RenderWare Graphics

User Guide

Volume I

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Foreword

About the User Guide

This is the RenderWare User Guide for release 3.5. The documentation has been updated for 3.5 and is organized into three volumes of general, platform independent material. Volume III includes Maestro documentation and a Recommended Reading appendix .

Xbox, GameCube and PlayStation 2 have a separate platform specific addendum, containing material which is only useful for that platform and which has been updated for 3.5.

Volume I contains the core library and the world library, giving basic immediate mode and retained mode functionality.

- Introduction

From the core library:
- Fundamental Types
- Initialization & Resource Management
- Plugin Creation and Usage
- The Camera, covering the basics of rendering
- Rasters, Images and Textures
- Immediate Mode
- Serialization
- Debugging & Error Handling

From the world library:
- World and Static Models
- Dynamic Models
- Lights

In Volume II elements of the animation systems, special effects and world management functionality are discussed

- Skinning
- Fundamental Types for Animation
- The Animation Toolkit
- Hierarchical Animation
- Morph
- Delta Morphing
- Material Effects
- Lightmaps
- PTank
- Standard Particles (**`RpPrtStd`**)
- B-splines and Bézier Patches
- Collision Detection
- Potentially Visible Sets (PVS)
- Geometry Conditioning

Volume III covers the utility libraries, which offer a variety of useful functionality and an in-depth coverage of PowerPipe, the key to customizing RenderWare for ultimate performance and unique functionality for your application.

- 2D Graphics Toolkits
- Maestro
- The User Data Plugin, on exporting user data
- PowerPipe Overview
- Pipeline Nodes

Platform specific documentation is included for PlayStation 2, Xbox and GameCube.

PlayStation 2:
- PS2All Overview
- Pipeline Delivery System (PDS)

Xbox:
- Multi-texturing in MatFX
- Multi-texturing on Xbox
- Xbox State Cache
- Xbox Pixel Shaders
- Xbox Vertex Format Compression

GameCube:
- Multi-texturing in MatFX
- Multi-texturing on GameCube

We realize that this User Guide does not cover every single feature in RenderWare Graphics, but we hope you will find it useful.

Please let us know what you think and feel free to offer any suggestions.

Regards,

The RenderWare Graphics Team

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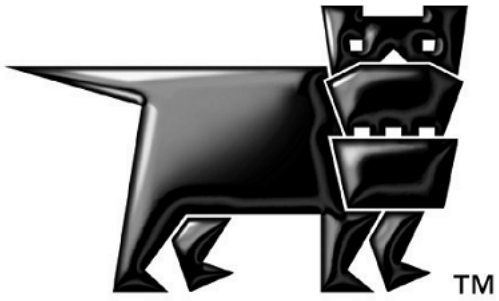
Chapter 1

Introduction



1.1 Welcome to RenderWare Graphics

Welcome to the RenderWare Graphics User Guide!

RenderWare Graphics is a powerful 3D graphics library. This User Guide is aimed at helping newcomers to RenderWare Graphics become familiar with the product. This is in addition to the on-line help, and support that is offered with the purchase of any RenderWare Platform component.

RenderWare Graphics is the result of many years of development, which began in 1991. The power and flexibility of the product has been increased with every release. RenderWare Graphics is a multi-platform Application Programming Interface (API), which is constantly being improved and updated to keep it at the cutting edge of 3D graphics.

To support the community of developers in the field, we offer our Fully Managed Support System. Accessible via a personalized web interface, this allows our technical support personnel to be contacted, the status of outstanding queries to be tracked, and our knowledge base to be searched and viewed, plus lots of other useful information. To find out more and register for the service, point your browser at https://support.renderware.com/.

If you are new to RenderWare Graphics, it is strongly suggested that you read this User Guide as you go along to acquaint yourself with its operation.

Similarly, if you've already been using RenderWare Graphics for a while, stick around! The User Guide is written by the people who created the library, so you might gain new insights, tricks and tips. Additionally it has been revised and expanded to cover all our latest new technology.

