bit PC".

configuration file

The configuration file for GRUB 2 looks markedly different from that for GRUB Legacy, and is also rather more complicated (it resembles a bash script more than a GRUB Legacy configuration file). The GRUB 2 authors assume that system managers will not create and maintain this file manually. Instead there is a command

`grub-mkconfig`

called `grub-mkconfig` which can generate a `grub.cfg` file. To do so, it makes use of a set of auxiliary tools (shell scripts) in `/etc/grub.d`, which, e. g., search `/boot` for Linux kernels to add to the GRUB boot menu. (`grub-mkconfig` writes the new configuration file to its standard output; the `update-grub` command calls `grub-mkconfig` and redirects its output to `/boot/grub/grub.cfg`.)

`update-grub`

You should therefore not modify `/boot/grub/grub.cfg` directly, since your distribution is likely to invoke `update-grub` after, e. g., installing a kernel update, which would overwrite your changes to `grub.cfg`.

Usually you can, for instance, add more items to the GRUB 2 boot menu by editing the `/etc/grub.d/40_custom` file. `grub-mkconfig` will copy the content of this file verbatim into the `grub.cfg` file. As an alternative, you could add your configuration settings to the `/boot/grub/custom.cfg` file, which will be read by `grub.cfg` if it exists.

For completeness' sake, here is an excerpt from a typical `grub.cfg` file. By analogy to the example in Section 16.2.2, a menu entry to start Linux might look like this for GRUB 2:

```
menuentry 'Linux' --class gnu-linux --class os {
  insmod gzio
  insmod part_msdos
  insmod ext2
```

```
  set root='(hd0,msdos2)'
  linux  /boot/vmlinuz root=/dev/hda2
  initrd /boot/initrd.img
}
```

(`grub-mkconfig` usually produces more complicated stuff.) Do note that the GRUB modules for decompression (`gzio`), for MS-DOS-like partitioning support (`part_msdos`) and the `ext2` file system must be loaded explicitly. With GRUB 2, partition numbering starts at 1 (it used to be 0 for GRUB Legacy), so `(hd0,msdos2)` refers to the second MS-DOS partition on the first hard disk. Instead of `kernel`, `linux` is used to start a Linux kernel.

16.2.5 Security Advice

The GRUB shell offers many features, in particular access to the file system without the `root` password! Even entering boot parameters may prove dangerous since it is easy to boot Linux directly into a `root` shell. GRUB makes it possible to close these loopholes by requiring a password.

boot parameters

password

For GRUB Legacy, the password is set in the `menu.lst` file. Here, the entry "`password --md5` ⟨*encrypted password*⟩" must be added to the global section. You can obtain the encrypted password via the `grub-md5-crypt` command (or "`md5crypt`" within the GRUB shell) and then use, e. g., the GUI to "copy and paste" it to the file. Afterwards, the password will need to be input whenever something is changed interactively in the GRUB menu.

You can also prevent particular systems from being booted by adding the `lock` option to the appropriate specific section within `menu.lst`. GRUB will query for the password when that system is to be booted. All other systems can still be started without a password.

Exercises

16.2 [2] Which file contains your boot loader's configuration? Create a new entry that will launch another operating system. Make a backup copy of the file first.

16.3 [!3] Prevent a normal user from circumventing `init` and booting directly into a shell. How do you generate a password request when a particular operating system is to be booted?

16.3 Kernel Parameters

Linux can accept a command line from the boot loader and evaluate it during the kernel start procedure. The parameters on this command line can configure device drivers and change various kernel options. This mechanism for Linux kernel runtime configuration is particularly helpful with the generic kernels on Linux distribution boot disks, when a system with problematic hardware needs to be booted. To do this, LILO supports the `append=`…option, while GRUB lets you append parameters to the `kernel` specification.

Linux kernel runtime configuration

Alternatively, you can enter parameters interactively as the system is being booted. You may have to grab GRUB's attention quickly enough (e. g., by pressing a cursor or shift key while the boot menu or splash screen is displayed). Afterwards you can navigate to the desired menu entry and type e. GRUB then presents you with the desired entry, which you can edit to your heart's content before continuing the boot operation.

There are various types of parameters. The first group overwrites hardcoded defaults, such as `root` or `rw`. Another group of parameters serves to configure de-

configuring device drivers

vice drivers. If one of these parameters occurs on the command line, the initialisation function for the device driver in question is called with the arguments specified there rather than the built-in default values.

Nowadays most Linux distributions use modular kernels that have only very few device drivers built in. Modular device drivers cannot be configured from the kernel command line.

During booting, if there are problems with a device driver that is built into the kernel, you can usually disable this driver by specifying the number 0 as the parameter for the corresponding boot parameter.

general settings

Finally, there are parameters governing general settings. These include, e. g., `init` or `reserve`. We shall be discussing some typical parameters from the multitude of possible settings. Further parameters can be found within the kernel sources' documentation area. Specific details for particular hardware must be researched in the manual or on the Internet.

`ro` This causes the kernel to mount the root partition read-only

`rw` This causes the kernel to mount the root partition with writing enabled, even if the kernel executable or the boot loader configuration file specify otherwise

`init=`⟨*program*⟩ Runs ⟨*program*⟩ (e. g., `/bin/bash`) instead of the customary `/sbin/init`

⟨*runlevel*⟩ Boots into runlevel ⟨*runlevel*⟩, where ⟨*runlevel*⟩ is generally a number between 1 and 5. Otherwise the initial runlevel is taken from `/etc/inittab`. (Irrelevant for computers running systemd.)

`single` Boots to single-user mode.

`maxcpus=`⟨*number*⟩ On a multi-processor (or, nowadays, multi-core) system, use only as many CPUs as specified. This is useful for troubleshooting or performance measurements.

`mem=`⟨*size*⟩ Specifies the amount of memory to be used. On the one hand, this is useful if the kernel cannot recognise the correct size by itself (fairly unlikely these days) or you want to check how the system behaves with little memory. The ⟨*size*⟩ is a number, optionally followed by a unit ("TokenG" for gibibytes, "`M`" for mebibytes, or "`K`" for kibibytes).

A typical mistake is something like `mem=512`. Linux is thrifty about system resources, but even it can't quite squeeze itself into 512 bytes (!) of RAM.

`panic=`⟨*seconds*⟩ Causes an automatic reboot after ⟨*seconds*⟩ in case of a catastrophic system crash (called a "kernel panic" in the patois, Edsger Dijkstra's dictum, "The use of anthropomorphic terminology when dealing with computing systems is a symptom of professional immaturity", notwithstanding).

`hd`*x*`=noprobe` Causes the kernel to ignore the disk-like device `/dev/hd`*x* (IDE disk, CD-ROM, …) completely. It is not sufficient to disable the device in the BIOS, as Linux will find and access it even so.

`noapic` and similar parameters like `nousb`, `apm=off`, and `acpi=off` tell Linux not to use certain kernel features. These options can help getting Linux to run at all on unusual computers, in order to analyse problems in these areas more thoroughly and sort them out.

A complete list of all parameters available on the kernel command line is given in the file `Documentation/kernel-parameters.txt`, which is part of the Linux source code. (However, before you install kernel sources just to get at this file, you should probably look for it on the Internet.)


Incidentally, if the kernel notices command-line options that do not correspond to kernel parameters, it passes them to the `init` process as environment variables.

`init` environment variables

16.4 System Startup Problems

16.4.1 Troubleshooting

Usually things are simple: You switch on the computer, stroll over to the coffee machine (or not—see Section 17.1), and when you come back you are greeted by the graphical login screen. But what to do if things don't work out that way?

The diagnosis of system startup problems sometimes isn't all that easy—all sorts of messages zoom by on the screen or (with some distributions) are not displayed at all, but hidden behind a nice little picture. The system logging service (`syslogd`) is also started only after a while. Fortunately, though, Linux does not leave you out in the cold if you want to look at the kernel boot messages at leisure.

For logging purposes, the system startup process can be divided into two phases. The "early" phase begins with the first signs of life of the kernel and continues up to the instant where the system logging service is activated. The "late" phase begins just then and finishes in principle when the computer is shut down.

The kernel writes early-phase messages into an internal buffer that can be displayed using the `dmesg` command. Various distributions arrange for these messages to be passed on to the system logging service as soon as possible so they will show up in the "official" log.

The system logging service, which we are not going to discuss in detail here, runs during the "late" phase. It will be covered in the Linup Front training manual, *Linux Administration II* (and the LPI-102 exam). For now it will be sufficient to know that most distribution place most messages sent to the system logging service into the `/var/log/messages` file. This is also where messages from the boot process end up if they have been sent after the logging service was started.


On Debian GNU/Linux, `/var/log/messages` contains only part of the system messages, namely anything that isn't a grave error message. If you would like to see *everything* you must look at `/var/log/syslog`—this contains all messages except (for privacy reasons) those dealing with authentication. The "early phase" kernel messages, too, incidentally.


Theoretically, messages sent after `init` was started but before the system logging service was launched might get lost. This is why the system logging service is usually among the first services started after `init`.

16.4.2 Typical Problems

Here are some of the typical snags you might encounter on booting:

The computer does not budge at all If your computer does nothing at all, it probably suffers from a hardware problem. (If you're diagnosing such a case by telephone, then do ask the obvious questions such as "Is the power cable plugged into the wall socket?"—perhaps the cleaning squad was desperate to find a place to plug in their vacuum cleaner—, and "Is the power switch at the back of the case switched to *On*?". Sometimes the simple things will do.) The same is likely when it just beeps or flashes its LEDs rhythmically but does not appear to actually start booting.


The beeps or flashes can allow the initiated to come up with a rough diagnosis of the problem. Details of hardware troubleshooting, though, are beyond the scope of this manual.

Things go wrong before the boot loader starts The firmware performs various self-tests and outputs error messages to the screen if things are wrong (such as malfunctioning RAM chips). We shall not discuss how to fix these problems. If everything works fine, your computer ought to identify the boot disk and launch the boot loader.

The boot loader does not finish This could be because the operating system cannot find it (e. g., because the drive it resides on does not show up in the firmware boot order) or it is damaged. In the former case you should ensure that your firmware does the Right Thing (not our topic). In the latter case you should receive at least a rudimentary error message, which together with the boot loader's documentation should allow you to come up with an explanation.

GRUB as a civilised piece of software produces clear-text error messages which are explained in more detail in the GRUB info documentation.

The cure for most of the fundamental (as opposed to configuration-related) boot loader problems, if they cannot be obviously reduced to disk or BIOS errors, consist of booting the system from CD-ROM—the distribution's "rescue system" or a "live distribution" such as Knoppix recommend themselves—and to re-install the boot loader.

The same applies to problems like a ruined partition table in the MBR. Should you ever accidentally overwrite your MBR, you can restore a backup (you do have one, don't you?) using `dd` or re-instate the partitioning using `sfdisk` (you do have a printout of your partition table stashed away somewhere, don't you?) and rewrite the boot loader.

In case of the ultimate worst-case partition table scenario, there are programs which will search the whole disk looking for places that look like file system superblocks, and (help) recover the partition scheme that way. We're keeping our fingers crossed on your behalf that you will never need to run such a program.

The kernel doesn't start Once the boot loader has done its thing the kernel should at least start (which generally leads to some activity on the screen). Distribution kernels are generic enough to run on most PCs, but there may still be problems, e. g., if you have a computer with extremely modern hardware which the kernel doesn't yet support (which is fatal if, for example, a driver for the disk controller is missing) or you have messed with the initial RAM disk (Shame, if you didn't know what you were doing!). It may be possible to reconfigure the BIOS (e. g., by switching a SATA disk controller into a "traditional" IDE-compatible mode) or to deactivate certain parts of the kernel (see Section 16.3) in order to get the computer to boot. It makes sense to have another computer around so you can search the Internet for help and explanations.

If you are fooling around with the kernel or want to install a new version of your distribution kernel, do take care to have a known-working kernel around. If you always have a working kernel in your boot loader menu, you can save yourself from the tedious job of slinging CDs about.

Other problems Once the kernel has finished its initialisations, it hands control off to the "init" process. You will find out more about this in Chapter 17. However, you should be out of the woods by then.

16.4.3 Rescue systems and Live Distributions

As a system administrator, you should always keep a "rescue system" for your distribution handy, since usually you need it exactly when you are least in a position to obtain it quickly. (This applies in particular if your Linux machine is your only computer.) A rescue system is a pared-down version of your distribution which you can launch from a CD or DVD (formerly a floppy disk or disks) and which runs in a RAM disk.

Should your Linux distribution not come with a separate rescue system on floppy disk or CD, then get a "live distribution" such as Knoppix. Live distributions are started from CD (or DVD) and work on your computer without needing to be installed first. You can find Knoppix as an ISO image on `http://www.knoppix.de/` or, every so often, as a freebie with computer magazines.

The advantage of rescue systems and live distributions consists in the fact that they work without involving your hard disk. Thus you can do things like `fsck` your root file system, which are forbidden while your system is running from hard disk. Here are a few problems and their solutions:

Hosed the kernel? Boot the rescue system and re-install the corresponding package. In the simplest case, you can enter your installed system's root file from the rescue system like so:

```
# mount -o rw /dev/sda1 /mnt                    Device name may differ
# chroot /mnt
# _                                  We are now seeing the installed distribution
```

After this you can activate the network interface or copy a kernel package from a USB key or CD-ROM and install it using the package management tool of your distribution.

Forgot the `root` password? Boot the rescue system and change to the installed distribution as above. Then do

```
# passwd
```

(You could of course fix this problem without a rescue system by restarting your system with "`init=/bin/bash rw`" as a kernel parameter.)

Live distributions such as Knoppix are also useful to check in the computer store whether Linux supports the hardware of the computer you have been drooling over for a while already. If Knoppix recognises a piece of hardware, you can as a rule get it to run with other Linux distributions too. If Knoppix does not recognise a piece of hardware, this may not be a grave problem (there might be a driver for it somewhere on the Internet that Knoppix does not know about) but you will at least be warned.

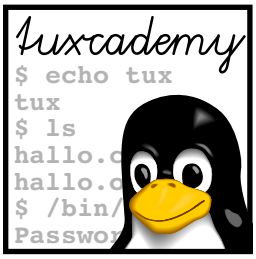
If there is a matching live version of your distribution—with Ubuntu, for example, the live CD and the installation CD are identical—, things are especially convenient, since the live distribution will typically recognise the same hardware that the installable distribution does.

Commands in this Chapter

dmesg Outputs the content of the kernel message buffer dmesg(8) 257
grub-md5-crypt Determines MD5-encrypted passwords for GRUB Legacy grub-md5-crypt(8) 255

Summary

- A boot loader is a program that can load and start an operating system.
- A boot manager is a boot lader that lets the user pick one of several operating systems or operating system installations.
- GRUB is a powerful boot manager with special properties—such as the possibility of accessing arbitrary files and a built-in command shell.
- The GRUB shell helps to install GRUB as well as to configure individual boot procedures.



17

System-V Init and the Init Process

Contents

Goals

- Understanding the System-V Init infrastructure
- Knowing `/etc/inittab` structure and syntax
- Understanding runlevels and init scripts
- Being able to shut down or restart the system orderly

Prerequisites

- Basic Linux system administration knowledge
- Knowledge of system start procedures (Chapter 16)

17.1 The Init Process

After the firmware, the boot loader, the operating system kernel and (possibly) the early userspace have done their thing, the "init process" takes over the reins. Its job is to finish system initialisation and supervise the ongoing operation of the system. For this, Linux locates and starts a program called `/sbin/init`.

/sbin/init

The init process always has process ID 1. If there is an early userspace, it inherits this from the process that was created to run `/init`, and subsequently goes on to replace its program text by that of the init process.

Incidentally, the init process enjoys a special privilege: it is the only process that cannot be aborted using "`kill -9`". (It can decide to shuffle off this mortal coil of its own accord, though.)

If the init process really quits, the kernel keeps running. There are purists who start a program as the init process that will set up packet filtering rules and then exit. Such a computer makes a practically impregnable firewall, but is somewhat inconvenient to reconfigure without a rescue system …

You can tell the Linux kernel to execute a different program as the init process by specifying an option like "`init=/sbin/myinit`" on boot. There are no special properties that this program must have, but you should remember that, if it ever finishes, you do not get another one without a reboot.

17.2 System-V Init

Basics The traditional infrastructure that most Linux distributions used to use is called "System-V init" (pronounced "sys-five init"). The "V" is a roman numeral 5, and it takes its name from the fact that it mostly follows the example of Unix System V, where something very similar showed up for the first time. That was during the 1980s.

System-V init

For some time there was the suspicion that an infrastructure designed approximately 30 years ago was no longer up to today's demands on a Linux computer's init system. (Just as a reminder: When System-V init was new, the typical Unix system was a VAX with 30 serial terminals.) Modern computers must, for example, be able to deal with frequent changes of hardware (cue USB), and that is something that System-V init finds relatively difficult to handle. Hence there were several suggestions for alternatives to System-V init. One of these—systemd by Lennart Poettering and Kay Sievers—seems to have won out and is the current or upcoming standard of practically all Linux distributions of importance (we discuss it in more detail in Chapter 18). Another is Upstart by Scott James Remnant (see Section 17.3).

runlevels

One of the characteristic features of System-V init are **runlevels**, which describe the system's state and the services that it offers. Furthermore, the init process ensures that users can log in on virtual consoles, directly-connected serial terminals, etc., and manages system access via modems if applicable. All of this is configured by means of the `/etc/inittab` file

/etc/inittab

The syntax of `/etc/inittab` (Figure 17.1), like that of many other Linux configuration files, is somewhat idiosyncratic (even if it is really AT&T's fault). All lines that are not either empty or comments— starting with "`#`" as usual—consist of four fields separated by colons:

Label The first field's purpose is to identify the line uniquely. You may pick an arbitrary combination of up to four characters. (Do yourself a favour and stick with letters and digits.) The label is not used for anything else.

```
# Standard runlevel
id:5:initdefault

# First script to be executed
si::bootwait:/etc/init.d/boot

# runlevels
l0:0:wait:/etc/init.d/rc 0
l1:1:wait:/etc/init.d/rc 1
l2:2:wait:/etc/init.d/rc 2
l3:3:wait:/etc/init.d/rc 3
#l4:4:wait:/etc/init.d/rc 4
l5:5:wait:/etc/init.d/rc 5
l6:6:wait:/etc/init.d/rc 6

ls:S:wait:/etc/init.d/rc S
~~:S:respawn:/sbin/sulogin

# Ctrl-Alt-Del
ca::ctrlaltdel:/sbin/shutdown -r -t 4 now

# Terminals
1:2345:respawn:/sbin/mingetty --noclear tty1
2:2345:respawn:/sbin/mingetty tty2
3:2345:respawn:/sbin/mingetty tty3
4:2345:respawn:/sbin/mingetty tty4
5:2345:respawn:/sbin/mingetty tty5
6:2345:respawn:/sbin/mingetty tty6

# Serial terminal
# S0:12345:respawn:/sbin/agetty -L 9600 ttyS0 vt102

# Modem
# mo:235:respawn:/usr/sbin/mgetty -s 38400 modem
```

Figure 17.1: A typical `/etc/inittab` file (excerpt)


This is not 100% true for lines describing terminals, where according to convention the label corresponds to the name of the device file in question, but without the "`tty`" at the beginning, hence `1` for `tty1` or `S0` for `ttyS0`. Nobody knows exactly why.

Runlevels The runlevels this line applies to. We haven't yet explained in detail how runlevels work, so excuse us for the moment for limiting ourselves to telling you that they are usually named with digits and the line in question will be considered in all runlevels whose digit appears in this field.


In addition to the runlevels with digits as names there is one called "`S`". More details follow below.

Action The third field specifies how to handle the line. The most important possibilities include

`respawn` The process described by this line will immediately be started again once it has finished. Typically this is used for terminals which, after the current user is done with their session, should be presented brand-new to the next user.

`wait` The process described by this line is executed once when the system changes to the runlevel in question, and `init` waits for it to finish.

`bootwait` The process described by this line will be executed once during system startup. `init` waits for it to finish. The runlevel field on this line will be ignored.

`initdefault` The runlevel field of this line specifies which runlevel the system shoud try to reach after booting.


With LSB-compliant distributions, this field usually says "`5`" if the system should accept logins on the graphical screen, otherwise "`3`". See below for details.


If this entry (or the whole file `/etc/inittab`) is missing, you will need to state a run level on the console.

`ctrlaltdel` Specifies what the system should do if the init process is being sent a `SIGINT`—which usually happens if anyone presses the Ctrl+Alt+Del combination. Normally this turns out to be some kind of `shutdown` (see Section 17.4).


There are a few other actions. `powerwait`, `powerfail`, `powerokwait`, and `powerfailnow`, for example, are used to interface System-V init with UPSs. The details are in the documentation (`init`(8) and `inittab`(5)).

Command The fourth field describes the command to be executed. It extends to the end of the line and you can put whatever you like.

If you have made changes to `/etc/inittab`, these do not immediately take effect. You must execute the "`telinit q`" command first in order to get `init` to reread the configuration file.

The Boot Script With System-V init, the init process starts a shell script, the boot script, typically `/etc/init.d/boot` (Novell/SUSE), `/etc/rc.d/init.d/boot` (Red Hat), or `/etc/init.d/rcS` (Debian). (The exact name occurs in `/etc/inittab`; look for an entry whose action is `bootwait`.)

The boot script performs tasks such as checking and possibly correcting the file systems listed in `/etc/fstab`, initialising the system name and Linux clock, and other important prerequisites for stable system operation. Next, kernel modules will be loaded if required, file systems mounted and so on. The specific actions and their exact order depend on the Linux distribution in use.


Today, `boot` usually confines itself to executing the files in a directory such as `/etc/init.d/boot.d` (SUSE) in turn. The files are executed in the order of their names. You can put additional files in this directory in order to execute custom code during system initialisation.

Exercises


17.1 [2] Can you find out where your distribution keeps the scripts that the boot script executes?


17.2 [!2] Name a few typical tasks performed by the boot script. In which order should these be executed?

Runlevels After executing the boot script, the init process attempts to place the system in one of the various runlevels. Exactly which one is given by `/etc/inittab` or determined at the system's boot prompt and passed through to `init` by the kernel. runlevels

The various runlevels and their meaning have by now been standardised across most distributions roughly as follows: standardised runlevels

1 Single-user mode with no networking

2 Multi-user mode with no network servers

3 Multi-user mode with network servers

4 Unused; may be configured individually if required

5 As runlevel 3, but with GUI login

6 Reboot

0 System halt


The system runs through the `S` (or `s`) runlevel during startup, before it changes over to one out of runlevels 2 to 5. If you put the system into runlevel 1 you will finally end up in runlevel `S`.

When the system is started, the preferred runlevels are 3 or 5—runlevel 5 is typical for workstations running a GUI, while runlevel 3 makes sense for server systems that may not even contain a video interface. In runlevel 3 you can always start a GUI afterwards or redirect graphics output to another computer by logging into your server from that machine over the network.


These predefined runlevels derive from the LSB standard. Not all distributions actually enforce them; Debian GNU/Linux, for example, mostly leaves runlevel assignment to the local administrator.


You may use runlevels 7 to 9 but you will have to configure them yourself.

During system operation, the runlevel can be changed using the `telinit` command. This command can only be executed as `root`: "`telinit 5`" changes immediately to runlevel ⟨*runlevel*⟩. All currently running services that are no longer required in the new runlevel will be stopped, while non-running services that are required in the new runlevel will be started. `telinit` command


You may use `init` in place of `telinit` (the latter is just a symbolic link to the former, anyway). The program checks its PID when it starts, and if it is not 1, it behaves like `telinit`, else `init`.

The `runlevel` command displays the previous and current runlevel: `runlevel`

```
# runlevel
N 5
```

Here the system is currently in runlevel 5, which, as the value "N" for the "previous runlevel" suggests, was entered right after the system start. Output such as "5 3" would mean that the last runlevel change consisted of bringing the system from runlevel 5 to runlevel 3.

We have concealed some more runlevels from you, namely the "on-demand runlevels" A, B, and C. You may make entries in /etc/inittab which are meant for any of these three runlevels and use the ondemand action, such as

```
xy:AB:ondemand:…
```

If you say something like

```
# telinit A
```

these entries are executed, but the actual runlevel does not change: If you were in runlevel 3 before the telinit command, you will still be there when it finishes. a, b, and c are synonyms for A, B, and C.

Exercises

17.3 [!2] Display the current runlevel. What exactly is being output? Change to runlevel 2. Check the current runlevel again.

17.4 [2] Try the on-demand runlevels: Add a line to /etc/inittab which applies to, e. g., runlevel A. Make init reread the inittab file. Then enter the »telinit A« command.

Init Scripts The services available in the various runlevels are started and stopped using the scripts in the /etc/init.d (Debian, Ubuntu, SUSE) or /etc/rc.d/init.d (Red Hat) directories. These scripts are executed when changing from one runlevel to another, but may also be invoked manually. You may also add your own scripts. All these scripts are collectively called **init scripts**.

init scripts

The init scripts>parametersinit scripts usually support parameters such asstart, stop, status, restart, or reload, which you can use to start, stop, …, the corresponding services. The "/etc/init.d/network restart" command might conceivably deactivate a system's network cards and restart them with an updated configuration.

Of course you do not need to start all services manually when the system is started or you want to switch runlevels. For each runlevel *r* there is a rc*r*.d directory in /etc (Debian and Ubuntu), /etc/rc.d (Red Hat), or /etc/init.d (SUSE). The services for each runlevel and the runlevel transitions are defined in terms of these directories, which contain symbolic links to the scripts in the init.d directory. These links are used by a script, typically called /etc/init.d/rc, to start and stop services when a runlevel is entered or exited.

runlevel directories

This is done according to the names of the links, in order to determine the starting and stopping order of the services. There are dependencies between various services—there would not be much point in starting network services such as the Samba or web servers before the system's basic networking support has been activated. The services for a runlevel are activated by calling all symbolic links in its directory that start with the letter "S", in lexicographical order with the start parameter. Since the link names contain a two-digit number after the "S", you can predetermine the order of invocation by carefully choosing these numbers. Accordingly, to deactivate the services within a runlevel, all the symbolic links starting with the letter "K" are called in lexicographical order with the stop parameter.

Activating services

If a running service is also supposed to run in the new run level, an extraneous restart can be avoided. Therefore, before invoking a `K` link, the `rc` script checks whether there is an `S` link for the same service in the new runlevel's directory. If so, the stopping and immediate restart are skipped.

Debian GNU/Linux takes a different approach: Whenever a new runlevel *r* is entered, *all* symbolic links in the *new* directory (`/etc/rcr.d`) are executed. Links beginning with a "`K`" are passed `stop` and links beginning with a "`S`" are passed `start` as the parameter.

Configuring services

To configure services in a runlevel or to create a new runlevel, you can in principle manipulate the symbolic links directly. However, most distributions deprecate this.

The Red Hat distributions use a program called `chkconfig` to configure runlevels. "`chkconfig quota 35`", for example, inserts the quota service not in runlevel 35, but runlevels 3 and 5. "`chkconfig -l`" gives a convenient overview of the configured runlevels.

The SUSE distributions use a program called `insserv` to order the services in each runlevel. It uses information contained in the init scripts to calculate a sequence for starting and stopping the services in each runlevel that takes the dependencies into account. In addition, YaST2 offers a graphical "runlevel editor", and there is a `chkconfig` program which however is just a front-end for `insserv`.

Nor do you have to create links by hand on Debian GNU/Linux—you may use the `update-rc.d` program. However, manual intervention is still allowed—`update-rc.d`'s purpose is really to allow Debian packages to integrate their init scripts into the boot sequence. With the

```
# update-rc.d mypackage defaults
```

command, the `/etc/init.d/mypackage` script will be started in runlevels 2, 3, 4, and 5 and stopped in runlevels 0, 1 and 6. You can change this behaviour by means of options. If you do not specify otherwise, `update-rc.d` uses the sequence number 20 to calculate the position of the service—contrary to SUSE and Red Hat, this is not automated.—The `insserv` command is available on Debian GNU/Linux as an optional package; if it is installed, it can manage at least those init scripts that do contain the necessary metadata like it would on the SUSE distributions. However, this has not been implemented throughout.

Exercises

17.5 [!2] What do you have to do to make the `syslog` service reread its configuration?

17.6 [1] How can you conveniently review the current runlevel configuration?

17.7 [!2] Remove the `cron` service from runlevel 2.

single-user mode

Single-User Mode In **single-user mode** (runlevel `S`), only the system administrator may work on the system console. There is no way of changing to other virtual consoles. The single-user mode is normally used for administrative work, especially if the file system needs to be repaired or the quota system set up.


You can mount the root file system read-only on booting, by passing the `S` option on the kernel command line. If you boot the system to single-user mode, you can also disable writing to the root file system "on the fly", using the `remount` and `ro` mount options: "`mount -o remount,ro /`" remounts the root partition read-only; "`mount -o remount,rw /`" undoes it again.


To remount a file system "read-only" while the system is running, no process may have opened a file on the file system for writing. This means that all such programs must be terminated using `kill`. These are likely to be daemons such as `syslogd` or `cron`.

It depends on your distribution whether or not you get to leave single-user mode, and how.


To leave single-user mode, Debian GNU/Linux recommends a reboot rather than something like »`telinit 2`«. This is because entering single-user mode kills all processes that are not required in signle-user mode. This removes some essential background processes that were started when the system passed through runlevel `S` during boot, which is why it is unwise to change from runlevel `S` to a multi-user runlevel.

Exercises


17.8 [!1] Put the system into single-user mode (*Hint:* `telinit`). What do you need to do to actually enter single-user mode?


17.9 [1] Convince yourself that you really are the single user on the system while single-user mode is active, and that no background processes are running.

17.3 Upstart

While System-V init traditionally stipulates a "synchronous" approach—the init system changes its state only through explicit user action, and the steps taken during a state change, like init scripts, are performed in sequence—, Upstart uses an "event-based" philosophy. This means that the system is supposed to react to external events (like plugging in an USB device). This happens "asynchronously". Starting and stopping services creates new events, so that—and that is one of the most important differences between System-V init and Upstart—a service can be restarted automatically if it crashes unexpectedly. (System-V init, on the other hand, wouldn't be bothered at all.)

Upstart has been deliberately designed to be compatible with System-V init, at least to a point where init scripts for services can be reused without changes.


Upstart was developed by Scott James Remnant, at the time an employee of Canonical (the company behind Ubuntu) and accordingly debuted in that distributon. Since Ubuntu 6.10 ("Edgy Eft") it is the standard init system on Ubuntu, although it used to be run in a System-V compatible mode at first; since Ubuntu 9.10 ("Karmic Koala") it is running in "native" mode.


It turns out that Ubuntu is currently in the process of switching over to systemd (see Chapter 18).


Since version 3.5 of the LPIC-1 certificate exams (as of 2 July 2012) you are expected to know that Upstart exists and what its major properties are. Configuration and operational details are not required.

```
# rsyslog - system logging daemon
#
# rsyslog is an enhanced multi-threaded replacement for the traditional
# syslog daemon, logging messages from applications

description     "system logging daemon"

start on filesystem
stop on runlevel [06]

expect fork
respawn

exec rsyslogd -c4
```

Figure 17.2: Upstart configuration file for job `rsyslog`

Upstart is also purported to accelerate the boot process by being able to initialise servides in parallel. In actual practice this isn't the case, as the limiting factor during booting is, for the most part, the speed with which blocks of data can be moved from disk to RAM. At the Linux Plumbers Conference 2008, Arjan van de Ven and Auke Kok demonstrated that it is possible to boot an Asus EeePC all the way to a usable desktop (i. e., not a Windows-like desktop with a churning hard disk in the background) within 5 seconds. This work was based on System-V init rather than Upstart.

Upstart configuration is based on the idea of "Jobs" that take on the role of init scripts (although init scripts, as we mentioned, are also supported). Upstart distinguishes "tasks"—jobs that run for a limited time and then shut themselves down—and "services"—jobs that run permanently "in the background". Jobs

Tasks can be long-running, too. The main criterion is that services—think of a mail, database, or web server—do not terminate of their own accord while tasks do.

Jobs are configured using files within the `/etc/init` directory. The names of these files derive from the job name and the "`.conf`" suffix. See Figure 17.2 for an example.

One of the main objectives of Upstart is to avoid the large amounts of template-like code typical for most System-V init scripts. Accordingly, the Upstart configuration file confines itself to stating how the service is to be started ("`exec rsyslogd -c4`"). In addition, it specifies that the service is to be restarted in case it crashes ("`respawn`") and how Upstart can find out which process to track ("`expect fork`" says that the `rsyslog` process puts itself into the background by creating a child process and then exiting—Upstart must then watch out for that child process).—Compare this to `/etc/init.d/syslogd` (or similar) on a typical Linux based on System-V init.

While with "classic" System-V init the system administrator assigns a "global" order in which the init scripts for a particular runlevel are to be executed, with Upstart the jobs decide "locally" where they want to place themselves within a network of dependencies. The "`start on` …" and "`stop on` …" lines stipulate events that lead to the job being started or stopped. In our example, `rsyslog` is started as soon as the file system is available, and stopped when the system transitions to the "runlevels" 0 (halt) or 6 (reboot). System-V init's runlevel directories with symbolic links are no longer required.

Upstart supports runlevels mostly for compatibility with Unix tradition and to ease the migration of System-V init based systems to Upstart. They are

not required in principle, but at the moment are still necessary to shut down the system (!).

Newer implementations of System-V init also try to provide dependencies between services in the sense that init script *X* is always executed after init script *Y* and so on. (This amounts to a scheme for automatic assignment of the priority numbers within the runlevel directories.) This is done using metadata contained in standardised comments at the beginning of the init scripts. The facilities that this approach provides do fall short of those of Upstart, though.

On system boot, Upstart creates the `startup` event as soon as its own initialisation is complete. This makes it possible to execute other jobs. The complete boot sequence derives from the `startup` event and from events being created through the execution of further jobs and expected by others.

For example, on Ubuntu 10.04 the `startup` event invokes the `mountall` task which makes the file systems available. Once that is finished, the `filesystem` event is created (among others), which in turn triggers the start of the `rsyslog` service from Figure 17.2.

With Upstart, the `initctl` command is used to interact with the `init` process:

```
# initctl list                                          Which jobs are running now?
alsa-mixer-save stop/waiting
avahi-daemon start/running, process 578
mountall-net stop/waiting
rc stop/waiting
rsyslog start/running, process 549
◁◁◁◁◁
# initctl stop rsyslog                                              Stop a job
rsyslog stop/waiting
# initctl status rsyslog                                  What is its status?
rsyslog stop/waiting
# initctl start rsyslog                                            Restart a job
rsyslog start/running, process 2418
# initctl restart rsyslog                                        Stop and start
rsyslog start/running, process 2432
```

The "`initctl stop`", "`initctl start`", "`initctl status`", and "`initctl stop`" can be abbreviated to "`stop`", "`start`", ….

17.4 Shutting Down the System

A Linux computer should not simply be powered off, as that could lead to data loss—possibly there are data in RAM that ought to be written to disk but are still waiting for the proper moment in time. Besides, there might be users logged in on the machine via the network, and it would be bad form to surprise them with an unscheduled system halt or restart. The same applies to users taking advantage of services that the computer offers on the Net.

It is seldom necessary to shut down a Linux machine that should really run continuously. You can install or remove software with impunity and also reconfigure the system fairly radically without having to restart the operating system. The only cases where this is really necessary include kernel changes (such as security updates) or adding new or replacing defective hardware inside the computer case.


The first case (kernel changes) is being worked on. The `kexec` infrastructure makes it possible to load a second kernel into memory and jump into it directly (without the detour via a system reboot). Thus it is quite possible that in the future you will always be able to run the newest kernel without actually having to reboot your machine.


With the correct kind of (expensive) hardware you can also mostly sort out the second case: Appropriate server systems allow you to swap CPUs, RAM modules, and disks in and out while the computer is running.

There are numerous ways of shutting down or rebooting the system:

- By valiantly pushing the system's on/off switch. If you keep it pressed until the computer is audibly shutting down the system will be switched off. You should only do this in cases of acute panic (fire in the machine hall or a sudden water influx). on/off switch
- Using the `shutdown` command. This is the cleanest method of shutting down or rebooting. `shutdown`
- For System-V init: The "`telinit 0`" command can be used to switch to runlevel 0. This is equivalent to a shutdown.
- Using the `halt` command. This is really a direct order to the kernel to halt the system, but many distributions arrange for `halt` to call `shutdown` if the system is not in runlevels 0 or 6 already.

  
  There is a `reboot` command for reboots, which like `halt` usually relies on `shutdown`. (In fact, `halt` and `reboot` are really the same program.) `reboot`

The commands are all restricted to the system administrator.


The key combination Ctrl+Alt+Del may also work if it is configured appropriately in `/etc/inittab` (see Section 17.1).


Graphical display managers often offer an option to shut down or reboot the system. You may have to configure whether the `root` password must be entered or not.


Finally, modern PCs may interpret a (short) press on the on/off switch as "Please shut down cleanly" rather than "Please crash right now".

Normally you will be using the second option, the `shutdown` command. It ensures that all logged-in users are made aware of the impending system halt, prevents new logins, and, according to its option, performs any requisite actions to shut down the system:

```
# shutdown -h +10
```

for example will shut down the system in ten minutes' time. With the `-r` option, the system will be restarted. With no option, the system will go to single-user mode after the delay has elapsed.


You may also give the time of shutdown/reboot as an absolute time:

```
# shutdown -h 12:00                                    High Noon
```


For `shutdown`, the `now` keyword is a synonym of "`+0`"—immediate action. Do it only if you are sure that nobody else is using the system.

Here is exactly what happens when the `shutdown` command is given:

broadcast message

1. All users receive a broadcast message saying that the system will be shut down, when, and why.
2. The `shutdown` command automatically creates the `/etc/nologin` file, which is checked by `login` (or, more precisely, the PAM infrastructure); its existence prevents new user logins (except for `root`).

   
   For consolation, users that the system turns away are being shown the content of the `/etc/nologin` file.

   The file is usually removed automatically when the system starts up again.
3. The system changes to runlevel 0 or 6. All services will be terminated by means of their init scripts (more exactly, all services that do not occur in runlevels 0 or 6, which is usually all of them).
4. All still-running processes are first sent `SIGTERM`. They may intercept this signal and clean up after themselves before terminating.
5. Shortly afterwards, all processes that still exist are forcibly terminated by `SIGKILL`.
6. The file systems are unmounted and the swap spaces are deactivated.
7. Finally, all system activities are finished. Then either a warm start is initiated or the computer shut off using APM or ACPI. If that doesn't work, the message "`System halted`" is displayed on the console. At that point you can hit the switch yourself.


You may pass some text to `shutdown` after the shut-down delay time, which is displayed to any logged-in users:

```
# shutdown -h 12:00 '
System halt for hardware upgrade.
Sorry for the inconvenience!
'
```


If you have executed `shutdown` and then change your mind after all, you can cancel a pending shutdown or reboot using

```
# shutdown -c "No shutdown after all"
```

(of course you may compose your own explanatory message).

wall

By the way: The mechanism that `shutdown` uses to notify users of an impending system halt (or similar) is available for your use. The command is called `wall` (short for "write to all"):

```
$ wall "Cake in the break room at 3pm!"
```

will produce a message of the form

```
Broadcast message from hugo@red (pts/1) (Sat Jul 18 00:35:03 2015):

Cake in the break room at 3pm!
```

on the terminals of all logged-in users.


If you send the message as a normal user, it will be received by all users who haven't blocked their terminal for such messages using "`mesg n`". If you want to reach those users, too, you must send the message as `root`.


Even if you're not logged in on a text terminal but are instead using a graphical environment: Today's desktop environments will pick up such messages and show them in an extra window (or something; that will depend on the desktop environment).


If you're `root` and the parameter of `wall` looks like the name of an existing file, that file will be read and its content sent as the message:

```
# echo "Cake in the break room at 3pm!" >cake.txt
# wall cake.txt
```

You don't get to do this as an ordinary user, but you can still pass the message on `wall`'s standard input. (You can do that as `root`, too, of course.) Don't use this for *War and Peace*.


If you're `root`, you can suppress the header line "`Broadcast message` …" using the `-n` option (short for `--nobanner`).

Exercises


17.10 [!2] Shut down your system 15 minutes from now and tell your users that this is simply a test. How do you prevent the actual shutdown (so that it *really* is simply a test)?


What happens if you (as `root`) pass `wall` the name of a non-existent file as its parameter?


17.11 [2] `wall` is really a special case of the `write` command, which you can use to "chat" with other users of the same computer in an unspeakably primitive fashion. Try `write`, in the easiest case between two different users in different windows or consoles. (`write` was a lot more interesting back when one had a VAX with 30 terminals.)

Commands in this Chapter

`chkconfig` Starts or shuts down system services (SUSE, Red Hat) `chkconfig`(8) 267

`halt` Halts the system `halt`(8) 271

`initctl` Supervisory tool for Upstart `initctl`(8) 270

`insserv` Activates or deactivates init scripts (SUSE) `insserv`(8) 267

`reboot` Restarts the computer `reboot`(8) 271

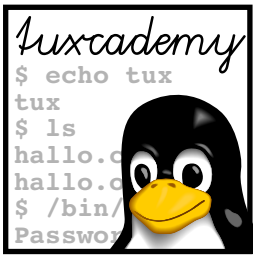
`runlevel` Displays the previous and current run level `runlevel`(8) 265

`shutdown` Shuts the system down or reboots it, with a delay and warnings for logged-in users `shutdown`(8) 271

`update-rc.d` Installs and removes System-V style init script links (Debian) `update-rc.d`(8) 267

Summary

- After starting, the kernel initialises the system and then hands off control to the `/sbin/init` program as the first userspace process.
- The `init` process controls the system and takes care, in particular, of activating background services and managing terminals, virtual consoles, and modems.
- The system distinguishes various "runlevels" (operating states) that are defined through different sets of running services.
- A single-user mode is available for large or intrusive administrative tasks.
- The `shutdown` command is a convenient way of shutting down or rebooting the system (and it's friendly towards other users, too).
- You can use the `wall` command to send a message to all logged-in users.
- Linux systems seldom need to be rebooted—actually only when a new operating system kernel or new hardware has been installed.



18

Systemd

Contents

Goals

- Understanding the systemd infrastructure
- Knowing the structure of unit files
- Understanding and being able to configure targets

Prerequisites

- Knowledge of Linux system administration
- Knowledge of system start procedures (Chapter 16)
- Knowledge about System-V init (Chapter 17)

18.1 Overview

Systemd, by Lennart Poettering and Kay Sievers, is another alternative to the old-fashioned System-V init system. Like Upstart, systemd transcends the rigid limitations of System-V init, but implements various concepts for the activation and control of services with much greater rigour than Upstart.

Systemd is considered the future standard init system by all mainstream distributions. On many of them—such as Debian, Fedora, RHEL, CentOS, openSUSE, and SLES—it is now provided by default. Even Ubuntu, originally the main instigator of Upstart, has by now declared for systemd.

dependencies

While System-V init and Upstart use explicit dependencies among services—for instance, services using the system log service can only be started once that service is running—, systemd turns the dependencies around. A service requiring the system log service doesn't do this because the log service needs to be running, but because it itself wants to send messages to the system log. This means it must access the communication channel that the system log service provides. Hence it is sufficient if *systemd itself* creates that communication channel and passes it to the system log service once that becomes available—the service wanting to send messages to the log will wait until its messages can actually be accepted. Hence, systemd can in principle create all communication channels first and then start all services simultaneously without regard to any dependencies whatsoever. The dependencies will sort themselves out without any explicit configuration.

This approach also works when the system is running: If a service is accessed that isn't currently running, systemd can start it on demand.

The same approach can in principle also be used for file systems: If a service wants to open a file on a file system that is currently unavailable, the access is suspended until the file system can actually be accessed.

units
targets

Systemd uses "units" as an abstraction for parts of the system to be managed such as services, communication channels, or devices. "Targets" replace SysV init's runlevels and are used to collect related units. For example, there is a target `multiuser.target` that corresponds to the traditional runlevel 3. Targets can depend on the availability of devices—for instance, a `bluetooth.target` could be requested when a USB Bluetooth adapter is plugged in, and it could launch the requisite software. (System-V init starts the Bluetooth software as soon as it is configured, irrespective of whether Bluetooth hardware is actually available.)

In addition, systemd offers more interesting properties that System-V init and Upstart cannot match, including:

- Systemd supports service activation "on demand", not just depending on hardware that is recognised (as in the Bluetooth example above), but also via network connections, D-Bus requests or the availability of certain paths within the file system.
- Systemd allows very fine-grained control of the services it launches, concerning, e. g., the process environment, resource limits, etc. This includes security improvements, e. g., providing only a limited view on the file system for certain services, or providing services with a private `/tmp` directory or networking environment.

  With SysV init this can be handled on a case-by-case basis within the init scripts, but by comparison this is very primitive and tedious.

- Systemd uses the Linux kernel's `cgroups` mechanism to ensure, e. g., that stopping a service actually stops all related processes.
- If desired, systemd handles services' logging output; the services only need to write messages to standard output.

- Systemd makes configuration maintenance easier, by cleanly separating distribution default and local customisations.
- Systemd contains a number of tools in C that handle system initialisation and do approximately what distribution-specific "runlevel S" scripts would otherwise do. Using them can speed up the boot process considerably and also improves cross-distribution standardisation.

Systemd is designed to offer maximum compatibility with System-V init and other "traditions". For instance, it supports the init scripts of System-V init if no native configuration file is available for a service, or it takes the file systems to be mounted on startup from the `/etc/fstab` file.

You can use the `systemctl` command to interact with a running systemd, e. g., to start or stop services explicitly:

```
# systemctl status rsyslog.service
● rsyslog.service - System Logging Service
   Loaded: loaded (/lib/systemd/system/rsyslog.service; enabled)
   Active: active (running) since Do 2015-07-16 15:20:38 CEST;▷
    ◁ 3h 12min ago
     Docs: man:rsyslogd(8)
           http://www.rsyslog.com/doc/
 Main PID: 497 (rsyslogd)
   CGroup: /system.slice/rsyslog.service
           └─497 /usr/sbin/rsyslogd -n
# systemctl stop rsyslog.service
Warning: Stopping rsyslog.service, but it can still be activated by:
  syslog.socket
# systemctl start rsyslog.service
```

Systemd calls such change requests for the system state "jobs", and puts them into a queue.

Systemd considers status change requests "transactions". If a unit is being started or stopped, it (and any units that depend on it) are put into a temporary transaction. Then systemd checks that the transaction is consistent—in particular, that no circular dependencies exist. If that isn't the case, systemd tries to repair the transaction by removing jobs that are not essential in order to break the cycle(s). Non-essential jobs that would lead to running services being stopped are also removed. Finally, systemd checks whether the jobs within the transaction would conflict with other jobs that are already in the queue, and refuses the transaction if that is the case. Only if the transaction is consistent and the minimisation of its impact on the system is complete, will its jobs be entered into the queue.

transactions

Exercises

18.1 [!1] Use "`systemctl status`" to get a picture of the units that are active on your computer. Check the detailed status of some interesting-looking units.

18.2 Unit Files

One of the more important advantages of systemd is that it uses a unified file format for all configuration files—no matter whether they are about services to be started, devices, communication channels, file systems, or other artefacts that systemd manages.


This is in stark contrast to the traditional infrastructure based on System-V init, where almost every functionality is configured in a different way: permanently running background services in `/etc/inittab`, runlevels and their services via init scripts, file systems in `/etc/fstab`, services that are run on demand in `/etc/inetd.conf`, … Every single such file is syntactically different from all others, while with systemd, only the details of the possible (and sensible) configuration settings differ—the basic file format is always the same.

A very important observation is: Unit files are "declarative". This means that they simply describe what the desired configuration *looks like*—unlike System V init's init scripts, which contain executable code that tries to *achieve* the desired configuration.


Init scripts usually consider of huge amounts of boilerplate code which depends on the distribution in question, but which you still need to read and understand line-per-line if there is a problem or you want to do something unusual. For somewhat more complex background services, init scripts of a hundred lines or more are not unusual. Unit files for systemd, though, usually get by with a dozen lines or two, and these lines are generally pretty straightforward to understand.


Of course unit files occasionally contain shell commands, for example to explain how a specific service should be started or stopped. These, however, are generally fairly obvious one-liners.

Syntax The basic syntax of unit files is explained in `systemd.unit`(5). You can find an example for a unit file in Figure 18.1. A typical characteristic is the subdivision into sections that start with a title in square brackets[1]. All unit files (no matter what they are supposed to do) can include `[Unit]` and `[Install]` sections (see below). Besides, there are sections that are specific to the purpose of the unit.

As usual, blank lines and comment lines are ignored. Comment lines can start with a `#` or `;`. Over-long lines can be wrapped with a `\` at the end of the line, which will be replaced by a space character when the file is read. Uppercase and lowercase letters are important!

options

Lines which are not section headers, empty lines, nor comment lines contain "options" according to a "⟨*name*⟩ = ⟨*value*⟩" pattern. Various options may occur several times, and systemd's handling of that depends on the option: Multiple options often form a list; if you specify an empty value, all earlier settings will be ignored. (If that is the case, the documentation will say so.)


Options that are not listed in the documentation will be flagged with a warning by systemd and otherwise ignored. If a section or option name starts with "`X-`", it is ignored completely (options in an "`X-`" section do not need their own "`X-`" prefix).


Yes/no settings in unit files can be given in a variety of ways. `1`, `true`, `yes`, and `on` stand for "yes", `0`, `false`, `no`, and `off` for "no".


Times can also be specified in various ways. Simple integers will be interpreted as seconds[2]. If you append a unit, then that unit applies (allowed units include `us`, `ms`, `s`, `min`, `h`, `d`, `w` in increasing sequence from microseconds to weeks—see `systemd.time`(7)). You can concatenate several time specifications with units (as in "`10min 30s`"), and these times will be added (here, 630 seconds).

[1] The syntax is inspired by the `.desktop` files of the "XDG Desktop Entry Specification" [XDG-DS14], which in turn have been inspired by the INI files of Microsoft Windows.

[2] Most of the time, anyway—there are (documented) exceptions.

```
#  This file is part of systemd.
#
#  systemd is free software; you can redistribute it and/or modify
#  it under the terms of the GNU Lesser General Public License as
#  published by the Free Software Foundation; either version 2.1
#  of the License, or (at your option) any later version.

[Unit]
Description=Console Getty
Documentation=man:agetty(8)
After=systemd-user-sessions.service plymouth-quit-wait.service
After=rc-local.service
Before=getty.target

[Service]
ExecStart=-/sbin/agetty --noclear --keep-baud console ▷
 ◁ 115200,38400,9600 $TERM
Type=idle
Restart=always
RestartSec=0
UtmpIdentifier=cons
TTYPath=/dev/console
TTYReset=yes
TTYVHangup=yes
KillMode=process
IgnoreSIGPIPE=no
SendSIGHUP=yes

[Install]
WantedBy=getty.target
```

Figure 18.1: A systemd unit file: `console-getty.service`

Searching and finding settings Systemd tries to locate unit files along a list of directories that is hard-coded in the program. Directories nearer the front of the list have precedence over directories nearer the end.

The details are system-dependent, at least to a certain degree. The usual list is normally something like

`/etc/systemd/system`	*Local configuration*
`/run/systemd/system`	*Dynamically generated unit files*
`/lib/systemd/system`	*Unit files for distribution packages*

Local customisation

Systemd offers various clever methods for customising settings without having to change the unit files generally provided by your distribution—which would be inconvenient if the distribution updates the unit files. Imagine you want to change a few settings in the `example.service` file:

- You can copy the distribution's `example.service` file from `/lib/systemd/system` to `/etc/systemd/system` and make any desired customisations. The unit file furnished by the distribution will then not be considered at all.
- You can create a directory `/etc/systemd/system/example.service.d` containing a file—for example, `local.conf`. The settings in that file override settings with the same name in `/lib/systemd/system/example.service`, but any settings not mentioned in `local.conf` stay intact.

  Take care to include any required section titles in `local.conf`, such that the options can be identified correctly.

  Nobody keeps you from putting several files into `/etc/systemd/system/example.service.d`. The only prerequisite is that file names must end in `.conf`. Systemd makes no stipulation about the order in which these files are read—it is best to ensure that every option occurs in just one single file.

Template unit files Sometimes several services can use the same or a very similar unit file. In this case it is convenient not to have to maintain several copies of the same unit file. Consider, for example, the terminal definition lines in `/etc/inittab`—it would be good not to have to have one unit file per terminal.

Instantiation

Systemd supports this by means of unit files with names like `example@.service`. You could, for example, have a file called `getty@.service` and then configure a virtual console on `/dev/tty2` simply by creating a symbolic link from `getty@tty2.service` to `getty@.service`. When this console is to be activated, systemd reads the `getty@.service` file and replaces the `%I` key, wherever it finds it, by whatever comes between `@` and `.` in the name of the unit file, i. e., `tty2`. The result of that replacement is then put into force as the configuration.

In fact, systemd replaces not just `%I` but also some other sequences (and that not just in template unit files). The details may be found in `systemd.unit`(5), in the "Specifiers" section.

Basic settings All unit files may contain the `[Unit]` and `[Install]` sections. The former contains general information about the unit, the latter provides details for its installation (for example, to introduce explicit dependencies—which we shall discuss later).

Here are some of the more important options from the `[Unit]` section (the complete list is in `systemd.unit`(5)):

`Description` A description of the unit (as free text). Will be used to make user interfaces more friendly.

Documentation A space-separated list of URLs containing documentation for the unit. The allowed protocol schemes include `http:`, `https:`, `file:`, `info:`, and `man:` (the latter three refer to locally-installed documentation). An empty value clears the list.

OnFailure A space-separated list of other units which will be activated if this unit transitions into the `failed` state.

SourcePath The path name of a configuration file from which this unit file has been generated. This is useful for tools that create unit files for systemd from external configuration files.

ConditionPathExists Checks whether there is a file (or directory) under the given absolute path name. If not, the unit will be classed as `failed`. If there is a `!` in front of the path name, then a file (or directory) with that name must *not* exist. (There are loads of other "`Condition…`" tests—for example, you can have the execution of units depend on whether the system has a particular computer architecture, is running in a virtual environment, is running on AC or battery power or on a computer with a particular name, and so on. Read up in `systemd.unit`(5).)

Exercises

18.2 [!2] Browse the unit files of your system under `/lib/systemd/system` (or `/usr/lib/systemd/system`, depending on the distribution). How many different `Condition…` options can you find?

18.3 Unit Types

Systemd supports a wide variety of "units", or system components that it can manage. These are easy to tell apart by the extensions of the names of the corresponding unit files. As mentioned in Section 18.2, all units share the same basic file format. Here is a list of the most important unit types:

.service A process on the computer that is executed and managed by systemd. This includes both background services that stay active for a long time (possibly until the system is shut down), and processes that are only executed once (for example when the system is booting).

When a service is invoked by name (such as `example`) but no corresponding unit file (here, `example.service`) can be found, systemd looks for a System-V init script with the same name and generates a service unit for that on the fly. (The compatibility is fairly wide-ranging but not 100% complete.)

.socket A TCP/IP or local socket, i. e., a communication end point that client programs can use to contact a server. Systemd uses socket units to activate background services on demand.

Socket units always come with a corresponding service unit which will be started when systemd notes activity on the socket in question.

.mount A "mount point" on the system, i. e., a directory where a file system should be mounted.

The names of these units are derived from the path name by means of replacing all slashes ("`/`") with hyphens ("`-`") and all other non-alphanumeric (as per ASCII) characters with a hexadecimal replacement such as `\x2d` ("`.`" is only converted if it is the first character of a path name). The name of the root directory ("`/`") becomes

"-", but slashes at the start or end of all other names are removed. The directory name /home/lost+found, for instance, becomes home-lost\ textbackslash x2bfound.

You can try this replacement using the "systemd-escape -p" command:

```
$ systemd-escape -p /home/lost+found
-home-lost\x2bfound
$ systemd-escape -pu home-lost\\x2bfound
/home/lost+found
```

The "-p" option marks the parameter as a path name. The "-u" option undoes the replacement.

.automount Declares that a mount point should be mounted on demand (instead of prophylactically when the system is booted). The names of these units result from the same path name transformation. The details of mounting must be described by a corresponding mount unit.

.swap Describes swap space on the system. The names of these units result from the path name transformation applied to the device or file name in question.

.target A "target", or synchronisation point for other units during system boot or when transitioning into other system states. Vaguely similar to System-V init's runlevels. See Section 18.5.

.path Observes a file or a directory and starts another unit (by default, a service unit of the same name) when, e. g., changes to the file have been noticed or a file has been added to an otherwise empty directory.

.timer Starts another unit (by default, a service unit of the same name) at a certain point in time or repeatedly at certain intervals. This makes systemd a replacement for cron and at.

(There are a few other unit types, but to explain all of them here would be carrying things too far.)

Exercises

18.3 [!2] Look for examples for all of these units on your system. Examine the unit files. If necessary, consult the manpages for the various types.

18.4 Dependencies

As we have mentioned before, systemd can mostly get by without explicit dependencies because it is able to exploit implicit dependencies (e. g., on communication channels). Even so, it is sometimes necessary to specify explicit dependencies. Various options in the [Unit] section of a service file (e.g., example.service) allow you to do just that. For example:

Requires Specifies a list of other units. If the current unit is activated, the listed units are also activated. If one of the listed units is deactivated or its activation fails, then the current unit will also be deactivated. (In other words, the current unit "depends on the listed units".)

The Requires dependencies have nothing to do with the *order* in which the units are started or stopped—you will have to configure that separately with After or Before. If no explicit order has been specified, systemd will start all units at the same time.


You can specify these dependencies without changing the unit file, by creating a directory called `/etc/systemd/system/example.service.requires` and adding symbolic links to the desired unit files to it. A directory like

```
# ls -l /etc/systemd/system/example.service.requires
lrwxrwxrwx 1 root root 34 Jul 17 15:56 network.target -> ▷
 ◁ /lib/systemd/system/network.target
lrwxrwxrwx 1 root root 34 Jul 17 15:57 syslog.service -> ▷
 ◁ /lib/systemd/system/syslog.service
```

corresponds to the setting

```
[Unit]
Requires = network.target syslog.service
```

in `example.service`.

`Wants` A weaker form of `Requires`. This means that the listed units will be started together with the current unit, but if their activation fails this has no influence on the process as a whole. This is the recommended method of making the start of one unit depend on the start of another one.


Here, too, you can specify the dependencies "externally" by creating a directory called `example.service.wants`.

`Conflicts` The reverse of `Requires`—the units listed here will be stopped when the current unit is started, and vice versa.


Like `Requires`, `Conflicts` makes no stipulation to the order in which units are started or stopped.


If a unit U conflicts with another unit V and both are to be started at the same time, this operation fails if both units are an essential part of the operation. If one (or both) units are not essential parts of the operation, the operation is modified: If only one unit is not mandatory, that one will not be started, if both are not mandatory, the one mentioned in `Conflicts` will be started and the one whose unit file contains the `Conflicts` option will be stopped.

`Before` (and `After`) These lists of units determine the starting order. If `example.service` contains the "`Before=example2.service`" option and both units are being started, the start of `example2.service` will be delayed until `example.service` has been started. `After` is the converse of `Before`, i. e., if `example2.service` contains the option "`After=example.service`" and both units are being started, the same effect results—`example2.service` will be delayed.


Notably, this has nothing to do with the dependencies in `Requires` and `Conflicts`. It is common, for example, to list units in both `Requires` and `After`. This means that the listed unit will be started before the one whose unit file contains these settings.

When deactivating units, the reverse order is observed. If a unit with a `Before` or `After` dependency on another unit is deactivated, while the other is being started, then the deactivation takes place before the activation no matter in which direction the dependency is pointing. If there is no `Before` or `After` dependency between two units, they will be started or stopped simultaneously.

Table 18.1: Common targets for systemd (selection)

Target	Description
`basic.target`	Basic system startup is finished (file systems, swap space, sockets, timers etc.)
`ctrl-alt-del.target`	Is executed when Ctrl+Alt+Del was pressed. Often the same as `reboot.target`.
`default.target`	Target which systemd attempts to reach on system startup. Usually either `multi-user.target` or `graphical.target`.
`emergency.target`	Starts a shell on the system console. For emergencies. Is usually activated by means of the "`systemd.unit=emergency.target`" on the kernel command line.
`getty.target`	Activates the statically-defined `getty` instances (for terminals). Corresponds to the `getty` lines in `/etc/inittab` on System-V init.
`graphical.target`	Establishes a graphical login prompt. Depends on `multi-user.target`.
`halt.target`	Stops the system (without powering it down).
`multi-user.target`	Establishes a multi-user system without a graphical login prompt. Used by `graphical.target`.
`network-online.target`	Serves as a dependency for units that require network services (*not* ones that provide network services), such as mount units for remote file systems. How exactly the system determines whether the network is available depends on the method for network configuration.
`poweroff.target`	Stops the system and powers it down.
`reboot.target`	Restarts the system.
`rescue.target`	Performs basic system initialisation and then starts a shell.

Exercises

18.4 [!1] What advantage do we expect from being able to configure dependencies via symbolic links in directories like `example.service.requires` instead of the `example.service` unit file?

18.5 [2] Check your system configuration for examples of `Requires`, `Wants` and `Conflicts` dependencies, with or without corresponding `Before` and `After` dependencies.

18.5 Targets

Targets in systemd are roughly similar to runlevels in System-V init: a possibility of conveniently describing a set of services. While System-V init allows only a relatively small number of runlevels and their configuration is fairly involved, systemd makes it possible to define various targets very easily.

Unit files for targets have no special options (the standard set of options for `[Unit]` and `[Install]` should be enough). Targets are only used to aggregate other units via dependencies or create standardised names for synchronisation points in dependencies (`local-fs.target`, for example, can be used to start units depending on local file systems only once these are actually available). An overview of the most important targets is in Table 18.1.

In the interest of backwards compatibility to System-V init, systemd defines a number of targets that correspond to the classical runlevels. Consider Table 18.2.

Table 18.2: Compatibility targets for System-V init

Ziele	Äquivalent
`runlevel0.target`	`poweroff.target`
`runlevel1.target`	`rescue.target`
`runlevel2.target`	`multi-user.target` (recommended)
`runlevel3.target`	`graphical.target` (recommended)
`runlevel4.target`	`graphical.target` (recommended)
`runlevel5.target`	`graphical.target` (recommended)
`runlevel6.target`	`reboot.target`

default target

You can set the default target which systemd will attempt to reach on system boot by creating a symbolic link from `/etc/systemd/system/default.target` to the desired target's unit file:

```
# cd /etc/systemd/system
# ln -sf /lib/systemd/system/multi-user.target default.target
```

(This is the moral equivalent to the `initdefault` line in the `/etc/inittab` file of System-V init.) A more convenient method is the "`systemctl set-default`" command:

```
# systemctl get-default
multi-user.target
# systemctl set-default graphical
Removed symlink /etc/systemd/system/default.target.
Created symlink from /etc/systemd/system/default.target to ▷
 ◁ /lib/systemd/system/graphical.target.
# systemctl get-default
graphical.target
```

(As you can see, that doesn't do anything other than tweak the symbolic link, either.)

Activate specific target

To activate a specific target (like changing to a specific runlevel on System-V init), use the "`systemctl isolate`" command:

```
# systemctl isolate multi-user
```

("File*.target" will be appended to the parameter if necessary). This command starts all units that the target depends upon and stops all other units.

"`systemctl isolate`" works only for units in whose `[Unit]` sections the "`AllowIsolate`" option is switched on.

To stop the system or to change to the rescue mode (System-V init aficionados would call this "single-user mode") there are the shortcuts

```
# systemctl rescue
# systemctl halt
# systemctl poweroff                                  Like halt, but with power-down
# systemctl reboot
```

These commands correspond roughly to their equivalents using "`systemctl isolate`", but also output a warning to logged-in users. You can (and should!) of course keep using the `shutdown` command.

You can return to the default operating state using

```
# systemctl default
```

Exercises

18.6 [!2] Which other services does the `multi-user.target` depend on? Do these units depend on other units in turn?

18.7 [2] Use "`systemctl isolate`" to change your system to the rescue (single-user) mode, and "`systemctl default`" to come back to the standard mode. (*Hint:* Do this from a text console.)

18.8 [2] Restart your system using "`systemctl reboot`" and then once again with `shutdown`. Consider the difference.

18.6 The `systemctl` Command

The `systemctl` command is used to control systemd. We have already seen a few applications, and here is a more systematic list. This is, however, still only a small excerpt of the complete description.

The general structure of `systemctl` invocations is

```
# systemctl ⟨subcommand⟩ ⟨parameters⟩ …
```

`systemctl` supports a fairly large zoo of subcommands. The allowable parameters (and options) depend on the subcommand in question.

unit names as parameters

Often unit names are expected as parameters. These can be specified either with a file name extension (like, e. g., `example.service`) or without (`example`). In the latter case, systemd appends an extension that it considers appropriate—with the `start` command, for example, "`.service`", with the `isolate` command on the other hand, "`.target`".

Commands for units The following commands deal with units and their management:

`list-units` Displays the units systemd knows about. You may specify a unit type (`service`, `socket`, …) or a comma-separated list of unit types using the `-t` option, in order to confine the output to units of the type(s) in question. You can also pass a shell search pattern in order to look for specific units:

```
# systemctl list-units "ssh*"
UNIT        LOAD   ACTIVE SUB     DESCRIPTION
ssh.service loaded active running OpenBSD Secure Shell server

LOAD   = Reflects whether the unit definition was properly loaded.
ACTIVE = The high-level unit activation state, i.e. generalization
         of SUB.
SUB    = The low-level unit activation state, values depend on
         unit type.

1 loaded units listed. Pass --all to see loaded but inactive units,
too. To show all installed unit files use 'systemctl
list-unit-files'.
```

As usual, quotes are a great idea here, so the shell will not vandalise the search patterns that are meant for systemd.

`start` Starts one or more units mentioned as parameters.


You can use shell search patterns here, too. The search patterns only work for units that systemd knows about; inactive units that are not in a failed state will not be searched, nor will units instantiated from templates whose exact names are not known before the instantiation. You should not overtax the search patterns.

stop Stops one or more units mentioned as parameters (again with search patterns).

reload Reloads the configuration for the units mentioned as parameters (if the programs underlying these units go along). Search patterns are allowed.


This concerns the configuration of the background services themselves, not the configuration of the services from systemd's point of view. If you want systemd to reload its own configuration with respect to the background services, you must use the "`systemctl daemon-reload`" command.


What exactly happens on a "`systemctl reload`" depends on the background service in question (it usually involves a `SIGHUP`). You can configure this in the unit file for the service.

restart Restarts the units mentioned as parameters (search patterns are allowed). If a unit doesn't yet run, it is simply started.

try-restart Like `restart`, but units that don't run are not started.

reload-or-restart (and `reload-or-try-restart`) Reloads the configuration of the named units (as per `reload`), if the units allow this, or restarts them (as per `restart` or `try-restart`) if they don't.


Instead of `reload-or-try-restart` you can say `force-reload` for convenience (this is at least somewhat shorter).

isolate The unit in question is started (including its dependencies) and all other units are stopped. Corresponds to a runlevel change on System-V init.

kill Sends a signal to one or several processes of the unit. You can use the `--kill-who` option to specify which process is targeted. (The options include `main`, `control`, and `all`—the latter is the default—, and `main` and `control` are explained in more detail in `systemctl`(1).) Using the `--signal` option (`-s` for short) you can determine which signal is to be sent.

status Displays the current status of the named unit(s), followed by its most recent log entries. If you do not name any units, you will get an overview of all units (possibly restricted to particular types using the `-t` option).


The log excerpt is usually abridged to 10 lines, and long lines will be shortened. You can change this using the `--lines` (`-n`) and `--full` (`-l`) options.


"`status`" is used for human consumption. If you want output that is easy to process by other programs, use "`systemctl show`".

cat Displays the configuration file(s) for one or more units (including fragments in configuration directories specifically for that unit). Comments with the file names in question are inserted for clarity.

help Displays documentation (such as man pages) for the unit(s) in question: For example,

```
$ systemctl help syslog
```

invokes the manual page for the system log service, regardless of which program actually provides the log service.

With most distributions, commands like

```
# service example start
# service example stop
# service example restart
# service example reload
```

work independently of whether the system uses systemd or System-V init.

In the next section, there are a few commands that deal with installing and deinstalling units.

Other commands Here are a few commands that do not specifically deal with particular units (or groups of units).

daemon-reload This command causes systemd to reload its configuration. This includes regenerating unit files that have been created at runtime from other configuration files on the system, and reconstructing the dependency tree.

Communication channels that systemd manages on behalf of background services will persist across the reload.

daemon-reexec Restarts the `systemd` program. This saves systemd's internal state and restores it later.

This command is mostly useful if a new version of `systemd` has been installed (or for debugging `systemd`. Here, too, communication channels that systemd manages on behalf of background services will persist across the reload.

is-system-running Outputs the current state of the system. Possible answers include:

initializing The system is in the early boot stage (the `basic.target`, `rescue.target`, or `emergency.target` targets have not yet been reached).

starting The system is in the late boot stage (there are still jobs in the queue).

running The system is running normally.

degraded The system is running normally, but one or more units are in a failed state.

maintenance One of the `rescue.target` or `emergency.target` targets are active.

stopping The system is being shut down.

Exercises

18.9 [!2] Use `systemctl` to stop, start, and restart a suitably innocuous service (such as `cups.service`) and to reload its configuration.

18.10 [2] The `runlevel` command of System-V init outputs the system's current runlevel. What would be an approximate equivalent for systemd?

18.11 [1] What is the advantage of

```
# systemctl kill example.service
```

versus

```
# killall example
```

(or "`pkill example`")?

18.7 Installing Units

To make a new background service available using systemd, you need a unit file, for example `example.service`. (Thanks to backwards compatibility, a System-V init script would also do, but we won't go there just now.) You need to place this in a suitable file (we recommend `/etc/systemd/system`. Next, it should appear when you invoke "`systemctl list-unit-files`":

```
# systemctl list-unit-files
UNIT FILE                                   STATE
proc-sys-fs-binfmt_misc.automount           static
org.freedesktop.hostname1.busname           static
org.freedesktop.locale1.busname             static
◁◁◁◁◁
example.service                             disabled
◁◁◁◁◁
```

The `disabled` state means that the unit is available in principle, but is not being started automatically.

Activating units

You can "activate" the unit, or mark it to be started when needed (e. g., during system startup or if a certain communication channel is being accessed), by issuing the "`systemctl enable`" command:

```
# systemctl enable example
Created symlink from /etc/systemd/system/multi-user.target.wants/▷
 ◁example.service to /etc/systemd/system/example.service.
```

The command output tells you what happens here: A symbolic link to the service's unit file from the `/etc/systemd/system/multi-user.target.wants` directory ensures that the unit will be started as a dependency of the `multi-user.target`.

You may ask yourself how systemd knows that the `example` unit should be integrated in the `multi-user.target` (and not some other target). The answer to that is: The `example.service` file has a section saying

```
[Install]
WantedBy=multi-user.target
```

After an `enable`, systemd does the equivalent of a "`systemctl daemon-reload`". However, no units will be started (or stopped).

You could just as well create the symbolic links by hand. You would, however, have to take care of the "`systemctl daemon-reload`" yourself, too.

If you want the unit to be started immediately, you can either give the

```
# systemctl start example
```

command immediately afterwards, or you invoke "`systemctl enable`" with the `--now` option.

You can start a unit directly (using "`systemctl start`") without first activating it with "`systemctl enable`". The former actually starts the service, while the latter only arranges for it to be started at an appropriate moment (e. g., when the system is booted, or a specific piece of hardware is connected).

You can deactivate a unit again with "`systemctl disable`". As with `enable`, systemd does an implicit `daemon-reload`.


Here, too, the unit will not be stopped if it is currently running. (You are just preventing it from being activated later on.) Use the `--now` option or an explicit "`systemctl stop`".


The "`systemctl reenable`" command is equivalent to a "`systemctl disable`" immediately followed by a "`systemctl enable`" for the units in question. This lets you do a "factory reset" of units.

Masking a unit

The "`systemctl mask`" command lets you "mask" a unit. This means to block it completely. This will not only prevent it from starting automatically, but will also keep it from being started by hand. "`systemctl unmask`" reverts that operation.


Systemd implements this by linking the name of the unit file in `/etc/systemd/system` symbolically to `/dev/null`. Thus, eponymous files in directories that systemd considers later (like `/lib/systemd/system`) will be completely ignored.

Exercises


18.12 [!2] What happens if you execute "`systemctl disable cups`"? (Watch the commands being output.) Reactivate the service again.


18.13 [2] How can you "mask" units whose unit files are in `/etc/systemd/system`?

Commands in this Chapter

`systemctl` Main control utility for systemd `systemctl`(1) 277, 286

Summary

- Systemd is a modern alternative to System-V init.
- "Units" are system components managed by systemd. They are configured using unit files.
- Unit files bear a vague resemblance to Microsoft Windows INI files.
- Systemd supports flexible mechanisms for local configuration and the automatic creation of similar unit files from "templates".
- Systemd lets you manage a multitude of different units—services, mount points, timers, …
- Dependencies between units can be expressed in various ways.
- "Targets" are units that vaguely correspond to System-V init's runlevels. They are used to group related services and for synchronisation.
- You can use the `systemctl` command to control systemd.
- Systemd contains powerful tools to install and deinstall units.

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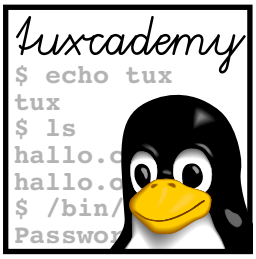


19

Time-controlled Actions—`cron` and `at`

Contents

Goals

- Executing commands at some future time using `at`
- Executing commands periodically using `cron`
- Knowing and using `anacron`

Prerequisites

- Using Linux commands
- Editing files

19.1 Introduction

An important component of system administration consists of automating repeated procedures. One conceivable task would be for the mail server of the company network to dial in to the ISP periodically to fetch incoming messages. In addition, all members of a project group might receive a written reminder half an hour before the weekly project meeting. Administrative tasks like file system checks or system backups can profitably be executed automatically at night when system load is noticably lower.

To facilitate this, Linux offers two services which will be discussed in the following sections.

19.2 One-Time Execution of Commands

19.2.1 at and batch

Using the at service, arbitrary shell commands may be executed once at some time in the future (time-shifted). If commands are to be executed repeatedly, the use of cron (Section 19.3) is preferable.

The idea behind at is to specify a time at which a command or command sequence will be executed. Roughly like this:

```
$ at 01:00
warning: commands will be executed using /bin/sh
at> tar cvzf /dev/st0 $HOME
at> echo "Backup done" | mail -s Backup $USER
at> Ctrl+D
Job 123 at 2003-11-08 01:00
```

This would write a backup copy of your home directory to the first tape drive at 1 A. M. (don't forget to insert a tape) and then mail a completion notice to you.

time specification

at's argument specifies when the command(s) are to be run. Times like "⟨*HH*⟩:⟨*MM*⟩" denote the next possible such time: If the command "at 14:00" is given at 8 A. M., it refers to the same day; if at 4 P. M., to the next.

You can make these times unique by appending today or tomorrow: "at 14:00 today", given before 2 P. M., refers to today, "at 14:00 tomorrow", to tomorrow.

Other possibilities include Anglo-Saxon times such as 01:00am or 02:20pm as well as the symbolic names midnight (12 A. M.), noon (12 P. M.), and teatime (4 P. M.) (!); the symbolic name now is mostly useful together with relative times (see below).

date specifications

In addition to times, at also understands date specifications in the format "⟨*MM*⟩⟨*DD*⟩⟨*YY*⟩" and "⟨*MM*⟩/⟨*DD*⟩/⟨*YY*⟩" (according to American usage, with the month before the day) as well as "⟨*DD*⟩.⟨*MM*⟩.⟨*YY*⟩" (for Europeans). Besides, American-style dates like "⟨*month name*⟩ ⟨*day*⟩" and "⟨*month name*⟩ ⟨*day*⟩ ⟨*year*⟩" may also be spelled out. If you specify just a date, commands will be executed on the day in question at the current time; you can also combine a date and time specification but must give the date after the time:

```
$ at 00:00 January 1 2005
warning: commands will be executed using /bin/sh
at> echo 'Happy New Year!'
at> Ctrl+D
Job 124 at 2005-01-01 00:00
```

Besides "explicit" time and date specification, you can give "relative" times and dates by passing an offset from some given point in time:

```
$ at now + 5 minutes
```

executes the command(s) five minutes from now, while

```
$ at noon + 2 days
```

refers to 12 P. M. on the day after tomorrow (as long as the `at` command is given before 12 P. M. today). `at` supports the units `minutes`, `hours`, `days` and `weeks`.

A single offset by one single measurement unit must suffice: Combinations such as

```
$ at noon + 2 hours 30 minutes
```

or

```
$ at noon + 2 hours + 30 minutes
```

are, unfortunately, disallowed. Of course you can express any reasonable offset in minutes …

`at` reads the commands from standard input, i. e., usually the keyboard; with the "`-f` ⟨*file*⟩" option you can specify a file instead. commands

`at` tries to run the commands in an environment that is as like the one current when `at` was called as possible. The current working directory, the umask, and the current environment variables (excepting `TERM`, `DISPLAY`, and _) are saved and reactivated before the commands are executed.

Any output of the commands executed by `at`—standard output and standard error output—is sent to you by e-mail. output

If you have assumed another user's identity using `su` before calling `at`, the commands will be executed using that identity. The output mails will still be sent to you, however.

While you can use `at` to execute commands at some particular point in time, the (otherwise analogous) `batch` command makes it possible to execute a command sequence "as soon as possible". When that will actually be depends on the current system load; if the system is very busy just then, `batch` jobs must wait. ASAP execution

An `at`-style time specification on `batch` is allowed but not mandatory. If it is given, the commands will be executed "some time after" the specified time, just as if they had been submitted using `batch` at that time.

`batch` is not suitable for environments in which users compete for resources such as CPU time. Other systems must be employed in these cases.

Exercises

19.1 [!1] Assume now is 1 March, 3 P. M. When will the jobs submitted using the following commands be executed?

1. `at 17:00`
2. `at 02:00pm`
3. `at teatime tomorrow`
4. `at now + 10 hours`

19.2 [1] Use the `logger` command to write a message to the system log 3 minutes from now.

19.2.2 at Utilities

Inspect at queue

The system appends at-submitted jobs to a queue. You can inspect the contents of that queue using atq (you will see only your own jobs unless you are root):

```
$ atq
123     2003-11-08 01:00 a hugo
124     2003-11-11 11:11 a hugo
125     2003-11-08 21:05 a hugo
```

The "a" in the list denotes the "job class", a letter between "a" and "z". You can specify a job class using the -q option to at; jobs in classes with "later" letters are executed with a higher nice value. The default is "a" for at jobs and "b" for batch jobs.

A job that is currently being executed belongs to the special job class "=".

Cancelling jobs

You can use atrm to cancel a job. To do so you must specify its job number, which you are told on submission or can look up using atq. If you want to check on the commands making up the job, you can do that with "at -c ⟨*job number*⟩".

daemon

The entity in charge of actually executing at jobs is a daemon called atd. It is generally started on system boot and waits in the background for work. When starting atd, several options can be specified:

-b ("batch") Determines the minimum interval between two batch job executions. The default is 60 seconds.

-l ("load") Determines a limit for the system load, above which batch jobs will not be executed. The default is 0.8.

-d ("debug") Activates "debug" mode, i. e., error messages will not be passed to syslogd but written to standard error output.

The atd daemon requires the following directories:

- at jobs are stored in /var/spool/atjobs. Its access mode should be 700, the owner is at.
- The /var/spool/atspool directory serves to buffer job output. Its owner should be at and access mode 700, too.

Exercises

19.3 [1] Submit a few jobs using at and display the job queue. Cancel the jobs again.

19.4 [2] How would you create a list of at jobs which is not sorted according to job number but according to execution time (and date)?

19.2.3 Access Control

/etc/at.allow
/etc/at.deny

The /etc/at.allow and /etc/at.deny files determine who may submit jobs using at and batch. If the /etc/at.allow file exists, only the users listed in there are entitled to submit jobs. If the /etc/at.allow file does not exist, the users *not* listed in /etc/at.deny may submit jobs. If neither one nor the other exist, at and batch are only available to root.

Debian GNU/Linux comes with a /etc/at.deny file containing the names of various system users (including alias, backup, guest, and www-data). This prevents these users from using at.

Here, too, the Ubuntu defaults correspond to the Debian GNU/Linux defaults.


Red Hat includes an empty `/etc/at.deny` file; this implies that any user may submit jobs.


The openSUSE default corresponds (interestingly) to that of Debian GNU/Linux and Ubuntu—various system users are not allowed to use `at`. (The explicitly excluded user `www-data`, for example, doesn't exist on openSUSE; Apache uses the identity of the `wwwrun` user.)

Exercises


19.5 [1] Who may use `at` and `batch` on your system?

19.3 Repeated Execution of Commands

19.3.1 User Task Lists

Unlike the `at` commands, the `cron` daemon's purpose is to execute jobs at periodic intervals. `cron`, like `atd`, should be started during system boot using an init script. No action is required on your side, though, because `cron` and `atd` are essential parts of a Linux system. All major distributions install them by default.

Every user has their own task list (commonly called `crontab`), which is stored in the `/var/spool/cron/crontabs` (on Debian GNU/Linux and Ubuntu; on SUSE: `/var/spool/cron/tabs`, on Red Hat: `/var/spool/cron`) directory under that user's name. The commands described there are executed with that user's permissions. task list


You do not have direct access to your task lists in the `cron` directory, so you will have to use the `crontab` utility instead (see below). See also: Exercise 19.6.

`crontab` files are organised by lines; every line describes a (recurring) point in time and a command that should be executed at that time. Empty lines and comments (starting with a "`#`") will be ignored. The remaining lines consist of five time fields and the command to be executed; the time fields describe the minute (0–59), hour (0–23), day of month (1–31), month (1–12 or the English name), and weekday (0–7, where 0 and 7 stand for Sunday, or the English name), respectively, at which the command is to be executed. Alternatively, an asterisk ("`*`") is allowed, which means "whatever". For example, syntax time fields command

```
58 17 * * * echo "News is coming on soon"
```

that the command will be executed daily at 5.58 P. M. (day, month and weekday are arbitrary).


The command will be executed whenever hour, minute, and month match exactly and *at least one* of the two day specifications—day of month or weekday—applies. The specification

```
1 0 13 * 5 echo "Shortly after midnight"
```

says that the message will be output on any 13th of the month *as well as* every Friday, not just every Friday the 13th.


The final line of a `crontab` file *must* end in a newline character, lest it be ignored.

In the time fields, `cron` accepts not just single numbers, but also comma-separated lists. The "`0,30`" specification in the minute field would thus lead to the command being executed every "full half" hour. Besides, ranges can be specified: "`8-11`" is equivalent to "`8,9,10,11`", "`8-10,14-16`" corresponds to "`8,9,10,14,15,16`". lists

Also allowed is a "step size" in ranges. "0-59/10" in the minute field is equivalent to "0,10,20,30,40,50". If—like here—the full range of values is being covered, you could also write "*/10".

month and weekday specifications

The names allowed in month and weekday specifications each consist of the first three letters of the English month or weekday name (e. g., may, oct, sun, or wed). Ranges and lists of names are not permissible.

command

The rest of the line denotes the command to be executed, which will be passed by cron to /bin/sh (or the shell specified in the SHELL variable, see below).

Percent signs (%) within the command must be escaped using a backslash (as in "\%"), lest they be converted to newline characters. In that case, the command is considered to extend up to the first (unescaped) percent sign; the following "lines" will be fed to the command as its standard input.

By the way: If you as the system administrator would rather not (as cron is wont to do) a command execution be logged using syslogd, you can suppress this by putting a "-" as the first character of the line.

assignments to environment variables

Besides commands with repetition specifications, crontab lines may also include assignments to environment variables. These take the form "⟨*variable*⟩=⟨*value*⟩" (where, unlike in the shell, there may be spaces before and after the "="). If the ⟨*value*⟩ contains spaces, it should be surrounded by quotes. The following variables are pre-set automatically:

SHELL This shell is used to execute the commands. The default is /bin/sh, but other shells are allowed as well.

LOGNAME The user name is taken from /etc/passwd and cannot be changed.

HOME The home directory is also taken from /etc/passwd. However, changing its value is allowed.

MAILTO cron sends e-mail containing command output to this address (by default, they go to the owner of the crontab file). If cron should send no messages at all, the variable must be set to a null value, i. e., MAILTO="".

19.3.2 System-Wide Task Lists

/etc/crontab

In addition to the user-specific task lists, there is also a system-wide task list. This resides in /etc/crontab and belongs to root, who is the only user allowed to change it. /etc/crontab's syntax is slightly different from that of the user-specific crontab files; between the time fields and the command to be executed there is the name of the user with whose privileges the command is supposed to be run.

Various Linux distributions support a /etc/cron.d directory; this directory may contain files which are considered "extensions" of /etc/crontab. Software packages installed via the package management mechanism find it easier to make use of cron if they do not have to add or remove lines to /etc/crontab.

Another popular extension are files called /etc/cron.hourly, /etc/cron.daily and so on. In these directories, software packages (or the system administrator) can deposit files whose content will be executed hourly, daily, … These files are "normal" shell scripts rather than crontab-style files.

crontab changes and cron

cron reads its task lists—from user-specific files, the system-wide /etc/crontab, and the files within /etc/cron.d, if applicable—once on starting and then keeps them in memory. However, the program checks every minute whether any crontab files have changed. The "mtime", the last-modification time, is used for this. If cron does notice some modification, the task list is automatically reconstructed. In this case, no explicit restart of the daemon is necessary.

Exercises

19.6 [2] Why are users not allowed to directly access their task lists in `/var/spool/cron/crontabs` (or wherever your distribution keeps them)? How does `crontab` access these files?

19.7 [1] How can you arrange for a command to be executed on Friday, the 13th, *only*?

19.8 [3] How does the system ensure that the tasks in `/etc/cron.hourly`, `/etc/cron.daily`, … are really executed once per hour, once per day, etc.?

19.3.3 Access Control

Which users may work with `cron` to begin with is specified, in a manner similar to that of `at`, in two files. The `/etc/cron.allow` file (sometimes `/var/spool/cron/allow`) lists those users who are entitled to use `cron`. If that file does not exist but the `/etc/cron.deny` (sometimes `/var/spool/cron/deny`) file does, that file lists those users who may *not* enjoy automatic job execution. If neither of the files exists, it depends on the configuration whether only `root` may avail himself of `cron`'s services or whether `cron` is "free for all", and any user may use it.

19.3.4 The `crontab` Command

Individual users cannot change their `crontab` files manually, because the system hides these files from them. Only the system-wide task list in `/etc/crontab` is subject to `root`'s favourite text editor.

Instead of invoking an editor directly, all users should use the `crontab` command. This lets them create, inspect, modify, and remove task lists. With

managing task lists

```
$ crontab -e
```

you can edit your `crontab` file using the editor which is mentioned in the `VISUAL` or `EDITOR` environment variables—alternatively, the `vi` editor. After the editor terminates, the modified `crontab` file is automatically installed. Instead of the `-e` option, you may also specify the name of a file whose content will be installed as the task list. The "`-`" file name stands for standard input.

With the `-l` option, `crontab` outputs your `crontab` file to standard output; with the `-r` option, an existing task list is deleted with prejudice.

With the "`-u` ⟨*user name*⟩" option, you can refer to another user (expect to be `root` to do so). This is particularly important if you are using `su`; in this case you should always use `-u` to ensure that you are working on the correct `crontab` file.

Exercises

19.9 [!1] Use the `crontab` program to register a cron job that appends the current date to the file `/tmp/date.log` once per minute. How can you make it append the date every other minute?

19.10 [1] Use `crontab` to print the content of your task list to the standard output. Then delete your task list.

19.11 [2] (For administrators:) Arrange that user `hugo` may *not* use the `cron` service. Check that your modification is effective.

19.3.5 Anacron

Using cron you can execute commands repeatedly at certain points in time. This obviously works only if the computer is switched on at the times in question – there is little point in configuring a 2am cron job on a workstation PC when that PC is switched off outside business hours to save electricity. Mobile computers, too, are often powered on or off at odd times, which makes it difficult to schedule the periodic automated clean-up tasks a Linux system needs.

The anacron program (originally by Itai Tzur, now maintained by Pascal Hakim), like cron, can execute jobs on a daily, weekly, or monthly basis. (In fact, arbitrary periods of n days are fine.) The only prerequisite is that, on the day in question, the computer be switched on long enough for the jobs to be executed—the exact time of day is immaterial. However, anacron is activated at most once a day; if you need a higher frequency (hours or minutes) there is no way around cron.

Unlike cron, anacron is fairly primitive as far as job management is concerned. With cron, potentially every user can create jobs; with anacron, this is the system administrator's privilege.

The jobs for anacron are specified in the /etc/anacrontab file. In addition to the customary comments and blank lines (which will be ignored) it may contain assignments to environment variables of the form

```
SHELL=/bin/sh
```

and job descriptions of the form

```
7 10 weekly run-parts /etc/cron.weekly
```

where the first number (here 7) stands for the period (in days) between invocations of the job. The second number (10) denotes how many minutes after the start of anacron the job should be launched. Next is a name for the job (here, weekly) and finally the command to be executed. Overlong lines can be wrapped with a "\" at the end of the line.

The job name may contain any characters except white space and the slash. It is used to identify the job in log messages, and anacron also uses it as the name of the file in which it logs the time the job was last executed. (These files are usually placed in /var/spool/anacron.)

When anacron is started, it reads /etc/anacrontab and, for each job, checks whether it was run within the last t days, where t is the period from the job definition. If not, then anacron waits the number of minutes given in the job definition and then launches the shell command.

You can specify a job name on anacron's command line to execute only that job (if any). Alternatively, you can specify shell search patterns on the command line in order to launch groups of (skilfully named) jobs with one anacron invocation. Not specifying any job names at all is equivalent to the job name, "*".

You may also specify the time period between job invocations symbolically: Valid values include @daily, @weekly, @monthly, @yearly and @annually (the last two are equivalent).

In the definition of an environment variable, white space to the left of the "=" is ignored. To the right of the "=", it becomes part of the variable's value. Definitions are valid until the end of the file or until the same variable is redefined.

Some "environment variables" have special meaning to `anacron`. With `RANDOM_DELAY`, you can specify an additional random delay[1] for the job launches: When you set the variable to a number t, then a random number of minutes between 0 and t will be added to the delay given in the job description. `START_HOURS_RANGE` lets you denote a range of hours (on a clock) during which jobs will be started. Something like

```
START_HOURS_RANGE=10-12
```

allows new jobs to be started only between 10am and 12pm. Like `cron`, `anacron` sends job output to the address given by the `MAILTO` variable, otherwise to the user executing `anacron` (usually `root`).

Usually `anacron` executes the jobs independently and without attention to overlaps. Using the `-s` option, jobs are executed "serially", such that `anacron` starts a new job only when the previous one is finished.

Unlike `cron`, `anacron` is not a background service, but is launched when the system is booted in order to execute any leftover jobs (the delay in minutes is used to postpone the jobs until the system is running properly, in order to avoid slowing down the start procedure). Later on you can execute `anacron` once a day from `cron` in order to ensure that it does its thing even if the system is running for a longer period of time than normally expected.

It is perfectly feasible to install `cron` and `anacron` on the same system. While `anacron` usually executes the jobs in `/etc/cron.daily`, `/etc/cron.weekly`, and `/etc/cron.monthly` that are really meant for `cron`, the system ensures that `anacron` does nothing while `cron` is active. (See also Exercise 19.13.)

Exercises

19.12 [!2] Convince yourself that `anacron` is working as claimed. (*Hint:* If you don't want to wait for days, try cleverly manipulating the time stamps in `/var/spool/anacron`.)

19.13 [2] On a long-running system that has both `cron` and `anacron` installed, how do you avoid `anacron` interfering with `cron`? (*Hint:* Examine the content of `/etc/cron.daily` and friends.)

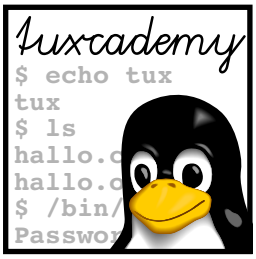
Commands in this Chapter

anacron	Executes periodic job even if the computer does not run all the time	anacron(8)	298
at	Registers commands for execution at a future point in time	at(1)	292
atd	Daemon to execute commands in the future using `at`	atd(8)	294
atq	Queries the queue of commands to be executed in the future	atq(1)	293
atrm	Cancels commands to be executed in the future	atrm(1)	294
batch	Executes commands as soon as the system load permits	batch(1)	293
crontab	Manages commands to be executed at regular intervals	crontab(1)	297

[1] Duh!

Summary

- With at, you can register commands to be executed at some future (fixed) point in time.
- The batch command allows the execution of commands as soon as system load allows.
- atq and atrm help manage job queues. The atd daemon causes the actual execution of jobs.
- Access to at and batch is controlled using the /etc/at.allow and /etc/at.deny files.
- The cron daemon allows the periodic repetition of commands.
- Users can maintain their own task lists (crontabs).
- A system-wide task list exists in /etc/crontab and—on many distributions—in the /etc/cron.d directory.
- Access to cron is managed similarly to at, using the /etc/cron.allow and /etc/cron.deny files.
- The crontab command is used to manage crontab files.



20

System Logging

Contents

Goals

- Knowing the syslog daemon and how to configure it
- Being able to manage log file using `logrotate`
- Understanding how the Linux kernel handles log messages

Prerequisites

- Basic knowledge of the components of a Linux system
- Handling configuration files

20.1 The Problem

Application programs need to tell their users something now and then. The completion of a task or an error situation or warning must be reported in a suitable manner. Text-oriented programs output appropriate messages on their "terminal"; GUI-based programs might use "alert boxes" or status lines whose content changes.

The operating system kernel and the system and network services running in the background, however, are not connected to user terminals. If such a process wants to output a message, it might write it to the system console's screen; on X11, such messages might show up in the `xconsole` window.

In multi-user mode, writing a system message to the system console only is not sufficient. Firstly, it is not clear that the message will actually be read by `root`, secondly, these screen messages cannot be saved and may easily get lost.

20.2 The Syslog Daemon

The solution of this problem consists of the syslog daemon or `syslogd`. Instead of outputting a message directly, system messages with a specific meaning can be output using the `syslog()` function, which is part of the Linux C runtime library. Such messages are accepted by `syslogd` via the local socket `/dev/log`.

Kernel messages are really handled by a different program called `klogd`. This program preprocesses the messages and usually passes them along to `syslogd`. See Section 20.4.

log `syslogd` proves very useful when debugging. It logs the different system messages and is—as its name suggests—a daemon program. The `syslogd` program is usually started via an init script while the system is booted. When it receives messages, it can write them to a file or sends them on across the network to another computer which manages a centralised log.

The common distributions (Debian GNU/Linux, Ubuntu, Red Hat Enterprise Linux, Fedora, openSUSE, …) have all been using, for various lengths of time, a package called "Rsyslog", which is a more modern implementation of a `syslogd` with more room for configuration. The additional capabilities are, however, not essential for getting started and/or passing the LPI exam. If you skip the first part of the Rsyslog configuration file, the remainder corresponds, to a very large extent, to what is discussed in this chapter. There is more about Rsyslog in Section 20.5.

Instead of `syslogd`, certain versions of the Novell/SUSE distributions, in particular the SUSE Linux Enterprise Server, use the Syslog-NG package instead of `syslogd`. This is configured in a substantially different manner. For the LPIC-1 exam, you need to know that Syslog-NG exists and roughly what it does; see Section 20.6.

The administrator decides what to do with individual messages. The configu-
`/etc/syslog.conf` ration file `/etc/syslog.conf` specifies which messages go where.

By default, Rsyslog uses `/etc/rsyslog.conf` as its configuration file. This is largely compatible to what `syslogd` would use. Simply ignore all lines starting with a dollar sign (`$`).

The configuration file consists of two columns and might look like this:

```
kern.warn;*.err;authpriv.none    /dev/tty10
kern.warn;*.err;authpriv.none   |/dev/xconsole
*.emerg                          *
```

Table 20.1: `syslogd` facilities

Facility	Meaning
`authpriv`	Confidential security subsystem messages
`cron`	Messages from `cron` and `at`
`daemon`	Messages from daemon programs with no more specific facility
`ftp`	FTP daemon messages
`kern`	System kernel messages
`lpr`	Printer subsystem messages
`mail`	Mail subsystem messages
`news`	Usenet news subsystem messages
`syslog`	`syslogd` messages
`user`	Messages about users
`uucp`	Messages from the UUCP subsystem
`local`r	($0 \leqslant r \leqslant 7$) Freely usable for local messages

Table 20.2: `syslogd` priorities (with ascending urgency)

Priority	Meaning
`none`	No priority in the proper sense—serves to exclude all messages from a certain facility
`debug`	Message about internal program states when debugging
`info`	Logging of normal system operations
`notice`	Documentation of particularly noteworthy situations during normal system operations
`warning`	(or `warn`) Warnings about non-serious occurrences which are not serious but still no longer part of normal operations
`err`	Error messages of all kinds
`crit`	Critical error messages (the dividing line between this and `err` is not strictly defined)
`alert`	"Alarming" messages requiring immediate attention
`emerg`	Final message before a system crash

```
*.=warn;*.=err                -/var/log/warn
*.crit                         /var/log/warn
*.*;mail.none;news.none       -/var/log/messages
```

The first column of each line determines which messages will be selected, and the second line says where these messages go. The first column's format is

⟨*facility*⟩.⟨*priority*⟩[;⟨*facility*⟩.⟨*priority*⟩]…

where the ⟨*facility*⟩ denotes the system program or component giving rise to the message. This could be the mail server, the kernel itself or the programs managing access control to the system. Table 20.1 shows the valid facilities. If you specify an asterisk ("*") in place of a facility, this serves as placeholder for any facility. It is not easily possible to define additional facilities; the "local" facilities `local0` to `local7` should, however, suffice for most purposes. facilities

The ⟨*priority*⟩ specifies how serious the message is. The valid priorities are summarised in Table 20.2. priorities

Who gets to determine what facility or priority is attached to a message? The solution is simple: Whoever uses the `syslog()` function, namely the developer of the program in question, must assign a facility and priority to their code's messages. Many programs allow the administrator to at least redefine the message facility.

selection criteria

A selection criterion of the form `mail.info` means "all messages of the mail subsystem with a priority of `info` and above". If you just want to capture messages of a single priority, you can do this using a criterion such as `mail.=info`. The asterisk ("`*`") stands for any priority (you could also specify "`debug`"). A preceding `!` implies logical negation: `mail.!info` deselects messages from the mail subsystem at a priority of `info` and above; this makes most sense in combinations such as `mail.*;mail.!err`, to select certain messages of low priority. `!` and `=` may be combined; `mail.!=info` deselects (exactly) those messages from the mail subsystem with priority `info`.

Multiple facilities—same priority

You may also specify multiple facilites with the same priority like `mail,news.info`; this expression selects messages of priority `info` and above that belong to the `mail` or `news` facilities.

actions

Now for the right-hand column, the messages' targets. Log messages can be handled in different ways:

- They can be written to a *file*. The file name must be specified as an absolute path. If there is a `-` in front of the path, then unlike normal `syslogd` operation, the file will not immediately be written to on disk. This means that in case of a system crash you might lose pending log messages—for fairly unimportant messages such as those of priority `notice` and below, or for messages from "chatty" facilities such as mail and news, this may not really be a problem.

  The file name may also refer to a device file (e. g., `/dev/tty10` in the example above).

- Log messages can be written to a *named pipe* (FIFO). The FIFO name must be given as an absolute path with a preceding "`|`". One such FIFO is `/dev/xconsole`.

- They can be passed *across the network* to another `syslogd`. This is specified as the name or IP address of the target system with a preceding `@` character. This is especially useful if a critical system state occurs that renders the local log file inaccessible; to deprive malicious crackers from a way to hide their traces; or to collect the log messages of all hosts in a network on a single computer and process them there.

  On the target host, the `syslogd` must have been started using the `-r` ("remote") option in order to accept forwarded messages. How to do that depends on your Linux distribution.

- They can be sent *directly to users*. The user names in question must be given as a comma-separated list. The message will be displayed on the listed users' terminals if they are logged in when the message arrives.

- They can be sent to *all logged-in users* by specifying an asterisk ("`*`") in place of a login name.

Changing configuration

As a rule, after installation your system already contains a running `syslogd` and a fairly usable `/etc/syslog.conf`. If you want to log more messages, for example because specific problems are occurring, you should edit the `syslog.conf` file and then send `syslogd` a `SIGHUP` signal to get it to re-read its configuration file.

You can test the `syslogd` mechanism using the `logger` program. An invocation of the form

```
$ logger -p local0.err -t TEST "Hello World"
```

produces a log message of the form

```
Aug  7 18:54:34 red TEST: Hello World
```

Most modern programming languages make it possible to access the `syslog()` function.

Exercises

20.1 [2] Find out when somebody last assumed `root`'s identity using `su`.

20.2 [!2] Reconfigure `syslogd` such that, in addition to the existing configuration, it writes all (!) messages to a new file called `/var/log/test`. Test your answer.

20.3 [3] (Requires two computers and a working network connection.) Reconfigure `syslogd` on the first computer such that it accepts log messages from the network. Reconfigure `syslogd` on the second computer such that it sends messages from facility `local0` to the first computer. Test the configuration.

20.4 [2] How can you implement a logging mechanism that is safe from attackers that assume control of the logging computer? (An attacker can always pretend further messages from being logged. We want to ensure that the attacker cannot change or delete messages that have already been written.)

20.3 Log Files

Log files are generally created below `/var/log`. The specific file names vary—refer to the `syslog.conf` file if you're in doubt. Here are some examples:

`/var/log`

Debian GU/Linux collects all messages except those to do with authentication in the `/var/log/syslog` file. There are separate log files for the `auth`, `daemon`, `kern`, `lpr`, `mail`, `user`, and `uucp` facilities, predictably called `auth.log` etc. On top of that, the mail system uses files called `mail.info`, `mail.warn`, and `mail.err`, which respectively contain only those messages with priority `info` etc. (and above). Debugging messages from all facilities except for `authpriv`, `news`, and `mail` end up in `/var/log/debug`, and messages of priority `info`, `notice`, and `warn` from all facilities except those just mentioned as well as `cron` and `daemon` in `/var/log/messages`.

The defaults on Ubuntu correspond to those on Debian GNU/Linux.

On Red Hat distributions, all messages with a priority of `info` or above, except those from `authpriv` and `cron`, are written to `/var/log/messages`, while messages from `authpriv` are written to `/var/log/secure` and those from `cron` to `/var/log/cron`. All messages from the mail system end up in `/var/log/maillog`.

OpenSUSE logs all messages except those from `iptables` and the `news` and `mail` facilities to `/var/log/messages`. Messages from `iptables` go to `/var/log/firewall`. Messages that are not from `iptables` and have priority `warn`, `err`, or `crit` are also written to `/var/log/warn`. Furthermore, there are the `/var/log/localmessages` file for messages from the `local*` facilities, the `/var/log/NetworkManager` file for messages from the `NetworkManager` program, and the `/var/log/acpid` file for messages from the ACPI daemon. The mail system writes its log both to `/var/log/mail` (all messages) and to the files `mail.info`, `mail.warn`, and `mail.err` (the latter for the priorities `err` and `crit`), while the news system writes its log to `news/news.notice`, `news/news.err`, and `news/news.crit` (according to the priority)—there is no overview log file for news. (If you think this is inconsistent and confusing, you are not alone.)

Some log files contain messages concerninig users' privacy and should thus only be readable by `root`. In most cases, the distributions tend to err towards caution and restrict the access rights to all log files.

Inspecting log files

You can peruse the log files created by `syslogd` using `less`; `tail` lends itself to long files (possibly using the `-f` option). There are also special tools for reading log files, the most popular of which include `logsurfer` and `xlogmaster`.

messages

The messages written by `syslogd` normally contain the date and time, the host name, a hint about the process or component that created the message, and the message itself. Typical messages might look like this:

```
Mar 31 09:56:09 red modprobe: modprobe: Can't locate ...
Mar 31 11:10:08 red su: (to root) user1 on /dev/pts/2
Mar 31 11:10:08 red su: pam-unix2: session started for ...
```

You can remove an overly large log file using `rm` or save it first by renaming it with an extension like `.old`. A new log file will be created when `syslogd` is next restarted. However, there are more convenient methods.

20.4 Kernel Logging

The Linux kernel does not send its log messages to `syslogd` but puts them into an internal "ring buffer". They can be read from there in various ways—via a specialised system call, or the `/proc/kmsg` "file". Traditionally, a program called `klogd` is used to read `/proc/kmsg` and pass the messages on to `syslogd`.

Rsyslog gets by without a separate `klogd` program, because it takes care of kernel log messages directly by itself. Hence, if you can't find a `klogd` on your system, this may very likely be because it is using rsyslog.

During system startup, `syslogd` and possibly `klogd` are not immediately available—they must be started as programs and thus cannot handle the kernel's start messages directly. The `dmesg` command makes it possible to access the kernel log buffer retroactively and look at the system start log. With a command such as

```
# dmesg >boot.msg
```

you can write these messages to a file and send it to a kernel developer.

Using the `dmesg` command you can also delete the kernel ring buffer (`-c` option) and set a priority for direct notifications: messages meeting or exceeding this priority will be sent to the console immediately (`-n` option). Kernel messages have priorities from 0 to 7 corresponding to the `syslogd` priorities from `emerg` down to `debug`. The command

```
# dmesg -n 1
```

for example causes only `emerg` messages to be written to the console directly. All messages will be written to `/proc/kmsg` in every case—here it is the job of postprocessing software such as `syslogd` to suppress unwanted messages.

Exercises

20.5 [2] What does `dmesg` output tell you about the hardware in your computer?

20.5 Extended Possibilities: Rsyslog

Rsyslog by Rainer Gerhards has replaced the traditional BSD `syslogd` on most common Linux distributions. Besides greater efficiency, rsyslog's goal is supporting various sources and sinks for log messages. For example, it writes messages not just to text files and terminals, but also a wide selection of databases.


According to its own web site, "rsyslog" stands for "rocket-fast syslog". Of course one should not overestimate the value of that kind of self-aggrandisement, but in this case the self-praise is not entirely unwarranted.

The basic ideas behind rsyslog are basically as follows:

- "Sources" pass messages on to "rulesets". There is one standard built-in ruleset (`RSYSLOG_DefaultRuleset`), but you as the user get to define others.
- Every ruleset may contain arbitrarily many rules (even none at all, even though that does not make a great deal of sense).
- A rule consists of a "filter" and an "action list". Filters make yes-no decisions about whether the corresponding action list will be executed.
- For each message, all the rules in the ruleset will be executed in order from the first to the last (and no others). All rules will always be executed, no matter how the filter decisions go, although there is a "stop processing" action.
- An action list may contain many actions (at least one). Within an action list, no further filters are allowed. The actions determine what happens to matching log messages.
- The exact appearance of log messages in the output may be controlled through "templates".

Rsyslog's configuration can be found in the `/etc/rsyslog.conf` file. In this file you may use three different styles of configuration setting in parallel:

- The traditional `/etc/syslog.conf` syntax ("sysklogd").
- An obsolete rsyslog syntax ("legacy rsyslog"). You can recognise this by the commands that start with dollar signs (`$`).
- The current rsyslog syntax ("RainerScript"). This is best suited for complex situations.

The first two flavours are line-based. In the current syntax, line breaks are irrelevant.

For very simple applications you can still—and should!—use the sysklogd syntax (as discussed in the previous sections). If you want to set configuration parameters or express complex control flows, RainerScript is more appropriate. You should avoid the obsolete rsyslog syntax (even if various Linux distributions don't do this in their default configurations), except that various features of rsyslog are only accessible using that syntax.


As usual, empty lines and comment lines will be ignored. Comment lines include both lines (and parts of lines) that start with a `#` (the comment then stops at the end of the line) and C-style comments that reach from a `/*`, disregarding line breaks, until a `*/`.


C-style comments may not be nested[1], but `#` comments may occur inside C-style comments. That makes C-style comments particularly useful to "comment out" large swathes of a configuration file in order to make it invisible to rsyslog.

Rsyslog offers various features that surpass those of BSD `syslogd`. For example, you can use extended filter expressions for messages:

```
:msg, contains, "FOO"    /var/log/foo.log
```

[1] You don't get to do that in C, either, so it shouldn't be a major nuisance.

Extended filter expressions always consist of a colon at the left margin, a "property" that rsyslog takes from the message, a filter operator (here, `contains`), and a search term. In our example, all log messages whose text contains the character sequence `FOO` will be written to the `/var/log/foo.log` file.

Apart from `msg` (the log message proper), the "properties" you may use include, for example, `hostname` (the name of the computer sending the message), `fromhost` (the name of the computer that forwarded the message to rsyslog), `pri` (the category and priority of the message as an undecoded number), `pri-text` (the category and priority as a text string, with the number appended, as in "`local0.err<133>`"), `syslogfacility` and `syslogseverity` as well as `syslogfacility-text` and `syslogseverity-text` for direct access to the category and priority, `timegenerated` (when the message was received) or `inputname` (the rsyslog module name of the source of the message). There are various others; look at rsyslog's documentation.

The allowable comparison operators are `contains`, `isequal`, `startswith`, `regex`, and `eregex`. These speak for themselves, except for the latter two—`regex` considers its parameter as a simple and `eregex` as an "extended" regular expression according to POSIX. All comparison operators take upper and lower case into account.

The `startswith` comparison is useful because it is considerably more efficient than a regular expression that is anchored to the start of the message (as long as you're looking for a constant string, anyway). You should, however, be careful, because what you consider the start of the message and what rsyslog thinks of that can be quite different. If rsyslog receives a message via the syslog service, this will, for example, look like

```
<131>Jul 22 14:25:50 root: error found
```

As far as rsyslog is concerned, `msg` does not start (as one might naively assume) at the `e` of `error`, but with the space character in front of it. So if you are looking for messages that start with `error`, you should say

```
:msg, startswith, " error"   /var/log/error.log
```

There is a nice addition on the "action side" of simple rules: With traditional `syslogd`, you have already seen that an entry like

```
local0.*       @red.example.com
```

will forward log messages to a remote host via the (UDP-based) syslog protocol. With rsyslog, you may also write

```
local0.*       @@red.example.com
```

to transmit log messages via TCP. This is potentially more reliable, especially if firewalls are involved.

At the other end of the TCP connection, of course, there must be a suitably configured rsyslog listening for messages. You can ensure this, for example, via

```
module(load="imtcp" MaxSessions="500")
input(type="imtcp" port="514")
```

In the obsolete syntax,

```
$ModLoad imtcp
$InputTCPMaxSessions 500
$InputTCPServerRun 514
```

does the same thing.

Do consider that only the UDP port 514 is officially reserved for the syslog protocol. The TCP port 514 is really used for a different purpose[2]. You can specify a different port just in case:

```
local0.*       @@red.example.com:10514
```

(and that works for UDP, too, if necessary). The changes required on the server side will be easy for you to figure out on your own.

The next level of complexity are filters based on expressions that may contain arbitrary Boolean, arithmetic, or string operations. These always start with an `if` at the very left of a new line:

```
if $syslogfacility-text == "local0" and $msg startswith " FOO" ▷
 ◁ and ($msg contains "BAR" or $msg contains "BAZ") ▷
 ◁ then /var/log/foo.log
```

(in your file this should all be on one line). With this rule, messages of category `local0` will be written to the `/var/log/foo.log` file as long as they start with `FOO` and also contain either `BAR` or `BAZ` (or both). (Watch for the dollar signs at the start of the property names.)

Rsyslog supports a large number of modules that determine what should happen to log messages. You might, for example, forward important messages by e-mail. To do so, you might put something like

```
module(load="ommail")
template(name="mailBody" type="string" string="ALERT\\r\\n%msg%")
if $msg contains "disk error" then {
    action(type="ommail" server="mail.example.com" port="25"
           mailfrom="rsyslog@example.com" mailto="admins@example.com"
           subject.text="disk error detected"
           body.enable="on" template="mailBody"
           action.execonlyonceeveryinterval="3600")
}
```

into your `/etc/rsyslog.conf`.

If you have an older version of rsyslog (before 8.5.0) you will need to use the obsolete syntax to configure the `ommail` module. That might, for example, look like

```
$ModLoad ommail
$ActionMailSMTPServer mail.example.com
$ActionMailFrom rsyslog@example.com
$ActionMailTo admins@example.com
$template mailSubject,"disk error detected"
$template mailBody,"ALERT\\r\\n%msg%"
$ActionMailSubject mailSubject
$ActionExecOnlyOnceEveryInterval 3600
if $msg contains "disk error" then :ommail:;mailBody
$ActionExecOnlyOnceEveryInterval 0q
```

[2] … even though nobody nowadays is still interested in the remote-shell service. Nobody reasonable, anyway.

Rsyslog's SMTP implementation is fairly primitive, since it supports neither encryption nor authentication. This means that the mail server you specify in the rsyslog configuration must be able to accept mail from rsyslog even without encryption or authentication.

By the way, rsyslog can handle Linux kernel log messages directly. You simply need to enable the `imklog` input module:

```
module(load="imklog")
```

or (obsolete syntax)

```
$ModLoad imklog
```

A separate `klogd` process is not necessary.

Detailed information on rsyslog is available, for example, in the online documentation [rsyslog].

Exercises

20.6 [!3] (If your distribution doesn't use rsyslog already.) Install rsyslog and create a configuration that is as close to your existing `syslogd` configuration as possible. Test it with (for example) `logger`. Where do you see room for improvement?

20.7 [2] PAM, the login and authentication system, logs sign-ons and sign-offs in the following format:

```
kdm: :0[5244]: (pam_unix) session opened for user hugo by (uid=0)
◁◁◁◁◁
kdm: :0[5244]: (pam_unix) session closed for user hugo
```

Configure rsyslog such that whenever a particular user (e. g. you) logs on or off, a message is displayed on the system administrator's (`root`'s) terminal if they are logged on. (*Hint:* PAM messages appear in the `authpriv` category.)

20.8 [3] (Cooperate with another class member if necessary.) Configure rsyslog such that all log messages from one computer are passed to another computer by means of a TCP connection. Test this connection using `logger`.

20.6 The "next generation": Syslog-NG

main advantages

Syslog-NG ("NG" for "new generation") is a compatible, but extended reimplementation of a syslog daemon by Balazs Scheidler. The main advantages of Syslog-NG compared to the traditional `syslogd` include:

- Filtering of messages based on their content (not just categories and priorities)
- Chaining of several filters is possible
- A more sophisticated input/output system, including forwarding by TCP and to subprocesses

The program itself is called `syslog-ng`.

For syslog clients there is no difference: You can replace a `syslogd` with Syslog-NG without problems.

You can find information about Syslog-NG in its manual pages as well as on [syslog-ng]. This includes documentation as well as a very useful FAQ collection.

Configuration file Syslog-NG reads its configuration from a file, normally `/etc/syslog-ng/syslog-ng.conf`. Unlike `syslogd`, Syslog-NG distinguishes various “entry types” in its configuration file. entry types

Global options These settings apply to all message sources or the Syslog-NG daemon itself.

Message sources Sylog-NG can read messages in various ways: from Unix-domain sockets or UDP like `syslogd`, but also, for example, from files, FIFOs, or TCP sockets. Every message source is assigned a name.

Filters Filters are Boolean expressions based on internal functions that can, for example, refer to the origin, category, priority, or textual content of a log message. Filters are also named.

Message sinks Syslog-NG includes all logging methods of `syslogd` and then some.

Log paths A “log path” connects one or several message sources, filters, and sinks: If messages arrive from the sources and pass the filter (or filters), they will be forwarded to the specified sink(s). At the end of the day, the configuration file consists of a number of such log paths.

Options You can specify various “global” options that control Syslog-NG’s general behaviour or determine default values for individual message sources or sinks (specific options for the sources or sinks take priority). A complete list is part of the Syslog-NG documentation. The general options include various settings for handling DNS and the forwarding or rewriting of messages’ sender host names.

If Syslog-NG on host *A* receives a message from host *B*, it checks the `keep_hostnames()` option. If its value is `yes`, *B* will be kept as the host name for the log. If not, the outcome depends on the `chain_hostnames()` option; if this is `no`, then *A* will be logged as the host name, if it is `yes`, then Syslog-NG will log *B*/*A*. This is particularly important if the log is then forwarded to yet another host.

Message Sources In Syslog-NG, message sources are defined using the `source` keyword. A message source collects one or more “drivers”. To accomplish the same as a “normal” `syslogd`, you would include the line

```
source src { unix-stream("/dev/log"); internal(); };
```

in your configuration; this tells Syslog-NG to listen to the Unix-domain socket `/dev/log`. `internal()` refers to messages that Syslog-NG creates by itself.

A Syslog-NG message source corresponding to the `-r` option of `syslogd` might look like this:

```
source s_remote { udp(ip(0.0.0.0) port(514)); };
```

Since that is the default setting,

```
source s_remote { udp(); };
```

would also do.

With `ip()`, you can let Syslog-NG listen on specific local IP addresses only. With `syslogd`, this isn’t possible.

The following source specification lets Syslog-NG replace the `klogd` program:

```
source kmsg { file("/proc/kmsg" log_prefix("kernel: ")); };
```

All message sources support another parameter, `log_msg_size()`, which specifies the maximum message length in bytes.

Table 20.3: Filtering functions for Syslog-NG

Syntax	Description
`facility(`⟨*category*⟩`[,`⟨*category*⟩ …`])`	Matches messages with one of the listed categories
`level(`⟨*priority*⟩`[,`⟨*priority*⟩ …`])`	Matches messages with one of the listed priorities
`priority(`⟨*priority*⟩`[,`⟨*priority*⟩ …`])`	Same as `level()`
`program(`⟨*regex*⟩`)`	Matches messages where the name of the sending program matches ⟨*regex*⟩
`host(`⟨*regex*⟩`)`	Matches messages whose sending host matches ⟨*regex*⟩
`match(`⟨*regex*⟩`)`	Matches messages which match the ⟨*regex*⟩ themselves
`filter(`⟨*name*⟩`)`	Invokes another filtering rule and returns its value
`netmask(`⟨*IP address*⟩`/`⟨*netmask*⟩`)`	Checks whether the IP address is in the given network

Filters Filters are used to sift through log messages or distribute them to various sinks. They rely on internal functions that consider specific aspects of messages; these functions can be joined using the logical operators, `and`, `or`, and `not`. A list of possible functions is shown in Table **??**.

You might, for example, define a filter that matches all messages from host `green` containing the text `error`:

```
filter f_green { host("green") and match("error"); };
```

With the `level()` (or `priority()` function, you can specify either one or more priorities separated by commas, or else a range of priorities like "`warn .. emerg`".

Message Sinks Like sources, sinks consist of various "drivers" for logging methods. For example, you can write messages to a file:

```
destination d_file { file("/var/log/messages"); };
```

You can also specify a "template" that describes in which format the message should be written to the sink in question. When doing so, you can refer to "macros" that make various parts of the message accessible. For instance:

```
destination d_file {
    file("/var/log/$YEAR.$MONTH.$DAY/messages"
         template("$HOUR:$MIN:$SEC $TZ $HOST [$LEVEL] $MSG\n")
         template_escape(no)
         create_dirs(yes)
    );
};
```

The `$YEAR`, `$MONTH`, etc. macros will be replaced by the obvious values. `$TZ` is the current time zone, `$LEVEL` the message priority, and `$MSG` the messaeg itself (including the sender's process ID). A complete list of macros is part of Syslog-NG's documentation.

The `template_escape()` parameter controls whether quotes (`'` and `"`) should be "escaped" in the output. This is important if you want to feed the log messages to, say, an SQL server.

Unlike `syslogd`, Syslog-NG allows forwarding messages using TCP. This is not just more convenient when firewalls are involved, but also ensures that no log messages can get lost (which might happen with UDP). You could define a TCP forwarding sink like this:

```
destination d_tcp { tcp("10.11.12.13" port(514); localport(514)); };
```

Also very useful is forwarding messages to programs using `program()`. Syslog-NG starts the program when it is started itself, and keeps it running until itself is stopped or it receives a `SIGHUP`. This is not just to increase efficiency, but serves as a precaution against denial-of-service attacks—if a new process is started for every new message, an attacker could shut off logging by sending large amounts of matching log messages. (Other messages that would point to these shenanigans might then be dropped to the floor.)

Log paths Log paths serve to bring sources, filters, and sinks together and to actually evaluate messages. They always start with the `log` keyword. Here are a few examples based on rules you know already from our `/etc/syslog.conf` discussion:

```
# Prerequisites
source s_all { internal(); unix-stream("/dev/log"); };
filter f_auth { facility(auth, authpriv); };
destination df_auth { file("/var/log/auth.log"); };

# auth,authpriv.*   /var/log/auth.log
log {
        source(s_all);
        filter(f_auth);
        destination(df_auth);
};
```

This rule causes all messages to do with authentication to be written to the `/var/log/auth.log` file. Of course, with `syslogd`, this can be done in one line …

Here is a somewhat more complex example:

```
# kern.warn;*.err;authpriv.none    /dev/tty10
filter f_nearly_all {
    (facility(kern) and priority(warn .. emerg))
    or (not facility(authpriv,kern));
};
destination df_tty { file("/dev/tty10"); };
log {
        source(s_all);
        filter(f_nearly_all);
        destination(df_tty);
};
```

Here, too, `syslogd`'s version is a little more compact, but on the other hand this description might be easier to follow.

Every message passes through all log paths, and will be logged by all matching ones (this behaviour equals that of `syslogd`). If you want a message to not be further considered after it has passed a particular log path, you can add the `flags(final)` option to that path.

`flags(final)` does not mean that the message is logged just once; it might have been logged by other paths before the path in question.


With `flags(fallback)`, you can declare a path to be the "default path". This path will only be considered for log messages that did not match any paths that were not marked `flags(fallback)`.

Exercises


20.9 [!3] Install Syslog-NG and create a configuration that is as close to your existing `syslogd` configuration as possible. Test it with (for example) `logger`. Where do you see room for improvement?


20.10 [2] PAM, the login and authentication system, logs sign-ons and sign-offs in the following format:

```
kdm: :0[5244]: (pam_unix) session opened for user hugo by (uid=0)
◁◁◁◁◁
kdm: :0[5244]: (pam_unix) session closed for user hugo
```

Configure Syslog-NG such that whenever a particular user (e. g. you) logs on or off, a message is displayed on the system administrator's (`root`'s) terminal if they are logged on. (*Hint:* PAM messages appear in the `authpriv` category.)


20.11 [3] (Cooperate with another class member if necessary.) Configure rsyslog such that all log messages from one computer are passed to another computer by means of a TCP connection. Test this connection using `logger`. Experiment with different settings for `keep_hostnames()` and `chain_hostnames()`.

20.7 The `logrotate` Program

Depending on the number of users and the number and type of running services, the log files can grow fairly large fairly quickly. To keep the system from inundation by garbage, you should on the one hand try to put the relevant directories (e. g., `/var/log` or `/var`) on their own partitions. On the other hand there is software which checks the log files periodically according to various criteria such as the size, truncates them and removes or archives old log files. This process is called "rotation", and one such program is `logrotate`.

`logrotate` is not a daemon, but will usually be executed once a day (or so) using `cron`—or a similar service.


`logrotate` refuses to modify a log file more than once a day, except if the decision depend on the size of the log file, you're using the `hourly` criterion, or the `--force` option (`-f` for short) was specified with `logrotate`.

`/etc/logrotate.conf`
`/etc/logrotate.d`

According to convention, `logrotate` is configured using the `/etc/logrotate.conf` file and the files within the `/etc/logrotate.d` directory. The `/etc/logrotate.conf` file sets up general parameters, which can be overwritten by the files in `/etc/logrotate.d` if necessary. In `/etc/logrotate.conf`, there is in particular the "`include /etc/logrotate.d`" parameter, which causes the files from that directory to be read in that place as if they were part of the `/etc/logrotate.conf` file.


In principle, `logrotate` reads all the files named on the command line as configuration files, and the content of files mentioned later overwrites that of files mentioned earlier. The `/etc/logrotate.conf` thing is just a (reasonable) convention which is put into action by means of a suitable invocation of `logrotate` in `/etc/cron.daily/logrotate` (or something equivalent).

```
/var/log/syslog
{
    rotate 7
    daily
    missingok
    notifempty
    delaycompress
    compress
    postrotate
        invoke-rc.d rsyslog rotate >/dev/null
    endscript
}
```

Figure 20.1: Example configuration for logrotate (Debian GNU/Linux 8.0)

We mention this here because it gives you the basic possibility to perform, without undue hassle, separate logrotate runs for log files which aren't part of the regular configuration. If, for example, you have an extremely fast-growing log file of, say, a popular web server, you can manage this using a separate logrotate instance that runs more often than once a day.

logrotate watches all files that it is told about by the aforementioned configuration files, not just those created by syslogd. By way of example, Figure 20.1 shows an excerpt of a configuration file for rsyslog from Debian GNU/Linux 8.

The first line of the example specifies the files that this configuration applies to (here, /var/log/syslog). You may enumerate several files or specify shell search patterns. After that, inside curly braces, there is a block of directives that define how logrotate should deal with the given files.

Typically, /etc/logrotate.conf contains directives that are outside of a brace-delimited block. These directives serve as defaults that apply to all log files in the configuration, unless something more specific is given in their own blocks of directives.

"rotate 7" means that at most seven old versions of each log file will be kept. old versions
When this maximum is reached, the oldest version of the log file will be deleted.

If you specify an address using mail, files will not be deleted but instead be sent to the address in question.

"rotate 0" deletes "rotated" log messages outright without keeping them at all.

The rotated files are numbered in sequence, this means that if the current version of the file is called /var/log/syslog, the immediately preceding version will be /var/log/syslog.1, the version preceding that will be /var/log/syslog.2, and so on.

You may use the date instead of the sequential numbers. This means that if today is July 20, 2015, and your logrotate run takes place daily in the wee hours, the immediately preceding version of the file is not called /var/log/syslog.1 but /var/log/syslog-20150720, the version preceding that will be called /var/log/syslog-20150719, and so on. To use this you must specify the "dateext" directive.

Using "dateformat", you can control exactly how the date-based file extension should look like. To do so, you need to specify a string that may contain the %Y, %m, %d, and %s keys. These stand for the (four-digit) year, calendar month, and calendar day (in each case two digits and, if necessary, with a leading zero) and the seconds since 1st January 1970, 12:00 am UTC. As you can surmise from the previous paragraph, the default is "-%Y%m%d".


When you use `dateformat`, you should note that `logrotate` does a lexicographic sort of file names when rotating in order to find out which file is the oldest. This works with "`-%Y%m%d`", but not with "`-%d%m%Y`".

Time periods "`daily`" means that log files should be rotated daily. Together with "`rotate 7`" this implies that you always have access to last week's logs.


There are also `weekly`, `monthly`, and `yearly`. With `weekly`, the file will be rotated when the current day of the week is earlier than the day of the week of the last rotation, or more than one week has passed since the last rotation (in the end, this means that rotation will take place on the first day of the week, which according to US custom is the Sunday). With `monthly`, the file will be rotated on the first `logrotate` run of the month (usually on the first of the month). With `yearly`, rotation takes place on the first `logrotate` run of the year. Theoretically, `hourly` rotates the log file every hour, but since `logrotate` is normally only run once a day, you will have to arrange for it to be run frequently enough.


An alternative criterion is "`size`". This will rotate a log file when a certain size has been exceeded. The file size is given as a parameter—without a unit, it will be taken to mean bytes, while the units `k` (or `K`), `M`, and `G` stand for kibibytes (2^{10} bytes), mebibytes (2^{20} bytes), or gibibytes (2^{30} bytes), respectively.


"`size`" and the time-based criteria are mutually exclusive. This means that if you specify a "`size`" criterion, rotation will depend solely on file size, no matter when the file was last rotated.


File size and time can be used together by means of the "`maxsize`" and "`minsize`" criteria. With "`maxsize`", you can specify a size which will cause `logrotate` to rotate the file even if the next official date has not been reached. With "`minsize`", the file will only be rotated at the specified point in time if it has exceeded the given size (small files will be skipped).

error messages "`missingok`" suppresses error messages if a log file could not be found. (The default is "`nomissingok`".) "`notifempty`" does not rotate a file if it is empty (the default here is "`ifempty`").

"`compress`" lets you specify that rotated versions of the log file should be compressed.


This is by default done with `gzip` unless you request a different command using "`compresscmd`". Options for that command (which you would otherwise pass on its command line) can be defined with "`compressoptions`". The default for `gzip` is "`-6`".

The "`delaycompress`" directive ensures that a freshly rotated file is not compressed immediately after the rotation but only on the next run. While usually the sequence of files would look like

```
/var/log/syslog  /var/log/syslog.1.gz  /var/log/syslog.2.gz  …
```

"`delaycompress`" would get you the sequence

```
/var/log/syslog  /var/log/syslog.1  /var/log/syslog.2.gz …
```

(in other words, `/var/log/syslog.1` remains uncompressed). You need this setting if there is a chance that the logging program (like rsyslog) might append data to the file after it has been renamed (rotated)—this can happen because rsyslog keeps the logfile open, and renaming the file is irrelevant as far as writing to it is concerned.

This implies that you need to notify rsyslog that there is a new log file. This is what the

```
postrotate
  invoke-rc.d rsyslog rotate >/dev/null
endscript
```

directive is for. The shell commands between "postrotate" and "endscript" are executed by logrotate whenever the log file has been rotated.

The command itself is basically irrelevant (the idea counts), but what happens in the end is that rsyslog's init script will be invoked, and it will send SIGHUP to the program. Other distributions also have their ways and means.

The SIGHUP then causes rsyslog to reread its configuration file and close and reopen all log files. Since /var/log/syslog was renamed earlier on, rsyslog opens a new log file under that name.—At this point, logrotate could compress the /var/log/syslog.1 file, but it has no way of knowing when rsyslog is really done with the file. This is why this is postponed until the file gets rotated again.

Between "postrotate" and "endscript" there may be several lines with commands. logrotate concatenates them all and passes them to the shell (/bin/sh) as a whole. The commands is passed the name of the log file as a parameter, and that is available there in the customary fashion as "$1".

The postrotate commands are executed once for every log file enumerated at the start of the configuration block. This means that the commands will perhaps be executed several times. You can use the "sharedscripts" directive to ensure that the commands are executed at most once for all files that match the search pattern (or not at all, if none of the files needed to be rotated).

You can use "create" to make sure that the log file is recreated immediately after the rotation and before the postrotate commands are executed. This uses the name of the old file. The file mode, owner, and group derive from the parameters to create; the three possibilities are

```
create 600 root adm                    File mode, user, and group
create root adm                        Just user and group
create                                 Nothing at all
```

Unspecified file properties are taken from the previous version of the file.

This is just a selection of the most important configuration parameters. Study logrotate(8) to see the full list.

Exercises

20.12 [!1] Which system-wide defaults does logrotate establish in your distribution?

20.13 [C]onsult /etc/logrotate.conf (and possibly logrotate(8)).

20.14 [3] Configure logrotate such that your new /var/log/test log file will be rotated once it exceeds a length of 100 bytes. 10 rotated versions should be kept, these older versions should be compressed and should use a name containing the date of their creation. Test your configuration.

Commands in this Chapter

klogd Accepts kernel log messages klogd(8) 302, 306
logger Adds entries to the system log files logger(1) 304
logrotate Manages, truncates and "rotates" log files logrotate(8) 314
logsurfer Searches the system log files for important events www.cert.dfn.de/eng/logsurf/ 305
syslogd Handles system log messages syslogd(8) 302
tail Displays a file's end tail(1) 305
xconsole Displays system log messages in an X window xconsole(1) 302
xlogmaster X11-based system monitoring program xlogmaster(1), www.gnu.org/software/xlogmaster/ 305

Summary

- The syslogd daemon can accept log messages from various system components, write them to files, or pass them on to users or other computers.
- Log messages may belong to diverse facilities and can have various priorities.
- Messages can be sent to syslogd using the logger command.
- Log files are generally placed in the /var/log directory.
- Syslog-NG is a compatible, but extended, reimplementation of a syslog daemon.
- logrotate can be used to manage and archive log files.

Bibliography

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rsyslog "Welcome to Rsyslog". http://www.rsyslog.com/doc/v8-stable/index.html

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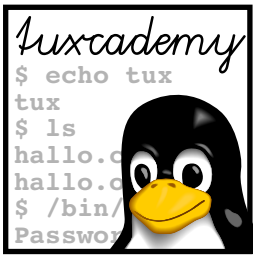


21

System Logging with Systemd and "The Journal"

Contents

Goals

- Understanding the fundamentals of journald
- Being able to configure journald
- Being able to issue simple journal queries
- Understanding how journald handles log files

Prerequisites

- Basic knowledge of Linux system components
- Ability to handle configuration files
- Knowledge of the traditional system log service (Chapter 20)
- Knowledge about systemd

21.1 Fundamentals

Systemd is a far-reaching renewal of the software that ensures the basic operation of a Linux computer. In a stricter sense, systemd is about starting and tracking services and managing resources. Systemd also contains an approach to system logging that is markedly different from the traditional syslogd method, the "journal", and the software components necessary to implement it.

While in the traditional approach the syslog daemon accepts log messages on UDP port 514 or the `/dev/log` socket, and (typically) writes them to text files (or forwards them to other hosts where they are written to text files), in the systemd world background services can simply write log messages to their standard error output channel and systemd will arrange for them to be passed to the logging service[1]. With systemd, log files are not text files (where every message is possibly written to several files), but messages are written to a (binary) database that can then be queried according to diverse criteria.

For example, it is quite easy to display all messages logged by a specific service during a specific period of time. In the traditional system this is fairly difficult.

In fairness, we should point out that the modern syslog implementations such as Rsyslog or Syslog-NG are, in principle, capable of writing log messages to a database. However, it will be your own responsibility to come up with a suitable database schema, to configure Rsyslog or Syslog-NG accordingly, and to develop software that allows you convenient access to the log messages. Systemd includes all this "out of the box".

The Journal isn't confined to textual log messages. It is, for instance, perfectly possible to store core dumps of crashed programs in the Journal (as long as they aren't ginormously oversized). Whether that is a unqualified great idea is, of course, debatable, and the systemd developers have already thought of an alternative method.

Systemd's log system can also interoperate with the traditional approach. If desired, it logs messages that arrive on `/dev/log` or UDP port 512, and can pass messages on to a traditional syslog daemon (or a modern reimplementation).

You have the Journal to thank, too, for the (very convenient) circumstance that "`systemctl status`" will show you the most recent log messages by the service in question:

```
# systemctl status ssh
● ssh.service - OpenBSD Secure Shell server
   Loaded: loaded (/lib/systemd/system/ssh.service; enabled)
   Active: active (running) since Mo 2015-07-27 13:37:22 CEST; 8h ago
 Main PID: 428 (sshd)
   CGroup: /system.slice/ssh.service
           └─428 /usr/sbin/sshd -D

Jul 27 13:37:23 blue sshd[428]: Server listening on 0.0.0.0 port 22.
Jul 27 13:37:23 blue sshd[428]: Server listening on :: port 22.
Jul 27 13:56:50 blue sshd[912]: Accepted password for hugo from ...sh2
Jul 27 13:56:50 blue sshd[912]: pam_unix(sshd:session): session ...=0)
Hint: Some lines were ellipsized, use -l to show in full.
```

As the final line of the output suggests, overlong lines are shortened such that they just fit on the screen. If you want to see them in full, you must invoke `systemctl` with the `-l` option.

[1] Systemd also offers its own API for log messages

Exercises

21.1 [2] What are the advantages and disadvantages of the traditional approach (text files in `/var/log`) compared to the database-like approach of the Journal?

21.2 Systemd and journald

The Journal is an integrated part of systemd. In the simplest case, systemd uses a limited-size ring buffer in `/run/log/journal` to store a certain number of log messages in RAM (which is sufficient if you want to pass the messages to a traditional log service). To take advantage of all Journal features, you should ensure that the log messages are permanently stored on disk. This is simply done by creating the directory for storage:

```
# mkdir -p /var/log/journal
# systemctl --signal=USR1 kill systemd-journald
```

(the `SIGUSR1` gets systemd to transfer the RAM-based Journal to the new file on disk).

The systemd component that takes care of the Journal is called `systemd-journald` (or journald to its friends).

The Journal is configured by means of the `/etc/systemd/journald.conf` file. The `[Journal]` section of this file (the only one) contains, for example, the `Storage` parameter, which can assume any of the following values:

`volatile` Log messages are stored only in RAM (in `/run/log/journal`), even if `/var/log/journal` exists.

`persistent` Log messages are preferably stored on disk (in `/var/log/journal`). The directory will be created if it doesn't exist. During early boot and if the disk is not writable, systemd falls back onto `/run/log/journal`.

`auto` Similar to `persistent`, but the existence of the `/var/log/journal` directory determines whether a persistent Journal will be written—if the directory does not exist, the volatile Journal in RAM will have to do.

`none` No log messages will be stored in the Journal at all. You can still pass messages to a traditional syslog service.

There are a few other interesting parameters. `Compress` specifies whether log files (at least those exceeding a certain size) will be transparently compressed; the default value is `yes`. `Seal` lets you ensure that persistent Journal files are protected against clandestine manipulation by means of a cryptographic signature. You will only need to furnish a key (the document explains how).

The `RateLimitInterval` and `RateLimitBurst` parameters are supposed to make it more difficult to flood the log with messages. If a service produces more than `RateLimitBurst` messages during a period of time given by `RateLimitInterval`, then all further messages until that period of time is over will be ignored (the log will contain only one message detailing the number of ignored messages). By default, the limit is 1000+messages in 30 seconds; if you set either of the parameters to zero, the limitation will be lifted.

`SyncIntervalSec` specifies how often the Journal will be synced to disk. The Journal will always be saved immediately after a message of priority `crit` (or above) has been logged; as long as no such message arrives, journald will wait for the interval specified by `SyncIntervalSec` before saving it again. The default value is "5 minutes".

Use the `journalctl` command to inspect the log:

```
# journalctl
-- Logs begin at Mo 2015-07-27 13:37:14 CEST, end at Mo 2015-07-27▷
 ◁ 22:20:47 CEST. --
Jul 27 13:37:14 blue systemd-journal[138]: Runtime journal is using 4.
Jul 27 13:37:14 blue systemd-journal[138]: Runtime journal is using 4.
Jul 27 13:37:14 blue kernel: Initializing cgroup subsys cpuset
Jul 27 13:37:14 blue kernel: Initializing cgroup subsys cpu
Jul 27 13:37:14 blue kernel: Initializing cgroup subsys cpuacct
Jul 27 13:37:14 blue kernel: Linux version 3.16.0-4-amd64 (debian-kern
Jul 27 13:37:14 blue kernel: Command line: BOOT_IMAGE=/boot/vmlinuz-3.
```

The output strongly resembles what you would find in `/var/log/messages`, but in fact includes various improvements (which are, unfortunately, less than obvious in a printed training manual):

- The log is displayed using your favourite display program for text files (typically `less`). Using `less`, you can look at the ends of over-long lines by using the horizontal arrow keys.

  
  This is determined by the value of the `SYSTEMD_PAGER` environment variable, failing that the value of `PAGER`, failing that `less`. Using the `SYSTEMD_LESS` environment variable you can specify options for `less` (if you don't use the system default, this variable is ignored, but then again you can put options into `SYSTEMD_PAGER` directly).

  
  If you invoke `journalctl` with the `--no-pager` option or set `SYSTEMD_PAGER` to `cat` or an empty string, the output will not be displayed page by page.

- The output includes all accessible log files, even rotated ones (we'll talk more about that later).
- Time stamps are in local (zone) time, not UTC.
- Log messages of priority `notice` or `warning` are displayed in bold face.
- Log messages of priority `error` (or higher) appear in red.

`systemd-journald` tries to make sensible use of the available space. This means that new messages are normally appended to the Journal, but if a certain upper limit for the size of the Journal is reached, it tries to remove old log messages.


You can specify the `SystemMaxUse` and `RuntimeMaxUse` parameters in the `/etc/systemd/journald.conf` file. These parameters describe how much space the Journal may take up under `/var/log/journal` and `/run/log/journal`, respectively. The `SystemKeepFree` and `RuntimeKeepFree` parameters, on the other hand, determine how much space must be kept free on the file systems in question. `systemd-journald` takes into account both values (`…MaxUse` and `…KeepFree`) and confines itself to the minimum size dictated by both.


The `Runtime…` values are used when the system is booting or no persistent Journal is used. The `System…` values apply to the persistent Journal if the system has been booted far enough. When determining the space used by the Journal, only files whose names end in `.journal` will be considered.


You may specify amounts in bytes or append one of the (binary) units `K`, `M`, `G`, `T`, `P` or `E`[2].

[2] We assume it will still be some time before you will have to specify a limit for the Journal in exbibytes (2^{60} bytes), but it is reassuring that the systemd developers are apparently planning for the future.


The default value for …MaxUse is 10% and the one for …KeepFree is 15% of the file system in question. If there is less space available when systemd-journald starts than the …KeepFree value dictates, the limit is reduced even further such that space for other material remains.

Like logrotate, systemd "rotates" the Journal to make room for new messages. To do so, the available space is subdivided into a number of files, so the oldest can be discarded from time to time. This rotation is transparent to users, because systemd-journald does it of its own accord when required and journalctl always evaluates the full Journal, no matter how many files it consists of.


The subdivision is governed by the SystemMaxFileSize and RuntimeMaxFileSize parameters within the /etc/systemd/journald.conf file. They specify how large individual Journal files may become—the default is "one eighth of the total space available for the Journal", so you will always have a "prehistory" of seven files and the current file.


You may also make the log file rotation depend on time: MaxFileSec determines the maximum time period before systemd starts a new log file. (Usually the size-based rotation is perfectly adequate.) You can use MaxRetentionSec to specify an upper limit for how long old log messages are kept around. The default value for MaxFileSec is 1month (0 means "unlimited") and that for MaxRetentionSec is 0 (the mechanism is disabled).

In /etc/systemd/journald.conf you can also configure log forwarding to a traditional syslog system. To do so, simply set

log forwarding

```
[Journal]
ForwardToSyslog=yes
```

Exercises


21.2 [!2] Configure your computer such that the Journal is stored persistently on disk. Ensure that this really works (e. g., by writing a message to the log using logger, rebooting the computer and then checking that the message is still there).


21.3 [2] Does your computer still have a traditional syslog daemon? If not, then install one (BSD syslogd or Rsyslog suggest themselves) and cause log messages to be forwarded to it. Convince yourself (e. g., using logger) that it works.

21.3 Log Inspection

You may use journalctl to direct very detailed queries to the Journal. We will investigate this further in this section, but here are a few introductory remarks.

Access rights While as root you get to see the complete log, as an ordinary user you will only be able to peruse your own log, namely the messages submitted by programs that you started yourself (or that the computer started on your behalf). If you want to have full access even as an ordinary user—we do recommend that even as an administrator you should, as far as possible, use a non-privileged user account, after all—you will need to ensure that you are part of the adm group:

```
# usermod -a -G adm hugo
```


You must log out and in again before this change will actually become effective.

Real-time Journal monitoring By analogy to the popular "`tail -f`" command, you can watch new messages being written to the Journal:

```
$ journalctl -f
```

This, too, will display 10 lines' worth of output before `journalctl` waits for further messages to arrive. As with the good old `tail`, you can set the number of lines using the `-n` option, and that works even without the `-f`.

Services and priorities You can use the `-u` option to restrict the output to those log messages written by a specific systemd unit:

```
$ journalctl -u ssh
-- Logs begin at Mo 2015-07-27 13:37:14 CEST, end at Di 2015-07-28 ▷
 ◁ 09:32:08 CEST. --
Jul 27 13:37:23 blue sshd[428]: Server listening on 0.0.0.0 port 22.
Jul 27 13:37:23 blue sshd[428]: Server listening on :: port 22.
Jul 27 13:56:50 blue sshd[912]: Accepted password for hugo from 192.16
Jul 27 13:56:50 blue sshd[912]: pam_unix(sshd:session): session opened
```


Instead of a specific unit name you can also give a shell search pattern to include several units. Or simply specify several `-u` options.

To only display messages of certain priorities, use the `-p` option. This takes either a single numerical or textual priority (`emerg` has the numerical value 0, `debug` 7) and limits the output to messages of that priority or above (below, if you go for numerical values). Or specify a range in the form

```
$ journalctl -p warning..crit
```

to see only those messages whose priority is in that range.


Of course you may combine the `-u` and `-p` options, too:

```
$ journalctl -u apache2 -p err
```

displays all error messages (or worse) from Apache.

The `-k` option limits the output to messages logged by the operating system kernel. This considers only messages written since the last system boot.

Time If you're only interested in messages from a certain period of time, you can limit the output accordingly. The `--since` and `--until` options let you specify a date or time in the "`2015-07-27 15:36:11`" format, and only messages written since or until that point in time will be output.


You can leave off the time completely, in which case "`00:00:00`" will be assumed. Or leave off just the seconds, then "`:00`" is implied. If you leave off the date (which of course requires a time, with or without seconds), `journalctl` will assume "today".


The `yesterday`, `today`, and `tomorrow` keywords stand for "`00:00:00`" yesterday, today, or tomorrow, respectively.


Relative time specifications are also allowed: "`-30m`" stands for "half an hour ago". ("`+1h`" stands for "in one hour", but it is unlikely that your system log will contain entries from the future[3].

[3] Unless you're the Doctor and are querying the Journal of the TARDIS.

Every system boot is assigned a unique identifier, and you can limit your search to the part of the Journal between one boot and the next. In the simplest case, "`journalctl -b`" will consider only messages from the current run:

```
$ journalctl -b -u apache2
```

With the `--list-boots` option, `journalctl` will output a list of boot identifiers to be found in the current Journal, together with the periods of time for which there are log entries:

```
$ journalctl --list-boots
-1 30eb83c06e054feba2716a1512f64cfc Mo 2015-07-27 22:45:08 CEST–▷
 ◁ Di 2015-07-28 10:03:31 CEST
 0 8533257004154353b45e99d916d66b20 Di 2015-07-28 10:04:22 CEST–▷
 ◁ Di 2015-07-28 10:04:27 CEST
```

You may refer to specific boots by passing to `-b` their index (`1` stands for the chronologically first boot in the log, `2` for the second, and so on) or the negative offset in the first column of the output of "`journalctl --list-boots`" (`0` refers to the current boot, `-1` the one before, and so on).

You may also specify the 32-character alphanumeric boot ID from the second column of "`journalctl --list-boots`" to search the Journal for that boot only. That, too, lets you add a positive or negative offset to identify boots before or after it: In the example above,

```
$ journalctl -b 8533257004154353b45e99d916d66b20-1
```

is a roundabout way of saying

```
$ journalctl -b 1
```

Arbitrary search operations If you specify a path name as a parameter, `journalctl` tries to do something reasonable with it:

- If it refers to an executable file, it looks for Journal entries made by that program.
- If it refers to a device file, it looks for entries concerning the device in question.

These search operations are special cases of a more general search mechanism offered by the Journal. Systemd does in fact log much more information than the traditional syslog mechanism[4]. You see that by invoking `journalctl` with the `--output=verbose` option (see Figure 21.1.)

The first line in Figure 21.1 is a time stamp for the message together with a "cursor". The cursor identifies the message inside the Journal and is needed, for example, to store log entries on remote computers.

The subsequent lines are Journal fields that refer to the message in question. Field names without a leading underscore derive from information submitted by the logging program, and as such are not necessarily trustworthy (the program could, for example, attempt to lie about its PID or its name—in `SYSLOG_IDENTIFIER`). Field names with a leading underscore are supplied by systemd and cannot be manipulated by the logging program.

[4] Again, in fairness, we must mention that these can do rather more than they must—even if they have sometimes acquired that functionality only very recently, in order to catch up with systemd's Journal.

```
Mo 2015-07-27 13:37:23.580820 CEST [s=89256633e44649848747d32096fb42▷
 ◁ 68;i=1ca;b=30eb83c06e054feba2716a1512f64cfc;m=11a1309;t=51bd9c6f▷
 ◁ 8812e;x=f3d8849a4bcc3d87]
    PRIORITY=6
    _UID=0
    _GID=0
    _SYSTEMD_SLICE=system.slice
    _BOOT_ID=30eb83c06e054feba2716a1512f64cfc
    _MACHINE_ID=d2a0228dc98041409d7e68858cac6aba
    _HOSTNAME=blue
    _CAP_EFFECTIVE=3fffffffff
    _TRANSPORT=syslog
    SYSLOG_FACILITY=4
    SYSLOG_IDENTIFIER=sshd
    SYSLOG_PID=428
    MESSAGE=Server listening on 0.0.0.0 port 22.
    _PID=428
    _COMM=sshd
    _EXE=/usr/sbin/sshd
    _CMDLINE=/usr/sbin/sshd -D
    _SYSTEMD_CGROUP=/system.slice/ssh.service
    _SYSTEMD_UNIT=ssh.service
    _SOURCE_REALTIME_TIMESTAMP=1437997043580820
```

Figure 21.1: Complete log output of `journalctl`

`PRIORITY`, `SYSLOG_FACILITY`, `SYSLOG_IDENTIFIER`, `SYSLOG_PID`, and `MESSAGE` derive from the syslog protocol and are pretty self-explanatory. `_UID`, `_GID`, `_HOSTNAME`, `_PID`, and `_SYSTEMD_UNIT` also explain themselves. `_BOOT_ID` is the identifier of the current boot, and `_MACHINE_ID` identifies the logging computer according to its entry in `/etc/machine-id`. `_CAP_EFFECTIVE` specifies the special capabilities of the logging process, and `_TRANSPORT` describes how the message reached systemd (apart from `syslog`, common sources are `stdout` for messages that the program wrote to its standard output or standard error output, or `kernel` for messages submitted by the operating system kernel via `/dev/klog`). `_COMM`, `_EXE`, and `_CMDLINE` all describe the command being executed. `_SYSTEMD_SLICE` and `_SYSTEMD_CGROUP` specify where in systemd's internal process management the logging process may be found. A more detailed explanation is available from `systemd.journal-fields`(7).

You may search for all of these fields simply by specifying them on `journalctl`'s command line:

```
$ journalctl _HOSTNAME=red _SYSTEMD_UNIT=apache2.service
```

Search terms using different fields are implicitly joined using AND. If the same field appears in several search terms, these are implicitly joined using OR.

There is also an explicit OR:

```
$ journalctl _HOSTNAME=red _UID=70 + _HOSTNAME=blue _UID=80
```

shows all processes with the UID 70 on the host `red` as well as all processes with the UID 80 on the host `blue`. (Naturally this only works if you consolidate both these Journals on your computer.)

Of course you can combine these search terms freely with options, e. g., to set up time limits or save typing:

```
$ journalctl -u apache2 _HOSTNAME=red
```

If (like us) you can never remember which values a search term could assume, you can simply ask the Journal:

```
$ journalctl -F _SYSTEMD_UNIT
session-2.scope
udisks2.service
session-1.scope
polkitd.service
dbus.service
user@1000.service
◁◁◁◁◁
```

As a further simplification, command line completion works for field names and values:

```
$ journalctl _SYS Tab                                                    becomes
$ journalctl _SYSTEMD_ Tab
_SYSTEMD_CGROUP= _SYSTEMD_OWNER_UID= _SYSTEMD_SESSION= _SYSTEMD_UNIT=
$ journalctl _SYSTEMD_U Tab                                              becomes
$ journalctl _SYSTEMD_UNIT= Tab Tab
acpid.service       lightdm.service       ssh.service
anacron.service     networking.service    systemd-journald.service
◁◁◁◁◁
$ journalctl _SYSTEMD_UNIT=ss Tab                                        becomes
$ journalctl _SYSTEMD_UNIT=ssh.service
```

The Journal and `journald` are immensely flexible and powerful and let the traditional method (text files in `/var/log`) appear pretty primitive in comparison.

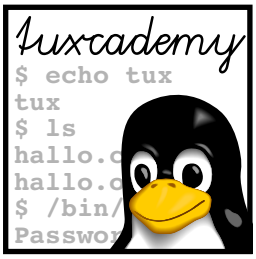
.

Exercises

21.4 [!2] Experiment with `journalctl`. How many different user identities have sent messages to the Journal on your computer? Did anything interesting happen yesterday between 1 p. m and 2 p. m.? What were the last 10 messages of priority `warning`? Think of some interesting questions yourself and answer them.

Summary

- The "Journal" is a modern system logging service made available by systemd. It relies on binary, database-like log files.
- The Journal is stored either in `/run/log/journal` or (for persistent logging to disk) in `/var/log/journal`.
- Within systemd, `systemd-journald` takes care of the Journal. You can access the Journal using `journalctl`.
- `journalctl` allows very sophisticated queries of the Journal



22

TCP/IP Fundamentals

Contents

Goals

- Knowing the basic structure of the TCP/IP protocol family
- Knowing the fundamentals of IP addressing
- Understanding the concepts of subnetting and routing
- Knowing the most important properties of and differences between TCP, UDP, and ICMP
- Knowing about the most important TCP and UDP services
- Knowing the most relevant differences between IPv4 and IPv6

Prerequisites

- Basic knowledge of computer networks and TCP/IP services from a user's point of view is helpful

22.1 History and Introduction

22.1.1 The History of the Internet

The history of networking computers reaches back almost to the beginning of the "computer age". Most of the early techniques are all but forgotten today—the "Internet" has won the day. But what is "the Internet", anyway, and where does it come from? In this section, we give a brief overview of its history and the development of world-wide computer communications. If you already know this from elsewhere, feel free to skip to the next section. Thank you very much.

ARPAnet The progenitor of today's Internet is ARPAnet, whose development was funded by the American defence department. It's the late 1960s.

The original object was not, as is often claimed, the construction of a communication infrastructure for the eventuality of nuclear war, but merely research into data communications, while at the same time improving communications between the corporations and universities engaged in defence research.

In 1969, the ARPAnet consisted of 4 nodes; from 1970 until 1972 the *Network Control Protocol* (NCP) was implemented as the basic communication standard on the ARPAnet. The most important service at the time was electronic mail.

NCP

In the 1970s, the idea of an "internet" that was supposed to connect already existing networks gained traction. Researchers tried to implement "TCP", a reliable communication protocol based on an unreliable transmission protocol (the idea of making available an unreliable communication protocol in the shape of UDP only came along later, which explains where the name "TCP/IP" (rather than "TCP/UDP/IP" or something similar) comes from). The first TCP implementations appeared in the early 1970s on "large" systems such as TOPS-20 or Tenex; shortly afterwards it was proved that it was possible to implement TCP even on workstation-class computers like the Xerox Alto, such that these computers could also be part of the Internet. The first ethernet was also developed at Xerox PARC in 1973.

Today's basic TCP/IP standards appeared in the early 1980s. They were trialled in BSD—the Unix variant developed at the University of California at Berkeley–, which led to its popularity among users and computer manufacturers. On 1 January 1983, the ARPAnet was converted from NCP to TCP/IP. Soon afterwards, the original ARPAnet was divided administratively into the two components, MILnet (for military applications) and ARPAnet (for defence research). Also in 1983, the development of DNS laid the groundworks for future expansion. In the subsequent years—1984 to 1986—, more TCP/IP-based networks were created, such as the National Science Foundation's NSFNET, and the notion of "the Internet" as the totality of all interconnected TCP/IP networks established itself.

"TCP/IP Flag Day"

MILnet

ARPAnet

NSFNET

At the end of 1989, Australia, Germany, Israel, Italy, Japan, Mexico, the Netherlands, New Zealand, and the United Kingdom were connected to the Internet. It now consisted of more than 160,000 nodes.

In 1990 the ARPAnet was officially decommissioned (it had been assimiliated into the Internet for a very long time), and in 1991 NFSNET was opened to commercial users. Commercial providers mushroomed. Today most of the network infrastructure is privately held.

Today we have a global network of interconnections with a uniform address space. We use open protocols and uniform communication methods, so everyone can join in the development and the net is available to anybody. Development of the Internet is far from finished, though; future improvements will try to address pressing problems such as address scarcity and the increased need for security.

22.1.2 Internet Administration

A global network like the Internet cannot function without administrative structures. These started out in the USA, since in the beginning most interconnected

networks were deployed in that country. It still remains there today, more precisely with the American Department of Commerce.

Various people are irked by the dominance of the USA as far as the Internet is concerned. Unfortunately it is very difficult to figure out what to do about it, as the Americans are not willing to pass the baton formally. On the other hand, the Department of Commerce pursues a marked *laissez-faire* approach, so the opponents can arrange themselves to a certain degree with the *status quo*.

Internet Society

Theoretically, control of the Internet rests in the hands of the "Internet Society" (ISOC), an international non-profit organisation founded in 1992. Its members consist of governments, corporations, universities, other organisations and even individuals (anybody may join).

The main goal of ISOC was to give a formal framework to somewhat vaguely defined institutions such as the IETF (see below) as well as to ensure their financial support. In addition, ISOC holds copyright to the RFCs, the normative documents for the Internet, which are freely available to everybody who is interested.

ISOC's activities fall into three broad categories:

Standards ISOC is the overarching structure for a number of organisations dealing with the technical development of the Internet. These include:

- The *Internet Architecture Board* (IAB) is the committee in charge of overseeing technical development of the Internet. The IAB takes care of publishing the RFCs and counsels ISOC leadership on technical matters.

  The IAB currently has about a dozen members (humans) who have been selected by the "IETF nominating committee", one chairperson also selected by the IETF nominating committee, and a few ex-officio members and representatives of other organisations.

- The *Internet Engineering Task Force* (IETF) is tasked with actually developing Internet standards and, while doing so, cooperates closely with institutions like ISO/IEC and the World Wide Web Consortium (W3C). The IETF is an open organisation without membership, which is operated by "volunteers" (whose employers usually foot the bill). Within IETF there is a large number of "working groups" that arrange themselves into "areas" according to their subject matter. Every area has one or two "area directors" who together with the IETF chair form the *Internet Engineering Steering Group* (IESG). This committee is responsible for the IETF's activities.

  Owing to its amorphous structure it is difficult to say how large IETF is at any given time. In the first years after its institution in 1986, attendance at its regular meetings changed between 30 and 120 people. Since the explosive growth of the Internet in the 1990s the circle has become somwhat larger, even though after the bursting of the "dot-com bubble" it dropped from 3000 people in 2000 down to about 1200 today.

  The IETF's mantra is "rough consensus and running code"—it does not require unanimous decisions but does want to see most of the group behind winning ideas. There is also a big emphasis on solutions that actually work in practice. This and the fact that most of the work is performed by volunteers can lead to IETF working groups taking very long to deliver results—especially if there are too few or too many interested people who want to contribute.

- The *Internet Corporation for Assigned Names and Numbers*, ICANN for short, is another non-profit organisation that was incorporated in 1998 to take over some things that, previously, other organisations (in particular IANA, see the next bullet) had been taking care of on behalf of the US government. In particular, this means the assignment of IP addresses and DNS top-level domain names. Especially the latter is an extremely political issue and every so often brooks conflict.
- The *Internet Assigned Numbers Authority* (IANA) is in charge of actually assigning IP addresses and operating the DNS root servers. Administratively, IANA is part of ICANN. In addition, IANA is responsible for the management of all globally unique names and numbers in Internet protocols published as RFCs. In that respect it cooperates closely with IETF and the RFC editors.

IANA delegates the assignment of IP addresses further to so-called *Regional Internet Registries* (RIRs), which each handle "distribution" (usually) to ISPs in some part of the world. Currently there are five RIRs, with RIPE NCC being in charge of Europe.

Education ISOC runs conferences, seminars, and workshops on important Internet issues, supports local Internet organisations and, through financial aid, enables experts in developing countries to take part in the discussion and development of the Internet.

Political Lobbying ISOC cooperates with governments and national and international bodies in order to further its ideas and values. The declared goal of ISO is "a future in which people in all parts of the world may use the Internet to improve their quality of life".

22.2 Technology

22.2.1 Overview

Computers process digital information. In the "real world", however, this information is represented by means of physical phenomena such as voltage, charge, or light, and the real world remains fiercely "analogue". The first challenge of data communication, then, is to transform the digital information inside the computer into something analogue—like, for example, a sequence of electrical impulses on a wire—for transmission to another computer, and transforms that back to digital information at the other end. The next challenge is to make this work if the first computer is in Berlin and the other one in New Zealand.

Local area networks
wide area networks

You can divide data networks very roughly, and without actually looking at the technology involved, into two groups: **Local area networks** (LANs) connect a small number of nodes in a geographically limited area, **wide area networks** (WANs) a potentially large number of nodes in a geographically very large ara.

With LANs, the owner (a company or other organisation or—frequently today—a household) is usually also the operator and the sole user, and the network offers high bandwidth (100 MBit/s and more). WANs, on the other hand, connect a multitude of different users who generally do not own the network, bandwidth is less, and usage more expensive.

There are many different networking technologies for very diverse requirements, ranging from very-short-range wireless connections (Bluetooth) and typical LAN technology like Ethernet to fiber connections based on ATM for WANs. As programmers and system administrators we do not want to be bothered with their gory electrical engineering details. Hence we talk about a "protocol stack"

and try to separate cleanly its individual components—the "electrical" part, the basic communication between computers on the same network, the basic communication between computers on different networks, and finally concrete "services" such as electronic mail or the World Wide Web. But first things first.

22.2.2 Protocols

A "protocol" is an agreed scheme governing how two (or more) nodes on a network talk to one another. The spectrum of possible protocols ranges from rules for electrical signals on an Ethernet cable or radio signals in a WLAN up to (for example) protocols governing access to an SQL database server. Protocols can be roughly divided into three classes:

Transmission protocols (often also called "access methods") govern data transmission essentially at the level of network cards and physical connections. Their make-up depends on the physical properties and restrictions arising from their implementation in "hardware". For example, the communication between two computers across a serial "null modem cable" is completely different from the transmission of data via a radio connection on a WLAN, and the transmission protocols used follow completely different requirements.

The most common transmission protocol in LANs is Ethernet, even though current Ethernet has hardly anything to do with the eponymous original of 1973 (O. K, both involve electricity, but the resemblance stops about there). Other standards such as token-ring or field bus systems only come up for special applications. Also popular today are WLAN access methods like IEEE 802.11.

Communication protocols serve to organise the communication between computers in different networks without presupposing detailed knowledge of the medium access methods used. To use your home PC in Germany to view a web site on kangaroos served by a server at a university in Australia, you do not want to have to know that your PC is connected via Ethernet to your home router, which talks ATM to the DSLAM in the telecom shed across the road, which passes data through fiber around a few corners to Australia and so on—you just enter `www.roos-r-us.au` in your browser. It is thanks to communications protocols that your PC can find the remote web server and exchange data with it.

Communication protocols are supposed to prevent you from having to mess with transmission protocols, but of course they cannot exist without those. The goal of communication protocols is to hide the transmission protocols' gory details from you—just like your car's accelerator pedal is used to protect you from having to know the precise control data for its electronic fuel injection control system.

The communication protocols of interest to us are, of course, IP, TCP, and UDP. We shall also look at ICMP as an "infrastructure protocol" providing diagnosis, control, and error notification.

Application protocols implement actual services like electronic mail, file transfer, or Internet telephony based on communication protocols. If communication protocols are useful to send random bits and bytes to Australia and get others back, application protocols let you make sense of these bits and bytes.

Typical application protocols that you as a Linux administrator might be confronted with include SMTP, FTP, SSH, DNS, HTTP, POP3, or IMAP, possibly with "secure", that is, authenticated and encrypted,

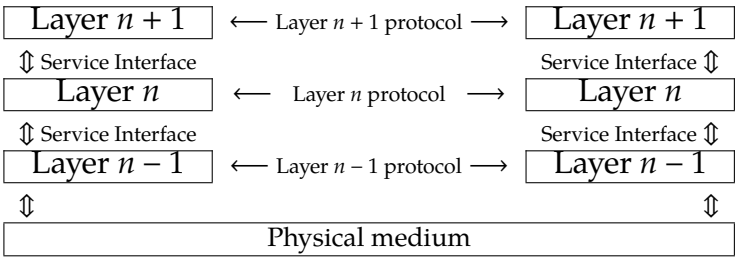


Figure 22.1: Protocols and service interfaces

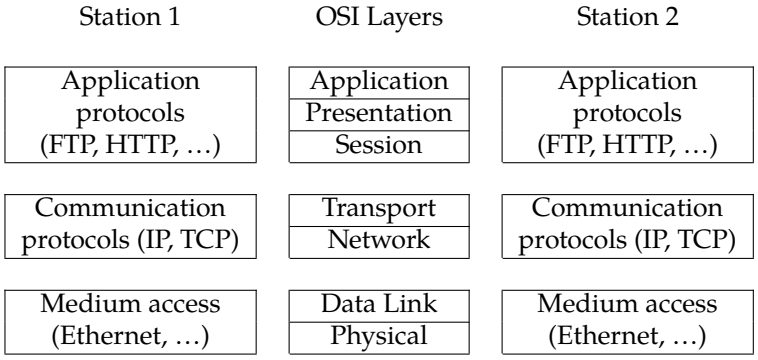


Figure 22.2: ISO/OSI reference model

offshoots. All of these protocols are used by application programs such as mail clients or web browsers, and are based on communication protocols such as TCP or UDP.

protocol data units

The data exchanged via a protocol are abstractly called protocol data units—depending on the protocol they may have more specific names like "packets", "datagrams", "segments", or "frames".

The fact that communication protocols are meant to hide the details of transmission protocols, and that application protocols are meant to hide the details of communication protocols lets us construct a "layer model" (Figure 22.1) where the transmission protocols take up the lowest and the application protocols the highest layer. (This is incidentally where the term "protocol stack" comes from.) Every layer on the sender's side receives data "from above" and passes it "below"; on the receiver's side it is received "from below" and passed on "above". Conceptually we still say that two nodes communicate "via HTTP", when in fact the HTTP data flow across TCP, IP, and a whole zoo of possible transmission protocols from one node to the next and still must pass the IP and TCP layers upwards before becoming visible again as HTTP data.

layer model

Technically, within each layer on the sender side, the corresponding protocol receives a "protocol data unit" at its service interface from the layer above and adds a "header" containing all the information important for its operation before passing it on across the service interface of the layer below. The layer below considers everything it receives on the service interface as data; the previous protocol's header is of no concern to the lower layer. On the receiving side, packets pass through the same layers in reverse order, and every layer removes "its" header before passing the "payload data" upwards.

header

The most well-known layer model is the "ISO/OSI reference model" (Figure 22.2). ISO/OSI (short for "Internation Organisation for Standardisation/Open Systems Interconnection") used to be the basis of a protocol family proposed by CCITT, the world organisation of telecommunications agencies and corporations.

ISO/OSI reference model

The ISO/OSI network standards never caught on—they were too baroque and impractical to be useful, and the standards documents were difficult to

get hold of—, but the reference model with its seven (!) layers has remained and is popularly used to explain the goings-on of data transmission.

Many protocol stacks cannot be directly mapped to the ISO/OSI reference model. On the one hand, this results from the fact that not every manufacturer adheres to the definitions made by the model, on the other hand various protocol stacks predate the OSI model. Nor should you commit the mistake of confusing the ISO/OSI reference model with a binding "standard" for the structure of networking software, or even a set of instructions for networking software implementation. The ISO/OSI reference model is merely a clarification of the concepts involved and makes them easier to discuss. Even so, here is a brief overview of the layers in the model:

- Layers 1 and 2 (physical and data link layers) describe how data is sent on the "wire". This includes the medium access scheme as well as the encoding of the data.
- Layer 3 (the network layer) defines the functions required for routing, including requisite addressing.
- The transport of application data is described in layer 4 (transport layer). This distinguishes between connection-oriented and connectionless services.
- The layers 5, 6 and 7 (session, presentation, and application layers) are often not explicitly discriminated in practice (e. g., with the TCP/IP protocols). These describe the system-independent representation of data within the network and the interfaces to application protocols.
- In addition, Andy Tanenbaum [Tan02] postulates Íayers 8 and 9 (the financial and political layers). While these layers are well-known in practice, they have so far not been incorporated into the official ISO/OSI reference model.

Exercises

22.1 [2] Review briefly the differences between transmission, communication, and application protocols. Name examples for the various types. (Do you know ones that are not part of the TCP/IP world?)

22.2 [1] What is the main difference between ISO/OSI layers 2 and 3?

22.3 TCP/IP

22.3.1 Overview

TCP/IP stands for "Transmission Control Protocol/Internet Protocol" and is currently the most wide-spread method of transferring data in computer networks ranging from two computers in a local network up to the world-wide Internet. TCP/IP is not just a single protocol but a plethora of different protocols built upon one another with possibly very different applications. This is called a "protocol family".

The protocols from the TCP/IP protocol family can roughly be placed in the context of the ISO/OSI layer model shown in Figure 22.2. Here, in brief, are the most important ones:

Medium access layer Ethernet, IEEE 802.11, PPP (these are, strictly speaking, not TCP/IP protocols)

Internet layer IP, ICMP, ARP

Transport layer TCP, UDP, …

Application layer HTTP, DNS, FTP, SSH, NIS, NFS, LDAP, …

In order to understand better the process of data communication, and to be able to localise and find errors that may occur, it is very useful to know the structure of the most important protocols and the make-up of the protocol data units involved. We shall now explain the most important TCP/IP protocols from the internet and transport layers.

Exercises

22.3 [2] Which other protocols of the TCP/IP protocol family can you think of? Which of the four layers do they belong to?

22.3.2 End-to-End Communication: IP and ICMP

IP IP connects two nodes. As an ISO/OSI layer 3 protocol it is responsible for the data finding its way across the Internet from the sender to the receiver. The catch is that this way can involve very long distances consisting of diverse independent sections using markedly different networking technologies and exhibiting markedly different communication parameters. Consider a user "surfing" the Internet at home. Their computer is connected via an analogue modem and the
ISP phone network, using PPP, to a dial-in computer on an ISP's premises which provides the actual connection to the Internet. The user's web requests are then sent half-way around the world by means of ATM on fiber optics lines before arriving in a university's computing center, from where they are passed across the FDDI-based campus network to a departmental router, which transmits the data to the web server connected by Ethernet. The web page content then takes the reverse way back. The various parts of the route use not only different networking technologies, but also different "local" addresses—-while no addressing is necessary at all using PPP (there are only two communication stations), Ethernet is based on 48-bit "MAC" addresses.

address space One of the achievements of IP is to make available a "global" address space which assigns a unique address to every node connected to the Internet, by which
routing that node can be identified. IP also provides routing from one system to another without regard to the actual networking technology in use.

connectionless protocol IP is a **connectionless protocol**, that is, unlike the traditional telephony network (for example) it provides no fixed connection (a "wire") for two systems to communicate[1], but the data to be transmitted is divided up in small pieces, the
datagrams so-called **datagrams**, which can then be addressed and delivered independently from each other. In principle, every datagram can take a different path to the receiver than the previous one; this makes IP resilient to failure of connections or routers as long as one route can be found from the source to the target node. IP does not give guarantees that all transmitted data will actually reach the receiving system, nor does it guarantee that the data which does in fact arrive will do so in the order in which it was sent. It is up to "higher-level" protocols to sort this out if the application requires it.

Imagine you want to send a long body of text to your aunt in Australia[2]. To do this "à la IP", you would write the text on a large number of individual postcards. Chances are that on the way down under your postcards will be mixed up, and the postman there is unlikely to drop them in your aunt's letter box in precisely the same order that you posted them here. It is also quite possible for the odd postcard to be delayed or lost somewhere on the way.

[1] Even the telephone network—affectionately called POTS (for "plain old telephone system")—no longer works this way.

[2] Read "Germany" if you are reading this in Australia.

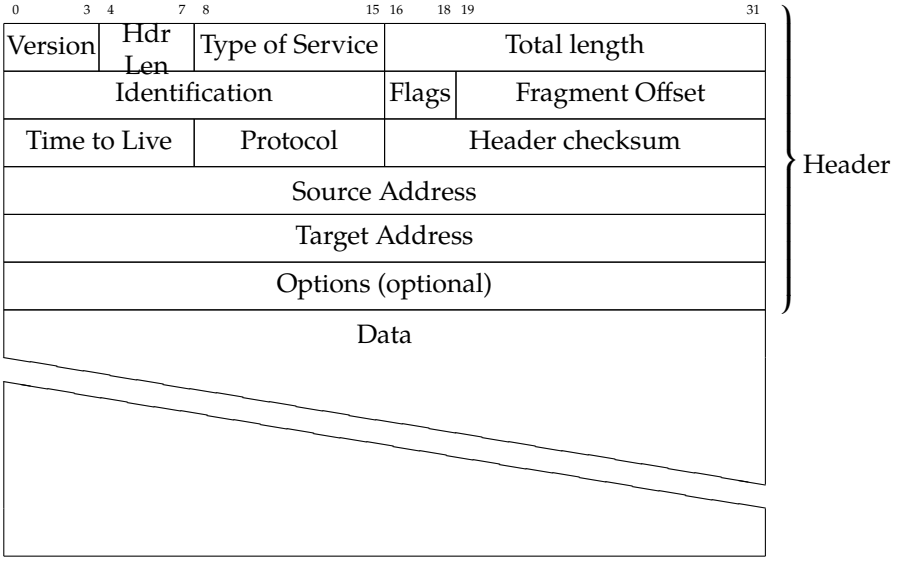


Figure 22.3: Structure of an IP datagram. Every line corresponds to 32 bits.

Why is this an advantage? The traditional telephone network with its wires connected from one end to the other was very susceptible to disturbances—if any segment on the way failed, the whole conversation broke down and needed to be reconstructed (a big deal, back in the days of manually prepared connections). If a problem or interruption develops during connectionless transmission, the network can look for alternative routes for future datagrams that detour around the damaged part. Methods like TCP make it possible to detect which data was lost due to the problem and arrange for it to be retransmitted.

Besides, IP takes care of **fragmentation**. IP datagrams may be up to 65535 bytes long, but most transmission protocols only allow much shorter protocol data units—with Ethernet, for example, at most 1500 bytes. Thus longer datagrams need to be "fragmented"—for transmission across such a medium the datagram is taken apart, split up into numbered fragments, and reassembled later. IP ensures that only datagrams with no missing fragments are officially considered received. fragmentation

The official specification of IP is [RFC0791]. You do not need to read this but it may be helpful against insomnia.

Figure 22.3 shows the structure of an IP datagram. We should briefly explain at least two of the fields:

- The "time to live" (or TTL) states the maximum life span of the datagram. It is set by the sender and decremented (reduced by 1) by each node the datagram passes through on its way to the recipient. If the TTL reaches zero, the datagram is dropped, and the sender is notified. This serves to prevent "flying Dutchmen"—datagrams that due to routing errors run in circles on the Internet without ever reaching their destination. (A common default value is 64, which considering the current extent of the Internet is usually more than enough.)
- The "type of service" (TOS) specifies the quality of service desired for the datagram. Theoretically you get to pick, in addition to one of seven precedence levels (which will be ignored), any of the attributes "low latency", "high throughput", "high reliability", or "low cost". Whether this makes any difference whatsoever as far as the actual transmission is concerned is anybody's guess, since these options are only advisory and routers like to ignore them altogether. (If that wasn't the case,

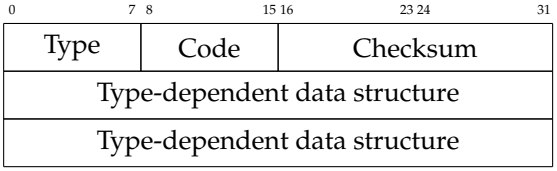


Figure 22.4: Structure of an ICMP packet

then probably all datagrams would have *all* these desirable options switched on.)

ICMP Another important protocol, is the "Internet Control Message Protocol", or ICMP for short (see Figure 22.4). It is used for network management and to report network problems, such as a failed connection or an unreachable subnet. The very well-known `ping` program, for example, uses two special ICMP messages (`echo request` and `echo reply`). The ICMP packet is encapsulated as data inside an IP datagram and contains further data fields depending on the code.

IP and Transmission Protocols To be able to use IP to transmit data regardless of the actual network technology used, we need to define on a case-by-case basis how IP datagrams are forwarded across the network in question—whether that is Ethernet, PPP over an analogue telephone line, ATM, WLAN, …

With Ethernet, for example, all nodes are connected (if only conceptually) to a shared medium—in "classic" Ethernet, a single long coaxial cable running from one node to the next, today more often using twisted-pair cables and a common star hub or switch. Everything a node sends is received by all the other nodes, but these usually pick up only those protocol data units that are actually addressed to them (today, switches help by "pre-sorting" the traffic). If two nodes transmit simultaneously, a collision occurs, which is handled by both nodes stopping transmission, waiting for a random period of time, and trying again. Such a shared Ethernet medium is also called a "segment".

collision

segment

Every Ethernet interface has a unique address, the 48-bit "MAC address" (short for "medium access control"). Ethernet protocol data units, the so-called frames, can be sent either to particular other nodes within the segment by specifying their MAC address as the recipient—the frame will be seen by all nodes but ignored by all but the addressed node—, or else broadcast to *all* other nodes on the segment.

MAC address

frames

broadcast

Ethernet adapters usually also support a so-called "promiscuous mode", in which all frames—even the ones that would otherwise be ignored as uninteresting—are passed to the operating system. This is used by interesting applications such as network analysis programs and cracker tools.

This is used to integrate IP and Ethernet. If a node (let's call it *A*) wants to communicate with another node (*B*) whose IP address it knows, but whose MAC address it doesn't know, it asks all connected nodes by Ethernet broadcast:

> Node *A*: Who here has IP address `203.177.8.4`?
> Node *B*: I do, and my MAC address is `00:06:5B:D7:30:6F`

This procedure follows the "Address Resolution Protocol" (ARP, [RFC0826]). Once node *A* has received node *B*'s MAC address, it stores it for a certain time in its "ARP cache" in order to not have to repeat the query for every frame; IP datagrams to nodes whose IP and MAC addresses are part of the ARP cache can be addressed directly at the Ethernet level by embeddng them as "payload data" into Ethernet frames. You can access the ARP cache using the `arp` command—not just to read, but also to write new entries. `arp` output could look like this:

ARP

ARP cache

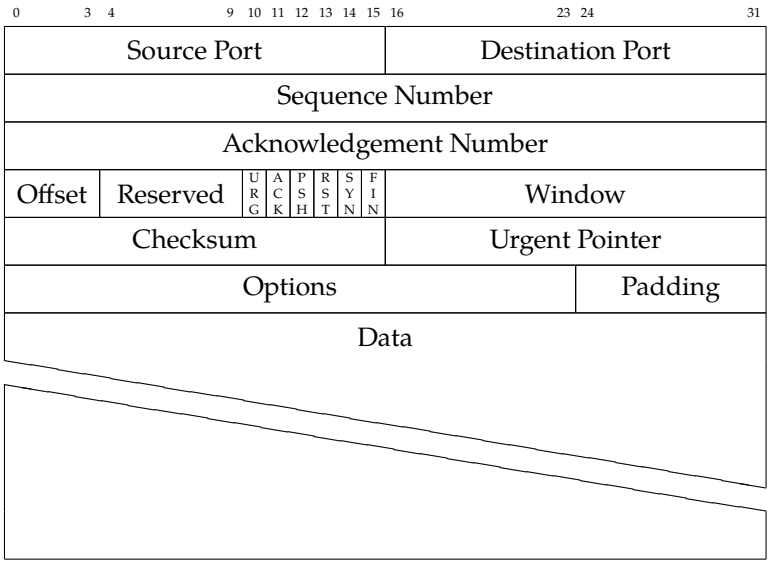


Figure 22.5: Structure of a TCP Segment

```
# arp
Address             Hwtype  Hwaddress          Flags  Mask  Iface
server.example.org  ether   00:50:DB:63:62:CD  C            eth0
```

Datagrams addressed to IP addresses that do not belong to nodes on the same Ethernet segment must be **routed** (Section 22.4.2). Routing

Exercises

22.4 [3] Estimate the minimal TTL that is necessary to be able to reach all other nodes on the Internet from your computer. How would you go about determining the minimal TTL required to reach a specific node? Is that number constant?

22.3.3 The Base for Services: TCP and UDP

TCP The "Transmission Control Protocol" (TCP) is a reliable, connection-oriented protocol defined in [RFC0793] (among others). Unlike the connectionless IP, TCP supports operations to open and tear down connections, which arrange for a "virtual" connection between the source and destination nodes—since TCP data, like all other data, is transmitted based on IP, the actual data transmission still happens unreliably and on a connectionless basis. TCP achieves reliability by means of the destination node acknowledging the receipt of each packet ("segment", in TCP parlance). Each of the two communicating nodes annotates its segments with sequence numbers, which the other node declares "received" in one of its next segments. If there is no such acknowlegement within a certain defined period of time, the sending node retries sending the segment in order to perhaps receive an acknowledgement then. To avoid loss of performance, a "sliding window" protocol is used so a number of segments can remain unacknowledged at the same time. Even so, TCP is considerably slower than IP. sequence numbers

In point of fact, TCP acknowledgements are based on octets (popularly known as bytes) rather than segments—but for our purposes the difference is mostly academic.

Every TCP segment contains a header of at least 20 bytes (Figure 22.5) in addition to the IP header. (Remember: The TCP segment *including* the TCP header

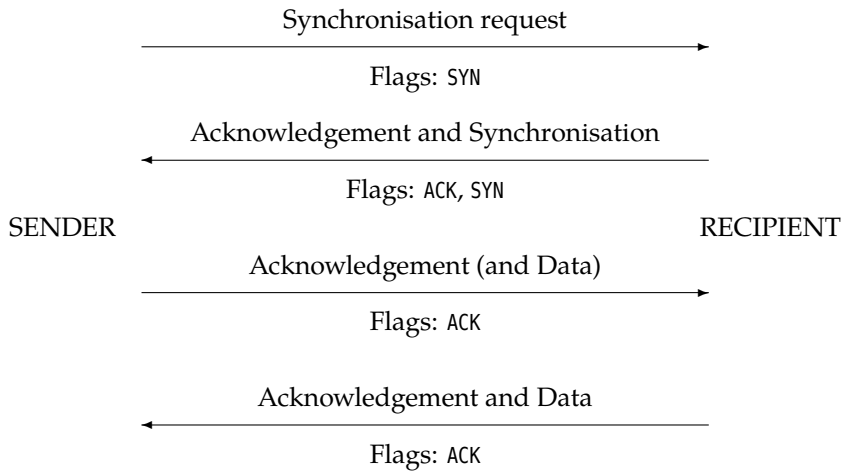


Figure 22.6: Starting a TCP connection: The Three-Way Handshake

is considered "data" by IP, the protocol of the layer below.) Errors in the data can be detected based on a checksum. Every system supports many independent, simultaneous TCP connections distinguished based on **port numbers**.

port numbers

The combination of an IP address and a port number together with the IP address and the port number of the "peer" is called a "socket". (The same TCP port on a node may take part in several TCP connections to different peers—defined by the peer's IP address and port number.)

three-way handshake

The virtual connection is built using the **three-way handshake** (see Figure 22.6). Using the three-way handshake, the communication peers agree on the sequence numbers to be used. Two **flags** in the TCP header, `SYN` and `ACK`, play an important role in this. The first data segment sent to the recipient has the `SYN` flag set and the `ACK` flag cleared. Such a segment indicates a connection request. The recipient acknowledges this using a TCP segment that has both the `SYN` and `ACK` flags set. The sender in turn acknowledges this segment using one that has the `ACK` flag set but not the `SYN` flag. At this point the connection has been established. Subsequent TCP segments also have the `ACK` flag set only.—At the end of the communication, the connection is torn down by means of a two-way handshake using the `FIN` flag.

flags

The two nodes need to agree about the start of a connection, but a connection can be torn down unilaterally. In fact this feature is required for commands like the following to work:

```
$ cat bla | ssh blue sort
```

This uses the Secure Shell (see Chapter 25) to run the `sort` command on node `blue`, and feeds data into its standard input. (`ssh` reads its standard input locally, forwards the data to the remote computer, and passes it to the `sort` command on its standard input.) `sort`, however, works by reading all of its standard input, then sorting the data it read, and writing the sorted data to its standard output, which is then passed by `ssh` back to the local computer (and the screen).—The problem is that `ssh` needs to signal the remote `sort` that all the input has been read, and that it can start sorting and outputting the data. This happens by closing the connection "to" the remote computer. The part of the connection reading "from" the remote computer, however, remains open and can transport the `sort` output back—if a connection teardown always affected both directions, this application would not work.

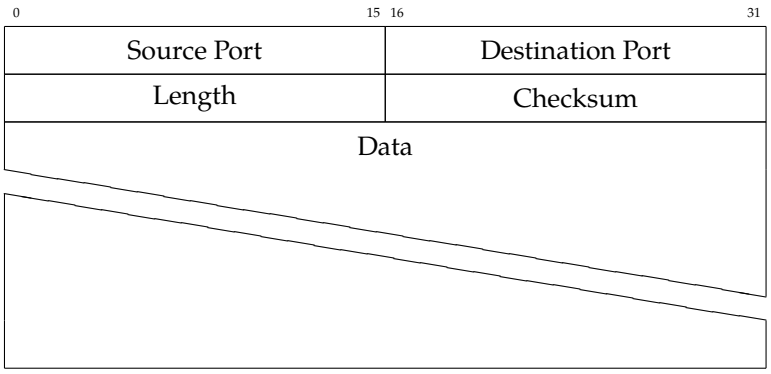


Figure 22.7: Structure of a UDP datagram

Of course, after a unilateral teardown data are still passed between the nodes in both directions, since the node that tore down the connection must still acknowledge the data it receives via the remaining part of the connection. It can no longer send payload data across the connection, though.

UDP Unlike TCP, the "User Datagram Protocol" (UDP) [RFC0768] is a connectionless and unreliable protocol. In fact it isn't much more than "IP with ports", since, like TCP, a node can support at most 65535 communication end points (UDP and TCP may use the same port number simultaneously for different purposes). UDP requires neither the connection initialisiation of TCP nor the acknowledgements, hence the protocol is much "faster"—the price to pay is that, as with IP, data can get lost or mixed up.

UDP is used either where there is only very little data to transmit, so that the cost of a TCP connection initialisation is very high in comparison—cue DNS—or where not every single bit counts but delays are unacceptable. With Internet telephony or video transmission, lost datagrams call attention to themselves through cracking noises or "snow" in the picture; a longer hiatus like the ones common with TCP would be much more obnoxious.

Ports TCP and UDP support the idea of ports, which allow a system to maintain more than one connection at any given time (OK, there are no "connections" with UDP, but even so …). There are 65536 ports each for TCP and UDP, which however cannot all be used sensibly: Port number 0 is a signal to the system's TCP/IP stack to pick an otherwise unused port.

Most ports are freely available to users of the system, but various ports are officially asigned to particular services. We distinguish **well-known ports** and **registered ports**. For example, the rules say that TCP port 25 on a system is reserved for its mail server, which is listening there to accept connections according to the "Simple Mail Transfer Protocol" (SMTP). Similarly, the TCP port 21 is reserved for the FTP server and so on. These assignments are published on a regular basis by IANA and can be found, for example, at `http://www.iana.org/assignments/port-numbers`.

well-known ports

registered ports

According to IANA, the "well-known ports" are ports 0 to 1023, while the "registered ports" are ports 1024 to 49151. If you want to release a program offering a new service, you should request one or more port numbers from IANA.

The remaining ports—from 49152 up to 65535—are called "dynamic and/or private ports" in IANA jargon. These are used for the client side of connections (it is unlikely that your system will need to maintain more than 16.000

```
# Network services, Internet style

echo       7/tcp
echo       7/udp
discard    9/tcp    sink null
discard    9/udp    sink null
systat     11/tcp   users
daytime    13/tcp
daytime    13/udp
netstat    15/tcp
qotd       17/tcp   quote
chargen    19/tcp   ttytst source
chargen    19/udp   ttytst source
ftp-data   20/tcp
ftp        21/tcp
fsp        21/udp   fspd
ssh        22/tcp                  # SSH Remote Login Protocol
ssh        22/udp                  # SSH Remote Login Protocol
telnet     23/tcp
smtp       25/tcp   mail
◁◁◁◁◁
```

Figure 22.8: The `/etc/services` file (excerpt)

connection to TCP servers at the same time) or for the implementation of "private" servers.

When IANA reserves a port number for a TCP-based protocol, it tends to reserve the same port number for UDP as well, even though the TCP protocol in question makes no sense with UDP, and vice versa. For example, port 80 is reserved for HTTP both as a TCP and a UDP port, even though UDP-based HTTP is not currently an interesting topic. This leaves elbow room for future extensions.

On a Linux system, a table of assignments is available in the `/etc/services` file (Figure 22.8). This table is used, for example, by the Internet daemon (`inetd` or `xinetd`) or the C library function `getservbyname()` to find the port corresponding to a given service name.

You can change `/etc/services`, e. g., to support your own services. Do watch for updates of the file by your distribution.

privileged ports

On Unix-like systems, ports 0 to 1023 are privileged—only `root` may open them. This is a security precaution against arbitrary users launching, e. g., their own web server on an otherwise unused port 80 in order to appear official.

22.3.4 The Most Important Application Protocols

In the previous section we introduced the idea of a "service". While communication protocols like TCP and UDP are concerned with moving data from one node to another, "services" usually rely on application protocols that assign meaning to the data exchanged using the communication protocol. If, for example, you send an e-mail message using SMTP, your computer contacts the remote SMTP server (via TCP on port 25), identifies itself, sends your address as well as that of the recipient (or recipients) and the actual message—in each case after the remote server prompted for them. The details of this conversation are specified by the application protocol, SMTP.

Table 22.1: Common application protocols based on TCP/IP

Port	C Prot	Name	Explanation
20	TCP	FTP	File transfer (data connections)
21	TCP	FTP	File transfer (control connections)
22	TCP	SSH	Secure (authenticated and encrypted) login to remote computers; secure file transfer
23	TCP	TELNET	Login to remote computers (insecure and obsolete)
25	TCP	SMTP	Electronic mail transfer
53	UDP/TCP	DNS	Name and address resolution and related directory services
80	TCP	HTTP	World Wide Web resource access
110	TCP	POP3	Access to remote e-mail mailboxes
123	UDP/TCP	NTP	Network Time Protocol (time synchronisation)
137	UDP	NETBIOS	NetBIOS name service
138	UDP	NETBIOS	NetBIOS datagram service
139	TCP	NETBIOS	NetBIOS session service
143	TCP	IMAP	Access to e-mail stored remotely
161	UDP	SNMP	Network management
162	UDP	SNMP	Traps for SNMP
389	TCP	LDAP	Directory service
443	TCP	HTTPS	HTTP via SSL (authenticated/encrypted)
465	TCP	SSMTP	SMTP via SSL (obsolete, don't use!)*
514	UDP	Syslog	Logging service
636	TCP	LDAPS	LDAP via SSL (authenticated/encrypted)*
993	TCP	IMAPS	IMAP via SSL (authenticated/encrypted)*
995	TCP	POP3S	POP3 via SSL (authenticated/encrypted)*

* These services may also be accessed via connections that are first established in the clear and then "upgraded" to authenticated and encrypted connections later on.

"Services" and "protocols" are not exactly equivalent. A "service" is something you want to use the computer for, such as e-mail, web access, or printing on a remote printer server. For many services on the Internet there are "canonical" protocols that recommend themselves—for e-mail, for example, there are hardly any alternatives to SMTP—, but some services use the same underlying protocol as others. The Web is usually accessed via HTTP and remote printer servers via the "Internet Printing Protocol" (IPP). However, if you look closely enough you will notice that IPP, as used today, is really glorified HTTP. The only difference is that HTTP uses TCP port 80 while IPP uses TCP port 631.

Table 22.1 shows a summary of some important application protocols. We will encounter several of them later on in this manual; others will covered in other Linup Front training manuals.

Bad news for LPIC-1 candidates: LPI wants you to know the port numbers and services from Table 22.1 by heart (LPI objective 109.1). Have fun swotting up.

22.4 Addressing, Routing and Subnetting

22.4.1 Basics

Every network interface in a system on a TCP/IP network has at least one IP address. In this case, an "interface" is that part of a system that is able to send and receive IP datagrams. A single system can contain more than one such interface and then generally uses more than one IP address. With

```
$ /sbin/ifconfig
```

or

```
$ /sbin/ip addr show
```

you can list the configured interfaces or network devices.

IP addresses

IP addresses are 32 bits long and are usually written as "dotted quads"—they are viewed as a sequence of four eight-bit numbers written in decimal notation as values between 0 and 255, like "`203.177.8.4`"[3]. Each IP address is assigned to be globally unique and denotes a node in a particular network on the Internet. To do so, IP addresses are split into a network and a host part. This split is variable and can be adapted to the number of node addresses required in a network. If the host part takes n bits, $32 - n$ bits remain for the network part. The split is documented by the **network mask**, which contains a binary 1 for each bit in the IP address belonging to the network part, and a binary 0 for each bit of the host part. The network mask is notated either as a dotted quad or—frequently—as the number of ones. "`203.177.8.4/24`" is thus an address in a network with a network mask of "`255.255.255.0`".

network mask

By way of an example, let's assume a 28-node network. The next higher power of 2 is $32 = 2^5$. This means that 5 bits are required to number all the nodes. The remaining 27 bits (32 – 5) identify the network and are the same in all systems on that network. The network mask is `255.255.255.224`, since the top three bits are set in the final "quad"—those with values 128, 64, and 32, or 224 altogether.

By convention, the first and last IP addresses in a network are reserved for special purposes: The first address (host part all binary zeroes) is the **network address**, the last address (host part all binary ones) the **broadcast address**. In the

network address
broadcast address

[3] Incidentally, it is quite legal and supported by most programs to give an IP address as a decimal number that has been "multiplied out"—in our example, 3417376772 instead of `203.177.8.4`. This is the key ingredient to "trick URLs" of the form `http://www.microsoft.com@3417376772/foo.html`.

Table 22.2: Addressing example

Meaning	IP Address binary	decimal
Network mask	11111111 11111111 11111111 11100000	255.255.255.224
Network address	11001011 10110001 00001000 00000000	203.177.8.0
Host addresses	11001011 10110001 00001000 00000001	203.177.8.1
⋮	⋮	⋮
	11001011 10110001 00001000 00011110	203.177.8.30
Broadcast address	11001011 10110001 00001000 00011111	203.177.8.31

example above, 203.177.8.0 is the network address and 203.177.8.31 the broadcast address. The numbers 1 to 30 are available for nodes (Table 22.2).

The address 255.255.255.255 is a broadcast address, but not for all of the Internet, but the local network segment (for example, all the stations on the same Ethernet). This address is used if no more precise address is known, for example if a node wants to obtain an IP address and network mask via DHCP.

22.4.2 Routing

Routing is used to send IP datagrams that cannot be delivered directly within the local network on to the correct destination[4]. In fact, you might argue that routing is the central property that sets TCP/IP apart from "toy protocols" such as NetBEUI and Appletalk, and which made the Internet, as we know it, possible in the first place.

Routing applies where the recipient of an IP datagram cannot be found within the same network as the sender. The sender can figure this out straightforwardly based on the desired recipient's IP address, by considering that part of the destination address that is "covered" by its own network mask and checking whether this matches its own network address. If this is the case, the recipient is "local" and can be reached directly (Section 22.3.2 on page 338).

If the recipient cannot be reached directly, the node (at least if it is a Linux host) consults a routing table which should contain at least a "default gateway", i. e., a node that takes care of forwarding datagrams that cannot be delivered outright. (This node usually needs to be reachable directly.) Such a node is called a "router" and is either a computer in its own right or else a special appliance manufactured for the purpose.

routing table

In principle, the router proceeds just like we described: It contains various network interfaces, each of which is assigned an address and a network mask, and can deliver datagrams immediately to nodes that according to the network masks of its interfaces can be identified as being part of one of "its" networks. Other directly reachable nodes acting as routers are called upon for more forwarding if necessary.

In real life, routing tables can be considerably more complex. For example, it is possible to forward datagrams directed to particular nodes or networks to other routers that are not the default gateway.

An important observation is that a node (PC or router) usually determines just the directly following routing step (also called "hop"), instead of specifying the complete path from the original sender of the datagram to the final recipient. This

[4] This was already foreseen in the Old Testament: "He leadeth me in the paths of righteousness for his name's sake." (Psalm 23:3) Of course on the Internet there are few better methods of completely ruining your reputation than a spectacularly wrong router misconfiguration.

Table 22.3: Traditional IP Network Classes

Class	Network part	Number of networks	Hosts per network	Addresses
Class A	8 Bit	128 – 126 usable	16.777.214 ($2^{24} - 2$)	0.0.0.0 – 127.255.255.255
Class B	16 Bit	16.384 (2^{14})	65.534 ($2^{16} - 2$)	128.0.0.0 – 191.255.255.255
Class C	24 Bit	2.097.152 (2^{21})	254 ($2^8 - 2$)	192.0.0.0 – 223.255.255.255
Class D	-	-	-	224.0.0.0 – 239.255.255.255
Class E	-	-	-	240.0.0.0 – 254.255.255.255

means that it is up to each router between the sender and recipient to pick that hop that it considers most sensible. Well-configured routers talk to their "neighbours" and can base their routing decisions on information about network load and possibly known blockages elsewhere in the network. A detailed discussion of this topic is beyond the scope of this manual.

In fact it is possible for a datagram to specify the complete path it wants to take to its destination. This is called "source routing", is universally frowned upon, and will be completely ignored by large parts of the network infrastructure, because on the one hand it is at odds with the idea of dynamic load distribution, and on the other hand it is a common vehicle for security issues.

22.4.3 IP Network Classes

network classes

Traditionally, the set of IP addresses from 0.0.0.0 to 255.255.255.0 was divided into several **network classes** which were called "class A", "class B", and "class C".

There are also "class D" (multicast addresses) and "class E" (experimental) addresses, but these are of little interest to the assignment of IP addresses to nodes.

Classes A to C differ by their network masks, which amounts to the number of networks available per class and the number of hosts available in these networks. While a class A address has an 8-bit network part, a class B address uses 16 bits, and a class C address 24. A fixed range of IP addresses was assigned to each of the network classes. (Table 22.3)

Due to the increasing scarcity of IP addresses the division of the IP address space into the three address classes was abandoned during the 1990s. Now we are using "classless inter-domain routing" (CIDR) according to [RFC1519]. While according to the "old" scheme the boundary between the network and host addresses could only occur in one of three different places, CIDR makes it possible to assign arbitrary network masks and thus fine-tune the size of the address range made available to a customer (usually an ISP) as well as work against the "explosion" of routing tables. An installation with sixteen adjacent "class C" networks (network mask "/24" can be viewed for routing purposes as one network with a /20 netmask—a considerable simplification, since routing tables can be that much simpler. On the Internet, addresses whose network part is more than 19 bits long are no longer routed directly; in general you must arrange for a provider to manage all of the addresses and forwards the IP datagrams suitably.

22.4.4 Subnetting

Frequently a large network is too imprecise or makes no sense otherwise. Hence operators often divide their networks into several smaller networks. This happens by adding another fixed part to the fixed network part of an IP address. In our previous example, subnetting might work approximately like this: Instead of a "large" network with 32 addresses (for 30 nodes) you might prefer two "smaller"

Table 22.4: Subnetting Example

Meaning	IP Address binary	decimal
Network mask	11111111 11111111 11111111 11110000	255.255.255.240
Network address (1)	11001011 10110001 00001000 00000000	203.177.8.0
Host addresses (1)	11001011 10110001 00001000 00000001	203.177.8.1
⋮	⋮	⋮
	11001011 10110001 00001000 00001110	203.177.8.14
Broadcast address (1)	11001011 10110001 00001000 00001111	203.177.8.15
Network address (2)	11001011 10110001 00001000 00010000	203.177.8.16
Host addresses (2)	11001011 10110001 00001000 00010001	203.177.8.17
⋮	⋮	⋮
	11001011 10110001 00001000 00011110	203.177.8.30
Broadcast address (2)	11001011 10110001 00001000 00011111	203.177.8.31

Table 22.5: Private IP address ranges according to RFC 1918

Adressraum	from	to
Class A	10.0.0.0	10.255.255.255
Class B	172.16.0.0	172.31.255.255
Class C	192.168.0.0	192.168.255.255

networks with up to 16 addresses (up to 14 nodes), for example to be able to deploy separate Ethernet cables for security. You can lengthen the network mask by 1 bit; the network, host, and broadcast addresses can be derived from this as above (Table 22.4).

subnets of different size

It isn't necessary for all subnets to have the same size. The `203.177.8.0/24` network, for example, could straightforwardly be subdivided into one subnet with 126 host addresses (e. g., `203.177.8.0/25` with the host addresses `203.177.8.1` to `203.177.8.126` and the broadcast address `203.177.8.127`) and two subnets with 62 host addresses (e. g., `203.177.8.128/26` and `203.177.8.192/26` with the respective host addresses of `203.177.8.192` up to `203.177.8.190` as well as `203.177.8.193` up to `203.177.8.255` and the broadcast addresses `203.177.8.191` and `203.177.8.255`).

smallest possible IP network

The smallest possible IP network has a 30-bit network part and a 2 bit station part. This amounts to a total of four addresses, one of which is the network address and one is the broadcast address, so two addresses are left over for statues. You will find this arrangement every so often with point-to-point links via modem or ISDN.

22.4.5 Private IP Addresses

Globally unique distribution of IP addresses

IP addresses are globally unique and must therefore be administered centrally. Hence you cannot pick your own e-mail address arbitrarily, but must apply for one—usually to your ISP, who in turn has been assigned a block of IP addresses by a national or international body (Section 22.1.2). The number of internationally possible network addresses is, of course, limited.

At the beginning of February 2011, IANA assigned the last five available `/8` address ranges to the five regional registries. It is probable that APNIC (Asia Pacific Network Information Centre) will run out of IP addresses first, possibly in mid-2011. After that, the only solutions will be begging or IPv6.

private addresses

According to [RFC1918], special IP address ranges, the private addresses, are

reserved for systems that are not connected to the Internet. These addresses will not be routed on the Internet at large (Table 22.5).

You can use these addresses with impunity within your local networks—including subnetting and all other bells and whistles.

22.4.6 Masquerading and Port Forwarding

IP addresses are a scarce resource today, and that will remain so until we have all converted to IPv6 (Section 22.5). Therefore it is highly probable that you will be assigned only one "official" (i. e., non-RFC 1918) address to connect all of your network to the Internet—with home networks or ones in small companies this is even the rule. The solution (an euphemism for "lame kludge") consists of "masquerading" as well as "port forwarding". Both approaches are based on the fact that only your router is connected to the Internet by means of a public IP address.

Masquerading

All other nodes within your network use addresses according to [RFC1918]. Masquerading implies that your router rewrites datagrams that nodes within your network send "outside" in order to replace those nodes' IP addresses by its own, and forwards the corresponding response datagrams to the proper senders. Both the nodes inside your network and "the Internet" are not aware of the fact—the former assume that they are talking directly to the Internet, while the latter only gets to see the (official) IP address of your router. Conversely, port forwarding enables nodes on the Internet to connect to services such as DNS, e-mail or HTTP through their respective ports on the *router*, while the router forwards the datagrams in question to a node on the inside that performs the actual service.

port forwarding

You should resist the temptation of making your router simultaneously your web, mail, or DNS server; the danger of an intruder compromising your router through one of the large server programs and therefore, in the worst case, getting access to all of your local network, is much too great.

Port forwarding and masquerading are two examples of a concept that is generally called NAT (network address translation). In particular, we can think of masquerading as "source NAT", since the sender address of outgoing datagrams is modified[5], while port forwarding is an instance of "destination NAT"—since the destination address of datagrams addressed to us is changed.

NAT

Exercises

22.5 [1] Can the following IP addresses with the given network mask be used as host addresses in the appropriate IP network? If not, why not?

	IP Address	Network mask
a)	`172.55.10.3`	`255.255.255.252`
b)	`138.44.33.12`	`255.255.240.0`
c)	`10.84.13.160`	`255.255.255.224`

22.6 [2] Which reasons could you have to divide the address range your ISP assigned to you into subnets?

22.7 [T]he network at IP address `145.2.0.0`, with the network mask `255.255.0.0`, was divided, using the subnet mask `255.255.240.0`, into the following subnets:

- `145.2.128.0`
- `145.2.64.0`

[5] The fact that we also need to rewrite the recipient address of incoming datagrams will be ignored for convenience.

- `145.2.192.0`
- `145.2.32.0`
- `145.2.160.0`

Which other subnets are also possible? Which subnet contains the station `145.2.195.13`?

22.5 IPv6

IPv4

The most popular incarnation of IP is version 4, or "IPv4" for short. Due to the explosive growth of the Internet, this version comes up against various limits—the main problems are the increasing scarcity of addresses, the chaotic assignment of addresses, and the highly complex routing resulting from this, as well as a fairly sketchy support of security mechanisms and tools for ensuring quality of service. IPv6 is supposed to sort this out.

IPv6

properties

The most important properties of IPv6 include:

- The length of addresses was increased from 32 to 128 bits, resulting in a total of $3.4 \cdot 10^{38}$ addresses. This would suffice to assign approximately 50.000 quadrillion[6] IP addresses (a 28-digit number) to each living person on Earth. That should be enough for the foreseeable future.
- IPv6 stations can automatically obtain configuration parameters from a router when they are connected to a network. If necessary, there is still a DHCPv6 protocol.
- There are only 7 fields in an IP header, so routers can process datagrams more quickly. You get get to use several headers if necessary.
- Extended support for options and extensions, which also contributes to router processing speed.
- Improved transmission of audio and video data and better support for realtime applications.
- Increased security by means of secured data transmission and mechanisms for authentication and integrity protection.
- Extensibility to ensure the future of the protocol. The protocol does not try to cover all possiblities, since the future brings new ideas that cannot be foreseen today. Instead, the protocol is open to the integration of additional functionality in a backwards-compatible manner.

implementation

Even though the standardisation of IPv6 has been finished for some time, the general implementation leaves much to be desired. In particular the service providers are still acting coyly. Linux already supports IPv6, so the conversion of a Linux-based infrastructure to the new standard will not present big problems. You can also transport IPv6 datagrams via IPv4 for testing purposes, by embedding them into IPv4 datagrams ("tunnelling"). Thus a company could base its internal network on IPv6 and even connect several premises via a "virtual" IPv6 network within the traditional IPv4 network.

We should also stress that IPv6 is a targeted replacement for IPv4. Most IP-based protocols—starting with TCP and UDP—remain unchanged. Only at the "infrastructure level" will some protocols become extraneous or be replaced by IPv6-based versions.

[6] What our American friends would call a "septillion"

22.5.1 IPv6 Addressing

IPv6 supports 2^{128} distinct addresses—an unimaginably large number. Essentially, every grain of sand on Earth could be assigned several addresses, but that isn't even the goal: The large address space enables much more flexible address assignment for various purposes, as well as much simplified routing.

Notation

Unlike IPv4 addresses, IPv6 addresses are not notated as decimal numbers, but instead as hexadecimal (base-16) numbers. Four hexadecimal digits are grouped and these groups are separated by colons. For example, an IPv6 address might look like

```
fe80:0000:0000:0000:025a:b6ff:fe9c:406a
```

Leading zeroes in a group may be omitted, and (at most) one run of "zero blocks" may be replaced by two colons. Hence, an abbreviated rendition of the address from the previous example might be

```
fe80::25a:b6ff:fe9c:406a
```

The IPv6 address `::1`—an abbreviation of

```
0000:0000:0000:0000:0000:0000:0000:0001
```

—corresponds to the IPv4 loopback address, `127.0.0.1`. IPv6 does not support "broadcast addresses" à la `192.168.1.255`—of which more anon.

Subnetting

IPv6 addresses may be divided into a 64-bit "network" part and a 64-bit "station" part. This implies that every IPv6 subnet contains 2^{64} addresses, i. e., 2^{32} times as many as the whole IPv4 internet! Subnetting using variable prefix lengths, as used in IPv4 (Section 22.4.4), is not supposed to be part of IPv6. However, it is assumed that your ISP will provide you with a "`/56`" address prefix so that you can use 256 subnets with 2^{64} addresses each, which shouldn't really cramp your style. (You can specify network prefixes by appending a slash and the decimal prefix length to an address—an address like `fe80::/16` describes the network where addresses start with `fe80` and then continue arbitrarily.)

types of IPv6 addresses

There are three basic types of IPv6 addresses:

- "Unicast" addresses apply to one particular network interface (a station may be equipped with several network interfaces, which will each have their own addresses).
- "Anycast" addresses refer to a group of network interfaces. These typically belong to different stations, and the "closest" station is supposed to answer. For example, you may address all routers in an IPv6 network by using the address resulting from appending an all-zero station part to the (64-bit) address prefix of the network.
- "Multicast" addresses are used to deliver the same packets to several network interfaces. As we said, IPv6 does not use broadcast; broadcast is a special case of multicast. The address `ff02::1`, for example, refers to all stations on the local network.

scopes

In addition, we can distinguish various scopes:

- "Global" scope applies to addresses that are routed within the whole (IPv6) internet.
- "Link-local" scope applies to addresses that are not routed and are only valid within the same network. Such addresses are commonly used for internal administrative purposes. Link-local addresses are always located within the `fe80::/64` network; the other 64 bits are, in the most straightforward instance, derived from the MAC address of the interface.

- "Site-local" scope applies to addresses that are only routed within one "site". Nobody knows exactly what this is supposed to mean, and site-local addresses have accordingly been deprecated (again). Site-local addresses use the `fec0::/10` prefix.
- "Unique-local" addresses are similar to site-local addresses and correspond roughly to the RFC 1918 addresses (`192.168.`*x.y* etc.) of IPv4. However, IPv6 does make it easy to use "proper", i. e., globally visible, addresses, so you do not have to resort to using unique-local addresses in order to assign your stations any addresses at all. Hence there is no compelling reason to use unique-local addresses in the first place, other than as a fallback position if something is terribly wrong with your "real" prefix. Unique-local addresses use the `fd00::/8` prefix, and you are allowed to pick your own next 40 bits for a `/48` network (but don't pick `fd00::/48`).

several addresses

It is important to stress that, with IPv6, every network interface can have several addresses. It gets an automatic link-local address, but can have several unique-local or global addresses on top of that with no problems whatsoever. All of these addresses carry equal weight.

ipv6calc

A useful command for the harried IPv6 administrator is `ipv6calc`, which makes handling IPv6 addresses easier. For instance, it will output information about an address:

```
$ ipv6calc --showinfo fe80::224:feff:fee4:1aa1
No input type specified, try autodetection... found type: ipv6addr
No output type specified, try autodetection... found type: ipv6addr
Address type: unicast, link-local
Error getting registry string for IPv6 address:▷
 ◁ reserved(RFC4291#2.5.6)
Interface identifier: 0224:feff:fee4:1aa1
EUI-48/MAC address: 00:24:fe:e4:1a:a1
MAC is a global unique one
MAC is an unicast one
OUI is: AVM GmbH
```

The address in question is a link-local unicast address whose station part hints at a device manufactured by AVM GmbH (in point of fact a FRITZ!Box, a type of DSL router/PBX/home server very popular in Germany).

`ipv6calc` also serves to convert addresses from one format into another. For example, you might simulate the method used to derive the station part of an IPv6 address (also called "EUI-64") from a MAC address:

```
$ ipv6calc --in mac --out eui64 00:24:fe:e4:1a:a1
No action type specified, try autodetection... found type: geneui64
0224:feff:fee4:1aa1
```

Commands in this Chapter

arp Allows access to the ARP cache (maps IP to MAC adresses) `arp`(8) 338
inetd Internet superserver, supervises ports and starts services `inetd`(8) 342
ipv6calc Utility for IPv6 address calculations `ipv6calc`(8) 351
xinetd Improved Internet super server, supervises ports and starts services `xinetd`(8) 342

Summary

- The Internet has its roots in the initial ARPAnet of the 1960s, was put on its present technological basis in the early 1980s, and experienced incredible growth in the 1980s and 1990s.
- The ISO/OSI reference model serves to provide terminology for the structure of computer communications.
- Today TCP/IP is the most popular protocol family for data transmission across computer networks.
- ICMP is used for network management and problem reporting.
- TCP provides a connection-oriented and reliable transport service based on IP.
- Like IP, UDP is connectionless and unreliable, but much simpler and faster than TCP.
- TCP and UDP use port numbers to distinguish between different connections on the same computer.
- Different TCP/IP services have fixed port numbers assigned for them. This assignment may be inspected in the `/etc/services` file.
- IP addresses identify nodes world-wide. They are 32 bits long and consist of a network and a host part. The network mask specifies the split between these.
- In former times, the available IP addresses were divided into classes. Today we use classless routing with variable-length network masks.
- IP networks can be further subdivided into subnetworks by adjusting the network mask.
- Some IP address ranges are reserved for use in local networks. They will not be routed by ISPs.
- IPv6 lifts various restrictions of the IPv4 common today, but so far has not been widely adopted.

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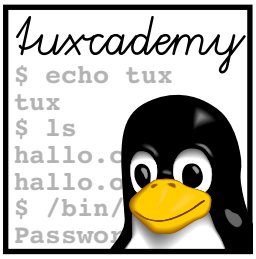


23

Linux Network Configuration

Contents

Goals

- Knowing the network configuration mechanisms of the most important distributions
- Being able to configure network interfaces
- Being able to set up static routes
- Being able to configure Linux as a DHCP and DNS client

Prerequisites

- Knowledge about Linux system administration
- Knowledge about TCP/IP fundamentals (Chapter 22)

23.1 Network Interfaces

23.1.1 Hardware and Drivers

Depending on the technology and medium access scheme used, Linux computers access the network by means of modems, ISDN adapters, Ethernet or WLAN cards or similar devices. The following sections concentrate mostly on the configuration of Ethernet adapters.

Like other hardware, a network interface on Linux is controlled by the kernel—today usually by means of modular drivers that are loaded dynamically on demand. Unlike, for example, hard disk partitions or printers, network interfaces do not appear as device files in the `/dev` directory, but are accessed via "interfaces". These interfaces are "virtual" in the sense that the kernel makes them available after a suitable driver has been loaded, and that a network interface can be accessed through more than one (mostly) independent interface. The interfaces are named; a typical name for an Ethernet interface would be `eth0`.

interfaces

Nowadays network adapters are recognised by the kernel when the system is booted; it can identify the correct driver by means of the adapter's PCI ID. It is up to the `udev` infrastructure to name the device and actually load the driver.

One obstacle that modern Linux distributions present here is that the interface name is tied to the adapter's MAC address. (Every network adapter has a globally unique MAC address which is set by the manufacturer.) Thus if you replace the network adapter inside a computer without resetting the information `udev` keeps about network adapters it has seen, chances are that your new adapter will be called `eth1`, and the configuration, which is based on an adapter called `eth0`, will not apply.

A typical place where such information ends up is the `/etc/udev/rules.d` directory. In a file like `70-persistent-net.rules` there might be lines such as

```
SUBSYSTEM=="net", DRIVERS=="?*",▷
 ◁ ATTRS{address}=="00:13:77:01:e5:4a", NAME="eth0"
```

which assign the name `eth0` to the adapter with the MAC address `00:13:77:01:e5:4a`. You can fix the MAC address by hand, or remove the line completely and have `udev` adapt the entry to the changed reality during the next system boot.

Don't tie yourself in knots if you are running Linux in a virtual machine and can't find the `70-persistent-net.rules` file. For most "virtual" network interfaces, it may not be created in the first place.

Formerly (before `udev`) it was up to the installation procedures provided by the distribution to come up with the correct drivers for network adapters, and to make these known to the system. Typically this was done by means of the `/etc/modules.conf` file, where entries such as

```
alias eth0 3c59x
```

needed to be placed—this would tell the kernel to load the driver module `3c59x.o` upon the first access to the `eth0` interface. But no more …

Of course the Linux kernel is not necessarily modular, even though the standard kernels in most distributions can't do without modules. If you compile your own kernel (see, for example, *Linux System Configuration*), you can put the drivers for your network interfaces directly into the kernel.

For special requirements, typically for computers with increased security needs such as packet-filtering routers or servers that are exposed to the Internet, you can even remove the module-loading infrastructure from the kernel completely. This makes it harder (albeit not impossible) for crackers to take over the system without being noticed.

23.1.2 Configuring Network Adapters Using `ifconfig`

Before you can use a network interface to access the network, it must be assigned an IP address, a network mask, and so on. Traditionally, this is done by hand using the `ifconfig` command:

```
# ifconfig eth0 192.168.0.75 up
# ifconfig eth0
eth0 Link encap:Ethernet  HWaddr 00:A0:24:56:E3:73
     inet addr:192.168.0.75 Bcast:192.168.0.255 Mask:255.255.255.0
     inet6 addr: fe80::2a0:24ff:fe56:e373/64 Scope:Link
     UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
     RX packets:0 errors:0 dropped:0 overruns:0 frame:0
     TX packets:6 errors:0 dropped:0 overruns:0 carrier:6
     collisions:0 txqueuelen:100
     RX bytes:0 (0.0 b)  TX bytes:460 (460.0 b)
     Interrupt:5 Base address:0xd800
```

After an IP address has been assigned, you can view the status of an interface by invoking the same command without specifying an IP address. This displays not only the current IP address but also the hardware type, the MAC (or hardware) address, the broadcast address, the network mask, the IPv6 address, and many other data. In the example you can see that the kernel will set items such as the network mask and broadcast address to default values (here those of a class C network, according to the first octet of the IP address) if no explicit values are given. Should the desired values deviate from the default you must specify them explicitly.

```
# ifconfig eth0 192.168.0.75 netmask 255.255.255.192 textbackslash
>      broadcast 192.168.0.64
# ifconfig eth0
eth0 Link encap:Ethernet  HWaddr 00:A0:24:56:E3:73
     inet addr:192.168.0.75 Bcast:192.168.0.64 Mask:255.255.255.192
     inet6 addr: fe80::2a0:24ff:fe56:e373/64 Scope:Link
◁◁◁◁◁
```

Using the parameters `up` and `down`, you can switch individual interfaces on and off with `ifconfig`.

By convention, the loopback interface has the IP address `127.0.0.1` and will be configured automatically. Should this not happen for some reason, or should the configuration be lost, you can do it yourself using

loopback interface

```
# ifconfig lo 127.0.0.1 up
```

For testing or for special requirements it may make sense to define an alias for an interface, using a different IP address, network mask, etc. This is no problem using `ifconfig`:

alias

```
# ifconfig eth0:0 192.168.0.111
# ifconfig eth0:0
eth0:0 Link encap:Ethernet  HWaddr 00:A0:24:56:E3:72
     inet addr:192.168.0.111 Bcast:192.168.0.255 Mask:255.255.255.0
     UP BROADCAST MULTICAST  MTU:1500  Metric:1
     Interrupt:5 Base address:0xd800
```

The alias name is constructed from the interface name by adding an extension separated by a colon. What the extension looks like is immaterial (there is nothing wrong with `eth0:Mr.X`), but by convention alias names are numbered sequentially: `eth0:0`, `eth0:1`, …

Exercises

23.1 [1] Which kernel module applies to your network adapter? Is it loaded?

23.2 [!1] Check whether your network adapter is running, and which IP address is assigned to it.

23.3 [!2] Assign a new IP address to your network adapter (possibly according to your instructor's directions). Check whether you can still reach other computers on the network.

23.1.3 Configuring Routing Using `route`

Every computer in a TCP/IP network requires routing, since even the simplest node contains at least two network interfaces—the loopback interface and the interface leading to the rest of the network, like an Ethernet or WLAN card or an Internet connection. The routes for the loopback interface and the networks that are directly connected to the network adapters are set up automatically by current Linux kernels when the adapters are initialised. Other routes—in particular, the "default route" which specifies where datagrams are sent in the absence of more specific instructions—must be configured explicitly.

In principle we are distinguishing between *static* and *dynamic* routing. With the former, routes are set up manually and seldom if ever changed. With the latter, the system talks to other routers in its vicinity and adapts its routes to the current state of the network. Dynamic routing requires the installation of a "routing daemon" such as `gated` or `routed` and will not be discussed further here. The rest of this section confines itself to explaining static routing.

routing table

The kernel maintains a routing table summarising the current routing configuration. It contains rules (the routes) that describe which datagrams should be sent where, based on their destination address. You can inspect the routing table using the `route` command:

```
# ifconfig eth0 192.168.0.75
# route
Kernel IP routing table
Destination  Gateway Genmask       Flags Metric Ref Use Iface
192.168.0.0  *       255.255.255.0 U     0      0   0   eth0
```

The columns in this table have the following meaning:

default route

- The first column contains the destination address. This can be network or node addresses or the entry for the default route (called `default`). The default route gives the address for all datagrams to which no other routes apply.
- The second column defines a router that the datagrams in question will be passed to. Valid entries at this point include node addresses or the "`*`" entry if the datagrams do not need to go to another router.
- The third column contains the network mask for the destination address. If the destination address is a single node, the value `255.255.255.255` appears. The default route has the value `0.0.0.0`.
- The fourth column contains flags describing the route in more detail, including:

  `U` The route is active ("up")

  `G` The route is a "gateway route", that is, it points to a router (rather than a network that is connected directly, as in "`*`").

H The route is a "host route", that is, the destination is a specific node. `G` and `H` are not mutually exclusive and may occur together.

- The fifth and sixth columns contain data which is important for dynamic routing: The "metric" in the fifth column gives the number of "hops" to the destination; it is not evaluated by the Linux kernel, but mostly useful for programs such as `gated`. The value in the sixth column is not used on Linux.
- The seventh column details how often the route has been used.
- Finally, the eighth column optionally contains the name of the interface that should be used to forward the datagrams. This mostly applies to routers that contain several interfaces, such as Ethernet adapters in different network segments or an Ethernet adapter and an ISDN adapter.

The example illustrates that, when `ifconfig` is used to assign an IP address, the kernel not only sets up the network mask and broadcast address, but also assigns at least one route—that which forwards all datagrams whose destination address is within the network that is directly connected to that interface.

A more complicated example for a routing table might look like

```
# route
Kernel IP Routentabelle
Ziel        Router      Genmask         Flags Metric Ref Use Iface
192.168.0.0 *           255.255.255.0   U     0      0   0   eth0
192.168.2.0 *           255.255.255.0   U     0      0   0   eth1
10.10.3.0   192.168.0.1 255.255.255.0   UG    0      0   0   eth0
112.22.3.4  *           255.255.255.255 UH    0      0   0   ppp0
default     112.22.3.4  0.0.0.0         UG    0      0   0   ppp0
```

The computer in this example is apparently a router containing three network interfaces. The first three routes are network routes, and according to their destination addresses datagrams will be routed either via `eth0`, `eth1`, or the router `192.168.0.1` (which may be reached via the first route). The fourth route is a "host route" enabling a point-to-point connection to an ISP's computer via the modem, `ppp0`. The fifth route is the corresponding default route forwarding all datagrams not addressed to the local networks `192.168.0.0/24`, `192.168.2.0/24`, or `10.10.3.0/24` to the world via the modem.

The `route` command serves not just to inspect but also to manipulate the routing table. To establish the example above (three local Ethernet segments and the PPP connection) the routing table must be constructed according to the following commands:

```
# route add -net 192.168.0.0 netmask 255.255.255.0 dev eth0
# route add -net 192.168.2.0 netmask 255.255.255.0 dev eth1
# route add -net 10.10.3.0 netmask 255.255.255.0 gw 192.168.0.1
# route add -host 112.22.3.4 dev ppp0
# route add default dev ppp0
```

The first two lines in the example are not strictly necessary, as the corresponding routes will be set up automatically when the interfaces are assigned their addresses.

More generally, `route` supports the following syntax to add and delete routes:

```
route add [-net|-host] ⟨destination⟩ [netmask ⟨netmask⟩]▷
 ◁      [gw ⟨gateway⟩] [[dev] ⟨interface⟩]
route del [-net|-host] ⟨destination⟩ [netmask ⟨netmask⟩]▷
 ◁      [gw ⟨gateway⟩] [[dev] ⟨interface⟩]
```

To add a route, you must specify the corresponding parameter (`add`); then you specify whether the route is a host or network route (`-host` or `-net`), followed by the destination. For a network route, a netmask must be specified either via the `netmask` ⟨*netmask*⟩ option or by appending a CIDR-style netmask to the destination address. For each route there must be either a router (⟨*gateway*⟩) or a destination interface covering the next hop.

The example routes could be deleted like this:

```
# route del -net 192.168.0.0 netmask 255.255.255.0
# route del -net 192.168.2.0 netmask 255.255.255.0
# route del -net 10.0.3.0 netmask 255.255.255.0
# route del -host 112.22.3.4
# route del default
```

To delete a route you need to specify the same parameters as when adding it—only the gateway or interface specifications may be left off. With duplicate destinations, e. g., the same destination network via two different interfaces, the newest (least recently inserted) route will be removed.

If a station is to be used as a gateway between several networks (as in the example), the kernel should forward incoming IP datagrams not intended for the station itself according to the routing table. This feature, known as **IP forwarding**, is disabled by default. Its current state can be inspected and changed using the `/proc/sys/net/ipv4/ip_forward` (pseudo) file. It contains only one character—a zero (disabled) or one (enabled)—, and is usually written to using `echo`:

IP forwarding

```
# cat /proc/sys/net/ipv4/ip_forward
0
# echo 1 > /proc/sys/net/ipv4/ip_forward
# cat /proc/sys/net/ipv4/ip_forward
1
```

Attention: Like the other command-based settings, this is lost when the computer is shut down. (Distributions have ways of making this setting permanent; for Debian GNU/Linux, include a line containing "`ip_forward=yes`" in the `/etc/network/options` file, for the Novell/SUSE distributions, put "`IP_FORWARD="yes"`" in `/etc/sysconfig/sysctl`. For Red Hat distributions, add a line containing

```
net.ipv4.ip_forward = 1
```

to the `/etc/sysctl.conf` file.)

23.1.4 Configuring Network Settings Using `ip`

The `ip` command can be used to set up both network interfaces and routes. It is the designated successor to the commands described above. Its syntax is roughly like

`ip` [⟨*options*⟩] ⟨*object*⟩ [⟨*command*⟩ [⟨*parameters*⟩]]

Possible ⟨*object*⟩s include `link` (parameters of a network interface), `addr` (IP address and other addresses of a network interface), and `route` (querying, adding, and deleting routes). There are specific commands for each object type.

If no command is given, the current settings are displayed according to the `list` and `show` commands. Other typical commands are `set` for `link` objects as well as `add` and `del` for `addr` and `route` objects.

Most commands require additional parameters, since if you want to assign an IP address using "`ip addr add`", you will have to specify what address you are talking about.

You can find out more about the requisite syntax by invoking `ip` using the `help` subcommand. Thus, "`ip help`" displays all possible objects, while "`ip link help`" shows all parameters pertaining to `link` objects including their syntax. Unfortunately the syntax is not always straightforward.


If you know your way around Cisco routers you will have noted a certain similarity to the Cisco `ip` command. This similarity is deliberate.

For example: If you wanted to assign an IP address to a network interface, you might use the following command:

```
# ip addr add local 192.168.2.1/24 dev eth0 brd +
```

Unlike `ifconfig`, `ip` *requires* the netmask and broadcast address to be present (even if specified indirectly using `brd +`). The `local` parameter is used to specify that an IP address for a local interface is forthcoming, but since this is the default parameter for "`ip addr add`", the `local` may also be left off. You can find out about default parameters from the `ip`(8) manual page.

Caution: Unlike `ifconfig`, after having been assigned an IP address, the interface is not yet activated. This must be done separately:

```
# ip addr show dev eth0
2: eth0: <BROADCAST,MULTICAST> mtu 1500 qdisc pfifo-fast qlen 100
        link/ether 00:a0:24:56:e3:72 brd ff:ff:ff:ff:ff:ff
        inet 192.168.2.1/24 brd 192.168.2.255 scope global eth0
# ip link set up dev eth0
# ip addr show dev eth0
2: eth0: <BROADCAST,MULTICAST,UP> mtu 1500 qdisc pfifo-fast qlen 100
        link/ether 00:a0:24:56:e3:72 brd ff:ff:ff:ff:ff:ff
        inet 192.168.2.1/24 brd 192.168.2.255 scope global eth0
        inet6 fe80::2a0:24ff:fe56:e372/64 scope link
```

You can also assign interface aliases using `ip`:

```
# ip addr add 192.168.0.222/24 dev eth0 brd + label eth0:0
```

It is useful to learn about `ip`, not only because it is the upcoming standard, but also because it is often more straightforward to use than the alternatives. For example, setting and deleting routes is easier than it is with `route`:

```
# ip route add 192.168.2.1 via 192.168.0.254
# ip route del 192.168.2.1
```

23.2 Persistent Network Configuration

One thing is for sure: Once you have figured out the correct network configuration for your system, you do not want to set it up over and over again. Unfortunately, though, the Linux kernel forgets all about it when it is shut down.

The various Linux distributions have solved this problem in different ways:


On Debian GNU/Linux and its derivatives, the network configuration is stored in the `/etc/network/interfaces` file. This file is mostly self-explanatory:

```
# cat /etc/network/interfaces
auto lo eth0

iface lo inet loopback

iface eth0 inet static                                    or ''... inet dhcp''
  address 192.168.0.2
  netmask 255.255.255.0
  network 192.168.0.0
  broadcast 192.168.0.255
  up route add -net 10.10.3.0/24 gw 192.168.0.1
  down route del -net 10.10.3.0/24 gw 192.168.0.1
```

In the file there is an entry for each interface. Using the `ifup` and `ifdown` commands, the interfaces can be activated or deactivated individually or (with the `-a`) collectively; when the system is booted, the `/etc/init.d/networking` script takes care of initialising the interfaces. (Alternatively, `udev` will do it, provided the interfaces in question are listed in a line like "`allow-hotplug eth0`". This is mostly interesting for network adapters that are not always available, like USB-based Ethernet or UMTS adapters.)—Lines starting with `up` contain commands that will be run when the interface is being brought up (in the order they are in the file); conversely, lines startign with `down` give commands to be executed when the interface is being shut down. You can find more examples for the strange and wonderful things that are possible with the Debian network configuration mechanism by looking at `interfaces`(5) and the `/usr/share/doc/ifupdown/examples/network-interfaces.gz` file.

YaST, the central configuration tool for the Novell/SUSE distributions, naturally contains modules to configure network adapters. Settings made using YaST are commonly stored as variables in files below `/etc/sysconfig`, where init scripts or the `SuSEconfig` program can pick them up. Network configuration settings in particular are stored in the `/etc/sysconfig/network` directory, and you can even modify the files in there manually. There is a file called `ifcfg-`⟨*interface*⟩ for each interface (e. g., `ifcfg-eth0`) which contains the settings for that particular interface. This could look like

```
BOOTPROTO='static'                                    or dhcp (among others)
BROADCAST='192.168.0.255'
ETHTOOL_OPTIONS=''
IPADDR='192.168.0.2'
MTU=''
NAME='79c970 [PCnet32 LANCE]'                              Name inside YaST
                                                          (VMware says hello)
NETMASK='255.255.255.0'                                 Or PREFIXLEN=24
NETWORK='192.168.0.0'
REMOTE_IPADDR=''                                       Remote peer with PPP
STARTMODE='auto'                                       or manual, hotplug, ...
USERCONTROL='no'
```

(a more detailed explanation can be found in `ifcfg`(5)). More general network settings go into `/etc/sysconfig/network/config`.—The SUSE distributions, too, support commands called `ifup` and `ifdown`, whose function, however, is subtly different from those on Debian GNU/Linux. At least the basic invocations like "`ifup eth0`" are the same, but even "`ifup -a`" doesn't work—to start or stop all interfaces, you must call "`rcnetwork start`" or "`rcnetwork stop`". (As a consolation prize, "`rcnetwork start eth0`" also works.) Typically

for SUSE, `rcnetwork` is nothing but a symbolic link to the `/etc/init.d/network` init script.

On the Novell/SUSE distributions you can configure routes using the `/etc/sysconfig/network/routes` file. The content of this file (shown here to match the example above) resembles the output of the `route` command:

```
# cat /etc/sysconfig/network/routes
10.10.3.0       192.168.0.1     255.255.255.0   eth0
112.22.3.4      0.0.0.0         255.255.255.255 ppp0
default         112.22.3.4      -               -
```

If no gateway is to be used, the correct value is "`0.0.0.0`", unset network masks or interface names are represented by a "`-`" character. Routes, too, are set by means of the "`rcnetwork restart`" command. As far as the last two routes in the example are concerned, it turns out that point-to-point routes for dialup connections are usually set up dynamically by the daemons in question (such as `pppd`).—If you want to define routes for specific interfaces, you can also put the lines in question into a file called `ifroute-`⟨*interface*⟩ (such as `ifroute-eth0`) rather than the `routes` file. The fourth column (the one containing the interface names) will then be replaced by the interface name if you leave it blank in the file.

Like SUSE, Fedora and the other Red Hat distributions use files inside a `/etc/sysconfig` directory to set various variables. As on SUSE, there are files like `ifcfg-eth0` for the configuration of each interface, but they are stored in a directory called `/etc/sysconfig/network-scripts`. However, SUSE files are not directly transferable, since their internal structure differs from the Red Hat files. On Red Hat, you might implement our example configuration for `eth0` as follows: The `/etc/sysconfig/network-scripts/ifcg-eth0` file contains

```
DEVICE=eth0
BOOTPROTO=none
ONBOOT=yes
NETWORK=192.168.0.0
NETMASK=255.255.255.0
IPADDR=192.168.0.2
USERCTL=no
```

The `ifup` and `ifdown` commands exist on Fedora, too, but as on SUSE you can only bring up or shut down one interface at any one time.

On Red Hat, static routes can be placed in a file inside `/etc/sysconfig/network-scripts` called `route-`⟨*interface*⟩ (for example, `route-eth0`). In this case, the format is like

```
ADDRESS0=10.10.3.0
NETMASK0=255.255.255.0
GATEWAY0=192.168.0.1
```

(additional routes use `ADDRESS1`, `NETMASK1`, …, `ADDRESS2` and so on). There is an older file format according to which every line of the file is simply appended to "`ip route add`", which lends itself to lines like

```
10.10.3.0/24 via 192.168.0.1
```

Finally, you can define static routes in `/etc/sysconfig/static-routes` without having to refer to individual interfaces. Lines in this file are only taken into account if they start with the `any` keyword; the remainder of the line is appended to "`route add -`" (Consistency? We don't need no steenkin' consistency!), such that a line like

```
any net 10.10.3.0 netmask 255.255.255.0 gw 192.168.0.1
```

executes the

```
route add -net 10.10.3.0 netmask 255.255.255.0 gw 192.168.0.1
```

command.

23.3 DHCP

DHCP, the "Dynamic Host Configuration Protocol" is used to save you as the administrator from having to define network parameters on every single host in the network. Instead, a Linux machine fetches its network parameters—apart from its IP address and accessories, typically the address of a default router and one or more DNS servers—from a remote DHCP server when the network adapter is brought up.

The prerequisite for this to work is, of course, an existing DHCP server. Explaining the installation and maintenance of a DHCP server is, sadly, beyond the scope of this manual, but if you are using one of the common DSL routers for Internet access or, at work, can avail yourself of the services of a competent IT department, this isn't really your problem—the required functionality will be readily available and/or can be straightforwardly activated.

Most Linux distributions make it very easy to use DHCP for configuration:

On Debian GNU/Linux or Ubuntu, simply replace, in `/etc/network/interfaces`, the line

```
iface eth0 inet static
```

and any following lines containing address or routing information by the line

```
iface eth0 inet dhcp
```

This causes the computer to obtain its address, network mask, and default route from the DHCP server. You can still use `up` and `down` to execute commands once the link has been brought up or before it is torn down.

On the Novell/SUSE distributions, change the

```
BOOTPROTO='static'
```

parameter in the file containing the configuration for the interface in question (`ifcfg-eth0` or whatever) to

```
BOOTPROTO='dhcp'
```

You may leave the `BROADCAST`, `IPADDR`, `NETMASK`, and `NETWORK` settings empty.

To use DHCP on Fedora and the other Red Hat distributions, change the configuration file of the interface to read

```
BOOTPROTO=none
```

instead of

```
BOOTPROTO=dhcp
```

You can simply omit the address parameters.

Generally, the distribution-specific network configuration methods support various other options such as VLAN (several "virtual" networks on the same wire that cannot see one another), encryption, or bonding (several network adapters work in parallel, for more capacity and/or fault tolerance). Another important use case is for a mobile computer to take part in several networks, such as at home and at the office. The options actually offered differ greatly between distributions and cannot be discussed here in detail.

23.4 IPv6 Configuration

SLAAC

To integrate your computer into an IPv6 network, in the ideal case you need to do nothing at all: The mechanism of "stateless address autoconfiguration" (SLAAC) makes it possible for everything to take place automatically. With IPv6, SLAAC plays approximately the role that DHCP would in IPv4, at least for simple applications.

Procedure

If a new IPv6 network interface is activated, the station first generates the appropriate link-local address. This assumes the `fe80::/64` prefix and derives the station part from the MAC address of the interface in question[1]. After that, the station sends a link-local "router solicitation" (RS) on that interface to the multicast address, `ff02::2`, which refers to all routers in the subnet. This causes the router (or routers) on the physical network of the interface to emit "router advertisements" (RA) containing the prefixes they are routing. On that basis, the station constructs additional (possibly globally visible) addresses for the interface.—RS and RA are part of the "Neighbor Discovery Protocol" (NDP), which in turn belongs to ICMPv6, the IPv6 counterpart to ICMP. RAs and the IPv6 addresses derived from them only remain valid for a certain time if they are not refreshed. Hence, routers send unsolicited RAs every so often; the RS only serves to avoid having to wait for the next unsolicited RA when a new interface is brought up, by making it possible to obtain the necessary information at once.

Advantages

The advantage of this approach is that it does not require explicit configuration within a DHCP server. It is also straightforward to obtain redundancy by configuring several routers within the same subnet. In addition, routers do not need to remember (as they would with DHCP) which station is currently using which IP address (hence, "stateless"). All of this does not mean, however, that in IPv6 you can do without DHCP altogether (there is DHCPv6), since there are important bits of information that can't be obtained via SLAAC (think "DNS server"—although there is a new, not yet widely supported, standard to fix that).

Querying addresses

You can check the addresses the system has assigned to an interface:

```
# ip addr show eth0
2: eth0: <BROADCAST,MULTICAST,UP,LOWER_UP> mtu 1500▷
 ◁ qdisc pfifo_fast state UP qlen 1000
  link/ether 70:5a:b6:9c:40:6a brd ff:ff:ff:ff:ff:ff
  inet 192.168.178.130/24 brd 192.168.178.255 scope global eth0
  inet6 2001:db8:56ee:0:725a:b6ff:fe9c:406a/64 scope global dynamic
     valid_lft 6696sec preferred_lft 3096sec
  inet6 fe80::725a:b6ff:fe9c:406a/64 scope link
     valid_lft forever preferred_lft forever
```

[1] The method for this is as follows: Consider the MAC address, *mn*:*op*:*qr*:*st*:*uv*:*wx*. The 3rd bit of *n* (counting from the left), which in a MAC address is always zero, is set to one (we shall call the result *n'*), and the station address is then *mn'op*:*qr*`ff:fe`*st*:*uvwx*. The MAC address `70:5a:b6:9c:40:6a`, for example, becomes the station address `725a:b6ff:fe9c:406a`.

This contains both the link-local address ("`scope link`", starting with `fe80::`) and a globally visible address ("`scope global dynamic`", beginning with `2001:`) which the interface has obtained via SLAAC. If you look closely, you can also correlate the MAC address (in the `link/ether` line) with the station parts of the IPv6 addresses.

privacy

Incidentally, the station parts of your IPv6 addresses, which are derived from your MAC addresses, are a potential problem for your privacy. If you always use the same source address to surf the 'net, it is trivial to correlate your activities (web sites visited and so on) with that address. Even if, as people will say, you have nothing to hide, nobody can fault you for the queasy feeling this might give you as a matter of principle. One way of ameliorating the problem are the "privacy extensions", which add a random, otherwise unused, station part for outgoing traffic and pick a new one every so often. The privacy extensions can be activated for an interface (here `eth0`) using `sysctl`:

```
# sysctl -w net.ipv6.conf.eth0.use_tempaddr=2
# ip link set dev eth0 down
# ip link set dev eth0 up
```

To make this setting permanent, enter it in `/etc/sysctl.conf`.

Manual configuration

Finally, it is still possible to assign IP adresses manually. You can do this either using `ifconfig`:

```
# ifconfig eth0 inet6 add 2001:db8:abcd::1/64
```

or using `ip`:

```
# ip addr add 2001:db8:abcd::1/64 dev eth0
```

How to make this configuration permanent will depend on your distribution; the techniques for this largely correspond to those discussed in Section 23.2.

23.5 Name Resolution and DNS

The DNS or "Domain Name System" is one of the fundamental ingredients for the scalability of the Internet. Its job is to assign human-readable names to network nodes and to find the corresponding IP addresses (or vice versa). It does this by means of a worldwide distributed "database" of DNS servers.

By now, DNS takes care of many other jobs, from figuring out the mail servers for a domain to helping with spam avoidance.

resolver

Programs on a Linux machine usually do not talk to the DNS directly, but avail themselves of the services of a "resolver". This is usually part of the C runtime library. The central configuration file for the resolver is called `/etc/resolv.conf`. It is used, e. g., to define the DNS servers that the resolver is to consult. There are five main directives:

`domain` ⟨*Name*⟩ (local domain) This is the domain name that the resolver tries to append to incomplete names (typically, those that do not contain a period).

Exactly which names are considered incomplete is governed by the `ndots` option (see Table 23.1).

`search` ⟨$Domain_1$⟩ ⟨$Domain_2$⟩ … (search list) As an alternative to a single entry using `domain`, you can specify a list of several domain names to be appended to incomplete names. The entries in the list are separated by spaces. At first the resolver tries the unchanged name. If this fails, the list entries are appended in order and these names are tried. `domain` and `search` are mutually exclusive; if both occur in a configuration, whichever line is last in the file wins.

Table 23.1: Options within `/etc/resolv.conf`

Option	Result
`debug`	Regular log messages are output to `stdout` (commonly unimplemented).
`ndots` ⟨*n*⟩	The minimum number of dots within a name which will cause the resolver to perform a direct query without accessing the search list.
`attempts` ⟨*n*⟩	The number of times the resolver will query a server before giving up. The maximum value is 5.
`timeout` ⟨*n*⟩	The initial time out for query attempts in seconds. The maximum value is 30.
`rotate`	Not only the first, but all specified servers will be queried in rotation.
`no-check-names`	Deactivates the standard check whether returned host names only contain allowable characters.

```
nameserver 192.168.10.1
nameserver 192.168.0.99
search     foo.example.com bar.example.com example.com
```

Figure 23.1: `/etc/resolv.conf` example

`nameserver` ⟨*IP address*⟩ (local DNS server) The local resolver will consult the DNS server given here. You may define up to three name servers in separate `nameserver` directives, which will be consulted in sequence if required.

`sortlist` ⟨*IP address*⟩[`/`⟨*network mask*⟩] (sort order) If several addresses are returned for a name, the one matching the specification here will be preferred. In the sort list there is room for up to ten entries.

`options` ⟨*Option*⟩ (options) This is used for specific resolver settings which are detailed (together with their default values) in Table 23.1. In practice these are seldom, if ever, changed.

You can see a typical `/etc/resolv.conf` file in Figure 23.1.

An alternative to DNS is the "local" resolution of host names and IP addresses by means of the `/etc/hosts` file. As the sole method for name resolution this is only of interest for small networks that are not connected to the Internet, but we should mention it nevertheless—if you only need to deal with a few computers, it is conceivably more straightforward to simply configure the DNS client side and assign names and addresses to your own computers using `/etc/hosts`. You do have to take care that the file is the same on all your computers.

For small networks we recommend the `dnsmasq` program, which makes the content of an `/etc/hosts` file available via DNS, while passing all other DNS queries on to the "real" DNS. It even works as a DHCP server on the side.

The content of the `/etc/hosts` file is plain ASCII text which may contain line-based entries as well as comments starting with "#". These entries contain an IP address in the first column and the "fully qualified domain name" (FQDN) of a host in the second. It is also permissible to add more names on the same line. Spaces or tabs can be used to separate columns. Figure 23.2 shows the content of a typical `/etc/hosts` file.

When the Internet was new—until the early 1980s—there was essentially one big `/etc/hosts` file for everybody, and domains hadn't been invented yet. At that time the Internet consisted of fewer nodes (thousands instead of

```
#
# hosts         This file describes a number of hostname-to-address
#               mappings for the TCP/IP subsystem.  It is mostly
#               used at boot time, when no name servers are running.
#               On small systems, this file can be used instead of a
#               "named" name server.
# Syntax:
#
# IP-Address  Full-Qualified-Hostname  Short-Hostname
#
# special IPv6 addresses

127.0.0.1       localhost
192.168.0.99    linux.example.com  linux
```

Figure 23.2: The `/etc/hosts` file (SUSE)

gazillions), but the maintenance and distribution of current versions of the file came to be a growing problem. Hence, DNS.

name resolution services

The exact mechanisms the C library uses for name resolution are controlled by means of a file called `/etc/nsswitch.conf`. This determines, for example, which name resolution services are used in which order. In addition there are rules for the resolution of user names, groups, etc., which will not concern us at this point. You can refer to `nsswitch.conf`(5) for a detailed description of its syntax and function.

The part of `/etc/nsswitch.conf` pertinent to host name resolution could look like:

```
hosts: files dns
```

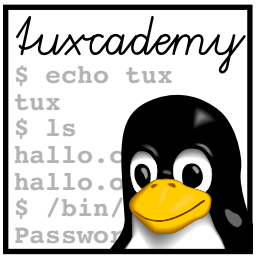
This means that the C library will try to resolve host names based on the local files (namely, `/etc/hosts`). Only if this fails will it query DNS.

Commands in this Chapter

dnsmasq	A lightweight DHCP and caching DNS server for small installations	dnsmasq(8)	367
ifconfig	Configures network interfaces	ifconfig(8)	356
ifdown	Shuts down a network interface (Debian)	ifdown(8)	362
ifup	Starts up a network interface (Debian)	ifup(8)	362
ip	Manages network interfaces and routing	ip(8)	360
route	Manages the Linux kernel's static routing table	route(8)	358

Summary

- Nowadays the Linux kernel loads networking drivers on demand using the `udev` infrastructure.
- The `ifconfig` command is used for low-level configuration of network interface parameters. You can use it to configure the loopback interface and to assign alias names for interfaces.
- Routes specify how IP datagrams should be forwarded to their destinations.
- The `route` command is used to configure routes.
- The `ip` command is a convenient replacement for `ifconfig` and `route`.
- The various Linux distributions offer different methods of persistent network configuration
- DHCP lets Linux hosts obtain networking parameters dynamically from a central server.
- Common name resolution mechanisms are based on DNS or local configuration files.
- The order of name resolution is specified in the `/etc/nsswitch.conf` file.



24

Network Troubleshooting

Contents

Goals

- Knowing strategies for network troubleshooting
- Being able to use tools like ping, traceroute, and netstat for problem analysis
- Being able to fix simple network configuration errors

Prerequisites

- Knowledge about Linux system administration
- Knowledge about TCP/IP fundamentals (Chapter 22)
- Knowledge about Linux network configuration (Chapter 23)

24.1 Introduction

System administrators love this: No sooner have you settled in comfortably in front of your computer with a nice cup of coffee or tea, looking forward to perusing the newest news on LWN.net, that a noxious person stands in the doorway: "I can't get on the network!" Alas for the peace and quiet. But what to do?

Computer networking is a difficult topic, and therefore you should not be surprised when All Sorts Of Things Go Wrong. In this chapter we show you the most important tools and strategies to find and iron out problems.

24.2 Local Problems

The first order of the day is to convince yourself that the network adapter is present and recognised. (For starters, do take a discreet look at the back of the computer to ascertain that the cable is still sitting in the correct socket, and that the ladies and gentlemen of the cleaning squad have not played "creative reconfiguration".)

Check the output of "`ifconfig -a`". With this parameter, the program gives you an overview of *all* network interfaces inside the computer, even the ones that are not currently configured. At least `lo` and `eth0` (if the computer is networked using Ethernet) should be visible. If this isn't the case, you have already found the first problem: Possibly there is something wrong with the driver, or the adapter is not being recognised.

If, instead of `eth0`, you only see something like `eth1`, it is possible that the network card was replaced, and `udev` assigned a new interface name to the card on account of its new MAC address. This shouldn't really happen with network cards that are reasonably firmly attached to the computer (or, if it does, it should happen because you, being the administrator, did it yourself), but perhaps your colleagues have surreptitiously swapped their PC(MCIA) network adapters or USB-based UMTS dongles. The remedy is to delete the line referring to the old device from the `/etc/udev/rules.d/70-persistent-net.rules` (or some such), and to correct the interface name in the line referring to the new device. Restart `udev` afterwards.

If the output of `ifconfig` shows nothing remotely resembling your network adapter, then check, using `lsmod`, whether the driver module in question was loaded at all. If you do not know what the driver module in question is to begin with, you can search the output of "`lspci -k`" for the stanza pertaining to your network adapter. This might look like

```
02.00.0 Ethernet controller: Broadcom Corporation NetXtreme▷
 ◁ BCM5751 Gigabit Ethernet PCI Express (rev 01)
        Kernel driver in use: tg3
        Kernel modules: tg3
```

In this case you should ascertain that the `tg3` module has been loaded.

24.3 Checking Connectivity With `ping`

If the output of `ifconfig` shows the interface and the parameters displayed with it look reasonable, too (check the IP address, the network mask—very important—, and the broadcast address, in particular), then it is time for some connectivity tests. The simplest tool for this is a program called `ping`, which takes an IP address (or a DNS name) and tries to send an ICMP `ECHO REQUEST` datagram to the host in question. That host should reply with an ICMP `ECHO REPLY` datagram, which `ping` receives and reports.

First, you should check whether the computer can talk to itself:

```
# ping 127.0.0.1
PING 127.0.0.1 (127.0.0.1) 56(84) bytes of data.
64 bytes from 127.0.0.1: icmp_seq=1 ttl=64 time=0.039 ms
64 bytes from 127.0.0.1: icmp_seq=2 ttl=64 time=0.039 ms
64 bytes from 127.0.0.1: icmp_seq=3 ttl=64 time=0.032 ms
64 bytes from 127.0.0.1: icmp_seq=4 ttl=64 time=0.040 ms
                                                    Interrupt using Ctrl+c ...
--- 127.0.0.1 ping statistics ---
4 packets transmitted, 4 received, 0% packet loss, time 2997ms
rtt min/avg/max/mdev = 0.032/0.037/0.040/0.006 ms
```

The output tells you that the "other host" (in this case merely the loopback interface on 127.0.0.1) can be reached reliably (no packets were lost).

What about "56(84) bytes of data"? Easy: An IP datagram header without options is 20 bytes long. Added to that is the header of an ICMP ECHO REQUEST datagram at 8 bytes. This explains the difference between 56 and 84. The magic number 56 results from the fact that ping normally ensures that exactly 64 bytes of payload data are transmitted inside each IP datagram, namely the 8-byte ICMP header and 56 bytes of "padding". If "enough" padding is available, namely at least the size of a struct timeval in C (eight bytes or so), ping uses the start of the padding for a timestamp to measure the packet round-trip time.

The next step should be to "ping" your network card interface. The output there should look approximately like the other one.

If you have arrived here without running into error messages, chances are that the basic networking functionality of your computer is working. The remaining possible sources of trouble rest elsewhere in the network or else farther up your computer's protocol stack.

The next ping goes to the default gateway (or another host on the local network). If this does not work at all, the network mask might be set up wrong (possibly on the other host!?). Other possibilities include hardware trouble, such as a kink in the cable or a broken plug—which would also explain a connection that sometimes works and sometimes doesn't.

The common rectangular plugs for Ethernet cables are kept in place using a plastic thingamajig which likes to break off, in which case contact is often flaky to impossible.

"Free-flying" cables are prone to accidents with sharp implements and do not like being run over with office chairs. If you suspect that a cable is faulty you can corroborate or deny that by exchanging it for a known-working one or testing it using an Ethernet cable tester. Of course cables should really be strung inside a proper conduit, on top of the false ceiling, or below the raised floor.

Now you can continue pinging hosts outside your local network. If this works this is a good sign; if you get no answers at all, you might be dealing with a routing problem or else an overzealous firewall that filters ICMP traffic à la ping at least partly (which it shouldn't, but some people do throw out the baby with the bathwater).

ping supports a great number of options that extend the testing possibilities or change the way the program works. The most important options for the purposes of testing are probably -f (flood ping) for quickly checking out intermittent network problems, and -s to specify a size for the datagrams.

Table 24.1: Important `ping` options

Option	Meaning
`-a`	Audible pings
`-b` ⟨*network address*⟩	Broadcast ping
`-c` ⟨*count*⟩	Number of datagrams to be sent (`ping` will exit afterwards)
`-f`	"Flood ping": A dot is output for every `ECHO REQUEST` datagram sent, and a backspace character for every `ECHO REPLY` received. The result is a row of dots that tells you how many datagrams have been dropped during transmission. If you haven't simultaneously specified the `-i` option, `ping` transmits at least 100 datagrams per second (more if the network can handle more). Only `root` may do that, though; normal users are limited to a minimum interval of 0.2 seconds.
`-i` ⟨*time*⟩	Waits for ⟨*time*⟩ seconds between sending two datagrams. The default is one second, except when flood pinging as `root`.
`-I` ⟨*sender*⟩	Sets the sender address for the datagrams. The ⟨*sender*⟩ may be an IP address or the name of an interface (in which case the IP address of that interface will be used).
`-n`	Display without DNS name resolution
`-s` ⟨*size*⟩	Determines the size of the "padding" in bytes; the default value is 56. Sometimes there are problems with very large datagrams that must be fragmented, and `ping` can help diagnose these by means of this option. (Long ago it used to be possible to crash computers using very large `ping` datagrams—the dreaded "ping of death".)


-a can come in useful if you have to creep around under a table to find a loose cable.

The corresponding command to test IPv6 is called ping6 and is invoked in a manner very similar to that of ping. You just need to take care to specify the interface you want to use. Watch for the "%eth0" at the end of the IPv6 address: ping6

```
$ ping6 fe80::224:feff:fee4:1aa1%eth0
PING fe80::224:feff:fee4:1aa1%eth0(fe80::224:feff:fee4:1aa1)▷
 ◁ 56 data bytes
64 bytes from fe80::224:feff:fee4:1aa1: icmp_seq=1 ttl=64 time=3.65 ms
64 bytes from fe80::224:feff:fee4:1aa1: icmp_seq=2 ttl=64 time=4.30 ms
◁◁◁◁◁
```

With link-local addresses, in particular, it is possible for several interfaces to use the same address, and ambiguities must thus be avoided. Other than that, the options of ping6 correspond for the most part to those of ping.

Exercises


24.1 [!2] Compare the packet round-trip times of a ping to 127.0.0.1 to those of a ping to a remote host (another computer on the LAN or the default gateway/DSL router/…).


24.2 [2] How long does your system take to send a million datagrams to itself in flood-ping mode?


24.3 [2] (If your local network supports IPv6.) Use ping6 to check the connectivity to any IPv6 routers on your LAN (multicast address ff02::2). What answers do you receive?

24.4 Checking Routing Using traceroute And tracepath

If you cannot reach a station outside your local network using ping, this could be due to a routing problem. Programs like traceroute and tracepath help you pinpoint these problems.


The typical case is that you can in fact reach all hosts on the local network but none beyond. The usual suspects are your default route on the one hand and the host the default route points to on the other. Make sure that the output of route (or "ip route list") shows the correct default route. If a ping to the default gateway works but a ping to a host beyond the default gateway doesn't, then something may be wrong with the gateway. Check whether another host can reach other hosts beyond the gateway, and whether your host is reachable *from* the gateway. (Also keep in mind that the default router may be running a packet filter that blocks ICMP.)


A different sort of problem can arise if you are not connected directly to the router that in turn connects you to the internet, but must go across a different router. In that case it is possible that you can send ping datagrams to the Internet router, but that its replies cannot reach you because it does not have a route that will direct traffic for "your" network to the intermediate router.

traceroute is basically an extended form of ping. This does not merely check a remote node for signs of life, but displays the route that datagrams take through the network. It keeps track of the routers the datagram passes through and the quality of the connection to the routers in question.

Unlike `ping`, this is not based on ICMP, but (traditionally) on UDP. `traceroute` sends three UDP datagrams to arbitrary ports on the destination node (one hopes that not all three of these have servers listening on them). The first three datagrams have a TTL of 1, the next three a TTL of 2, and so on. The first router on the way to the destination decrements the TTL by 1. For the first round of datagrams, which only had a TTL of 1 in the first place, this means curtains—they are dropped, and the sender gets an ICMP `TIME EXCEEDED` message, which (being an IP datagram) contains the router's IP address. The second three datagrams are dropped by the second router and so on. That way you can follow the exact route of the datagrams towards the destination. Of course, the destination node itself doesn't send `TIME EXCEEDED` but `PORT UNREACHABLE`, so `traceroute` can notice that it is done.

The procedure looks roughly like this:

```
$ traceroute www.linupfront.de
traceroute to www.linupfront.de (31.24.175.68), 30 hops max,▷
 ◁ 60 byte packets
 1  fritz.box (192.168.178.1)  5.959 ms  5.952 ms  5.944 ms
 2  217.0.119.34 (217.0.119.34)  28.889 ms  30.625 ms  32.575 ms
 3  87.186.202.242 (87.186.202.242)  35.163 ms  36.961 ms  38.551 ms
 4  217.239.48.134 (217.239.48.134)  41.413 ms  43.002 ms  44.908 ms
 5  xe-11-0-1.fra29.ip4.gtt.net (141.136.101.233)  46.769 ms  ▷
 ◁ 49.231 ms  51.282 ms
 6  xe-8-1-2.fra21.ip4.gtt.net (141.136.110.101)  53.412 ms ▷
 ◁ xe-0-2-3.fra21.ip4.gtt.net (89.149.129.37)  49.198 ms ▷
 ◁ xe-8-1-2.fra21.ip4.gtt.net (141.136.110.101)  52.314 ms
 7  21cloud-gw.ip4.gtt.net (77.67.76.90)  52.547 ms  30.822 ms▷
 ◁  30.018 ms
 8  s0a.linupfront.de (31.24.175.68)  38.127 ms  38.406 ms  38.402 ms
```

The output consists of several numbered lines. One line corresponds to a group of three datagrams. It shows the node sending the `TIME EXCEEDED` message as well as the transmission time of the three datagrams.

Asterisks in the output mean that there was no answer for one of the datagrams within (usually) five seconds. That happens.

Maybe you are wondering why the output finishes with `s0a.linupfront.de` even though we wanted to reach `www.linupfront.de`. This is not a problem; the `www.linupfront.de` web site—together with a few other useful services—is hosted on a machine we call `s0a.linupfront.de`, and that happens to be the answer that DNS provides if you ask it for the name belonging to the IP address, `31.24.175.68`.

The fact that IP networks use packet switching implies, theoretically, that the output of `traceroute` is just a momentary snapshot. If you try it again, the new datagrams might in principle take a completely different route to the destination. However, this does not occur very often in practice.

The traditional technique based on UDP datagrams doesn't work in all cases today, as there are overzealous firewalls that drop datagrams addressed to "unlikely" UDP ports. You can use the `-I` option to get `traceroute` to use ICMP instead of UDP (it then works essentially like `ping`). If you need to deal with an especially overzealous firewall that filters ICMP as well, you can use a TCP-based technique by means of the `-T` option (short for "`-M tcp`"). This tries to address port 80 on the destination node and recommends itself particularly if the destination node is a web server. (You can request a different port by means of the `-p` option.)

The "TCP-based technique" does not actually open a connection to the destination node and thus stays invisible to application programs there. `traceroute` also offers some other methods.


You can use traceroute with IPv6 by giving the -6 option. A convenient abbreviation for this is traceroute6. Everything else stays the same. traceroute6

The tracepath program does basically the same thing as traceroute, but does not offer most of the tricky options and can be invoked by regular users (without root privileges). In addition, it determines the "path MTU" (of which more anon). Here is some exemplary output produced by tracepath: tracepath

```
$ tracepath www.linupfront.de
 1?: [LOCALHOST]                          pmtu 1500
 1:  fritz.box                             13.808ms
 1:  fritz.box                              5.767ms
 2:  p5B0FFBB4.dip0.t-ipconnect.de         11.485ms pmtu 1492
 2:  217.0.119.34                          48.297ms
 3:  87.186.202.242                        46.817ms asymm  4
 4:  217.239.48.134                        48.607ms asymm  5
 5:  xe-11-0-1.fra29.ip4.gtt.net           47.635ms
 6:  xe-7-1-0.fra21.ip4.gtt.net            49.070ms asymm  5
 7:  21cloud-gw.ip4.gtt.net                48.792ms asymm  6
 8:  s0a.linupfront.de                     57.063ms reached
     Resume: pmtu 1492 hops 8 back 7
```

Just like traceroute, tracepath outputs the addresses of all routers on the route to the destination node. The remainder of the line shows the time the datagrams took as well as additional iinformation; "asymm 5", for example, means that the router's answer took 5 hops instead of the 4 hops of the request, but this information isn't always reliable.

This brings us to the "path MTU" problem, which can be explained as follows: Fundamentally, IP allows datagrams of up to 65535 bytes, but not every medium access scheme can actually transmit these datagrams in one piece. Ethernet, for example, allows frames of at most 1518 bytes, including 14 bytes for the frame header and 4 bytes for a checksum at the end of the frame. This means that an Ethernet frame can carry at most 1500 bytes of payload, and if the IP layer above wants to transmit a larger datagram, that datagram must be "fragmented", that is, split across several frames. We say that the "maximum transmission unit", or MTU, for Ethernet is 1500.

Of course the IP implementation of the sending node cannot foresee which medium access schemes will be used on the way to the destination and whether fragmentation will be necessary (and, if so, how large the fragments may be). This only comes out when data are actually transmitted. Routers should *really* be handling this transparently—if a datagram arrives at one end that is too big to be sent out in its entirety at the other end, the router could fragment it—, but router manufacturers like to shirk this resource-intensive work. Instead, datagrams are typically sent with the "don't fragment" bit in the header switched on, which forbids other routers to break them up further. If such a datagram arrives at a point where it is too big for the next hop, the router in question uses ICMP to send a "destination unreachable; fragmentation needed but forbidden; MTU would be *n*" message. In this case the sending node can try again using smaller fragments. This method is called "path MTU discovery".

The whole thing can still go gloriously wrong, namely if an overzealous firewall along the way blocks ICMP traffic. In this case the error messages concerning the required MTU never reach the sender of the datagrams, who consequently hasn't the faintest idea of what is going on. In practice this leads to web pages not being displayed correctly, and/or connections that simply "hang". The problem arises most conspicuously where "Deutsche Telekom"-style ADSL is in use, since that uses a protocol called "PPP over Ethernet" (PPPoE), which subtracts 8 bytes from the usual 1500-byte Ethernet MTU for management purposes. The problems normally disappear if you set the MTU for the interface in question to 1492 manually. The remote node then adheres to that value.

On Debian GNU/Linux (and Ubuntu) you can set the MTU for a statically configured interface by adding a `mtu` clause to the interface definition in `/etc/network/interfaces`:

```
iface eth0 inet static
    ◁◁◁◁◁
    mtu 1492
    ◁◁◁◁◁
```

This value should then become effective the next time the interface is started.

If your interface is configured via DHCP and the DHCP server sends the wrong MTU (which might happen), then you can remove the `interface-mtu` clause from the `request` entry in the `/etc/dhcp/dhclient.conf` file. This will make Linux default to the standard value of 1500 during the next DHCP negotiation. You can specify a different value explicitly using

```
iface eth0 inet dhcp
    ◁◁◁◁◁
    post-up /sbin/ifconfig eth0 mtu 1492
    ◁◁◁◁◁
```

The alternative command

```
iface eth0 inet dhcp
    ◁◁◁◁◁
    post-up /sbin/ip link set dev eth0 mtu 1492
    ◁◁◁◁◁
```

also works.

On the SUSE distributions you can set the MTU in the `ifcfg-` file corresponding to the interface in question (there is an `MTU=` line). Alternatively you can use the "`/etc/sysconfig` editor" offered by YaST, under "Hardware/Network". You then need to restart the network interface manually (using `ifdown`/`ifup`) or reboot the computer.

Like SUSE, the Red Hat distributions allow an MTU setting in the `ifcfg-` file of the interface in question. Here, too, you need to restart the interface to make the new setting effective.

If you're using IPv6: `tracepath6` is to `tracepath` what `traceroute6` is to `traceroute`.

24.5 Checking Services With `netstat` And `nmap`

If you would like to run a service but client hosts cannot connect to it, being rejected with error messages like

```
Unable to connect to remote host: Connection refused
```

you should ensure that the service actually "listens" for connections as it should. You can do this, for example, with the `netstat` program:

```
$ netstat -tul
Active Internet connections (only servers)
Proto Recv-Q Send-Q Local Address       Foreign Address  State
tcp        0      0 red.example.com:www *:*              LISTEN
tcp        0      0 red.example.com:ftp *:*              LISTEN
tcp        0      0 red.example.com:ssh *:*              LISTEN
```

The -l option causes netstat to display "listening" programs only. With the -t and -u options you can confine netstat's output to TCP-based and UDP-based services, respectively.

In the output, the columns have the following meanings:

Proto The protocol (tcp, udp, raw, …) used by the socket.

Recv-Q The number of bytes of data that have been received but not been picked up by the application program.

Send-Q The number of bytes sent out that have not yet been acknowledged by the remote host.

Local Address Local address and port number of the socket. An asterisk ("*") in this place for "listening" sockets means they are listening on all available addresses, e. g., on 127.0.0.1 *and* the IP address of the Ethernet card.

Foreign Address The address and port number of the socket on the remote host.

State The state of the socket. raw sockets do not have states and udp sockets usually not either. States defined for tcp sockets include the following:

ESTABLISHED A connection is established.

SYN_SENT The socket tries to establish a connection and has sent the first packet of the three-way handshake, but not yet received a reply.

SYN_RECV The socket (a "listening" one) has received and acknowledged a connection request.

FIN_WAIT1 The socket is closed, the connection is in the process of being torn down.

FIN_WAIT2 The connection is torn down and the socket waits for confirmation from the remote host.

TIME_WAIT After the connection has been torn down, the socket waits to process packets that may still remain in the network.

CLOSE The socket is not being used.

CLOSE_WAIT The remote host has closed the connection and waits for the local host to close it too.

LISTEN The socket "listens" for incoming connections. Such sockets are only displayed if you have specified the -l or -a options.

Without -t or -u, netstat, in addition to its TCP and UDP listings, outputs information about active Unix domain sockets. These are largely uninteresting.

If you leave off the -l option, you get a list of active network connections instead (those where your computer operates as a server as well as those where it acts as the client).

If your service does not show up in the output of "netstat -tul", this indicates that the program in question isn't running. If the service does occur in the list, one possibility is that clients are rejected by a firewall configuration before they even reach it. On the other hand, it is possible that the port in question is blocked by another program which for some reason does not work correctly. In this case you can use "netstat -tulp" to display the process ID and name of the the program serving the port. This takes root privileges, however.

netstat assumes that you have at least shell access, if not root privileges, on the computer where you want to execute the program. But what about checking "from outside" which ports are available on a host? There are solutions for this, too. The nmap program is a **port scanner** which checks for open, filtered, and unused TCP and UDP ports on a computer over the network. Of course the "computer" can just as well be a firewall infrastructure, thus nmap can help you uncover gaps in your security strategy.

port scanner


nmap is not automatically part of a Linux installation. You will probably have to install it manually.


The scanning of computers that are not part of your immediate jurisdiction can be a crime! (In some places—like Germany—, even *owning* "hacker" tools like nmap can get you in trouble if you are unlucky and/or make some bad moves.) Therefore do restrict yourself to computers where it is abundantly clear that you are allowed to use nmap. For additional security, get your client or sufficiently exalted boss to sign off on it in writing.

In the simplest case you give nmap the name or IP address of the computer to be examined (be prepared for a certain delay):

```
# nmap blue.example.com

Starting Nmap 4.68 ( http://nmap.org ) at 2009-02-04 00:09 CET
Interesting ports on blue.example.com (172.16.79.2):
Not shown: 1710 closed ports
PORT     STATE SERVICE
22/tcp   open  ssh
25/tcp   open  smtp
53/tcp   open  domain
80/tcp   open  http
443/tcp  open  https
MAC Address: 00:50:56:FE:05:04 (VMWare)

Nmap done: 1 IP address (1 host up) scanned in 9.751 seconds
```

nmap considers ports "open" if a service can be reached. Ports for which the target host returns an error message are marked "closed", while ports where there is no reaction at all (e. g., because the inquiry packets are simply thrown away by the target host or a firewall, and not even an error message is sent in reply) are designated "filtered".


If you do not specify otherwise, nmap analyses the target host's TCP ports using a "SYN scan". For each of the ports under consideration, the program sends a TCP segment with the SYN flag set (as if it wanted to start a new connection). If the target host answers with a TCP segment that has the SYN and ACK flags set, nmap assumes that the port is in use. However, it takes no further action (in particular, it does not acknowledge the segment), so the "half-open" connection is thrown out by the target host after the statutory timeouts have occurred. If instead the target host answers with a segment with the RST flag set, the port is "closed". If after several tries there is no answer or only ICMP unreachability messages, the port is set to "filtered".—SYN scans require root privileges.


Other techniques that nmap offers include the "TCP connect scan" (which does not require special privileges but is clumsy and easily recognised by the target host), the "UDP scan" and several other variants of TCP-based scans, e. g., to discover firewall rulesets. Consult the documentation in nmap(1).


nmap can not only identify the active ports on a host, but can in many cases even tell you which software is used to serve the ports. For this, you need to specify the -A option and be *very* patient indeed. For this, nmap relies on a database of "signatures" of diverse programs that comes with the software.


The features of nmap surpass by far what we can present in this training manual. Read the documentation (in nmap(1)) and at all times be aware on the legal restriction mentioned earlier.

24.6 Testing DNS With `host` And `dig`

If connections to hosts addressed by name take ages to set up or fail to be established after some delay, while trying to make the same connection based on the IP address is as quick as usual, the DNS may be to blame. Conversely, your computer may take a long time to connect because the remote host tries to find a name for *your* IP address and runs into some problem or other there. To test DNS, you can, for instance, use the `host` and `dig` programs.


"And what about `nslookup`?" we hear you say. Sorry, but `nslookup` has been deprecated for a while and is only still supported for compassionate reasons.

`host` is a very simple program, which in the most straightforward case accepts a DNS name and outputs the IP address(es) that derive from it:

```
$ host www.linupfront.de
www.linupfront.de is an alias for s0a.linupfront.de.
s0a.linupfront.de has address 31.24.175.68
```

And it also works the other way round:

```
$ host 193.99.144.85
85.144.99.193.in-addr.arpa domain name pointer www.heise.de
```

(Don't ask.)

You can compare the output of several DNS servers by specifying the IP address (or the name, but the IP address is safer) as part of your query:

```
$ host www.linupfront.de 127.0.0.1
Using domain server:
Name: 127.0.0.1
Address: 127.0.0.1#53
Aliases:

www.linupfront.de is an alias for s0a.linupfront.de.
s0a.linupfront.de has address 31.24.175.68
```

In this way you can check whether a DNS server gives the correct answers.


You can request particular types of DNS record by using the `-t` option, as in

```
$ host -t mx linupfront.de                                    MX record desired
linupfront.de mail is handled by 10 s0a.linupfront.de
```


With `-l` you can obtain a list of the most important names in a domain—at least if you're allowed. Together with the `-a` option, this gives you a list of *all* names.

The `dig` program does essentially what `host` does, but allows for more detailed analysis. It provides more extensive output than `host`:

```
$ dig www.linupfront.de

; <<>> DiG 9.9.5-10-Debian <<>> www.linupfront.de
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 1443
;; flags: qr rd ra; QUERY: 1, ANSWER: 2, AUTHORITY: 0, ADDITIONAL: 0
```

```
;; QUESTION SECTION:
;www.linupfront.de.             IN      A

;; ANSWER SECTION:
www.linupfront.de.      3600    IN      CNAME   s0a.linupfront.de.
s0a.linupfront.de.      3600    IN      A       31.24.175.68

;; Query time: 51 msec
;; SERVER: 127.0.0.1#53(127.0.0.1)
;; WHEN: Wed Jul 22 18:00:34 CEST 2015
;; MSG SIZE  rcvd: 69
```

To resolve IP addresses into names, you must specify the `-x` option:

```
$ dig -x 31.24.175.68

; <<>> DiG 9.9.5-10-Debian <<>> -x 31.24.175.68
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 63823
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 0, ADDITIONAL: 0

;; QUESTION SECTION:
;68.175.24.31.in-addr.arpa.     IN      PTR

;; ANSWER SECTION:
68.175.24.31.in-addr.arpa. 86400 IN     PTR     s0a.linupfront.de.

;; Query time: 50 msec
;; SERVER: 127.0.0.1#53(127.0.0.1)
;; WHEN: Wed Jul 22 18:01:31 CEST 2015
;; MSG SIZE  rcvd: 74
```

To query a specific DNS server, give its address after a `@`:

```
$ dig www.linupfront.de @192.168.20.254
```

You can specify a DNS record type after the name you're looking for:

```
$ dig linupfront.de mx

; <<>> DiG 9.9.5-10-Debian <<>> linupfront.de mx
;; global options: +cmd
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 15641
;; flags: qr rd ra; QUERY: 1, ANSWER: 1, AUTHORITY: 0, ADDITIONAL: 0

;; QUESTION SECTION:
;linupfront.de.                 IN      MX

;; ANSWER SECTION:
linupfront.de.          3600    IN      MX     10 s0a.linupfront.de.

;; Query time: 49 msec
;; SERVER: 127.0.0.1#53(127.0.0.1)
;; WHEN: Wed Jul 22 17:59:36 CEST 2015
;; MSG SIZE  rcvd: 51
```

In principle, you can also use the `getent` command to test name resolution: `getent`

```
$ getent hosts www.linupfront.de
31.24.175.68    s0a.linupfront.de www.linupfront.de
```

The difference between `host` and `dig` on the one side and `getent` on the other side is that the former two query the DNS directly. The latter command, however, queries the C library. This means on the one hand that the lookup order given in `/etc/nsswitch.conf` is obeyed. On the other hand you will receive the answer in the form that you would otherwise encounter in `/etc/hosts`.

In `/etc/nsswitch.conf` there is usually a line like

```
hosts: files dns
```

This means that `/etc/hosts` will be looked at first, then DNS. The advantage is that you get to see exactly what application programs using the C library get to see. For example, for some reason there might be a definition in `/etc/hosts` for some name, which then has precedence over the DNS (because the DNS will no longer be consulted after a match in `/etc/hosts`).

From other `getent` applications, you may be used to something like

```
$ getent passwd
```

giving you a list of all users known to the system, in `/etc/passwd` format, even if the users aren't all listed in the local password file. This may work for users but doesn't have to (if you are working in a large enterprise, your user database administrators may have prevented this). For DNS, a command like

```
$ getent hosts
```

will *definitely* not lead to all names in the worldwide DNS being listed. (Which is probably for the best, all things considered.)

DNS is a very intricate topic with ample room for mistakes. However, the detailed diagnosis of DNS problems requires considerable knowledge. DNS is treated in detail in the Linup Front training manual, *The Domain Name System*.

24.7 Other Useful Tools For Diagnosis

24.7.1 `telnet` and `netcat`

The `telnet` command is used to log on to a remote host using the TELNET protocol or—more generally—to contact an arbitrary TCP port. TELNET should no longer be used for remote access, as no strong authentication is used and data is transmitted in the clear (without encryption). The Secure Shell (`ssh`, Chapter 25) is a reasonable alternative.

The `telnet` client program, however, is very suitable to test many other services. With "`telnet` ⟨*address*⟩ ⟨*service*⟩`''`, a connection to any port can be established ("⟨*service*⟩" is either a port number or a service name from "`/etc/services`"). Therefore "`telnet 192.168.0.100 80`" opens a connection to a web server. In this case it would even be possible to request resources from the server using suitable HTTP commands. Here's a different example:

```
$ telnet 192.168.0.1 22
Trying 192.168.0.1...
Connected to 192.168.0.1.
Escape character is '^]'.
SSH-2.0-OpenSSH_6.7p1 Debian-6
```

In this case, `telnet` connects to the SSH port on a remote host, the remote `sshd` answers with its protocol and program version.

The "escape character" lets you take a "time-out" from the TCP connection in order to enter `telnet` commands. The most interesting commands are probably `close` (terminates the connection), `status` (displays the connection status), and `!` (can be used to execute commands on the local computer while the connection is ongoing):

```
$ telnet 192.168.0.1 22
Trying 192.168.0.1...
Connected to 192.168.0.1.
Escape character is '^]'.
SSH-2.0-OpenSSH_6.7p1 Debian-6
Ctrl+Esc
telnet> status
Connected to 192.168.0.1.
Operating in obsolete linemode
Local character echo
Escape character is '^]'.
_
```

The "`!`" command may be deactivated in your copy of `telnet`. In that case you can still suspend the `telnet` program to the background using the `z` command (think "shell job control"), and reactivate it again later with the shell's `fg` command.

An alternative to the TELNET client, `telnet`, is the `netcat` program. In the simplest case, `netcat` behaves like `telnet` (even though it is much less chatty):

```
$ netcat 192.168.0.1 22
SSH-2.0-OpenSSH_6.7p1 Debian-6
```

The command is frequently called `nc` instead of (or in addition to) `netcat`. The rest stays the same, though.

There are two popular versions of `netcat` in circulation, a "traditional" version (by somebody called "Hobbit") and one from the OpenBSD system. The latter has many more features (such as support for IPv6 or Unix domain sockets). For the rest of this section we are assuming the OpenBSD `netcat`.

On Debian GNU/Linux, the default `netcat` is the traditional version (from the `netcat-traditional` package). If you want to use the souped-up version, you need to install the `netcat-openbsd` package. The OpenBSD `netcat` installs itself under the `nc` name *only*; the traditional version remains accessible as `netcat` unless you deinstall that package.

In addition to the client side of a TCP connection, `netcat` also implements the server side if desired (it doesn't do anything particularly useful by itself, though). For example, you can make it listen to a connection on port 4711 using the

```
$ nc -l 4711
```

command. You can then, in a different window, use

```
$ nc localhost 4711
```

to connect to your "server". Whatever you type on the client side appears on the server and vice-versa. The poor person's file transfer works as follows: On the target host, type

poor person's file transfer

```
$ nc -l 4711 >myfile
```

and on the source host, type

```
$ nc red.example.com 4711 <myfile
```

24.7.2 tcpdump

The tcpdump program is a network sniffer which analyses the packets moving through a network interface. The network adapter is switched to "promiscuous mode", where it reads and reports all packets (and not, as usual, only those addressed to the local interface). Therefore the command can only be used by the root user.

network sniffer

Here is a brief example of its use:

```
# tcpdump -ni eth0
tcpdump: listening on eth0
14:26:37.292993 arp who-has 192.168.0.100 tell 192.168.0.1
14:26:37.293281 arp reply 192.168.0.100 is-at 00:A0:24:56:E3:75
14:26:37.293311 192.168.0.1.35993 > 192.168.0.100.21: S 140265170:
140265170(0) ...
14:26:37.293617 192.168.0.100.21 > 192.168.0.1.35993: S 135130228:
135130228(0) ack 140265171 ...
14:26:37.293722 192.168.0.1.35993 > 192.168.0.100.21: . ack 1 ...
                                                    Program interrupted
5 packets received by filter
0 packets dropped by kernel
```

This example shows how a connection to an FTP server is assembled. The "-ni eth0" parameters switch off DNS and port name resolution and involve the eth0 interface only. For each packet, the program displays the exact time, source and destination hosts, any flags in the TCP header (S: SYN bit), the sequence number of the data, a possibly-set ACK bit, the expected sequence number of the next segment, and so on.

The first packet shown here does not contain a destination address, it is an ARP query: The computer with the 192.168.0.100 address is asked for its MAC address—which it presents in the second packet. The next few packets show a typical three-way handshake.

24.7.3 wireshark

wireshark is a network sniffer like tcpdump. However, wireshark comes with a much more impressive feature set. It is a GUI program which allows for detailed analysis of all network packets. Its output consists of three window panes: The topmost displays incoming packets, the bottommost decodes the data in hexadecimal notation, and the center pane allows the convenient and detailed dissection of header information (and payload data).

Like nmap, wireshark is not a standard Unix tool and usually needs to be installed specifically. Both tcpdump and wireshark must be used with care, since it is easy to break existing law even within a LAN. After all, there might be data displayed which are nobody's business.

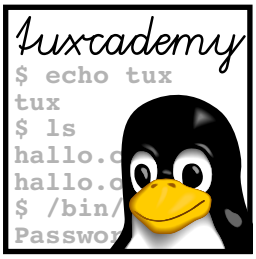
Until some years ago, the wireshark program was called ethereal and may conceivably be found under this name on older machines.

Commands in this Chapter

getent	Gets entries from administrative databases	getent(1)	382
host	Searches for information in the DNS	host(1)	381
nmap	Network port scanner, analyses open ports on hosts	nmap(1)	379
ping	Checks basic network connectivity using ICMP	ping(8)	372
ping6	Checks basic network connectivity (for IPv6)	ping(8)	373
tcpdump	Network sniffer, reads and analyzes network traffic	tcpdump(1)	385
telnet	Opens connections to arbitrary TCP services, in particular TELNET (remote access)	telnet(1)	383
tracepath	Traces path to a network host, including path MTU discovery	tracepath(8)	377
tracepath6	Equivalent to tracepath, but for IPv6	tracepath(8)	378
traceroute	Analyses TCP/IP routing to a different host	traceroute(8)	375

Summary

- Programs like netstat, telnet, nmap, tcpdump or wireshark provide powerful tools to diagnose problems with network services.



25

The Secure Shell

Contents

Goals

- Knowing how to use and configure the Secure Shell (SSH)

Prerequisites

- Knowledge about Linux system administration
- Knowledge about TCP/IP fundamentals (Chapter 22)
- Knowledge about Linux network configuration (Chapter 23)
- A basic awareness of cryptography is helpful

25.1 Introduction

SSH ("Secure Shell") is a TCP/IP-based networking protocol. It provides data transmission in a public network using strong authentication and encryption. Its applications include interactive sessions, file transfer, and the secure forwarding of other protocols ("tunneling").

Encryption is important to keep unauthorised people listening to the network traffic from being able to read the content being transferred. Authentication ensures one the one hand that you as the user are talking to the correct server, and on the other hand that the server lets you access the correct user account.

OpenSSH

OpenSSH, which comes with most Linux distributions, is a freely available implementation of this protocol. This implementation contains some SSH clients as well as an SSH server (`sshd`).

attacks

Used properly, SSH can prevent the following attacks:

- "DNS spoofing", i. e., forged or adulterated DNS entries.
- "IP spoofing", where an attacker sends datagrams from one host which pretend that they come from another (trusted) host.
- IP source routing, where a host can pretend that datagrams come from another (trusted) host.
- Sniffing of passwords and content transmitted in the clear on hosts along the transmission path.
- Manipulation of transmitted data by hosts along the transmission path.
- Attacks on the X11 server by means of sniffed authentication data and spoofed connections to the X11 server.

Use

SSH offers a complete replacement for the insecure TELNET, RLOGIN and RSH protocols. In addition, it enables users to copy files from or to remote hosts and is thus a secure replacement for RCP and many applications of FTP.

protocol versions

There are two versions of the SSH protocol, 1 and 2. Most servers can accept connections using both versions. Still, please do avoid version 1, which exhibits various security vulnerabilities.

25.2 Logging Into Remote Hosts Using `ssh`

To log into a remote host using SSH, you need to invoke the `ssh` command, for example like

```
$ ssh blue.example.com
hugo@blue.example.com's password: geHe1m
Last login: Mon Feb  2 10:05:25 2009 from 192.168.33.1
Debian GNU/Linux (etch/i686) blue.example.com
hugo@blue:~$ _
```

`ssh` assumes that your user name on the remote host is the same as the local one. If this isn't the case, you can set your remote user name like

```
$ ssh hschulz@blue.example.com
```

Under the hood, approximately the following steps take place to establish the connection:

- Client and server send each other information about their host keys, supported cryptographic schemes, and so on. The client checks whether the server's public key is the same as it used to (see below for more information) and negotiates a shared secret with the server, which then serves as the (symmetric) key to encrypt the connection. At the same time the client checks the server's authenticity and breaks the connection if there is any doubt. The (gory) details are in [RFC4253].
- The server checks the client's authenticity using one of several different methods (in this case it asks for a password). The password is already sent over the encrypted connection and, unlike other protocols like FTP or TELNET, cannot be "sniffed" by people who listen in.

The first step is quite important. The following example shows what happens if you contact the remote host for the first time:

```
$ ssh blue.example.com
The authenticity of host 'blue.example.com (192.168.33.2)' can't be▷
 ◁ established.
RSA key fingerprint is 81:24:bf:3b:29:b8:f9:f3:46:57:18:1b:e8:40:5a▷
 ◁ :09.
Are you sure you want to continue connecting (yes/no)? _
```

The host `blue.example.com` is still unknown here, and `ssh` asks you to verify its host key. *This is to be taken seriously.* If you skip this verification step, you lose the guarantee that nobody is listening in to your connection.

The danger is here that somebody will intercept your connection request and pretend that they are `blue.example.com`. Behind the scenes they can establish their own connection to `blue.example.com` and pass everything along that you (naively) send to them, and conversely forward `blue`'s answers back to you. You don't see the difference, but the attacker can read everything that you transmit. This is called a "man-in-the-middle attack".

To check, you need to contact the remote system's administrator (e. g., by telephone) and ask them to read their public host key's "fingerprint". This can be displayed using "`ssh-keygen -l`" and must be identical to the "`RSA key fingerprint`" from the SSH login dialogue.

The SSH key pairs of a host can be found in the `ssh_host_`*x*`_key` and `ssh_host_`*x*`_key.pub` files within the `/etc/ssh` directory. *x* stands for a specific cryptographic method which clients can use to check the server's authenticity.

SSH key pairs

Possible values for *x* include (July 2015):

`rsa` The RSA algorithm. This is secure (according to the current state of the art), as long as you use keys that are longer than 1024 bits. (2048 bits sound good. Use 4096 bits if you're Edward Snowden or are otherwise assuming that organisations like the NSA have it in for you specifically—and not only accidentally at random.)

`dsa` The DSA algorithm. This only allows 1024-bit keys and should be avoided today, also because it is susceptible to weaknesses in random number generation.

`ecdsa` The DSA algorithm based on elliptic curves. This lets you pick between 256, 384, and 521 bits[1]. (Elliptic curves do not need as many bits, so the lower numbers are unproblematic.)

[1] Yes, indeed 521, this is not a typo for 512. ($2^{521} - 1$ is a Mersenne prime number, and that makes the implementation faster. 521 bits are pretty much overkill, though.

ed25519 A fast and (according to current knowledge) very secure method invented by Daniel J. Bernstein. Within the Secure Shell context this is still fairly new.

You probably won't go wrong with 2048-bit RSA, at least for the next few years. If you're sure that your clients and servers support Ed25519, then that is a suitable alternative.

A "key pair", just so we mention this, is a set of two matching keys (!), one private and one public. The public key may be told to everyone as long as the private key stays confidential. Whatever is encrypted using the public key can *only* be decrypted using the private key from the same pair, and vice versa.

If the remote host's public key is authentic, then reply to the question with "`yes`". `ssh` then stores the public key in the `~/.ssh/known_hosts` file to use as a base for comparison during future connection requests.

Should you ever see a message like

```
$ ssh blue.example.com
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@    WARNING: REMOTE HOST IDENTIFICATION HAS CHANGED!     @
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
IT IS POSSIBLE THAT SOMEONE IS DOING SOMETHING NASTY!
Someone could be eavesdropping on you right now (man-in-the-middle▷
 ◁ attack)!
It is also possible that the RSA host key has just been changed.
The fingerprint for the RSA key sent by the remote host is
38:fa:2e:d3:c7:c1:0f:26:2e:59:e8:16:a4:0a:0b:94.
Please contact your system administrator.
Add correct host key in /home/hugo/.ssh/known_hosts to get rid of▷
 ◁ this message.
Offending key in /home/hugo/.ssh/known_hosts:4
RSA host key for blue.example.com has changed and you have requested▷
 ◁ strict checking.
Host key verification failed.
```

when trying to establish an `ssh` connection, you may be about to become the victim of a man-in-the-middle attack—the public key that the server presents does not equal the one stored for the server in the `known_hosts` file. You should contact the remote host's administrator to find out what is going on—perhaps the host key needed to be changed for other reasons.

You can change this behaviour by changing the appropriate setting in the `~/.ssh/config` file:

`StrictHostKeyChecking ask`	*default setting*
`StrictHostKeyChecking no`	*always accept everything*
`StrictHostKeyChecking yes`	*never accept anything new*

When "`StrictHostKeyChecking yes`" is set, you can only establish connections to hosts that are already in your `known_hosts` file. All others will be refused.

After having established a connection using `ssh`, you can use the remote host as if you sat in front of it. You can close the connection using `exit` or Ctrl+d.

Unless you specify otherwise, during interactive `ssh` sessions the tilde ("~") will be considered a special "escape character" if it occurs immediately after a newline character. This lets you control `ssh` during an ongoing session. In particular, the "~." sequence will close the connection, which may come in useful if a program has become stuck at the "other end". You can do other interesting things—look at the "ESCAPE CHARACTERS" section of `ssh`(1).

Incidentally, ssh does not restrict you to interactive sessions, but lets you execute single commands on the remote host:

```
$ ssh blue.example.com hostname
hugo@blue.example.com's password: geHe1m
blue.example.com
$ _
```

Of course you need to take into account that the shell on *your* computer will try to process the command line in order to replace shell wildcard patterns etc. before it is transmitted to the remote host. Use backslashes or quotes if you are in doubt.

Exercises

25.1 [!1] Use the ssh command to log in to another host (if necessary, your instructor will tell you which one). What happens? Log out and log in again to the same host. What is different?

25.2 [2] Remove the remote host's entry created during Exercise 25.1 from the ~/.ssh/known_hosts file and set the StrictHostKeyChecking parameter in the ~/.ssh/ssh_config file to yes. Try logging in to the remote host again. What happens? What happens if the option StrictHostKeyChecking is set to no?

25.3 [2] Must the ~/.ssh/known_hosts file be readable for the user only and if so, why? (If not, why not?)

25.4 [!2] Execute the hostname and date commands on the remote host, using a single invocation of the ssh command.

25.3 Other Useful Applications: scp and sftp

Using scp you can copy files between two hosts via an SSH connection:

```
$ scp blue.example.com:hello.c .
hugo@blue.example.com's password: geHe1m
hello.c   100% |**********************| 33 KB   00:01
```

The syntax is based on the cp command: Just like with cp, you can specify two file names (source and destination) or a list of file names and a destination directory. With the -r option, scp copies directory contents recursively.

You may even copy files between two different remote hosts:

```
$ scp hugo@blue.example.com:hello.c \
>    hschulz@pink.example.com:hello-new.c
```

The sftp command is inspired loosely by common FTP clients, but needs an SSH connection. It has nothing whatsoever to do with FTP otherwise—in particular, you cannot use it to communicate with an FTP server.

After having established a connection using a command like

```
$ sftp hugo@blue.example.com
```

you can use commands such as get, put, or mget to transfer files between your local host and the remote host, inspect the contents of a directory on the remote host using ls, and change into different directories there by means of cd. At the beginning of a session you will be placed in your home directory on the remote computer.

25.4 Public-Key Client Authentication

Normally the SSH server will authenticate you as a user by means of a pasword that is assigned to your account on the server (usually in `/etc/passwd` or `/etc/shadow`). Since the password is queried only after the encrypted connection has already been established, this is in principle safe from unwanted listeners. However, you may be bothered by the fact that your password itself is stored on the server—even though it is encrypted, the password file could fall in the hands of crackers who then apply "John the Ripper" to it. It would be better if nothing secret about you would be stored on the remote host at all.

You can achieve this by using public-key client authentication instead of the simple password-based client authentication. In a nutshell, you create a key pair consisting of a public and a private key and deposit the public key on the SSH server. The public key does not need to be specially protected (it is a *public* key, after all); you will need to sit on the private key, but it will never leave your own computer (which you never let out of your sight, don't you?).


You can also put your private key on an USB stick if you think that will be more secure.

The server can authenticate you as the rightful owner of the private key matching the deposited public key by generating a random number, encrypting it using the public key, and sending it to you. You decrypt (or rather, your `ssh` decrypts) the encrypted random number using the private key. The result is returned to the server, which compares it to its original random number, and if the two match it believes you that you are yourself.


Of course all of this takes place across the encrypted connection and is therefore secure from unwanted listeners and scumbags that want to mess with your data.

To use public-key client authentication, you first need to generate a key pair. This is done using the `ssh-keygen` command:

```
$ ssh-keygen -t rsa -b 2048                                    or ed25519
Generating public/private rsa key pair.
Enter file in which to save the key (/home/hugo/.ssh/id_rsa): ↩
Created directory '/home/hugo/.ssh'.
Enter passphrase (empty for no passphrase): secret
Enter same passphrase again: secret
Your identification has been saved in /home/hugo/.ssh/id_rsa.
Your public key has been saved in /home/hugo/.ssh/id_rsa.pub.
The key fingerprint is:
39:ab:15:f4:2f:c4:e6:21:26:c4:43:d7:27:22:a6:c4 hugo@blue
The key's randomart image is:
+---[RSA 2048]----+
|   .  . ..       |
|    Eoo.. o .    |
|   . o+... o     |
|    .. o +       |
|      . S *      |
|       o 0 o     |
|        o o .    |
|       o   .     |
|      .          |
+-----------------+
```

The command first asks where you would like the key pair to be stored. The default is reasonable and you should simply confirm it.

Next, `ssh-keygen` asks for a "passphrase". This is used to encrypt the private key in order to prevent somebody who happens to find your private key from impersonating you to the SSH server.


You can (and should) really use a longer sentence here. A shorter password from a variegated mixture of letters, digits, and special caharacter is probably O. K., too. The usual rules for that kind of secret apply.

You must use keys without a passphrase for non-interactive SSH connections, e. g., for shell scripts and `cron` jobs. In this case you just press ↩ when you are asked for the passphrase.


It is possible to connect a public key on the server with a particular command. Client connections using this public key will then not launch a shell session; instead, the command in question will be started directly. This can significantly mitigate the security risk connected with unencrypted private keys for the use of scripts.

The result of `ssh-keygen` are the two files `id_rsa` and `id_rsa.pub` in the `~/.ssh` directory. The former contains the private and the latter the public key.


If you have specified "`-t ed25519`" during the key generation, the files are, of course, called `id_ed25519` and `id_ed25519.pub`.


The `ssh-keygen` command also shows you the fingerprint of the public key and a "randomart image". The latter is a graphical representation of the public key, a kind of graphical fingerprint. Theoretically this should enable you to tell at a glance whether a public key has changed or not. The idea is, with all due respect, debatable.


Of course nobody prevents you from invoking `ssh-keygen` multiple times in order to generate several key pairs with different encryption methods. (Or several key pairs with the same encryption method for use with different servers. You will naturally need to ensure that these use different file names.)

The next step is to deposit the public key, i. e., the content of the `id_rsa.pub` file, in the `~/.ssh/authorized_keys` file in your user account on the remote host. This is most easily done using the `ssh-copy-id` command:

```
$ ssh-copy-id hugo@blue.example.com
hugo@blue.example.com's password: geHe1m                    Ein letztes Mal
Now try logging into the machine, with "ssh 'hugo@blue.example.com'",▷
 ◁ and check in:

  .ssh/authorized_keys

to make sure we haven't added extra keys that you weren't expecting.

$ _
```


Of course you could just as well do that "the hard way" using `scp` and/or `ssh`. Just make sure not to overwrite any keys that may already exist in `~/.ssh/authorized_keys` and that you would want to hang on to.


If you set the `PasswordAuthentication` entry in the `/etc/ssh/sshd_config` file on the server to `no` and `PubkeyAuthentication` to `yes`, then users can *only* authenticate via the public key method. This is basically a good idea since crackers enjoy running automatic programs that try obvious passwords on SSH servers.

Public-key authentication, if you are using a passphrase, is not more convenient than password authentication, but considerably more secure. If you want to log in to the same host as the same user several times in a row, constantly re-entering the passphrase can be a nuisance, though. The `ssh-agent` was developed to help with this.

ssh-agent

The `ssh-agent` program remembers the passphrase and passes it to SSH client programs as needed. The program is started using, e. g., "`ssh-agent bash`". This opens a new `bash`, in which you must add the passphrase using `ssh-add`:

ssh-add

```
$ ssh-add
Enter passphrase for /home/test/.ssh/id_rsa: Quoth the raven
Identity added: /home/test/.ssh/id_rsa (/home/test/.ssh/id_rsa)
```

Every instance of `ssh`, `scp`, or `sftp` started from the new shell gets the passphrase from the SSH agent. The agent "forgets" the passphrase once you leave the shell using `exit` or instruct it, using "`ssh-add -D`", to forget all stored identities..

With Debian GNU/Linux, the login shell/GUI may be started with the `ssh-agent` active right away, so you can `ssh-add` your passphrase at the very beginning of your session.

To be fair, we ought to mention that `ssh-agent` increases convenience to the detriment of security. If you leave your computer unattended (or if you lose your "suspended" laptop), an unauthorised person might be able to use the SSH programs without being asked for a passphrase. The same applies to programs that somehow get access to your session, such as viruses, worms and other vermin …

Exercises

25.5 [!2] Using `ssh-keygen`, create an RSA key pair for SSH version 2. (Remember, at least 2048 bits!) Install the public key on the remote host and check that you are no longer asked for the remote password upon login. What do you need to enter instead?

25.6 [!1] Determine your public key's "fingerprint".

25.7 [2] Under what circumstances might you want to refrain from using a passphrase for your private key?

25.5 Port Forwarding Using SSH

25.5.1 X11 Forwarding

executing GUI programs

Using X11 forwarding, you can execute graphical programs on a remote host, where graphics output and keyboard/mouse input take place on your local computer. You merely need to use `ssh` to log in to the remote host, giving the `-X` (uppercase X!) option. On the server side, X11 forwarding (parameter `X11Forwarding` in `/etc/ssh/sshd_config`) must be enabled.

After logging in using "`ssh -X` [⟨*user name*⟩`@`]⟨*host*⟩" you may execute arbitrary X clients whose input and output are directed to the local X server. This is due to several factors:

- When logging in using `-X`, the `DISPLAY` variable is set up to point to a "proxy" X server provided by `sshd`. This directs X clients started on the remote host to this server.
- Everything a remote X client sends to the proxy X server is sent to the (real) X server on the SSH client.

- All the X11 traffic is encrypted so eavesdroppers cannot listen in (tunneling).


You can also enable X11 forwarding globally in order to avoid having to type the `-X` option. You just need to add "`ForwardX11 yes`" to your `~/.ssh_config` (or `/etc/ssh/ssh_config` for a system-wide default).

X11 forwarding is preferable to the standard X packet redirection (using `DISPLAY`) not only because of its increased security but also because it is much more convenient. You pay for this with some extra effort for encryption, which on modern hardware ought to be barely noticeable.


Even X11 forwarding is not without its security risks. Users who can circumvent file access rights on the remote host (e. g., because they are `root`) may access your local X11 display. For this reason you should probably avoid enabling X11 forwarding globally. The same risk exists, of course, with "conventional" X11 redirection using `DISPLAY`.

25.5.2 Forwarding Arbitrary TCP Ports

SSH can forward and tunnel not only the X protocol, but also nearly every other TCP-based protocol. This can be set up using the `-R` and `-L` options. The following command tunnels connections to the local TCP port 10110 first via an SSH connection to the computer `blue.example.com`. From there it continues (unencrypted) to the TCP port 110 (POP3) on the `mail.example.com` host:

Port forwarding

```
$ ssh -L 10110:mail.example.com:110 hugo@blue.example.com
```

The benefit of this approach is approximately as follows: Imagine your firewall blocks POP3 but passes SSH. By means of the port redirection you can enter the internal network via SSH and then connect from the `blue.example.com` host to the mail server on the internal network. In your mail program you need to specify `localhost` and the local TCP port 10110 as the "POP3 server".


You could theoretically forward the local TCP port 110, but you need to be `root` to do it.


The name of the forwarding destination host (here `mail.example.com`) is resolved from the perspective of the SSH server (here `blue.example.com`). This means that a redirection of the form

```
$ ssh -L 10110:localhost:110 hugo@blue.example.com
```

connects you to port 110 on `blue.example.com` rather than your own computer.


A port forwarding like

```
-L 10110:mail.example.com:10
```

opens port 10110 on *all* IP addresses on your computer. This opens the redirection, in principle, to all other hosts that can reach this port over the network. To prevent this you can use the fact that `ssh` allows you to specify a local address for the redirected port: With

```
-L localhost:10110:mail.example.com:110
```

the redirection only applies to the local interface.

If you invoke ssh as shown, you get an interactive session on top of the port forwarding. If you do not need this—because the forwarding takes place within a cron job—you can specify the -N option, which restricts ssh to do the port forwarding and not establish an interactive session.

Another (possibly better) technique for automatically forwarding services uses a ssh invocation like

```
$ ssh -f -L 10110:mail.example.com:110 blue sleep 10
$ getmail_fetch -p10110 localhost hugomail MaIl123 Maildir/
```

The -f option causes the ssh process to go to the background immediately before the "sleep 10" command is executed. This means that a command that you execute immediately after the ssh command (here getmail_fetch, which retrieves e-mail via POP3) has 10 seconds to establish a connection to the local port 10110. The ssh process exits either after 10 seconds or else when the (last) connection via the local port 10110 is torn down, whichever occurs later.

Port forwarding also works the other way round:

```
$ ssh -R 10631:localhost:631 hugo@blue.example.com
```

opens the TCP port 10631 *on the SSH server*, and connections that programs there make with that port will be redirected across the SSH connection to your local host. Your local host then takes care of redirecting the decrypted data to the destination, here port 631 on your local host itself. (This type of port forwarding is considerably less important than the one using -L.)

The -R port forwarding usually binds the remote port to the localhost interface on the SSH server. In principle you can pick another interface as shown above ("*" implies "all"), but whether that works depends on the configuration of the SSH server.

You can also add port forwarding after the fact. Do this using the "~C" key combination (it must be an uppercase C), which gives you a "command line":

```
◁◁◁◁◁                                   An SSH session is in progress here
remote$ ↩
remote$ ~ C
ssh> -L 10025:localhost:25
Forwarding port.
◁◁◁◁◁                                   SSH session goes on
```

On the "command line" you can add -L and -R options (among other things), as if you had typed them directly on the ssh command line. Using -KR, followed by the port number, you can also cancel an -R port forwarding (unfortunately there is no -KL). With the "~#" command you can check the currently active connections:

```
◁◁◁◁◁
remote$ ~#
The following connections are open:
  #2 client-session (t4 r0 i0/0 o0/0 fd 6/7 cfd -1)
  #3 direct-tcpip: listening port 10025 for localhost port 25, ▷
   ◁ connect from 127.0.0.1 port 57250 ▷
   ◁ (t4 r1 i0/0 o0/0 fd 9/9 cfd -1)
◁◁◁◁◁
```

As you have undoubtedly gleaned from the preceding sections, ssh provides the opportunity for all sorts of shenanigans that would bring tears to the eyes of a corporate IT security officer. Please do consider this chapter a presentation of some of the features of ssh, not a recommendation to actually

use as many of them as possible (at least not without a sound reason). As the operator of an SSH server you should, in particular, study its documentation (such as `sshd_config`(5)) in order to find out how to suppress use of the more dangerous options. Unfortunately there is not enough room in this manual for a complete treatment of the SSH server configuration.

Exercises

25.8 [!1] How can you use `ssh` to conveniently start X11 clients as `root` from an unprivileged user account on the same host?

25.9 [3] Use `ssh` to forward port 4711 (or some other suitable local port) to the `echo` port (port 7) of a remote host. Check using a packet sniffer (`tcpdump` or `wireshark`) that a connection to the local port 4711, e. g. using "`telnet localhost 4711`", actually causes an encrypted data transfer to the remote host and is decrypted only there.

Commands in this Chapter

scp	Secure file copy program based on SSH	`scp`(1)	391
sftp	Secure FTP-like program based on SSH	`sftp`(1)	391
ssh	"'Secure shell"', creates secure interactive sessions on remote hosts	`ssh`(1)	388
ssh-add	Adds private SSH keys to `ssh-agent`	`ssh-add`(1)	394
ssh-agent	Manages private keys and pass phrases for SSH	`ssh-agent`(1)	394
ssh-copy-id	Copies public SSH keys to other hosts	`ssh-copy-id`(1)	393
ssh-keygen	Generates and manages keys for SSH	`ssh-keygen`(1)	392
sshd	Server for the SSH protocol (secure interactive remote access)	`sshd`(8)	388

Summary

- The Secure Shell allows convenient and secure interactive sessions on remote hosts (and thus replaces TELNET, RSH and RLOGIN) as well as the secure transmission of files similar to RCP or FTP.
- OpenSSH is a powerful, freely available Secure Shell implementation.
- The user may choose from password authentication and public key authentication. The latter is more secure but more difficult to set up.
- The Secure Shell can forward X11 graphics display and interaction as well as arbitrary TCP connections across the encrypted channel.

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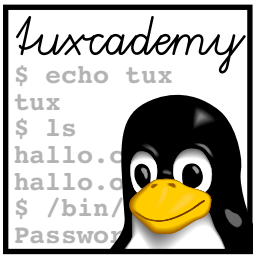


26

Software Package Management Using Debian Tools

Contents

Goals

- Knowing the basics of Debian packaging tools
- Being able to use dpkg for package management
- Being able to use apt-get, apt-cache, and aptitude
- Being aware of the principles of Debian package integrity
- Knowing how to convert RPM packages to Debian packages using alien

Prerequisites

- Knowledge of Linux system administration
- Experience with Debian GNU/Linux or a Debian GNU/Linux derivative is helpful

26.1 Overview

Software packages in Debian GNU/Linux and derived distributions such as Ubuntu, Knoppix, Xandros, or Sidux are maintained using the `dpkg` tools. It serves to install software packages, to manage dependencies, to catalog installed software, to control updates to software packages, and to de-install packages that are no longer required. Program such as `aptitude` serve as front-ends to `dpkg`, allowing the convenient selection of software packages. The `debconf` infrastructure is used to configure packages upon installation.

The Debian and Red Hat package management systems were developed at about the same time and have different strengths and weaknesses. As usual in the free software community, the religious wars around `dpkg` and `rpm` have not led to one of the competitors carrying the day. With the increasing popularity of Debian derivatives—most notably Ubuntu—this remains unlikely for the foreseeable future, too.

The LSB standard for a basic Linux infrastructure that third-party vendors can port their software to does prescribe a restricted version of RPM as its package format. However, this does not imply that a LSB-compliant Linux distribution must be RPM-based from the ground up, but only that it must be able to install software packages from third-party vendors that conform to the LSB flavour of RPM.

For Debian GNU/Linux, this is of course a piece of cake. The reason why Debian GNU/Linux is not officially touted as "LSB-compliant" is because LSB is run by an industry consortium of which Debian, being a non-commercial project, is not a member. The description for the `lsb` package on Debian GNU/Linux states:

> The intent of this package is to provide a best current practice way of installing and running LSB packages on Debian GNU/Linux. Its presence does not imply that Debian fully complies with the Linux Standard Base, and should not be construed as a statement that Debian is LSB-compliant.

While its title talks about "Debian tools", everything in this chapter also applies to Ubuntu, since Ubuntu takes substantial parts of its infrastructure from Debian GNU/Linux. We shall be pointing out significant differences that do exist.

26.2 The Basis: `dpkg`

26.2.1 Debian Packages

packages
package names

Within the Debian infrastructure, the software on the system is divided into packages. Packages have names that indicate the software contained within and their version. The

```
hello_2.8-2_amd64.deb
```

file, for example, contains the `hello` program's 2.8 version; in particular this is the second release of this package within the distribution (for a future 2.9 package the count would start over at 1). Packages like `apt` which have been specifically developed for Debian do not include a "Debian release number". The `amd64` indicates that the package contains architecture-specific parts for Intel and AMD x86 processors (and compatibles) in 64-bit mode—32-bit packages use `i386`, and packages that contain only documentation or architecture-independent scripts use `all` instead.

A Debian package is an archive created using the ar program and generally contains three components: package structure

```
$ ar t hello_2.8-2_amd64.deb
debian-binary
control.tar.gz
data.tar.gz
```

The debian-binary file contains the version number of the package format (currently 2.0). In control.tar.gz there are Debian-specific scripts and control files, and data.tar.gz contains the actual package files. During installation, control.tar.gz is unpacked first, so that a possible preinst script can be executed prior to unpacking the actual package files. After this, data.tar.gz will be unpacked, and the package will be configured if necessary by executing the postinst script from control.tar.gz. installation

Exercises

26.1 [2] Obtain an arbitrary Debian package (such as hello) and take it apart using ar and tar. Can you find the installation scripts? Which information is contained in control.tar.gz, and which is in data.tar.gz?

26.2.2 Package Installation

You can easily install a locally-available Debian package using the

```
# dpkg --install hello_2.8-2_amd64.deb
```

command, where --install can be abbreviated to -i. With --unpack and --configure (-a), the unpacking and configuration steps can also be executed separately.

In real life, the short option names such as -i are convenient. However, if you intend to pass the LPI-101 exam, you should be sure to learn the long option names as well, since these, vexatingly, occur in the exam questions. In the case of -i and --install, it is probably straightforward to come up with the correspondence; with -a and --configure, this is already somewhat less obvious.

Options for dpkg can be given on the command line or else placed in the /etc/dpkg/dpkg.cfg file. In this file, the dashes at the start of the option names must be omitted. dpkg.cfg

If a package is installed using "dpkg --install", even though an earlier version already exists on the system, the older version is deinstalled before configuring the new one. If an error occurs during installation, the old version can be restored in many cases. Upgrade

There are various reasons that might prevent a successful package installation, including: installation problems

- The package requires one or more other packages that either have not yet been installed, or that are not included in the same installation operation. The corresponding check can be disabled using the --force-depends option—but this can severely mess up the system.
- An earlier version of the package is installed and set to hold (e. g., using aptitude). This prevents newer versions of the package from being installed.
- The package tries to unpack a file that already exists on the system and belongs to a different package, unless the current package is explicitly labeled as "replacing" that package, or the --force-overwrite option was specified.

conflicts Some packages conflict with each other (see the possibilities for package dependencies on page 405). For example, only one mail transport program may be installed at one time; if you want to install, e. g., Postfix, Exim (the Debian default MTA) must be removed at the same time. `dpkg` manages this if certain conditions are fulfilled.

Virtual packages Sometimes packages do not depend on a particular other package but on a "virtual" package describing a feature that can, in principle, be provided by any of several other packages, such as `mail-transport-agent`, which is provided by packages like `postfix`, `exim`, or `sendmail`. In this case it is possible to replace, say, Exim by Postfix in spite of dependencies, as a program providing the "virtual" functionality will be available at all times.

Exercises

26.2 [1] Download a Debian package—say, `hello`—from `ftp.debian.org` (or any other Debian mirror) and install it using `dpkg`. (If you use anything else, such as `apt-get`—see next section—, you're cheating!) You can find Debian packages on the server reasonably conveniently given their names, by looking in `pool/main` for a subdirectory corresponding to the first character of the name, and in there looking for a subdirectory whose name is that of the package[1], in our case `pool/main/h/hello`. Exception: Since very many package names start with `lib`, a package like `libfoobar` ends up in `pool/main/libf`.

26.3 [2] Locate the current list of virtual packages in Debian GNU/Linux. Where did you find it? When did the last update take place?

26.2.3 Deleting Packages

A package is removed using the

```
# dpkg --remove hello
```

command ("`dpkg -r`", for short). Its configuration files (all the files listed in the `conffiles` file within `control.tar.gz`), though, are kept around in order to facilitate a subsequent reinstallation of the package. The

```
# dpkg --purge hello
```

(or "`dpkg -P`") command removes the package including its configuration files.

The "configuration files" of a Debian package are all files in the package whose names occur in the `conffiles` file in `control.tar.gz`. (Look at `/var/lib/dpkg/info/`⟨*package name*⟩`.conffiles`.)

Removal problems Package removal does not necessarily work, either. Possible obstacles include:

- The package is required by one or more other packages that are not about to be removed as well.
- The package is marked "essential" (to system functionality). The shell, for example, cannot simply be removed since some important scripts could no longer be executed.

Here, too, the relevant checks can be disabled using suitable `--force-`… options (at your own risk).

Exercises

26.4 [1] Remove the package you installed during Exercise 26.2. Make sure that its configuration files are removed as well.

[1] The source code package, really, which may differ. So don't get too fancy.

26.2.4 Debian Packages and Source Code

When dealing with source code, a basic principle of the Debian project is to distinguish clearly between the original source code and any Debian-specific changes. Accordingly, all changes are placed in a separate archive. In addition to the Debian-specific control files, these include more or less extensive fixes and customisations to the software itself. For each package version, there is also a "source control file" (using the .dsc suffix) containing checksums for the original archive and the changes file, which will be digitally signed by the Debian maintainer in charge of the package:

source control file

```
$ ls hello*
-rw-r--r-- 1 anselm anselm   6540 Jun  7 13:18 hello_2.8-2.debian.tar.gz
-rw-r--r-- 1 anselm anselm   1287 Jun  7 13:18 hello_2.8-2.dsc
-rw-r--r-- 1 anselm anselm 697483 Mai 27 23:47 hello_2.8.orig.tar.gz
```

You can also see that the original source code archive does not change for all of the 2.8 version of the program (it does not contain a Debian release number). Every new version of the Debian package of hello's 2.8 version comes with new .dsc and .debian.tar.gz files. The latter contains all the changes relative to the original archive (rather than the hello_2.8-2 package).

In former times, the Debian project used a less complicated structure where there was one single file (created with diff) containing all Debian-specific changes—in our example, hypothetically hello_2.8-2.diff.gz. This approach is still supported, and you may find this structure with older packages that have not been changed to use the new method instead. The new structure does have the advantage that different changes—like the introduction of the Debian-specific control files and any changes to the actual original code—can be more cleanly separated, which greatly simplifies maintaining the package within the Debian project.

The dpkg-source command is used to reconstruct a package's source code from the original archive and the Debian changes such that you can recompile your own version of the Debian package. To do so, it must be invoked with the name of the source control file as an argument:

dpkg-source

```
$ dpkg-source -x hello_2.8-2.dsc
```

The original archive and the .debian.tar.gz or .diff.gz file must reside in the same directory as the source control file. dpkg-source also places the unpacked source code there.

dpkg-source is also used when generating source archives and Debian change files during Debian package preparation. However, this topic is beyond the scope of the LPIC-1 certification.

Preparing Debian packages

Exercises

26.5 [1] Obtain the source code for the package you installed during Exercise 26.2, and unpack it. Take a look at the debian subdirectory of the resulting directory.

26.2.5 Package Information

You can obtain a list of installed packages using "dpkg --list" (-l, for short):

package list

```
$ dpkg --list
Desired=Unknown/Install/Remove/Purge/Hold
| Status=Not/Installed/Config-files/Unpacked/Failed-config/H
```

```
|/ Err?=(none)/Hold/Reinst-required/X=both-problems (Status,
||/ Name           Version        Description
+++-==============-==============-========================
ii  a2ps           4.13b+cvs.2003 GNU a2ps - 'Anything to Po
ii  aalib1         1.4p5-19       ascii art library
ii  abcm2ps        4.0.7-1        Translates ABC music descr
ii  abcmidi        20030521-1     A converter from ABC to MI
◁◁◁◁◁
```

shell search patterns

(truncated on the right for space reasons) This list can be narrowed down using shell search patterns:

```
$ dpkg -l lib*-tcl
Desired=Unknown/Install/Remove/Purge/Hold
| Status=Not/Installed/Config-files/Unpacked/Failed-config/H
|/ Err?=(none)/Hold/Reinst-required/X=both-problems (Status,
||/ Name           Version        Description
+++-==============-==============-========================
pn  libdb3-tcl     <none>         (no description available)
un  libdb4.0-tcl   <none>         (no description available)
un  libdb4.1-tcl   <none>         (no description available)
un  libmetakit-tcl <none>         (no description available)
ii  libsqlite-tcl  2.8.9-1        SQLite TCL bindings
rc  libsqlite0-tcl 2.6.1-2        SQLite TCL bindings
```

The packages with version "<none>" are part of the distribution but are either not installed on the current system (status un) or have been removed (status pn).

package status

You can find out about an individual package's status with the --status (-s) option:

```
$ dpkg --status hello
Package: hello
Status: install ok installed
Priority: optional
Section: devel
Installed-Size: 553
Maintainer: Santiago Vila <sanvila@debian.org>
Architecture: amd64
Version: 2.8-2
Depends: libc6 (>= 2.4), dpkg (>= 1.15.4) | install-info
Description: The classic greeting, and a good example
 The GNU hello program produces a familiar, friendly greeting. It
  allows non-programmers to use a classic computer science tool which
  would otherwise be unavailable to them.
  .
  Seriously, though: this is an example of how to do a Debian package.
  It is the Debian version of the GNU Project's `hello world' program
  (which is itself an example for the GNU Project).
Homepage: http://www.gnu.org/software/hello/
```

Besides the package name (Package:), its output includes information about the package's status and priority (from required via important, standard and optional down to extra) and its approximate area of interest (Section:). The Maintainer: is the person who is in charge of the package on behalf of the Debian project.

Priorities

Packages of priority required are necessary for proper operation of the system (usually because dpkg depends on them). The important priority encompasses packages one would expect to be available on a Unix-like system[2].

[2]The definition is something like "A package is important if, should it be missing, experienced Unix users would shake their heads and go "WTF?".

`standard` adds those packages that make sense for a net but not overly restrictive system running in text mode—this priority describes what you get if you install Debian GNU/Linux without selecting any additional packages. The `optional` priority applies to everything you might want to install if you do not look too closely and have no particular requirements. This includes things like the X11 GUI and a whole load of applications (such as TEX). There should be no conflicts within `optional`. Finally, `extra` is used for all packages that conflict with packages of other priorities, or that are only useful for specialised applications.


Packages may not depend on packages of lower priority. For this to hold in all cases, the priorities of some packages have deliberately been tweaked.

An important area of information are the package dependencies, of which there are several types: package dependencies

Depends The named packages must be configured for the package to be able to be configured. As in the preceding example, specific versions of the packages may be called for.

Pre-Depends The named packages must be completely installed before installation of the package can even begin. This type of dependency is used if, for example, the package's installation scripts absolutely require software from the other package.

Recommends A non-absolute but very obvious dependency. You would nearly always install the named packages alongside this package, and only refrain from doing so in very unusual circumstances.

Suggests The named packages are useful in connection with the package but not required.

Enhances Like `Suggests`, but in reverse—this package is useful for the named package (or packages).

Conflicts This package cannot be installed at the same time as the named packages.

If a package isn't installed locally at all, "`dpkg --status`" only outputs an error message:

```
# dpkg -s xyzzy
Package `xyzzy' is not installed and no info is available.
Use dpkg --info (= dpkg-deb --info) to examine archive files,
and dpkg --contents (= dpkg-deb --contents) to list their contents.
```

The `--listfiles` (`-L`) option provides a list of files within the package: list of files

```
$ dpkg --listfiles hello
/.
/usr
/usr/share
/usr/share/doc
/usr/share/doc/hello
/usr/share/doc/hello/changelog.Debian.gz
/usr/share/doc/hello/copyright
/usr/share/doc/hello/NEWS
/usr/share/doc/hello/changelog.gz
/usr/share/info
/usr/share/info/hello.info.gz
/usr/share/man
```

```
/usr/share/man/man1
/usr/share/man/man1/hello.1.gz
/usr/share/locale
◁◁◁◁◁
```

package search

Finally, you can use the `--search` (or `-s`) option to find out which package (if any) claims a given file. Search patterns are allowed:

```
$ dpkg -S bin/m*fs
dosfstools: /sbin/mkdosfs
cramfsprogs: /usr/sbin/mkcramfs
util-linux: /sbin/mkfs.cramfs
smbfs: /sbin/mount.smbfs
◁◁◁◁◁
```

The search may take some time, though.

If you're looking for the package for a file that is *not* on your system—for example, if you plan to install that package afterwards—, you can use the search form on `http://www.debian.org/distrib/packages#search_contents`. This allows you to search any or all Debian distributions and architectures as well as to search for exact file name matches and file names containing certain search terms.

Exercises

26.6 [3] How many packages whose names start with `lib` are installed on your system? How many of those packages have priority `required`?

26.2.6 Package Verification

integrity of an installed package

The integrity of an installed package can be checked using the `debsums` program (from the eponymous package):

```
$ debsums hello
/usr/share/doc/hello/changelog.Debian.gz    OK
/usr/share/doc/hello/copyright              OK
/usr/share/doc/hello/NEWS                   OK
/usr/share/doc/hello/changelog.gz           OK
/usr/share/info/hello.info.gz               OK
◁◁◁◁◁
```

This compares the MD5 checksums of the individual files with the content of the corresponding file in `/var/lib/dpkg/info` (here, `hello.md5sums`). If an actual file's checksum does not match the set value, `FAILED` is displayed in place of `OK`.

protection from intruders

`debsums` can uncover "inadvertent" changes to a package's files, but does not provide protection from intruders who maliciously modify files. After all, a cracker could place the checksum of a modified file in its package's `md5sums` list. Neither does this method help agains "Trojan" packages that hide malicious code behind an innocuous facade. We shall be coming back to the "integrity of packages" topic in Section 26.4.

Exercises

26.7 [!2] Change a file in an installed Debian package. (Look for a not-so-important one, like that from Exercise 26.2.) You could, for example, append a few lines of text to the `README.Debian` file (be `root`). Check the integrity of the package's files using `debsums`.

26.3 Debian Package Management: The Next Generation

26.3.1 APT

dpkg is a powerful tool, but still somewhat restricted in its potential. For example, it is a bit aggravating that it will notice unfilled dependencies between packages, but then just throw in the towel instead of contributing constructively to a solution of the problem. Furthermore, while it is nice be able to install locally-available packages, one would wish for convenient access to FTP or web servers offering packages.

The dselect program, which in the early days of Debian served as an interactive front-end to package management, is officially deprecated today—its inconvenience was proverbial, even though reading the manual did help as a rule.

Quite early in the history of the Debian project (by today's standards), the Debian community started developing APT, the "Advanced Packaging Tool". This project, in its significance as in its ultimate pointlessness, is comparable to the quest of the Knights of the Round Table for the Holy Grail, but, like the Grail quest, APT development led to many noble deeds along the way. Although few dragons were slain and damsels freed from distress, the APT developers produced very important and powerful "partial solutions" whose convenience and feature set remains unequalled (which is why some RPM-based distributions have begun to ad-"apt" them for their purposes).

26.3.2 Package Installation Using apt-get

The first of these tools is apt-get, which represents a sort of intelligent superstructure for dpkg. It does not offer an interactive interface for package selection, but could initially be used as a back-end for dselect, to install packages selected in dselect. Today it is mostly useful on the command line. The most important properties of apt-get include the following:

- apt-get can manage a set of installation sources simultaneously. For example, it is possible to use a "stable" Debian distribution on CD-ROM in parallel to a HTTP-based server containing security updates. Packages are normally installed from CD-ROM; only if the HTTP server offers a more current version of a package will it be fetched from the network. Certain packages can be requested from certain sources; you can, for example, use a stable Debian distribution for the most part but take some packages from a newer "unstable" distribution. — Several installation sources
- It is possible to update all of the distribution at once (using "apt-get dist-upgrade"), with dependencies being resolved even in the face of package renamings and removals. — Upgrades
- A multitude of auxiliary tools allows, e. g., setting up caching proxy servers for Debian packages (apt-proxy), installing packages on systems that are not connected to the Internet (apt-zip), or retrieving a list of bugs for a package before actually installing it (apt-listbugs). With apt-build, you can compile packages with specific optimisations for your system and create a local package repository containing such packages. — auxiliary tools

Package sources for apt-get are declared in /etc/apt/sources.list: — package sources

```
deb http://ftp.de.debian.org/debian/ stable main
deb http://security.debian.org/ stable/updates main
deb-src http://ftp.de.debian.org/debian/stable main
```

Binary packages will be fetched from `http://ftp.de.debian.org/`, as will the corresponding source code. In addition, the `security.debian.org` server is accessed, on which the Debian project places updated package version that fix security bugs.

operating procedure

The standard operating procedure using `apt-get` is as follows: First you update the local package availability database:

```
# apt-get update
```

This consults all package sources and integrates the results into a common package list. You can install packages using "`apt-get install`":

```
# apt-get install hello
Reading Package Lists... Done
Building Dependency Tree... Done
The following NEW packages will be installed:
  hello
0 upgraded, 1 newly installed, 0 to remove and 0 not upgraded.
Need to get 68.7kB of archives.
After unpacking 566kB of additional disk space will be used.
```

This will also install or upgrade all packages mentioned in `Depends:` dependencies, as well as any packages that these packages depend upon, and so on.

You may also install several packages at the same time:

```
# apt-get install hello python
```

or install some packages and install others simultaneously: The

```
# apt-get install hello- python python-django+
```

command would remove the `hello` package and install the `python` and `python-django` packages (including their dependencies). The "+" is not mandatory but allowed. With "`apt-get remove`" you can remove packages directly.

simple update

The "`apt-get upgrade`" installs the newest available versions of all packages installed on the system. This will not remove installed packages nor install new packages; packages that cannot be updated without such actions (because dependencies have changed) remain at their present state.

"intelligent" update

The "`apt-get dist-upgrade`" command enables an "intelligent" conflict resolution scheme which tries to resolve changed dependencies by judiciously removing and installing packages. This prefers more important packages (according to their priority) over less important ones.

source code

You can fetch a package's source code using the "`apt-get source`" command:

```
# apt-get source hello
```

This also works if the binary package is one of several that have been created from a (differently named) source package.

The `apt` programs are usually configured by means of the `/etc/apt/apt.conf` file. This includes options for `apt-get`, `apt-cache`, and other commands from the `apt` bunch.

Exercises

26.8 [!1] Use `apt-get` to install the `hello` package and then remove it again.

26.9 [1] Download the source code for the `hello` package using `apt-get`.

26.3.3 Information About Packages

Another useful program is `apt-cache`, which searches `apt-get`'s package sources: `apt-cache`

```
$ apt-cache search hello                                    hello in name or description
⋖⋖⋖⋖⋖
grhino-data - othello/reversi boardgame - data-files
gtkboard - many board games in one program
hello - The classic greeting, and a good example
hello-debhelper - The classic greeting, and a good example
jester - board game similar to Othello
⋖⋖⋖⋖⋖
$ apt-cache show hello
Package: hello
Version: 2.8-2
Installed-Size: 553
Maintainer: Santiago Vila <sanvila@debian.org>
Architecture: amd64
⋖⋖⋖⋖⋖
```

The output of "`apt-cache show`" mostly corresponds to that of "`dpkg --status`", except that it works for all packages in a package source, no matter whether they are installed locally, while `dpkg` only deals with packages that are actually installed.

There are also a few other interesting `apt-cache` subcommands: `depends` displays all the dependencies of a package as well as the names of packages fulfilling that dependency:

```
$ apt-cache depends hello
hello
  Depends: libc6
 |Depends: dpkg
  Depends: install-info
```

The vertical bar in the second dependency line indicates that the dependency in this line or the one in the following line must be fulfilled. In this example, the `dpkg` package or the `install-info` package must be installed (or both).

Conversely, `rdepends` lists the names of all packages depending on the named package:

```
$ apt-cache rdepends python
python
Reverse Depends:
  libboost-python1.4.1
  mercurial-nested
  mercurial-nested
  python-apt
  python-apt
⋖⋖⋖⋖⋖
```

If a package occurs several times in the list, this is probably because the original package specified it several times, typically with version numbers. The `python-apt` package, for example, contains among other things

```
… python (>= 2.6.6-7~), python (<< 2.8), …
```

to signal that it will only work with particular versions of the Debian Python package.

`stats` provides an overview of the content of the package cache:

```
$ apt-cache stats
Total package names: 33365 (1335k)                    All packages in the cache
  Normal packages: 25672                              Packages that really exist
  Pure virtual packages: 757                          Placeholders for functionality
  Single virtual packages: 1885                       Just one implementation
  Mixed virtual packages: 267                         Several implementations
  Missing: 4784                  Packages in dependencies that no (longer?) exist
Total distinct versions: 28955 (1506k)                Package versions in the cache
Total distinct descriptions: 28955 (695k)
Total dependencies: 182689 (5115k)                    Number of pairwise relationships
Total ver/file relations: 31273 (500k)
Total Desc/File relations: 28955 (463k)
Total Provides mappings: 5747 (115k)
Total globbed strings: 100 (1148)
Total dependency version space: 756k
Total slack space: 73.5k
Total space accounted for: 8646k
```

Exercises

26.10 [2] How can you find *all* packages that must be installed for a particular package to work? (Compare the output of "`apt-cache depends x11-apps`" to that of "`apt-cache depends libxt6`".)

26.3.4 `aptitude`

The program `aptitude` does package selection and management and has taken over the old `dselect`'s rôle in Debian GNU/Linux. On the console or inside a terminal emulator, it features an interactive user interface with menus and dialogs, but also provides command-line options that are roughly compatible to those of `apt-get`. Since Debian 4.0 (popularly called "etch"), `aptitude` is the recommended program for package installation and updates.

Newer versions of `aptitude` include a GTK+-based user interface that can be installed optionally.

improvements

Compared to `apt-get` and `dselect`, `aptitude` offers various improvements, including:

- It does not necessarily need to be invoked as `root`, but asks for the `root` password before actions requiring administrator privileges are performed.
- It can remember which packages have been installed to fulfil dependencies, and remove these automatically if all packages depending on them have been removed. (In the meantime `apt-get` has learned to do that, too; see `apt-get`(8), the `autoremove` command.)
- With `aptitude`, you have interactive access to all versions of a package available from various package sources, not just the most up-to-date one.

interactive UI

The `aptitude` command invokes the interactive UI (Figure 26.1). Near the top of the console (or terminal, as the case may be) you see a "menu bar", below that there is a line with a short help message and a line with the program's version number. The remainder of the screen is split in two parts: The upper half displays an overview of the various types of package (updated, new, installed, and so on), the lower half is used for explanatory messages.

With the ↑ and ↓ keys you can navigate in the package list. Lines starting wiht `---` represent the headings of "subtrees" of the package list, and ↩ can be

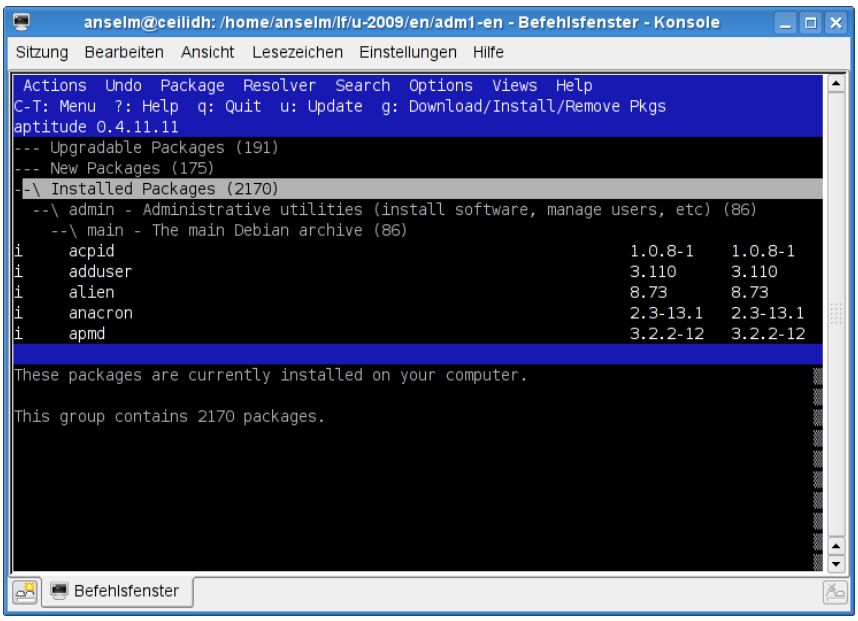


Figure 26.1: The `aptitude` program

used to "open" the next level of such a subtree. (You can open all of the subtree by typing] .) / gives you a window that lets you enter a search term (or regular expression) for a package name. When scrolling through the package lists, explanations for the packages encountered are displayed in the lower part of the screen, and you can scroll these up or down using the a and z keys. The i key lets you change from the explanatory text to a representation of the dependencies.

If the cursor bar sits on a package's line, you can select it for installation or updating using the + key, or mark it for deletion using -. If you want to remove it completely (as in "`dpkg --purge`"), use _. = sets a package's status to "hold", which means that it will no longer be automatically upgraded.

With u, you can update the package lists (like "`apt-get update`") and then check the "Updated Packages" subtree to find which packages `aptitude` would update. Using U, you can mark all of these packages for actual updating. The "New Packages" subtree displays those packages added since the last update; f empties this list and places these packages among the "normal" lists. The Ctrl+t key combination opens the menu bar, in which you can move using the arrow keys and select a function using ↩.

The g command starts the actual installation, update, or package removal. At first it shows an overview of the planned actions, which you may revise using the usual commands. Another g starts the actual work: First all required new packages are fetched, then `aptitude` calls `dpkg` to atually install or remove the desired packages.


Contrary to popular perception, `aptitude` is not really a front-end to `apt-get`, but does by itself whatever `apt-get` would otherwise do.

If conflicts occur, `aptitude` offers solution strategies by way of suitable proposals for installations, updates, or package removals, from which you can pick the one that is most appropriate. solution strategies


In its default configuration, `aptitude` automatically installs even those packages that a package marks `Recommended:`. This is not always what is wanted and can be switched off from the "Options" menu.


You can install and use `aptitude` on Ubuntu, but it is not the recommended program. For this reason, it does not agree 100% with the graphical tools

proposed for package management by Ubuntu—so you should either do everything like Ubuntu recommends, or else do everything using `aptitude`.

26.4 Debian Package Integrity

integrity of complete packages

The `debsums` program is used to check the integrity of the files in a single package (Section 26.2.6). This is nice but does not ensure that an attacker has not manipulated both the files in the package and the `.md5sums` file containing the original checksums. The question remains: How does the Debian project ensure the integrity of complete packages (and, based on this, the integrity of the whole distribution)? This works as follows:

- Every Debian package is cryptographically signed by a Debian developer. This means that the receipient of the package can use the developer's public key to verify that they received the package in the state it was in when the developer released it.

  The Debian developer who signed the package must not necessarily have been the person who assembled it. In principle, every Debian developer may sign and release any package in Debian (a "non-maintainer upload"), and this is being done in practice for timely updates fixing critical security holes and to adopt "orphaned" packages. Furthermore, there are numerous people who help with Debian GNU/Linux and, even though they are not formally Debian developers (or whose applications for developer status are pending), maintain packages. These people cannot by themselves release packages, but must do this via a "sponsor" who must be a Debian developer. The sponsor assumes the responsibility that the package is reasonable.

  You should not overestimate the security gained through digital signatures: A developer's signature does not guarantee that there is no malicious code in a package, but only that the developer signed the package. Theoretically it is possible for a cracker to pass the Debian developer accreditation procedure and be able to release official packages into the distribution—whose control scripts most users will execute uncritically as `root`. Most other Linux distributions share the same weaknesses.

- The Debian infrastructure only accepts packages for publication that have been signed by a Debian developer.

- On the Debian server (and all servers mirroring Debian GNU/Linux) there is a file (or several) called `Packages.gz` for each current Debian distribution. This file contains the MD5 checksums of all packages in the distribution, as they are on the server; since the server only accepts packages from accredited developers, these are authentic.

- For each current Debian distribution on the server there is a file called `Release`, which contains the MD5 checksums of the `Packages.gz` file(s) involved. This file is cryptographically signed (the signature is in a file called `Release.gpg`).

With this chain of checksums and signatures, the integrity of packages in the distribution can be checked:

- A new package is downloaded and its MD5 checksum is determined.

- We check whether the signature of the `Release` file is correct, and, if so, read the MD5 checksum of `Packages.gz` from that file.

- With that checksum, we verify the integrity of the actual `Packages.gz` file.
- The MD5 checksum of the package given in `Packages.gz` must match that of the downloaded file.

If the MD5 checksum of the downloaded file does not match the "nominal value" from `Packages.gz`, the administrator is made aware of this fact and the package is not installed (just yet, anyway).


It is possible to configure a Debian system such that it *only* installs packages that can be verified in this way. (Usually all you get is warnings which can be overridden manually.) With this, you can construct an infrastructure where only packages from a considered-safe-and-sensible "subdistribution" can be installed. These packages may be from Debian GNU/Linux or else have been made available locally.


The APT infrastructure only trusts package sources for which a public GnuPG key has been placed in the `/etc/apt/trusted.gpg`. The `apt-key` program is used to maintain this file.


The current public keys for Debian package sources are contained in the `debian-archive-keyring` package and can be renewed by updating this file. (Debian rotates the keys on a yearly basis).

You can find out more about managing signed packages in Debian in [F+07, chapter 7]. We explain GnuPG in the Linup Front training manual *Linux Administration II*.

26.5 The debconf Infrastructure

Sometimes questions come up during the installation of software packages. For example, if you are installing a mail server package, it is important to know, in order to generate an appropriate configuration file, whether the computer in question is connected directly to the Internet, whether it is part of a LAN with its own dedicated mail server, or whether it uses a dial-up connection to access the net. It is also necessary to know the domain the computer is to use for its messages and so on.

The debconf mechanism is designed to collect this information and to store it for future use. It is basically a database for system-wide configuration settings, which can, for example, be accessed by the installation scripts of a package. To manipulate the database, debconf supports modular user interfaces covering all tastes from very simple textual prompts to text-oriented dialogs and various graphical desktop applications such as KDE and GNOME. There are also interfaces to popular programming languages like Python.

You can redo the initial debconf-based configuration of a software package at any time by giving a command like

```
# dpkg-reconfigure my-package
```

`dpkg-reconfigure` repeats the questions asked during the original installation process of the package, using the pre-set user interface.


You can select another user interface on an *ad-hoc* basis by means of the `--frontend` (or `-f`) option. The possible names are given in `debconf`(7) if you have installed the `debconf-doc` package. The default is `dialog`.


To change the user interface temporarily if you are not calling `dpkg-reconfigure` directly, use the `DEBCONF_FRONTEND` environment variable:

```
# DEBCONF_FRONTEND=noninteractive aptitude upgrade
```

With `dpkg-reconfigure`, you can also control the level of detail of the questions you will be asked. Use the `--priority` (or `-p`) option followed by a priority. The possible priorities are (in descending order):

`critical` Questions you absolutely must answer lest terrible things happen.

`high` Questions without a sensible default—your opinion counts.

`medium` Questions with a sensible default.

`low` Trivial questions with a default that works most of the time.

If you say something like

```
# dpkg-reconfigure --priority=medium my-package
```

you will be asked all priority `critical`, `high`, and `medium` questions; any priority `low` questions will be skipped.

For *ad-hoc* changes if debconf is called indirectly, there is also the `DEBCONF_PRIORITY` environment variable.

The debconf infrastructure is fairly complex but useful. For example, it is possible to put the answers into an LDAP database that is accessible to all computers on a network. You can thus install a large number of machines without manual intervention. To explain this in detail would, however, be beyond the scope of this manual.

Exercises

26.11 [1] How can you change the pre-set user interface for debconf on a permanent basis?

26.6 `alien`: Software From Different Worlds

Many software packages are only available in the popular RPM format. Commercial packages in particular are more likely to be offered for the Red Hat or SUSE distributions, even though nothing would prevent anyone from trying the software on Debian GNU/Linux (serious use may be precluded by the loss of manufacturer support if a non-approved platform is used). You cannot install RPM packages on a Debian system directly, but the `alien` program makes it possible to convert the package formats of various Linux distributions—besides RPM also the Stampede and Slackware formats (not that these are desperately required)—to the Debian package format (and vice-versa).

Important: While `alien` will let you convert packages from one format to another, there is no guarantee whatsoever that the resulting package will be useful in any way. On the one hand, the programs in the package may depend on libraries that are not available (or not available in the appropriate version) in the target distribution—since `alien` does not deal with dependencies, you must sort out any problems of this type manually. On the other hand, it is quite possible that the package integrates itself into the source distribution in a way that is impossible or difficult to replicate on the target distribution.

As a matter of principle, the farther "down" a package sits in the system the smaller the probability that `alien` will do what you want. With packages that consist of a few executable programs without bizarre library dependencies, the corresponding manual pages, and a few example files, chances are good for `alien` to do the Right Thing. With system services that must integrate into the system boot sequence, things may well look different. And you should not even *think* of replacing `libc` …

`alien` is used, in particular, to convert LSB-compliant software packages for installation on a Debian GNU/Linux system—LSB specifies RPM as the software distribution package format.

After these introductory remarks, we'll show you quickly how to use `alien` to convert a RPM package to a Debian package:

```
# alien --to-deb paket.rpm
```

(Where `--to-deb` represents the default case and may be left out.) The reverse is possible using

```
# alien --to-rpm paket.deb
```

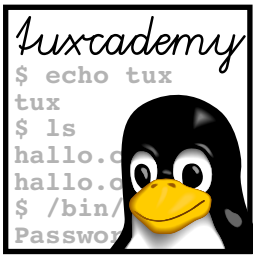
To assemble and disassemble RPM files, the `rpm` program must be installed (which is available as a package for Debian GNU/Linux); to assemble `deb` packages you need a few pertinent Debian packages which are listed in `alien`(1p). (As mentioned in Section 26.2, you can take `deb` packages to bits on almost all Linux systems using "on-board tools" such as `tar`, `gzip`, and `ar`.)

Commands in this Chapter

`alien` Converts various software packaging formats `alien`(1) 414
`apt-get` Powerful command-line tool for Debian GNU/Linux package management `apt-get`(8) 407
`aptitude` Convenient package installation and maintenance tool (Debian) `aptitude`(8) 410
`dpkg` Debian GNU/Linux package management tool `dpkg`(8) 400
`dpkg-reconfigure` Reconfigures an already-installed Debian package `dpkg-reconfigure`(8) 413

Bibliography

F+07 Javier Fernández-Sanguino Peña, et al. "Securing Debian Manual", 2007. `http://www.debian.org/doc/manuals/securing-debian-howto/`



27

Package Management with RPM and YUM

Contents

Goals

- Knowing the basics of RPM and related tools
- Being able to use rpm for package management
- Being able to use YUM

Prerequisites

- Knowledge of Linux system administration
- Experience with an RPM-based Linux distribution is helpful

27.1 Introduction

The "Red Hat Package Manager" (RPM, for short) is a tool for managing software packages. It supports the straightforward installation and deinstallation of packages while ensuring that different packages do not conflict and that dependencies between the packages are taken into account. In addition, RPM allows you to specify package queries and to ensure the integrity of packages.

RPM's core is a database. Software packages add themselves when they are installed and remove themselves again when they are deinstalled. To allow this, software packages must be provided in a specific format, i. e., as RPM packages.

The RPM package format is used used by many distributions (including those by Red Hat, Novell/SUSE, TurboLinux, and Mandriva). An arbitrary RPM package, though, cannot generally be installed on any RPM-based distribution without forethought: Since the RPM package contains compiled software, it must fit the processor architecture in use; since file system structure, the type of service control (init scripts, etc.), and the internal description of dependencies differ between distributions or even between different versions of the same distribution, careless installation across distribution may cause problems.

RPM was originally developed by Red Hat and was accordingly called "Red Hat Package Manager" at first. Since various other distributions have taken to using the program, it has been renamed to "RPM Package Manager".

At the moment there is a certain controversy as to who is in charge of further development of this critical piece of infrastructure. After a long hiatus, during which nobody really bothered to put out a canonical version, some Fedora developers tried in 2006/7 to restart RPM development as an officially distribution-neutral project (this project is now led by Panu Matilainen of Red Hat, with developers affiliated with some other RPM-using distributions in support). Independently, Jeff Johnson, the last official RPM developer at Red Hat (who is no longer with the company), is putting work into RPM and claims that his code represents "the official code base"—although no Linux distribution seems to pay attention.

file name

An RPM package has a compound file name, for example

```
openssh-3.5p1-107.i586.rpm
```

which usually consists of the package name (`openssh-3.5p1-107`), the architecture (`i586`) and the `.rpm` suffix. The package name is used to identify the package internally once it has been installed. It contains the name of the software (`openssh`) and the software version as assigned by its original developers (`3.5p1`) followed by a release number (`107`) assigned by the package builder (the distributor).

basic mode

The "RPM Package Manager" is invoked using the `rpm` command, followed by a basic mode. The most important modes will be discussed presently, excepting the modes for initialising the RPM database and constructing and signing RPM packages, which are outside the scope of this course.

options

There is a number of global options as well as supplementary, mode-specific options. Since some modes and supplementary options are identical, the mode must (unlike with `tar`) be specified first.

Global options include `-v` and `-vv`, which increase the "verbosity" of RPM's output.

RPM's configuration is stored within the `/usr/lib/rpm` directory; local or individual customisations are made within the `/etc/rpmrc` or `~/.rpmrc` files, but should not be necessary for normal operations.

27.2 Package Management Using rpm

27.2.1 Installation and Update

An RPM package is installed in -i mode, followed by the package file's path name, such as

```
# rpm -i /tmp/openssh-3.5p1-107.i586.rpm
```

You may also specify the path as an HTTP or FTP URL in order to install package files that reside on remote serers. It is permissible to specify several packages at once, as in "rpm -i /tmp/*.rpm".

Additionally, there are the two related modes -U ("upgrade") and -F ("freshen"). The former removes any older versions of a package as well as installing the new one, while the latter installs the package only if an earlier version is already installed (which is subsequently removed).

All three modes support a number of options, which must absolutely be mentioned *after* the mode. Besides -h ("hash mark", for a progress bar) there is --test, which prevents the actual installation and only checks for possible conflicts.

When a conflict occurs, the package in question is not installed. Conflicts arise if

- an already-installed package is to be installed again,
- a package is to be installed even though it is already installed in a different version (mode -i) or a more current version (mode -U),
- the installation would overwrite a file belonging to a different package,
- a package requires a different package which is not already installed or about to be installed.

If the installation fails for any of these reasons, you can force it to be performed through options. For example, the --nodeps option disables the dependency check.

Further options can influence the installation itself (rather than just the security checks). For example, you can move packages to different directories on installation. This is the only way to install, e. g., Apache 1.3 and Apache 2.0 at the same time, since usually both of them would claim /sbin/http for themselves: one of the two must move to /usr/local.

27.2.2 Deinstalling Packages

Packages can be deinstalled using -e ("erase") mode, e. g.,

```
# rpm -e openssh-3.5p1-107
```

Note that you need to specify the *internal* package name rather than the package file path, since RPM does not remember the latter. (The next section will tell you how to find out the package name.) You can also abbreviate the package name as long as it stays unique. If there is no other openssh package, you might also remove it by

```
# rpm -e openssh
```

Again, RPM takes care not to remove packages that other packages depend upon.

The --test and --nodeps options have the same meaning as upon installation; they must also appear after the mode.

When deinstalling, all of the package's installed files will be removed unless they are configuration files that you have changed. These will not be removed but merely renamed by appending the .rpmsave suffix. (The RPM package determines which of its files will be considered configuration files.)

configuration files

27.2.3 Database and Package Queries

The "RPM Package Manager" becomes even more useful if you do not just consider it a package installation and removal tool, but also an information source. The mode for this is `-q` ("query"), and you can specify in more detail what kind of information you would like to obtain and from which package.

Specifying the Package Without further options, `rpm` expects an internal package name, which may be abbreviated, and it outputs the full package name:

```
$ rpm -q openssh
openssh-3.5p1-107
```

This makes it easy to determine how current your system is. You can also find the package claiming a file, using the `-f` option:

```
$ rpm -qf /usr/bin/ssh
openssh-3.5p1-107
```

This lets you relate unknown files to a package. As a third possibility, you can obtain a list of *all* installed packages with the `-a` option:

```
$ rpm -qa
```

This list may of course be processed further, as in the following example:[1]

```
$ rpm -qa | grep cups
cups-client-1.1.18-82
cups-libs-1.1.18-82
kdelibs3-cups-3.1.1-13
cups-drivers-1.1.18-34
cups-drivers-stp-1.1.18-34
cups-1.1.18-82
```

Finally, RPM allows you to query a non-installed package. Use `-p` followed by the package file's name:

```
$ rpm -qp /tmp/openssh-3.5p1-107.i586.rpm
openssh-3.5p1-107
```

This does not look too spectacular, since the internal package name was already part of the package file name. But the file name might have been changed until it no longer had anything to do with the actual package name, and secondly, there are other questions that you might want to ask.

Specifying the Query If you are not just interested in the package name, you can extend your query. Every extension may be combined with every way of specifying a packet. Via

```
$ rpm -qi openssh
```

you can obtain detailed information (`-i`) about the package; while `-l` provides a list of all files belonging to the package, together with `-v` it forms an equivalent to the `ls -l` command:

[1] The naming and arrangement of packages is the package preparer's concern; differences may occur depending on the distribution and version.

```
$ rpm -qlf /bin/bash
/bin/bash
/bin/sh
<<<<<
$ rpm -qlvf /bin/bash
-rwxr-xr-x  root  root   491992 Mar 14  2003 /bin/bash
lrwxrwxrwx  root  root        4 Mar 14  2003 /bin/sh -> bash
<<<<<
```

It is important to note that the files listed for a package are only those that show up in the RPM database, namely those that a package brought along when it was installed. This does not include files that were generated during installation (by the package's installation scripts) or during system operation (log files, etc.).

We have already seen that RPM treats configuration files specially (when deinstalling). The second class of special files are documentation files; these can be omitted from installation. The `-c` and `-d` options of query mode behave like `-l`, but they confine themselves to configuration and documentation files, respectively.

Advanced Queries The following details are not relevant for LPIC-1, but they will improve your understanding of RPM's concepts and database structure.

dependencies

Dependencies between packages can belong to various types. For example, a package may simply require a shell, i. e., `/bin/sh`. By means of

```
$ rpm -qf /bin/sh
bash-2.05b-105
```

it is straightforward to find out that this file is provided by the `bash` package (the same can be done for non-installed packages).

Things are different, e. g., for the SAINT package, a security analysis tool which requires a web browser. Every specific dependency on a particular web browser would be unduly limiting. For this reason, RPM lets packages provide or depend upon "capabilities". In our example, SAINT requires the abstract capability "web browser". The files and capabilities that a package requires can be queried using the `--requires` option:[2]

```
$ rpm -q --requires saint
web_browser
/bin/rm
/bin/sh
/usr/bin/perl
<<<<<
```

The packages providing these capabilities can be found using the `--whatprovides` option:

```
$ rpm -q --whatprovides web_browser
w3m-0.3.2.2-53
mozilla-1.2.1-65
lynx-2.8.4-391
```

For SAINT, you need just one of these packages.

In the same manner, the `--provides` and `--whatrequires` options allow you to query the services (or files, with the `-l` option) that a package offers, and a service's consumers.

[2] Here, again, the assignment and naming of capabilities is up to the package preparer; it may thus differ between distributions and versions.

27.2.4 Package Verification

Pre-Installation Checks Two things may happen to a package which might preclude its installation: It may have been damaged during the download, i. e., the package is erroneous. Or the package is not what it pretends to be, i. e., it has been falsified—for example, because some malicious person tries to pass a "Trojan" package off as the original.

RPM safeguards you against both scenarios: with

```
$ rpm --checksig /tmp/openssh-3.5p1-107.i586.rpm
/tmp/openssh-3.5p1-107.i586.rpm: md5 gpg OK
```

an MD5 checksum of the package is compared to the checksum contained within itself, which guarantees the proper transmission of the package. In addition, the signature within the package, which was created using the private PGP or GPG key of the package preparer, is checked using the package preparer's public key. This guarantees that the correct package has arrived.

Should the MD5 checksum be correct but not the signature, the output looks correspondingly different:

```
$ rpm --checksig /tmp/openssh-3.5p1-107.i586.rpm
/tmp/openssh-3.5p1-107.i586.rpm: md5 GPG NOT OK
```

Of course your distributor's public key must be available on your system for the signature checks.

Post-Installation Verification RPM lets you compare certain values within the RPM database to the file system. This is done by means of the `-V` ("verify") mode; instead of one or more internal package names, this mode can use all specifications made available for the query mode.

```
# rpm -V openssh
.......T c /etc/init.d/sshd
S.5....T c /etc/pam.d/sshd
S.5....T c /etc/ssh/ssh_config
SM5....T c /etc/ssh/sshd_config
.M......   /usr/bin/ssh
```

This output contains all files for which at least one "required" value from the database differs from the "actual" value within the file system: a "`.`" signifies agreement, while a letter indicates a deviation. The following checks are performed: access mode and file type (`M`), owner and group (`U`, `G`); for symbolic links, the path of the referenced file (`L`); for device files, major and minor device numbers (`D`); for plain files the size (`S`), modification time (`T`), and content (`5`). Since configuration files are unlikely to remain in their original state, they are labeled with a `c`.

Even though the verification of installed packages using RPM cannot replace an "intrusion detection system" (why should an intruder not modify the RPM database as well?), it can be useful to limit the damage, e. g., after a hard disk crash.

27.2.5 The `rpm2cpio` Program

RPM packages are essentially `cpio` archives with a prepended "header". You can use this fact to extract individual files from an RPM package without having to install the package first. Simply convert the RPM package to a `cpio` archive using the `rpm2cpio` program, and feed the archive into `cpio`. Since `rpm2cpio` works as a filter, you can easily connect the two programs using a pipe:

```
$ rpm2cpio hello-2.4-1.fc10.i386.rpm \
> | cpio -idv ./usr/share/man/man1/hello.1.gz
./usr/share/man/man1/hello.1.gz
387 blocks
$ zcat usr/share/man/man1/hello.1.gz | head
.\" DO NOT MODIFY THIS FILE!  It was generated by help2man 1.35.
.TH HELLO "1" "December 2008" "hello 2.4" "User Commands"
.SH NAME
hello \- friendly greeting program
◁◁◁◁◁
```

Exercises

27.1 [2] Use `rpm2cpio` and `cpio` to display the list of files contained in an RPM package.

27.3 YUM

27.3.1 Overview

The `rpm` program is useful but does have its limits. As a basic tool it can install packages that are available as files or URLs, but, for example, does not help with locating appropriate, possibly installable packages. Many RPM-based distributions use YUM (short for "Yellow Dog Updater, Modified", after the distribution for which the program was originally developed) to enable access to package sources (repositories) available on the Internet or on CD-ROM.

package sources

In RPM-based distributions, YUM takes up approximately the same "ecological niche" occupied by `apt-get` in Debian GNU/Linux and its derivatives.

YUM is usually controlled via the command line, but the "`yum shell`" command starts a "YUM shell" where you can enter multiple YUM commands interactively.

27.3.2 Package Repositories

YUM introduces the concept of *package repositories*. A package repository is a set of RPM packages that is available via the network and allows the installation of packages with YUM. The "`yum repolist`" command outputs a list of configured package repositories:

```
$ yum repolist
Loaded plugins: refresh-packagekit
repo id        repo name                   status
fedora         Fedora 10 - i386            enabled: 11416
updates        Fedora 10 - i386 - Updates  enabled:  3324
repolist: 14740
```

"`yum repolist disabled`" yields a list of known but disabled repositories:

```
$ yum repolist disabled
Loaded plugins: refresh-packagekit
repo id           repo name                     status
fedora-debuginfo  Fedora 10 - i386 - Debug      disabled
fedora-source     Fedora 10 - Source            disabled
```

```
rawhide           Fedora - Rawhide - Development disabled
◁◁◁◁◁
```

To enable a repository, you need to give the `--enablerepo=` option, followed by the "repo ID" from the list. This only works in connection with a "genuine" `yum` command; `repolist` is fairly innocuos:

```
$ yum --enablerepo=rawhide repolist
Loaded plugins: refresh-packagekit
rawhide                                  | 3.4 kB   00:00
rawhide/primary_db                       | 7.2 MB   00:14
repo id        repo name                   status
fedora         Fedora 10 - i386            enabled: 11416
rawhide        Fedora - Rawhide - Development  enabled: 12410
updates        Fedora 10 - i386 - Updates      enabled:  3324
repolist: 27150
```

You can disable a repository using the `--disablerepo` option.

Repositories are most conveniently made known to YUM by means of configuration files in the `/etc/yum.repos.d` directory. (You could also enter them into `/etc/yum.conf` directly, but this is more inconvenient to manage.)

YUM keeps itself current as far as the content of repositories is concerned. There is no equivalent to the Debian tools' "`apt-get update`".

27.3.3 Installing and Removing Packages Using YUM

To install a new package using YUM, you merely need to know its name. YUM checks whether the active repositories contain an appropriately-named package, resolves any dependencies the package may have, downloads the package and possibly other packages that it depends upon, and installs all of them:

```
# yum install hello
Setting up Install Process
Parsing package install arguments
Resolving Dependencies
--> Running transaction check
---> Package hello.i386 0:2.4-1.fc10 set to be updated
--> Finished Dependency Resolution

Dependencies Resolved

================================================================
 Package       Arch      Version         Repository     Size
================================================================
Installing:
 hello         i386      2.4-1.fc10      updates        68 k

Transaction Sum
================================================================
Install      1 Package(s)
Update       0 Package(s)
Remove       0 Package(s)

Total download size: 68 k
Is this ok [y/N]: y
Downloading Packages:
hello-2.4-1.fc10.i386.rpm                    |  68 kB     00:00
```

```
====================== Entering rpm code ======================
Running rpm_check_debug
Running Transaction Test
Finished Transaction Test
Transaction Test Succeeded
Running Transaction
  Installing     : hello                                   1/1
====================== Leaving rpm code =======================

Installed:
  hello.i386 0:2.4-1.fc10

Complete!
```

YUM accepts not just simple package names, but also package names with architecture specifications, version numbers, and release numbers. Check `yum`(8) to find the allowable formats.

Removing packages is just as simple:

```
# yum remove hello
```

This will also remove packages that this package depends upon—as long as these are not required by another installed package, anyway.

Instead of "`yum remove`" you can also say "`yum erase`"—the two are equivalent.

You can update packages using "`yum update`":

```
# yum update hello
```

checks whether a newer version of the package is available and installs that if this is the case. YUM takes care that all dependencies are resolved. "`yum update`" without a package name attempts to update all installed packages.

When the `--obsoletes` is specified (the default case), `yum` tries to handle the case where one package has been replaced by another (of a different name). This makes full upgrades of the whole distribution easier to perform.

"`yum upgrade`" is the same as "`yum update --obsoletes`"—but saves some typing in the case that you have switched off the `obsoletes` option in the configuration.

YUM supports the idea of "package groups", i. e., packages that together are useful for a certain task. The available package groups can be displayed using "`yum grouplist`":

```
$ yum grouplist
Loaded plugins: refresh-packagekit
Setting up Group Process
Installed Groups:
   Administration Tools
   Authoring and Publishing
   Base
   Dial-up Networking Support
   Editors
<<<<<
```

If you want to know which packages a group consists of, use "`yum groupinfo`":

```
$ yum groupinfo 'Printing Support'
Loaded plugins: refresh-packagekit
Setting up Group Process

Group: Printing Support
 Description: Install these tools to enable the system to▷
 ◁ print or act as a print server.
 Mandatory Packages:
   cups
   ghostscript
 Default Packages:
   a2ps
   bluez-cups
   enscript
◁◁◁◁◁
```

A group is considered "installed" if all its "mandatory" packages are installed. Besides these there are "default packages" and "optional packages".

"`yum groupinstall`" lets you install the packages of a group. The configuration option `group_package_types` determines which class package will actually be installed—usually the "mandatory" and the "default packages".

"`yum groupremove`" removes all packages of a group, *without* taking into account package classes (`group_package_types` is ignored). Note that packages can belong to more than one group at the same time, so they may be missing from group X after having been removed along with group Y.

27.3.4 Information About Packages

The "`yum list`" command is available to find out which packages exist:

```
$ yum list gcc
Loaded plugins: refresh-packagekit
Installed Packages
gcc.i386              4.3.2-7              installed
```

You can also give a search pattern (it is best to put it inside quotes so the shell will not mess with it):

```
$ yum list "gcc*"
Loaded plugins: refresh-packagekit
Installed Packages
gcc.i386              4.3.2-7              installed
gcc-c++.i386          4.3.2-7              installed
Availabe Packages
gcc-gfortran.i386     4.3.2-7              fedora
gcc-gnat.i386         4.3.2-7              fedora
◁◁◁◁◁
```

The "installed packages" are installed on the local system, while the "available packages" can be fetched from repositories. The repository offering the package is displayed on the far right.

To restrict the search to locally installed, or uninstalled but available, packages, you can use "`yum list installed`" or "`yum list available`":

```
$ yum list installed "gcc*"
Loaded plugins: refresh-packagekit
```

```
Installed Packages
gcc.i386              4.3.2-7              installed
gcc-c++.i386          4.3.2-7              installed
$ yum list available "gcc*"
Loaded plugins: refresh-packagekit
Available Packages
gcc-gfortran.i386     4.3.2-7              fedora
gcc-gnat.i386         4.3.2-7              fedora
⋘⋘⋘
```

"`yum list updates`" lists the packages that are installed and for which updates are available, while "`yum list recent`" lists the packages that have "recently" arrived in a repository. "`yum list extras`" points out packages that are installed locally but are *not* available from any repository.

To find out more about a package, use "`yum info`":

```
$ yum info hello
Loaded plugins: refresh-packagekit
Installed Packages
Name       : hello
Arch       : i386
Version    : 2.4
Release    : 1.fc10
Size       : 186 k
Repo       : installed
Summary    : Prints a Familiar, Friendly Greeting
URL        : http://www.gnu.org/software/hello/
License    : GPLv3+ and GFDL and BSD and Public Domain
Description: Hello prints a friendly greeting. It also serves as a
           : sample GNU package, showing practices that may be
           : useful for GNU projects.
```

The advantage over "`rpm -qi`" is that "`yum info`" also works for packages that are not installed locally but are available from a repository.

You con otherwise use "`yum info`" like "`yum` list"—"`yum info installed`", for example, displays detailed information about *all* installed packages.

Using "`yum search`", you can search for all packages in whose name or description a given string occurs:

```
$ yum search mysql
Loaded plugins: refresh-packagekit
========================== Matched: mysql ======================
dovecot-mysql.i386 : MySQL backend for dovecot
koffice-kexi-driver-mysql.i386 : Mysql-driver for kexi
libgda-mysql.i386 : MySQL provider for libgda
⋘⋘⋘
```

Unfortunately, the resulting list is unsorted and a little difficult to read. `yum` uses boldface to emphasise the places where the search string occurs.

You can examine a package's dependencies using "`yum deplist`":

```
$ yum deplist gcc
Loaded plugins: refresh-packagekit
Finding dependencies:
package: gcc.i386 4.3.2-7
```

```
  dependency: binutils >= 2.17.50.0.17-3
   provider: binutils.i386 2.18.50.0.9-7.fc10
  dependency: libc.so.6(GLIBC_2.3)
   provider: glibc.i386 2.9-2
◁◁◁◁◁
```

27.3.5 Downloading Packages

If you want to download a package from a repository but do not want to install it outright, you can use the `yumdownloader` program. A command like

```
$ yumdownloader --destdir /tmp hello
```

searches the repositories for the `hello` package just like YUM would and downloads the corresponding file to the `/tmp` directory.

The `--resolve` option causes dependencies to be resolved and any other missing packages to be downloaded as well—but only those that are not installed on the local system.

With the `--urls` option, nothing is downloaded at all, but `yumdownloader` outputs the URLs of the packages it would otherwise have downloaded.

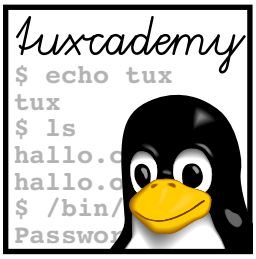
With the `--source` option, `yumdownloader` downloads source RPMs instead of binary RPMs.

Commands in this Chapter

cpio	File archive manager	cpio(1)	422
rpm	Package management tool used by various Linux distributions (Red Hat, SUSE, …)	rpm(8)	418
rpm2cpio	Converts RPM packages to `cpio` archives	rpm2cpio(1)	422
vimtutor	Interactive introduction to `vim`	vimtutor(1)	430
yum	Convenient RPM package maintenance tool	yum(8)	423

Summary

- RPM is a system for Linux software package management which is used by various distributions such as those by Red Hat and Novell/SUSE.
- YUM is a front-end for `rpm` that gives access to package repositories over the network.



A

Sample Solutions

This appendix contains sample solutions for selected exercises.

1.2 There is a copy of `linux-0.01.tar.gz` on `ftp.kernel.org`.

1.3

1. False. GPL software may be sold for arbitrary amounts of money, as long as the buyer receives the source code (etc.) and the GPL rights.
2. False. Companies are encouraged to develop products based on GPL code, but these products must also be distributed under the GPL. Of course a company is not required to give away their product to the world at large—it only needs to make the source code available to its direct customers who bought the executables, but these may make full use of their rights to the software under the GPL.
3. True.
4. False. You may *use* a program freely without having accepted the GPL (it is not a contract). The GPL governs just the *redistribution* of the software, and you can peruse the GPL before doing that. (Interactive programs are supposed to call your attention to the GPL.) The observation is true that only those conditions can be valid that the software recipient could know *before* the purchase of the product; since the GPL gives to the recipient rights that he would otherwise not have had at all—such as the right to distribute original or modified code—this is not a problem: One may ignore the GPL completely and still do all with the software that copyright allows for. This is a marked difference to the EULAs of proprietary programs; these try to establish a contract relationship in which the buyer explicitly *gives away* rights that he would otherwise have been entitled to by copyright law (such as the right to inspect the program to find out its structure). This of course only works *before* the purchase (if at all).

1.5 This exercise can of course not be answered correctly in printed courseware. Look around—on `ftp.kernel.org` or in the weekly edition of `http://lwn.net/`.

2.2 In both cases, the message "`Login incorrect`" appears, but only after the password has been prompted for and entered. This is supposed to make it difficult to guess valid user names (those that do not elicit an error message right away). The way the system is set up, a "cracker" cannot tell whether the user name was

invalid already, or whether the password was wrong, which makes breaking into the system a lot more difficult.

2.5 Decency forbids us from printing a sample program here. It is reasonably simple using the (deprecated) C function `getpass`(3).

3.2 In the login shell, the output is "`-bash`", whereas in the "subshell" it is "`bash`". The minus sign at the beginning tells the shell to behave as a login shell rather than a "normal" shell, which pertains to the initialisation.

3.3 `alias` is an internal command (does not work otherwise). `rm` is an external command. Within bash, `echo` and `test` are internal commands but are also available as external commands (executable program files), since other shells do not implement them internally. In bash's case, they are internal mostly for reasons of efficiency.

4.2 Try "`apropos process`" or "`man -k process`".

4.5 The format and tools for info files were written in the mid-1980s. HTML wasn't even invented then.

5.1 In theory, you could start every program on the system and check whether it behaves like a text editor … but that might take more time than this exercise is worth. You could, for example, begin with a command like "`apropos edit`" and see which of the man pages in the output correspond with an actual text editor (rather than an editor for graphics, icons, X resources or some such). Text editors from graphical desktop environments such as KDE or GNOME frequently do not actually have man pages, but are documented within the desktop environment, so it can be useful to check the desktop's menus for a submenu such as "Editors" or "Office". The third possibility is to use a package management command—such as "`rpm -qa`" or "`dpkg -l`"—to obtain a list of installed software packages and check for text editors there.

5.2 The program is called `vimtutor`.

6.1 In Linux, the current directory is a process attribute, i. e., every process has its own current directory (with DOS, the current directory is a feature of the drive, which of course is inappropriate in a multi-user system). Therefore `cd` must be an internal command. If it was an external command, it would be executed in a new process, change that process's current directory and quit, while the invoking shell's current directory would remain unchanged throughout the process.

6.4 If a file name is passed to `ls`, it outputs information about that file only. With a directory name, it outputs information about all the files in that directory.

6.5 The `-d` option to `ls` does exactly that.

6.6 This could look approximately like so:

```
$ mkdir -p grd1-test/dir1 grd1-test/dir2 grd1-test/dir3
$ cd grd1-test/dir1
$ vi hello
$ cd
$ vi grd1-test/dir2/howdy
$ ls grd1-test/dir1/hallo grd1-test/dir2/howdy
grd1-test/dir1/hello
```

```
grd1-test/dir2/howdy
$ rmdir grd1-test/dir3
$ rmdir grd1-test/dir2
rmdir: grd1-test/dir2: Directory not empty
```

To remove a directory using `rmdir`, it must be empty (except for the entries "`.`" and "`..`", which cannot be removed).

6.7 The matching names are, respectively

(a) `prog.c`, `prog1.c`, `prog2.c`, `progabc.c`

(b) `prog1.c`, `prog2.c`

(c) `p1.txt`, `p2.txt`, `p21.txt`, `p22.txt`

(d) `p1.txt`, `p21.txt`, `p22.txt`, `p22.dat`

(e) all names

(f) all names except `prog` (does not contain a period)

6.8 "`ls`" without arguments lists the content of the current directory. Directories in the current directory are only mentioned by name. "`ls`" with arguments, on the other hand (and in particular "`ls *`"—`ls` does not get to see the search pattern, after all) lists information about the given arguments. For directories this means that the *content* of the directories is listed as well.

6.9 The "`-l`" file (visible in the output of the first command) is interpreted as an option by the `ls` command. Thus it does not show up in the output of the second command, since `ls` with path name arguments only outputs information about the files specified as arguments.

6.10 If the asterisk matched file names starting with a dot, the recursive deletion command "`rm -r *`" would also apply to the "`..`" entry of a directory. This would delete not just subdirectories of the current directory, but also the enclosing directory and so on.

6.11 Here are the commands:

```
$ cd
$ cp /etc/services myservices
$ mv myservices src.dat
$ cp src.dat /tmp
$ rm src.dat /tmp/src.dat
```

6.12 When you rename a directory, all its files and subdirectories will automatically be "moved" so as to be within the directory with its new name. An `-R` to `mv` is therefore completely unnecessary.

6.13 The simple-minded approach—something like "`rm -file`"—fails because `rm` misinterprets the file name as a sequence of options. The same goes for commands like "`rm "-file"`" or "`rm '-file'`". The following methods work better:

1. With "`rm ./-file`", the dash is no longer at the start of the parameter and thus no longer introduces an option.
2. With "`rm -- -file`", you tell `rm` that there are definitely no options after the "`--`" but only path names. This also works with many other programs.

6.14 During the replacement of the "*", the "-i" file is picked up as well. Since the file names are inserted into the command line in ASCII order, rm sees a parameter list like

```
-i a.txt b.jpg c.dat                                    or whatever
```

and considers the "-i" the *option* -i, which makes it remove files only with confirmation. We hope that this is sufficient to get you to think things over.

6.15 If you edit the file via one link, the new content should also be visible via the other link. However, there are "clever" editors which do not overwrite your file when saving, but save a new file and rename it afterwards. In this case you will have two different files again.

6.16 If the target of a symbolic link does not exist (any longer), accessing that "dangling" link will lead to an error message.

6.17 To itself. You can recognise the file system root directory by this.

6.18 On this system, the /home directory is on a separate partition and has inode number 2 on that partition, while the / directory is inode number 2 on its own file system. Since inode numbers are only unique within the same physical file system, the same number can show up for different files in "ls -i" output; this is no cause for concern.

6.19 Hard links are indistinguishable, equivalent names for the same file (or, hypothetically, directory). But every directory has a "link" called ".." referring to the directory "above". There can be just one such link per directory, which does not agree with the idea of several equivalent names for that directory. Another argument against hard links on directories is that for every name in the file system tree there must be a unique path leading to the root directory (/) in a finite number of steps. If hard links to directories were allowed, a command sequence such as

```
$ mkdir -p a/b
$ cd a/b
$ ln .. c
```

could lead to a loop.

6.20 The reference counter for the subdirectory has the value 2 (one link results from the name of the subdirectory in ~, one from the "." link in the subdirectory itself). If there were additional subdirectories within the directory, their ".." links would increment the reference counter beyond its minimum value of 2.

6.21 The chain of symbolic links will be followed until you reach something that is not a symbolic link. However, the maximum length of such chains is usually bounded (see Exercise 6.22).

6.22 Examining this question becomes easier if you can use shell loops (see Section 8.6). Something like

```
$ touch d
$ ln -s d L1
$ i=1
$ while ls -lH L$i >/dev/null
> do
>   ln -s L$i L$((i+1))
```

```
>   i=$((i+1))
> done
```

creates a "chain" of symbolic links where every link points to the previous one. This is continued until the "`ls -lH`" command fails. The error message will tell you which length is still allowed. (On the author's computer, the result is "40", which in real life should not unduly cramp anybody's style.)

6.23 Hard links need hardly any space, since they are only additional directory entries. Symbolic links are separate files and need one inode at least (every file has its own inode). Also, some space is required to store the name of the target file. In theory, disk space is assigned to files in units of the file system's block size (1 KiB or more, usually 4 KiB), but there is a special exception in the `ext` file systems for "short" symbolic links (smaller than approximately 60 bytes), which can be stored within the inode itself and do not require a full data block. Other file systems such as the Reiser file system can handle short files of any type very efficiently, thus the space required for symbolic links ought to be negligible.

6.24 One possible command could be "`find / -size +1024k -print`".

6.25 The basic approach is something like

```
find . -maxdepth 1 ⟨tests⟩ -ok rm '{}' \;
```

The ⟨*tests*⟩ should match the file as closely as possible. The "`-maxdepth 1`" option restricts the search to the current directory (no subdirectories). In the simplest case, use "`ls -i`" to determine the file's inode number (e.g., 4711) and then use

```
find . -maxdepth 1 -inum 4711 -exec rm -f '{}' \;
```

to delete the file.

6.26 Add a line like

```
find /tmp -user $LOGNAME -type f -exec rm '{}' \;
```

or—more efficiently—

```
find /tmp -user $LOGNAME -type f -print0 \
    | xargs -0 -r rm -f
```

to the file `.bash_logout` in your home directory. (The `LOGNAME` environment variable contains the current user name.)

6.27 Use a command like "`locate '*/README'`". Of course, something like "`find / -name README`" would also do the trick, but it will take *a lot* longer.

6.28 Immediately after its creation the new file does not occur in the database and thus cannot be found (you need to run `updatedb` first). The database also doesn't notice that you have deleted the file until you invoke `updatedb` again.—It is best not to invoke `updatedb` directly but by means of the shell script that your distribution uses (e. g., `/etc/cron.daily/find` on Debian GNU/Linux). This ensures that `updatedb` uses the same parameters as always.

6.29 `slocate` should only return file names that the invoking user may access. The `/etc/shadow` file, which contains the users' encrypted passwords, is restricted to the system administrator (see *Linux Administration I*).

7.1 A (probable) explanation is that the `ls` program works roughly like this:

```
Read directory information to list l;
if (option -U not specified) {
    Sort the entries of l;
}
Write l to standard output;
```

That is, everything is being read, then sorted (or not), and then output.

The other explanation is that, at the time the `filelist` entry is being read, there has not in fact been anything written to the file to begin with. For efficiency, most file-writing programs buffer their output internally and only call upon the operating system to write to the file if a substantial amount of data has been collected (e. g. 8192 bytes). This can be observed with commands that produce very much output relatively slowly; the output file will grow by 8192 bytes at a time.

7.2 When `ls` writes to the screen (or, generally, a "screen-like" device), it formats the output differently from when it writes to a "real" file: It tries to display several file names on the same line if the file names' length permits, and can also colour the file names according to their type. When output is redirected to a "real" file, just the names will be output one per line, with no formatting.

At first glance this seems to contradict the claim that programs do not know whether their output goes to the screen or elsewhere. This claim is correct in the normal case, but if a program is seriously interested in whether its output goes to a screen-like device (a "terminal") it can ask the system. In the case of `ls`, the reasoning behind this is that terminal output is usually looked at by people who deserve as much information as possible. Redirected output, on the other hand, is processed by other programs and should therefore be simple; hence the limitation to one file name per line and the omission of colors, which must be set up using terminal control characters which would "pollute" the output.

7.3 The shell arranges for the output redirection before the command is invoked. Therefore the command sees only an empty input file, which usually does not lead to the desired result.

7.4 The file is read from the beginning, and all that is read is appended to the file at the same time, so that it grows until it takes up all the free space on the disk.

7.5 You need to redirect standard output to standard error output:

```
echo Error >&2
```

7.6 There is nothing wrong in principle with

```
… | tee foo | tee bar | …
```

However, it is easier to write

```
… | tee foo bar | …
```

See also `tee`'s documentation (man page or info page).

7.7 Pipe the list of file names through "`cat -b`".

7.8 One method would be "`head -n 13 | tail -n 1`".

7.10 `tail` notices it, emits a warning, and continues from the new end of file.

7.11 The `tail` window displays

```
Hello
orld
```

The first line results from the first `echo`; the second `echo` overwrites the complete file, but "`tail -f`" knows that it has already written the first six characters of the file ("`Hello`" and a newline character)—it just waits for the file to become longer, and then outputs whatever is new, in particular, "`orld`" (and a newline character).

7.12 With "`a`", invisible characters are displayed using their symbolic names like "`cr`" or "`lf`", with "`c`" using backslash sequences such as "`\r`" or "`\n`". With "`a`", the space character appears as "`sp`".

7.13 The desired range of values ($0 \ldots 65535 = 2^{16} - 1$) corresponds exactly to the range of values that can be stored in two bytes. Thus we must read two bytes from `/dev/random` and output them as a decimal number:

```
$ r=`od -An -N2 -tu2 /dev/random`
$ echo $r
4711
```

The `-N2` option reads two bytes, and `-tu2` formats them as an unsigned 2-byte decimal number. `-An` suppresses the position offset (see Table 7.4).

7.14 Try

```
$ echo "ALEA IACTA EST" | tr A-Z D-ZA-C
DOHD LDFWD HVW
$ echo "DOHD LDFWD HVW" | tr A-Z X-ZA-W
ALEA IACTA EST
```

Similar to Caesar's cipher is the "ROT13" method used, e. g., to publish potentially-offensive jokes on USENET while preventing sensitive persons from accidentally seeing them (the method leaves something to be desired as far as "real" encryption of private content is concerned). ROT13 can be described by the command "`tr A-Za-z N-ZA-Mn-za-m`"; the advantage of this method is that you get the original text again if you apply it twice over. The ROT13 routine in a news reader can thus be used for decryption as well as encryption, which simplifies the code.

7.15 The easy way is of course "`tr AEIOU AAAAA`". To save typing, "`tr AEIOU A`" will also do.

7.16 One way to do this is

```
$ tr -cs '[:alpha:]' '\n'
```

The "`-c [:alpha:] \n`" converts all non-letters to newline characters, the `-s` option causes runs of these newline characters to be replace by a single newline. It is advisable to put the parameters in single quotes to keep the brackets from being processed by the shell. (If you want to do this for German-language text, you should set the `LANG` environment to `de_DE` (or some such) to ensure that umlauts and "ß" are considered letters.)

7.17 To make this work, the "`-`" character must occur at the end of $\langle s_1 \rangle$—if it occurs at the beginning, "`-az`" will look like a command option (which `tr` does not understand), if it occurs in the middle, "`a-z`" looks like a character range. Alternatively, with more typing, you could circumscribe the "`-`" character by "`[=-=]`" (see Table 7.6), which may occur anywhere in the string.

7.18 Use something like "`cat -T`" (see the documentation) or "`od -tc`".

7.19 The command to do this is "`nl -v 100 -l 2 frog.txt`".

7.20 The `tac` command is your friend:

```
$ tac frog.txt | cat -n | tac
```

("`nl -ba`" would have been fine instead of "`cat -n`").

7.21 With the first command, `wc` considers all input files separately and outputs a line of totals in addition to the results for the individual files. With the second command, `wc` considers its standard input, where the fact that this consists of three separate files is no longer evident. Therefore, with the second command, there is just one line of output instead of four.

7.24 The line containing the name "de Leaping" is sorted wrongly, since on that line the second field isn't really the first name but the word "Leaping". If you look closely at the examples you will note that the sorted output is always correct—regarding "Leaping", not "Gwen". This is a strong argument for the second type of input file, the one with the colon as the separator character.

7.25 You can sort the lines by year using "`sort -k 1.4,1.8`". If two lines are equal according to the sort key, `sort` makes an "emergency comparison" considering the whole line, which in this case leads to the months getting sorted correctly within every year. If you want to be sure and very explicit, you could also write "`sorkt -k 1.4,1.8 -k 1.1,1.2`".

7.26 With the solution of Exercise 7.16, the matter is straightforward:

```
$ tr -cs '[:alpha:]' '\n' | sort -uf
```

The `-u` option to `sort` ensures that from a sequence of equal words, only the first word will be output. The `-f` option treats uppercase and lowercase letters as identical ("`LC_COLLATE=en_GB`" would do that as well).

7.30 Use something like

```
cut -d: -f 4 /etc/passwd | sort -u | wc -l
```

The `cut` command isolates the group number in each line of the user database. "`sort -u`" (see also Exercise 7.26) constructs a sorted list of all group numbers containing each group number exactly once. Finally, "`wc -l`" counts the number of lines in that list. The result is the number of different primary groups in use on the system.

8.1 For example:

1. `%d-%m-%Y`
2. `%y-%j (WK%V)`
3. `%Hh%Mm%Ss`

8.2 We don't know either, but try something like "`TZ=America/Los_Angeles date`".

8.4 If you change an environment variable in the child process, its value in the parent process remains unmodified. There are ways and means to pass information back to the parent process but the environment is not one.

8.5 Start a new shell and remove the `PATH` variable from the environment (without deleting the variable itself). Try starting external programs.—If `PATH` does not exist at all, the shell will not start external programs.

8.6 Unfortunately we cannot offer a system-independent sample solution; you need to see for yourself (using `which`).

8.7 Using `whereis`, you should be able to locate two files called `/usr/share/man/man1/crontab.1.gz` and `/usr/share/man/man5/crontab.5.gz`. The former contains the documentation for the actual `crontab` command, the latter the documentation for the format of the files that `crontab` creates. (The details are irrelevant for this exercise; see *Advanced Linux*.)

8.8 `bash` uses character sequences of the form "`!`⟨*character*⟩" to access previous commands (an alternative to keyboard functions such as Ctrl+r which have migrated from the C shell to `bash`). The "`!"`" character sequence, however, counts as a syntax error.

8.9 None.

8.10 If the file name is passed as a parameter, `wc` insists on outputting it together with the number of lines. If `wc` reads its standard input, it only outputs the line count.

8.11 Try something like

```
#!/bin/bash
pattern=$1
shift
◁◁◁◁◁
for f
do
    grep $pattern "$f" && cp "$f" backup
done
```

After the `shift`, the regular expression is no longer the first parameter, and that must be taken into account for "`for f`".

8.12 If the `-f` file test is applied to a symbolic link, it always applies to the file (or directory, or whatever) that the link refers to. Hence it also succeeds if the name in question is really just a symbolic link. (Why does this problem *not* apply to `filetest2`?)

8.14 With the first command line, you need to wait 10 seconds for a new shell command prompt. With the second, the waiting time amounts to 5 seconds, after which the second `sleep` is started in the background. With the third line, the new command prompt appears immediately, after two background processes have been created.

9.2 You can find out about this using something like

```
ls /bin /sbin /usr/bin /usr/sbin | wc -l
```

Alternatively, you can hit Tab twice at a shell prompt—the shell will answer something like

```
Display all 2371 possibilities? (y or n)
```

and that is—depending on PATH—your answer. (If you are logged in as a normal—non-privileged—user, the files in /sbin and /usr/sbin will not normally be included in the total.)

9.3 Use "grep ⟨*pattern*⟩ *.txt /dev/null" instead of "grep ⟨*pattern*⟩ *.txt". Thus grep always has at least two file name parameters, but /dev/null does not otherwise change the output.—The GNU implementation of grep, which is commonly found on Linux, supports an -H option which does the same thing but in a non-portable manner.

9.4 With cp to an existing file, the file is opened for writing and truncated to length 0, before the source data is written to it. For /dev/null, this makes the data disappear. With mv to an existing file, the target file is first removed—and that is a directory operation which, disregarding the special nature of /dev/null, simply removes the name null from the directory /dev and creates a new file called null with the content of foo.txt in its place.

9.6 It is inadvisable because firstly it doesn't work right, secondly the data in question isn't worth backing up anyway since it is changing constantly (you would be wasting lots of space on backup media and time for copying), and thirdly because such a backup could never be restored. Uncontrolled write operations to, say, /proc/kcore will with great certainty lead to a system crash.

10.1 Access control applies to normal users but not the administrator. root may do anything! The root account should only be used to execute commands that really require root's privileges, e. g., to partition the disk, to create file systems, to add user accounts, or to change system configuration files. All other actions should be performed from an unprivileged account. This includes invoking administration commands to gather information (where possible) and unpacking tar archives.

10.2 As root you may do anything, therefore it is very easy to damage the system, e. g., through inadvertently mistyped commands.

10.3 This question aims at a comparison to other operating systems. Depending on the system in question, there are no access controls at all (DOS, Windows 95/98) or different methods for access control (Windows NT/2000/XP or Windows Vista). Accordingly, the former do not support administrator access (as opposed to normal user access), while the latter even allow the creation of several administrator accounts.

10.4 Basically you can log in as root, or create a UID 0 shell using su. The latter method is better, e. g., because the change including the former UID is logged.

10.5 The shell prompt often looks different. In addition, the id command may help.

10.6 You can either log in directly or `su`. For frequent changes, it is a good idea to log in on two consoles at the same time, and obtain a `root` shell using `su` on one. Alternatively, you could open several terminal windows on a GUI.

10.7 You will generally find the log entry in `/var/log/messages`.

10.10 The obvious advantage is that administration is possible from anywhere, if necessary by using an internet-enabled cell phone on the beach, and without having to have access to specialised hardware or software. The obvious disadvantage is that you need to secure access to the administration tool very carefully, in order to prevent unbidden guests to "misconfigure" your system (or worse). This may imply that (the obvious advantage notwithstanding) you may be able to provide the administration tool only from within the local network, or that you should secure access to it using strong cryptography (e. g., SSL with client certificates). If you consider deploying Webmin in your company, you should discuss the possibility of external access *very carefully* with the appropriate decision makers and/or corporate data protection officers in order to avoid extremely dire consequences that could hit you if problems appear. Consider yourself warned.

11.1 By their respective numerical UIDs and GIDs.

11.2 This works but is not necessarily a good idea. As far as the system is concerned, the two are a single user, i. e., all files and processes with that UID belong to both user names.

11.3 A pseudo-user's UID is used by programs in order to obtain particular well-defined access rights.

11.4 Whoever is in group `disk` has block-level read and write permission to the system's disks. With knowledge of the file system structure it is easy to make a copy of `/bin/sh` into a SUID `root` shell (Section 12.5) by changing the file system metadata directly on disk. Thus, group `disk` membership is tantamount to `root` privileges; you should put nobody into the `disk` group whom you would not want to tell the `root` password outright.

11.5 You will usually find an "`x`". This is a hint that the password that would usually be stored there is indeed stored in another file, namely `/etc/shadow`, which unlike the former file is readable only for `root`.

11.6 There are basically two possibilities:

1. Nothing. In this case the system should turn you away after you entered your password, since no user account corresponds to the all-uppercase user name.
2. From now on, the system talks to you in uppercase letters only. In this case your Linux system assumes that you are sitting in front of an absolutely antediluvial terminal (1970s vintage or so) that does not support lowercase letters, and kindly switches its processing of input and output data such that uppercase letters in the input are interpreted as lowercase, and lowercase letters in the output are displayed as uppercase. Today this is of limited benefit (except if you work in a computer museum), and you should log out as quickly again as possible before your head explodes. Since this behaviour is so atavistic, not every Linux distribution goes along with it, though.

11.7 Use `getent`, `cut`, and `sort` to generate lists of user names for the databases, and `comm` to compare the two lists.

11.8 Use the `passwd` command if you're logged in as user `joe`, or "`passwd joe`" as `root`. In `joe`'s entry in the `/etc/shadow` file there should be a different value in the second field, and the date of the last password change (field 3) should show the current date (in what unit?)

11.9 As `root`, you set a new password for him using "`passwd dumbo`", as you cannot retrieve his old one even though you are the administrator.

11.10 Use the command "`passwd -n 7 -x 14 -w 2 joe`". You can verify the settings using "`passwd -S joe`".

11.11 Use the `useradd` command to create the user, "`usermod -u`" to modify the UID. Instead of a user name, the files should display a UID as their owner, since no user name is known for that UID …

11.12 For each of the three user accounts there should be one line in `/etc/passwd` and one in `/etc/shadow`. To work with the accounts, you do not necessarily need a password (you can use `su` as `root`), but if you want to login you do. You can create a file without a home directory by placing it in `/tmp` (in case you forgot—a home directory for a new user would however be a good thing).

11.13 Use the `userdel` command to delete the account. To remove the files, use the "`find / -uid ⟨`*UID*`⟩ -delete`" command.

11.14 If you use "`usermod -u`", you must reassign the user's file to the new UID, for example by means of "`find / -uid ⟨`*UID*`⟩ -exec chown test1 {} \;`" or (more efficiently) "`chown -R --from=⟨`*UID*`⟩ test1 /`". In each case, ⟨*UID*⟩ is the (numerical) former UID.

11.15 You can either edit `/etc/passwd` using `vipw` or else call `usermod`.

11.16 Groups make it possible to give specific privileges to groups [sic!] of users. You could, for example, add all HR employees to a single group and assign that group a working directory on a file server. Besides, groups can help organise access rights to certain peripherals (e. g., by means of the groups `disk`, `audio`, or `video`).

11.17 Use the "`mkdir ⟨`*directory*`⟩`" command to create the directory and "`chgrp ⟨`*groupname*`⟩ ⟨`*directory*`⟩`" to assign that directory to the group. You should also set the SGID bit to ensure that newly created files belong to the group as well.

11.18 Use the following commands:

```
# groupadd test
# gpasswd -a test1 test
Adding user test1 to group test
# gpasswd -a test2 test
Adding user test2 to group test
# gpasswd test
Changing the password for group test
New Password:x9q.Rt/y
Re-enter new password:x9q.Rt/y
```

To change groups, use the "`newgrp test`" command. You will be asked for the password only if you are not a member of the group in question.

12.1 A new file is assigned to your current primary group. You can't assign a file to a group that you are not a member of—unless you are `root`.

12.3 077 and "'`u=rwx,go=`"', respectively.

12.5 This is the SUID or SGID bit. The bits cause a process to assume the UID/GID of the executable file rather than that of the executing user. You can see the bits using "`ls -l`". Of course you may change all the permissions on your own files. However, at least the SUID bit only makes sense on binary executable files, not shell scripts and the like.

12.6 One of the two following (equivalent) commands will serve:

```
$ umask 007
$ umask -S u=rwx,g=rwx
```

You may perhaps ask yourself why this umask contains `x` bits. They are indeed irrelevant for files, as files are not created executable by default. However it might be the case that subdirectories are desired in the project directory, and it makes sense to endow these with permissions that allow them to be used reasonably.

12.7 The so-called "sticky bit" on a directory implies that only the owner of a file (or the owner of the directory) may delete or rename it. You will find it, e. g., on the `/tmp` directory.

12.9 This doesn't work with the `bash` shell (at least not without further trickery). We can't speak for other shells here.

12.11 You cannot do this with `chattr` alone, since various attributes can be displayed with `lsattr` but not set with `chattr`. Read up on the details in `chattr`(1).—In addition, some attributes are only defined for "plain" files while others are only defined for directories; you will, for example, find it difficult to make the `D` and `E` attributes visible for the same "file system object" at the same time. (The `E` attribute is to do with transparent compression, which cannot be used on directories, while `D` only applies to directories—write operations to such directories will be performed synchronously.)

13.1 In the directory of a process below `/proc` there is a file called `environ` which contains the environment variables of that process. You can output this file using `cat`. The only blemish is that the variables in this file are separated using zero bytes, which looks messy on the screen; for convenience, you might use something like "`tr "\0" "\n" </proc/4711/environ`" to display the environment.

13.2 Funnily enough, the limit is not documented in any obvious placees. In `/usr/include/linux/threads.h` on a Linux 2.6 kernel, the constant `PID_MAX_LIMIT` is defined with a value of 32768; this is the lowest value that will by default *not* be assigned to processes. You can query the actual value in `/proc/sys/kernel/pid_max` (or even change it—the maximum for 32-bit platforms is actually 32768, while on 64-bit systems you may set an arbitrary value of up to 2^{22}, which is approximately 4 million).

The PIDs assigned to processes rise monotonically at first. When the abovementioned limit is reached, assignment starts again with lower PIDs, where PIDs that are still being used by processes are of course not given again to others. Many low PIDs are assigned to long-running daemons during the boot process, and for this reason after the limit has been reached, the search for unused PIDs starts again not at PID 1 but at PID 300. (The details are in the `kernel/pid_namespace.c` file within the Linux source code.)

13.4 As we said, zombies arise when the parent process does not pick up the return code of a child process. Thus, to create a zombie you must start a child process and then prevent the parent process from picking up its return code, for example by stopping it by means of a signal. Try something like

```
$ sh
$ echo $$                                                    In the subshell
12345
$ sleep 20
                                                    In a different window:
$ kill -STOP 12345
                                                                  Wait
$ ps u | grep sleep
joe 12346 0.0  0.0  3612  456 pts/2  Z 18:19 0:00 sleep 20
```

13.5 Consult `ps`(1).

13.6 Try

```
$ ps -o pid,ppid,state,cmd
```

13.7 Usually `SIGCHLD` ("child process finished"—sometimes called `SIGCLD`), `SIGURG` (urgent data was received on a network connection) and `SIGWINCH` (the size of the window for a text-based program was changed). These three events are so inane that the process should not be terminated on their account.

13.8 Something like

```
$ pgrep -u hugo
```

should suffice.

13.10 Use, e. g., the "`renice -10` ⟨*PID*⟩" command. You can only specify negative nice values as `root`.

14.2 `sda1`, `sda2`, `sda5`, `sda6`, and `sdb1`, `sdb5`, `sdb6`, `sdb7`.

15.2 Use `tune2fs` with the `-c`, `-u` and `-m` options.

15.3 `mkreiserfs /dev/sdb5`

15.6 `/etc/fstab` contains all frequently-used file systems and their mount points, while `/etc/mtab` contains those file systems that are actually mounted at the moment.

16.1 The boot loader can be placed inside the MBR, in another (partition) boot sector, or a file on disk. In the two latter cases, you will need another boot loader that can "chain load" the Linux boot loader. Be that as it may, for a Linux system you absolutely need a boot loader that can boot a Linux kernel, such as GRUB (there are others).

16.3 Assign a password preventing the unauthorised entry of kernel parameters. With GRUB Legacy, e. g., using

```
password --md5 ⟨encrypted keyword⟩
```

`lock` helps with the password request for a specific operating system.

17.3 You can display the previous and current runlevel using `runlevel`. If the previous runlevel is "`N`" that means "none"—the system started into the current runlevel. To change, say "`init 2`", then "`runlevel`" again to check.

17.4 A possible entry for the `inittab` file might be

```
aa:A:ondemand:/bin/date >/tmp/runlevel-a.txt
```

This entry should write the current time to the mentioned file if you activate it using "`telinit A`". Don't forget the "`telinit q`" to make `init` reread its configuration file.

17.5 Call the `syslog` init script with the `restart` or `reload` parameters.

17.6 For example, by using "`chkconfig -l`" (on a SUSE or Red Hat system).

17.7 It is tempting just to remove the symbolic links from the runlevel directory in question. However, depending on the distribution, they may reappear after the next automated change. So if your distribution uses a tool like `chkconfig` or `insserv` you had better use that.

17.8 You should be prepared for the system asking for the `root` password.

17.10 Use the

```
# shutdown -h +15 'This is just a test'
```

command; everything that you pass to `shutdown` after the delay will be sent to your users as a broadcast message. To cancel the shutdown, you can either interrupt the program using the Ctrl+C key combination (if you started `shutdown` in the foreground), or give the "`shutdown -c`" command.

17.10 The file name will be sent as the message.

18.4 The unit file does not need to be modified in order to express dependencies. This makes the automatic installation and, in particular, deinstallation of units as part of software packages easier (e. g., in the context of a distribution-specific package management tool) and allows the seamless updating of unit files by a distribution.

18.10 There is no exact equivalent because systemd does not use the runlevel concept. You can, however, display all currently active targets:

```
# systemctl list-units -t target
```

18.11 "`systemctl kill`" guarantees that the signal will only be sent to processes belonging to the unit in question. The other two commands send the signal to all processes whose name happens to be `example`.

18.13 You can't ("`systemctl mask`" outputs an error message). You must deactivate the service and then remove, move, or rename the unit file.

19.1 (a) On 1 March, 5 P. M.; (b) On 2 March, 2 P. M.; (c) On 2 March, 4 P. M.; (d) On 2 March, 1 A. M.

19.2 Use, e. g., "`at now + 3 minutes`".

19.4 One possibility might be "`atq | sort -bk 2`".

19.6 Your task list itself is owned by you, but you do not have permission to write to the `crontabs` directory. Debian GNU/Linux, for example, uses the following permission bits:

```
$ ls -ld /var/spool/cron/crontabs
drwx-wx--T 2 root crontab 4096 Aug 31 01:03 /var/spool/cron/crontabs
```

As usual, `root` has full access to the file (in fact regardless of the permission bits) und members of the `crontab` group can write to files in the directory. Note that members of that group have to know the file names in advance, because the directory is not searchable by them (`ls` will not work). The `crontab` utility is a set-GID program owned by the `crontab` group:

```
$ ls -l $(which crontab)
-rwxr-sr-x 1 root crontab 27724 Sep 28 11:33 /usr/bin/crontab
```

So it is executed with the access permissions of the `crontab` group, no matter which users invokes the program. (The set-GID mechanism is explained in detail in the document *Linux System Administration I*.)

19.7 Register the job for the 13th of every month and check within the script (e. g., by inspecting the result of "`date +%u`") if the current day is a Friday.

19.8 The details depend on the distribution.

19.9 Use something like

```
* * * * logger -p local0.info "cron test"
```

To write the date to the file every other minute, you could use the following line:

```
0,2,4,◁◁◁◁◁,56,58 * * * * /bin/date >>/tmp/date.log
```

But this one is more convenient:

```
*/2 * * * * /bin/date >>/tmp/date.log
```

19.10 The commands to accomplish this are »`crontab -l`« and »`crontab -r`«.

19.11 You should add `hugo` to the `/etc/cron.deny` file (on SUSE distributions, `/var/spool/cron/deny`) or delete him from `/etc/cron.allow`.

19.13 `/etc/cron.daily` contains a script called `0anacron` which is executed as the first job. This script invokes "`anacron -u`"; this option causes `anacron` to update the time stamps without actually executing jobs (which is the next thing that `cron` will do). When the system is restarted, this will prevent `anacron` from running jobs unnecessarily, at least if the re-boot occurs after `cron` has done its thing.

20.1 Such events are customarily logged by `syslogd` to the `/var/log/messages` file. You can solve the problem most elegantly like

```
# grep 'su: (to root)' /var/log/messages
```

20.2 Insert a line

```
*.*                -/var/log/test
```

anywhere in `/etc/syslog.conf`. Then tell `syslogd` using "`kill -HUP …`" to re-read its configuration file. If you check `/var/log` afterwards, the new file should already be there and contain some entries (which ones?).

20.3 On the receiving system, `syslogd` must be started using the `-r` parameter (see p. 304). The sending system needs a configuration line of the form

```
local0.*     @blue.example.com
```

(if the receiving system is called "`blue.example.com`").

20.4 The only safe method consists of putting the log out of the attacker's reach. Therefore you must send the messages to another host. If you don't want the attacker to be able to compromise that host, too, then you should connect the logging host to the one storing the log by means of a serial interface, and configure `syslogd` such that it sends the messages to the corresponding device (`/dev/ttyS0` or something). On the storing host, a simple program can accept the messages on the serial interface and store them or process them further. Alternatively, you could of course also use an (old-fashioned) dot-matrix printer with fan-fold paper.

20.5 You can, among other things, expect information about the amount and usage of RAM, available CPUs, disks and other mass storage devices (IDE and SCSI), USB devices and network cards. Of course the details depend on your system and your Linux installation.

20.10 Versuchen Sie etwas wie

```
# We assume a suitable source definition.
filter login_hugo {
    facility(authpriv)
      and (match("session opened") or match("session closed"))
      and match("user hugo");
};
destination d_root { usertty("root"); };
log { source(...);
    filter(login_hugo);
    destination(d_root);
};
```

20.14 In `/etc/logrotate.d`, create an arbitrarily-named file containing the lines

```
/var/log/test {
    compress
    dateext
    rotate 10
    size 100
    create
}
```

21.1 Text files are, in principle, amenable to the standard Unix tools (`grep` etc.) and, as such, ideologically purer. They can be inspected without specialised software. In addition, the concept is very well understood and there are gazillions of tools that help evaluate the traditional log files. Disadvantages include the fact that text files are difficult to search, and any sort of targeted evaluation is either extremely tedious or else requires additional (non-standardised) software. There is no type of cryptographic protection against the manipulation of log entries, and the amount of information that can be written to the log is limited.

22.2 ISO/OSI layer 2 describes the interaction between two nodes that are connected directly (e. g., via Ethernet). Layer 3 describes the interaction among nodes that are not networked directly, and thus includes routing and media-independent addressing (e. g., IP over Ethernet or Token-Ring or …).

22.3 You can look to the `/etc/services` and (possibly) `/etc/protocols` files for inspiration. You will have to assign the protocols to layers by yourself. *Hint:* Practically everything mentioned in `/etc/services` belongs to the application layer.

22.4 It is, of course, impossible to give a specific answer, but usually a TTL of 30–40 should be more than sufficient. (The default value is 64.) You can determine the minimal TTL by means of sending successive packets with increasing TTL (starting at TTL 1) to the desired target. If you receive an ICMP error message from some router telling you that the packet was discarded, the TTL is still too low. (The `traceroute` program automates this procedure.) This "minimal" TTL is naturally not a constant, since IP does not guarantee a unique path for packet delivery.

22.5

1. The `127.55.10.3` address cannot be used as a host address since it is that network's broadcast address.
2. The `138.44.33.12` address can be used as a host address.
3. The `10.84.13.160` address is the network address of the network in question and is thus unavailable as a host address.

22.6 For example, to implement certain network topologies or assign parts of the address range to computers in different providers.

22.7 There are 16 subnets altogether (which is obvious from the fact that the subnet mask has four more bits set than the original netmask). Further subnets are `145.2.0.0`, `145.2.16.0`, `145.2.48.0`, `145.2.80.0`, `145.2.96.0` `145.2.112.0`, `145.2.144.0`, `145.2.176.0`, `145.2.208.0`, `145.2.224.0`, and `145.2.240.0`. The node with the IP address `145.2.195.13` is part of the `145.2.192.0` subnet.

23.1 `lsmod` displays all loaded modules. "`rmmod` ⟨*module name*⟩" tries to unload a module, which will fail when the module is still in use.

23.2 This is done most easily with `ifconfig`.

23.3 Use "`ifconfig` ⟨*interface*⟩ ⟨*IP address*⟩". To check whether other computers can be reached, use the `ping` command.

24.1 The former should be on the order of tens of microseconds, the latter—depending on the networking infrastructure—in the vicinity of milliseconds.

24.2 Try something like

```
# ping -f -c 1000000 localhost
```

The total running time is at the end of the penultimate line of output from `ping`. (On the author's system it takes approximately 13 seconds.)

24.3 For example:

```
$ ping6 ff02::2%eth0
PING ff02::2%eth0(ff02::2) 56 data bytes
64 bytes from fe80::224:feff:fee4:1aa1: icmp_seq=1 ttl=64 time=12.4 ms
64 bytes from fe80::224:feff:fee4:1aa1: icmp_seq=2 ttl=64 time=5.27 ms
64 bytes from fe80::224:feff:fee4:1aa1: icmp_seq=3 ttl=64 time=4.53 ms
Ctrl+c
--- ff02::2%eth0 ping statistics ---
3 packets transmitted, 3 received, 0% packet loss, time 2003ms
rtt min/avg/max/mdev = 4.531/7.425/12.471/3.581 ms
```

25.1 During the first login procedure, `ssh` should ask you to confirm the remote host's public server key. During the second login procedure, the public server key is already stored in the `~/.ssh/known_hosts` file and does not need to be reconfirmed.

25.2 In the first case, the connection is refused, since no public server key for the remote host is available from `~/.ssh/known_hosts`. In the second case, the connection is established without a query.

25.3 The file contains public keys only and thus does not need to be kept secret.

25.6 Use something like

```
$ ssh-keygen -l -f ~/.ssh/id_rsa.pub
```

(Does it make a difference whether you specify `id_rsa.pub` or `id_rsa`?)

25.7 Noninteractive programs that need to use an SSH connection are often unable to enter a passphrase. In restricted cases like these, it is conceivable to use a private key without a passphrase. You should then make use of the possibility to make a public key on the remote host useable for specific commands only (in particular the ones that the noninteractive program needs to invoke). Details may be found in `sshd`(8).

25.8 Try "`ssh -X root@localhost`".

25.9 One possible command line might be

```
# ssh -L 4711:localhost:7 user@remote.example.com
```

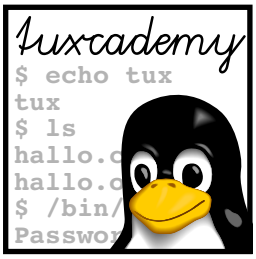
Do consider that `localhost` is evaluated from the perspective of the `remote` host. Unfortunately, `ssh` does not allow symbolic names of well-known ports (as per `/etc/services`).

26.11 Try

```
# dpkg-reconfigure debconf
```

27.1 This is most easily done using something like

```
$ rpm2cpio ⟨package⟩ | cpio -t
```



B

Example Files

In various places, the fairy tale *The Frog King*, more exactly *The Frog King, or Iron Henry*, from *German Children's and Domestic Fairy Tales* by the brothers Grimm, is used as an example. The fairy tale is presented here in its entirety to allow for comparisons with the examples.

```
The Frog King, or Iron Henry

In olden times when wishing still helped one, there lived a king whose
daughters were all beautiful, but the youngest was so beautiful that
the sun itself, which has seen so much, was astonished whenever it
shone in her face.

Close by the king's castle lay a great dark forest, and under an old
lime-tree in the forest was a well, and when the day was very warm,
the king's child went out into the forest and sat down by the side of
the cool fountain, and when she was bored she took a golden ball, and
threw it up on high and caught it, and this ball was her favorite
plaything.

Now it so happened that on one occasion the princess's golden ball did
not fall into the little hand which she was holding up for it, but on
to the ground beyond, and rolled straight into the water.  The king's
daughter followed it with her eyes, but it vanished, and the well was
deep, so deep that the bottom could not be seen. At this she began to
cry, and cried louder and louder, and could not be comforted.

And as she thus lamented someone said to her, »What ails you, king's
daughter? You weep so that even a stone would show pity.«

She looked round to the side from whence the voice came, and saw a
frog stretching forth its big, ugly head from the water. »Ah, old
water-splasher, is it you,« she said, »I am weeping for my golden
ball, which has fallen into the well.«

»Be quiet, and do not weep,« answered the frog, »I can help you, but
what will you give me if I bring your plaything up again?«

»Whatever you will have, dear frog,« said she, »My clothes, my pearls
and jewels, and even the golden crown which I am wearing.«
```

The frog answered, »I do not care for your clothes, your pearls and jewels, nor for your golden crown, but if you will love me and let me be your companion and play-fellow, and sit by you at your little table, and eat off your little golden plate, and drink out of your little cup, and sleep in your little bed - if you will promise me this I will go down below, and bring you your golden ball up again.«

»Oh yes,« said she, »I promise you all you wish, if you will but bring me my ball back again.« But she thought, »How the silly frog does talk. All he does is to sit in the water with the other frogs, and croak. He can be no companion to any human being.«

But the frog when he had received this promise, put his head into the water and sank down; and in a short while came swimming up again with the ball in his mouth, and threw it on the grass. The king's daughter was delighted to see her pretty plaything once more, and picked it up, and ran away with it.

»Wait, wait,« said the frog. »Take me with you. I can't run as you can.« But what did it avail him to scream his croak, croak, after her, as loudly as he could. She did not listen to it, but ran home and soon forgot the poor frog, who was forced to go back into his well again.

The next day when she had seated herself at table with the king and all the courtiers, and was eating from her little golden plate, something came creeping splish splash, splish splash, up the marble staircase, and when it had got to the top, it knocked at the door and cried, »Princess, youngest princess, open the door for me.«

She ran to see who was outside, but when she opened the door, there sat the frog in front of it. Then she slammed the door to, in great haste, sat down to dinner again, and was quite frightened.

The king saw plainly that her heart was beating violently, and said, »My child, what are you so afraid of? Is there perchance a giant outside who wants to carry you away?«

»Ah, no,« replied she. »It is no giant but a disgusting frog.«

»What does that frog want from you?«

»Yesterday as I was in the forest sitting by the well, playing, my golden ball fell into the water. And because I cried so, the frog brought it out again for me, and because he so insisted, I promised him he should be my companion, but I never thought he would be able to come out of his water. And now he is outside there, and wants to come in to me.«

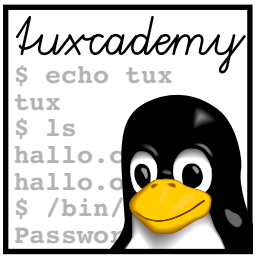
In the meantime it knocked a second time, and cried, »Princess, youngest princess, open the door for me, do you not know what you said to me yesterday by the cool waters of the well. Princess, youngest princess, open the door for me.«

Then said the king, »That which you have promised must you perform. Go and let him in.«

She went and opened the door, and the frog hopped in and followed her, step by step, to her chair. There he sat and cried, »Lift me up beside

```
you.« She delayed, until at last the king commanded her to do it. Once
the frog was on the chair he wanted to be on the table, and when he
was on the table he said, »Now, push your little golden plate nearer
to me that we may eat together.« The frog enjoyed what he ate, but
almost every mouthful she took choked her.

At length he said, »I have eaten and am satisfied, now I am tired,
carry me into your little room and make your little silken bed ready,
and we will both lie down and go to sleep.«  The king's daughter began
to cry, for she was afraid of the cold frog which she did not like to
touch, and which was now to sleep in her pretty, clean little bed.

But the king grew angry and said, »He who helped you when you were in
trouble ought not afterwards to be despised by you.«

So she took hold of the frog with two fingers, carried him upstairs,
and put him in a corner, but when she was in bed he crept to her and
said, »I am tired, I want to sleep as well as you, lift me up or I
will tell your father.«

At this she was terribly angry, and took him up and threw him with all
her might against the wall. »Now, will you be quiet, odious frog,«
said she. But when he fell down he was no frog but a king's son with
kind and beautiful eyes. He by her father's will was now her dear
companion and husband. Then he told her how he had been bewitched by a
wicked witch, and how no one could have delivered him from the well
but herself, and that to-morrow they would go together into his
kingdom.

And indeed, the next morning a carriage came driving up with eight
white horses, which had white ostrich feathers on their heads, and
were harnessed with golden chains, and behind stood the young king's
servant Faithful Henry.

Faithful Henry had been so unhappy when his master was changed into a
frog, that he had caused three iron bands to be laid round his heart,
lest it should burst with grief and sadness. The carriage was to
conduct the young king into his kingdom. Faithful Henry helped them
both in, and placed himself behind again, and was full of joy because
of this deliverance.

And when they had driven a part of the way the king's son heard a
cracking behind him as if something had broken. So he turned round and
cried, »Henry, the carriage is breaking.« »No, master, it is not the
carriage. It is a band from my heart, which was put there in my great
pain when you were a frog and imprisoned in the well.«

Again and once again while they were on their way something cracked,
and each time the king's son thought the carriage was breaking, but it
was only the bands which were springing from the heart of Faithful
Henry because his master was set free and was happy.
```

(Linup Front GmbH would like to point out that the authors strongly disapprove of any cruelty to animals.)



C

LPIC-1 Certification

C.1 Overview

The *Linux Professional Institute* (LPI) is a vendor-independent non-profit organization dedicated to furthering the professional use of Linux. One aspect of the LPI's work concerns the creation and delivery of distribution-independent certification exams, for example for Linux professionals. These exams are available world-wide and enjoy considerable respect among Linux professionals and employers.

Through LPIC-1 certification you can demonstrate basic Linux skills, as required, e. g., for system administrators, developers, consultants, or user support professionals. The certification is targeted towards Linux users with 1 to 3 years of experience and consists of two exams, LPI-101 and LPI-102. These are offered as computer-based multiple-choice and fill-in-the-blanks tests in all Pearson VUE and Thomson Prometric test centres. On its web pages at `http://www.lpi.org/`, the LPI publishes **objectives** outlining the content of the exams.

objectives

This training manual is part of Linup Front GmbH's curriculum for preparation of the LPI-101 exam and covers part of the official examination objectives. Refer to the tables below for details. An important observation in this context is that the LPIC-1 objectives are not suitable or intended to serve as a didactic outline for an introductory course for Linux. For this reason, our curriculum is not strictly geared towards the exams or objectives as in "Take classes x and y, sit exam p, then take classes a and b and sit exam q." This approach leads many prospective students to the assumption that, being complete Linux novices, they could book n days of training and then be prepared for the LPIC-1 exams. Experience shows that this does not work in practice, since the LPI exams are deviously constructed such that intensive courses and exam-centred "swotting" do not really help.

Accordingly, our curriculum is meant to give you a solid basic knowledge of Linux by means of a didactically reasonable course structure, and to enable you as a participant to work independently with the system. LPIC-1 certification is not a primary goal or a goal in itself, but a natural consequence of your newly-obtained knowledge and experience.

C.2 Exam LPI-101

The following table displays the objectives for the LPI-101 exam and the materials from the "Concise Linux" series covering these objectives. The numbers in the columns for the individual manuals refer to the chapters containing the material in question.

No	Wt	Title	LXK1
101.1	2	Determine and configure hardware settings	14
101.2	3	Boot the system	16–18
101.3	3	Change runlevels/boot targets and shutdown or reboot system	17–18
102.1	2	Design hard disk layout	14
102.2	2	Install a boot manager	16
102.3	1	Manage shared libraries	–
102.4	3	Use Debian package management	26
102.5	3	Use RPM and YUM package management	27
103.1	4	Work on the command line	3–4
103.2	3	Process text streams using filters	7
103.3	4	Perform basic file management	6, 15.3
103.4	4	Use streams, pipes and redirects	7
103.5	4	Create, monitor and kill processes	13
103.6	2	Modify process execution priorities	13
103.7	2	Search text files using regular expressions	7
103.8	3	Perform basic file editing operations using vi	5
104.1	2	Create partitions and filesystems	14–15
104.2	2	Maintain the integrity of filesystems	15
104.3	3	Control mounting and unmounting of filesystems	15
104.4	1	Manage disk quotas	–
104.5	3	Manage file permissions and ownership	12
104.6	2	Create and change hard and symbolic links	6
104.7	2	Find system files and place files in the correct location	6, 9

C.3 Exam LPI-102

The following table displays the objectives for the LPI-102 exam and the materials from the "Concise Linux" series covering these objectives. The numbers in the columns for the individual manuals refer to the chapters containing the material in question.

No	Wt	Title	LXK1
105.1	4	Customize and use the shell environment	–
105.2	4	Customize or write simple scripts	–
105.3	2	SQL data management	–
106.1	2	Install and configure X11	–
106.2	1	Setup a display manager	–
106.3	1	Accessibility	–
107.1	5	Manage user and group accounts and related system files	11
107.2	4	Automate system administration tasks by scheduling jobs	19
107.3	3	Localisation and internationalisation	–
108.1	3	Maintain system time	–
108.2	3	System logging	20–21
108.3	3	Mail Transfer Agent (MTA) basics	–
108.4	2	Manage printers and printing	–
109.1	4	Fundamentals of internet protocols	22–23
109.2	4	Basic network configuration	23–24
109.3	4	Basic network troubleshooting	23–24
109.4	2	Configure client side DNS	23
110.1	3	Perform security administration tasks	11, 23–24
110.2	3	Setup host security	11, 23
110.3	3	Securing data with encryption	25

C.4 LPI Objectives In This Manual

101.1 Determine and configure hardware settings

Weight 2
Description Candidates should be able to determine and configure fundamental system hardware.
Key Knowledge Areas

- Enable and disable integrated peripherals
- Configure systems with or without external peripherals such as keyboards
- Differentiate between the various types of mass storage devices
- Know the differences between coldplug and hotplug devices
- Determine hardware resources for devices
- Tools and utilities to list various hardware information (e.g. `lsusb`, `lspci`, etc.)
- Tools and utilities to manipulate USB devices
- Conceptual understanding of sysfs, udev, dbus

The following is a partial list of the used files, terms and utilities:

- `/sys/`
- `/proc/`
- `/dev/`
- `modprobe`
- `lsmod`
- `lspci`
- `lsusb`

101.2 Boot the system

Weight 3
Description Candidates should be able to guide the system through the booting process.
Key Knowledge Areas

- Provide common commands to the boot loader and options to the kernel at boot time
- Demonstrate knowledge of the boot sequence from BIOS to boot completion
- Understanding of SysVinit and systemd
- Awareness of Upstart
- Check boot events in the log files

The following is a partial list of the used files, terms and utilities:

- `dmesg`
- BIOS
- bootloader
- kernel
- initramfs
- `init`
- SysVinit
- systemd

101.3 Change runlevels/boot targets and shutdown or reboot system

Weight 3

Description Candidates should be able to manage the SysVinit runlevel or systemd boot target of the system. This objective includes changing to single user mode, shutdown or rebooting the system. Candidates should be able to alert users before switching runlevels/boot targets and properly terminate processes. This objective also includes setting the default SysVinit runlevel or systemd boot target. It also includes awareness of Upstart as an alternative to SysVinit or systemd.

Key Knowledge Areas

- Set the default runlevel or boot target
- Change between runlevels/boot targets including single user mode
- Shutdown and reboot from the command line
- Alert users before switching runlevels/boot targets or other major system events
- Properly terminate processes

The following is a partial list of the used files, terms and utilities:

- `/etc/inittab`
- `shutdown`
- `init`
- `/etc/init.d/`
- `telinit`
- systemd
- `systemctl`
- `/etc/systemd/`
- `/usr/lib/systemd/`
- `wall`

102.1 Design hard disk layout

Weight 2

Description Candidates should be able to design a disk partitioning scheme for a Linux system.

Key Knowledge Areas

- Allocate filesystems and swap space to separate partitions or disks
- Tailor the design to the intended use of the system
- Ensure the `/boot` partition conforms to the hardware architecture requirements for booting
- Knowledge of basic features of LVM

The following is a partial list of the used files, terms and utilities:

- `/` (root) filesystem
- `/var` filesystem
- `/home` filesystem
- `/boot` filesystem
- swap space
- mount points
- partitions

102.2 Install a boot manager

Weight 2

Description Candidates should be able to select, install and configure a boot manager.

Key Knowledge Areas

- Providing alternative boot locations and backup boot options

- Install and configure a boot loader such as GRUB Legacy
- Perform basic configuration changes for GRUB 2
- Interact with the boot loader

The following is a partial list of the used files, terms and utilities:

- `menu.lst`, `grub.cfg` and `grub.conf`
- `grub-install`
- `grub-mkconfig`
- MBR

102.4 Use Debian package management

Weight 3

Description Candidates should be able to perform package management using the Debian package tools.

Key Knowledge Areas

- Install, upgrade and uninstall Debian binary packages
- Find packages containing specific files or libraries which may or may not be installed
- Obtain package information like version, content, dependencies, package integrity and installation status (whether or not the package is installed)

The following is a partial list of the used files, terms and utilities:

- `/etc/apt/sources.list`
- `dpkg`
- `dpkg-reconfigure`
- `apt-get`
- `apt-cache`
- `aptitude`

102.5 Use RPM and YUM package management

Weight 3

Description Candidates should be able to perform package management using RPM and YUM tools.

Key Knowledge Areas

- Install, re-install, upgrade and remove packages using RPM and YUM
- Obtain information on RPM packages such as version, status, dependencies, integrity and signatures
- Determine what files a package provides, as well as find which package a specific file comes from

The following is a partial list of the used files, terms and utilities:

- `rpm`
- `rpm2cpio`
- `/etc/yum.conf`
- `/etc/yum.repos.d/`
- `yum`
- `yumdownloader`

103.1 Work on the command line

Weight 4

Description Candidates should be able to interact with shells and commands using the command line. The objective assumes the Bash shell.

Key Knowledge Areas

- Use single shell commands and one line command sequences to perform basic tasks on the command line
- Use and modify the shell environment including defining, referencing and exporting environment variables
- Use and edit command history
- Invoke commands inside and outside the defined path

The following is a partial list of the used files, terms and utilities:

- `bash`
- `echo`
- `env`
- `export`
- `pwd`
- `set`
- `unset`
- `man`
- `uname`
- `history`
- `.bash_history`

103.2 Process text streams using filters

Weight 3

Description Candidates should should be able to apply filters to text streams.

Key Knowledge Areas

- Send text files and output streams through text utility filters to modify the output using standard UNIX commands found in the GNU textutils package

The following is a partial list of the used files, terms and utilities:

- `cat`
- `cut`
- `expand`
- `fmt`
- `head`
- `join`
- `less`
- `nl`
- `od`
- `paste`
- `pr`
- `sed`
- `sort`
- `split`
- `tail`
- `tr`
- `unexpand`
- `uniq`
- `wc`

103.3 Perform basic file management

Weight 4

Description Candidates should be able to use the basic Linux commands to manage files and directories.

Key Knowledge Areas

- Copy, move and remove files and directories individually
- Copy multiple files and directories recursively
- Remove files and directories recursively
- Use simple and advanced wildcard specifications in commands
- Using find to locate and act on files based on type, size, or time
- Usage of tar, cpio and dd

The following is a partial list of the used files, terms and utilities:

- `cp`
- `find`
- `mkdir`
- `mv`
- `ls`
- `rm`
- `rmdir`
- `touch`
- `tar`
- `cpio`
- `dd`
- `file`
- `gzip`
- `gunzip`
- `bzip2`
- `xz`
- file globbing

103.4 Use streams, pipes and redirects

Weight 4

Description Candidates should be able to redirect streams and connect them in order to efficiently process textual data. Tasks include redirecting standard input, standard output and standard error, piping the output of one command to the input of another command, using the output of one command as arguments to another command and sending output to both stdout and a file.

Key Knowledge Areas

- Redirecting standard input, standard output and standard error
- Pipe the output of one command to the input of another command
- Use the output of one command as arguments to another command
- Send output to both stdout and a file

The following is a partial list of the used files, terms and utilities:

- `tee`
- `xargs`

103.5 Create, monitor and kill processes

Weight 4

Description Candidates should be able to perform basic process management.

Key Knowledge Areas

- Run jobs in the foreground and background

- Signal a program to continue running after logout
- Monitor active processes
- Select and sort processes for display
- Send signals to processes

The following is a partial list of the used files, terms and utilities:

- `&`
- `bg`
- `fg`
- `jobs`
- `kill`
- `nohup`
- `ps`
- `top`
- `free`
- `uptime`
- `pgrep`
- `pkill`
- `killall`
- `screen`

103.6 Modify process execution priorities

Weight 2

Description Candidates should be able to manage process execution priorities.

Key Knowledge Areas

- Know the default priority of a job that is created
- Run a program with higher or lower priority than the default
- Change the priority of a running process

The following is a partial list of the used files, terms and utilities:

- `nice`
- `ps`
- `renice`
- `top`

103.7 Search text files using regular expressions

Weight 2

Description Candidates should be able to manipulate files and text data using regular expressions. This objective includes creating simple regular expressions containing several notational elements. It also includes using regular expression tools to perform searches through a filesystem or file content.

Key Knowledge Areas

- Create simple regular expressions containing several notational elements
- Use regular expression tools to perform searches through a filesystem or file content

The following is a partial list of the used files, terms and utilities:

- `grep`
- `egrep`
- `fgrep`
- `sed`
- `regex`(7)

103.8 Perform basic file editing operations using vi

Weight 3

Description Candidates should be able to edit text files using `vi`. This objective includes `vi` navigation, basic `vi` modes, inserting, editing, deleting, copying and finding text.

Key Knowledge Areas

- Navigate a document using `vi`
- Use basic `vi` modes
- Insert, edit, delete, copy and find text

The following is a partial list of the used files, terms and utilities:

- `vi`
- `/`, `?`
- `h`, `j`, `k`, `l`
- `i`, `o`, `a`
- `c`, `d`, `p`, `y`, `dd`, `yy`
- `ZZ`, `:w!`, `:q!`, `:e!`

104.1 Create partitions and filesystems

Weight 2

Description Candidates should be able to configure disk partitions and then create filesystems on media such as hard disks. This includes the handling of swap partitions.

Key Knowledge Areas

- Manage MBR partition tables
- Use various mkfs commands to create various filesystems such as:
  - ext2/ext3/ext4
  - XFS
  - VFAT
- Awareness of ReiserFS and Btrfs
- Basic knowledge of gdisk and parted with GPT

The following is a partial list of the used files, terms and utilities:

- `fdisk`
- `gdisk`
- `parted`
- `mkfs`
- `mkswap`

104.2 Maintain the integrity of filesystems

Weight 2

Description Candidates should be able to maintain a standard filesystem, as well as the extra data associated with a journaling filesystem.

Key Knowledge Areas

- Verify the integrity of filesystems
- Monitor free space and inodes
- Repair simple filesystem problems

The following is a partial list of the used files, terms and utilities:

- du
- df
- fsck
- e2fsck
- mke2fs
- debugfs
- dumpe2fs
- tune2fs
- XFS tools (such as xfs_metadump and xfs_info)

104.3 Control mounting and unmounting of filesystems

Weight 3

Description Candidates should be able to configure the mounting of a filesystem.

Key Knowledge Areas

- Manually mount and unmount filesystems
- Configure filesystem mounting on bootup
- Configure user mountable removable filesystems

The following is a partial list of the used files, terms and utilities:

- /etc/fstab
- /media/
- mount
- umount

104.5 Manage file permissions and ownership

Weight 3

Description Candidates should be able to control file access through the proper use of permissions and ownerships.

Key Knowledge Areas

- Manage access permissions on regular and special files as well as directories
- Use access modes such as suid, sgid and the sticky bit to maintain security
- Know how to change the file creation mask
- Use the group field to grant file access to group members

The following is a partial list of the used files, terms and utilities:

- chmod
- umask
- chown
- chgrp

104.6 Create and change hard and symbolic links

Weight 2

Description Candidates should be able to create and manage hard and symbolic links to a file.

Key Knowledge Areas

- Create links
- Identify hard and/or soft links
- Copying versus linking files

- Use links to support system administration tasks

The following is a partial list of the used files, terms and utilities:

- `ln`
- `ls`

104.7 Find system files and place files in the correct location

Weight 2

Description Candidates should be thoroughly familiar with the Filesystem Hierarchy Standard (FHS), including typical file locations and directory classifications.

Key Knowledge Areas

- Understand the correct locations of files under the FHS
- Find files and commands on a Linux system
- Know the location and purpose of important file and directories as defined in the FHS

The following is a partial list of the used files, terms and utilities:

- `find`
- `locate`
- `updatedb`
- `whereis`
- `which`
- `type`
- `/etc/updatedb.conf`

107.1 Manage user and group accounts and related system files

Weight 5

Description Candidates should be able to add, remove, suspend and change user accounts.

Key Knowledge Areas

- Add, modify and remove users and groups
- Manage user/group info in password/group databases
- Create and manage special purpose and limited accounts

The following is a partial list of the used files, terms and utilities:

- `/etc/passwd`
- `/etc/shadow`
- `/etc/group`
- `/etc/skel/`
- `chage`
- `getent`
- `groupadd`
- `groupdel`
- `groupmod`
- `passwd`
- `useradd`
- `userdel`
- `usermod`

107.2 Automate system administration tasks by scheduling jobs

Weight 4

Description Candidates should be able to use `cron` or `anacron` to run jobs at regular intervals and to use `at` to run jobs at a specific time.

Key Knowledge Areas

- Manage `cron` and `at` jobs
- Configure user access to `cron` and `at` services
- Configure `anacron`

The following is a partial list of the used files, terms and utilities:

- `/etc/cron.{d,daily,hourly,monthly,weekly}/`
- `/etc/at.deny`
- `/etc/at.allow`
- `/etc/crontab`
- `/etc/cron.allow`
- `/etc/cron.deny`
- `/var/spool/cron/`
- `crontab`
- `at`
- `atq`
- `atrm`
- `anacron`
- `/etc/anacrontab`

108.2 System logging

Weight 3

Description Candidates should be able to configure the syslog daemon. This objective also includes configuring the logging daemon to send log output to a central log server or accept log output as a central log server. Use of the systemd journal subsystem is covered. Also, awareness of rsyslog and syslog-ng as alternative logging systems is included.

Key Knowledge Areas

- Configuration of the syslog daemon
- Understanding of standard facilities, priorities and actions
- Configuration of `logrotate`
- Awareness of rsyslog and syslog-ng

The following is a partial list of the used files, terms and utilities:

- `syslog.conf`
- `syslogd`
- `klogd`
- `/var/log/`
- `logger`
- `logrotate`
- `/etc/logrotate.conf`
- `/etc/logrotate.d/`
- `journalctl`
- `/etc/systemd/journald.conf`
- `/var/log/journal/`

109.1 Fundamentals of internet protocols

Weight 4

Description Candidates should demonstrate a proper understanding of TCP/IP network fundamentals.

Key Knowledge Areas

- Demonstrate an understanding of network masks and CIDR notation
- Knowledge of the differences between private and public »dotted quad« IP addresses
- Knowledge about common TCP and UDP ports and services (20, 21, 22, 23, 25, 53, 80, 110, 123, 139, 143, 161, 162, 389, 443, 465, 514, 636, 993, 995)
- Knowledge about the differences and major features of UDP, TCP and ICMP
- Knowledge of the major differences between IPv4 and IPv6
- Knowledge of the basic features of IPv6

The following is a partial list of the used files, terms and utilities:

- `/etc/services`
- IPv4, IPv6
- Subnetting
- TCP, UDP, ICMP

109.2 Basic network configuration

Weight 4

Description Candidates should be able to view, change and verify configuration settings on client hosts.

Key Knowledge Areas

- Manually and automatically configure network interfaces
- Basic TCP/IP host configuration
- Setting a default route

The following is a partial list of the used files, terms and utilities:

- `/etc/hostname`
- `/etc/hosts`
- `/etc/nsswitch.conf`
- `ifconfig`
- `ifup`
- `ifdown`
- `ip`
- `route`
- `ping`

109.3 Basic network troubleshooting

Weight 4

Description Candidates should be able to troubleshoot networking issues on client hosts.

Key Knowledge Areas

- Manually and automatically configure network interfaces and routing tables to include adding, starting, stopping, restarting, deleting or reconfiguring network interfaces
- Change, view, or configure the routing table and correct an improperly set default route manually
- Debug problems associated with the network configuration

The following is a partial list of the used files, terms and utilities:

- `ifconfig`
- `ip`
- `ifup`
- `ifdown`
- `route`
- `host`
- `hostname`
- `dig`
- `netstat`
- `ping`
- `ping6`
- `traceroute`
- `traceroute6`
- `tracepath`
- `tracepath6`
- `netcat`

109.4 Configure client side DNS

Weight 2
Description Candidates should be able to configure DNS on a client host.
Key Knowledge Areas

- Query remote DNS servers
- Configure local name resolution and use remote DNS servers
- Modify the order in which name resolution is done

The following is a partial list of the used files, terms and utilities:

- `/etc/hosts`
- `/etc/resolv.conf`
- `/etc/nsswitch.conf`
- `host`
- `dig`
- `getent`

110.1 Perform security administration tasks

Weight 3
Description Candidates should know how to review system configuration to ensure host security in accordance with local security policies.
Key Knowledge Areas

- Audit a system to find files with the suid/sgid bit set
- Set or change user passwords and password aging information
- Being able to use nmap and netstat to discover open ports on a system
- Set up limits on user logins, processes and memory usage
- Determine which users have logged in to the system or are currently logged in
- Basic sudo configuration and usage

The following is a partial list of the used files, terms and utilities:

- `find`
- `passwd`
- `fuser`
- `lsof`
- `nmap`

- chage
- netstat
- sudo
- /etc/sudoers
- su
- usermod
- ulimit
- who, w, last

110.2 Setup host security

Weight 3

Description Candidates should know how to set up a basic level of host security.

Key Knowledge Areas

- Awareness of shadow passwords and how they work
- Turn off network services not in use
- Understand the role of TCP wrappers

The following is a partial list of the used files, terms and utilities:

- /etc/nologin
- /etc/passwd
- /etc/shadow
- /etc/xinetd.d/
- /etc/xinetd.conf
- /etc/inetd.d/
- /etc/inetd.conf
- /etc/inittab
- /etc/init.d/
- /etc/hosts.allow
- /etc/hosts.deny

110.3 Securing data with encryption

Weight 3

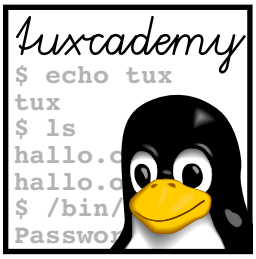
Description The candidate should be able to use public key techniques to secure data and communication.

Key Knowledge Areas

- Perform basic OpenSSH 2 client configuration and usage
- Understand the role of OpenSSH 2 server host keys
- Perform basic GnuPG configuration, usage and revocation
- Understand SSH port tunnels (including X11 tunnels)

The following is a partial list of the used files, terms and utilities:

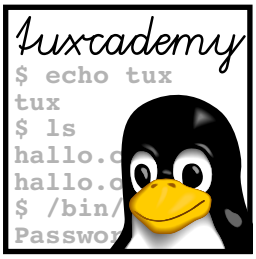
- ssh
- ssh-keygen
- ssh-agent
- ssh-add
- ~/.ssh/id_rsa and id_rsa.pub
- ~/.ssh/id_dsa and id_dsa.pub
- /etc/ssh/ssh_host_rsa_key and ssh_host_rsa_key.pub
- /etc/ssh/ssh_host_dsa_key and ssh_host_dsa_key.pub
- ~/.ssh/authorized_keys
- ssh_known_hosts
- gpg
- ~/.gnupg/



D

Command Index

This appendix summarises all commands explained in the manual and points to their documentation as well as the places in the text where the commands have been introduced.



Index

This index points to the most important key words in this document. Particularly important places for the individual key words are emphasised by **bold** type. Sorting takes place according to letters only; "`~/.bashrc`" is therefore placed under "B".