RenderWare Graphics is a module of Criterion Software's RenderWare Platform, the tailored set of open and extensible middleware tools which allows you to focus on content and gameplay. For further information on the other Components (including RenderWare Audio, RenderWare AI and RenderWare Physics) please visit www.renderware.com or contact your account manager.

1.1.1 What you Should Know

This User Guide makes some assumptions about your level of proficiency with real-time 3D graphics programming:

- This Guide is *not* aimed at complete newcomers to the field of computer graphics. If you are new to all this, check out the *Recommended Reading* appendix for links to online articles and books you can use as a starting point.

- Secondly, this User Guide will not go into detail about the mathematics upon which most 3D graphics programming is founded. The whole point of graphics libraries such as RenderWare Graphics is to do the math for you.

  That said, some college-level math is required to understand some concepts. If your knowledge of the principles and practices of matrix and vector manipulation is limited, the *Recommended Reading* appendix contains pointers to relevant texts that can help you with this area.

- This User Guide assumes you are an experienced programmer with a thorough knowledge of the C (or C++) programming language. You should also be comfortable with the concepts behind object-oriented programming.

- The User Guide is platform-neutral so it will not cover any specific development environment. Platform-specific variations and optimization notes will be provided in an appendix.

1.1.2 What is RenderWare Graphics?

- A graphics library

  RenderWare Graphics is a 2D and 3D graphics API. It is used by programmers to create real-time 3D graphics applications, such as computer games and simulations.

- Multi-platform

  RenderWare Graphics has multi-platform, portable API that allows high level functionality to be achieved on all platforms, with platform specific optimizations to get the best from the hardware pipelines.

  RenderWare Graphics is available for Sony PlayStation 2, Microsoft Xbox, NINTENDO GAMECUBE, Microsoft Windows (Direct3D 8), Microsoft Windows (OpenGL) and Apple MacOS (OpenGL).

- Customizable

  RenderWare Graphics has a component-based approach to its architecture based around a small-footprint, thin-layer core library, supplemented by a number of *Plugins* and *Toolkits*.

  Plugins are the key to RenderWare Graphics' power; they can extend existing objects and add new objects of their own that can also be further extended.

  Even the Retained Mode API is a Plugin, which gives RenderWare Graphics the unique feature of being the only 3D graphics library that can support any number of Retained Mode APIs.

Further, this Plugin mechanism is fully exposed. You can write your own Plugins, extending and adding objects, for your own requirements - we even encourage you to do so, as we do not claim to have thought of everything!

- Compatible with many third-party tools and middleware

  RenderWare Graphics is a module of Criterion Software's RenderWare Platform, the tailored set of middleware tools offering a tightly integrated game development framework, which includes graphics, audio and physics modules, with other Components planned for availability in the future.

1.1.3 Design philosophy

The design brief for RenderWare Graphics was to create a 3D graphics library that would never be obtrusive. We have tried hard to make sure the library is the most powerful multi-platform 3D library available.

Platform Independent Development

RenderWare Graphics has been designed from the ground up to let you get the most out of all its supported platforms – with *no* compromises. APIs are provided which expose low-level features and optimization opportunities to the developer, so the best performance can be obtained from your projects.

The price for this is a little extra work during the porting process: each platform has different hardware, and different advantages and disadvantages. RenderWare Graphics gives you the freedom to choose how far you go down the optimization route:

- Need to create a product quickly for more than one platform? No problem: use the common API features – the facilities provided as standard across all platforms – and treat it as an ordinary cross-platform library.

- Alternatively, writing custom PowerPipe nodes and plugins enables RenderWare Graphics to be fine-tuned to specialized performance requirements. The purchase of a source code license gives the developer ultimate control over RenderWare Graphics.

RenderWare Graphics gives you the freedom to take either route, or indeed any path between these two extremes.

Such flexibility does come at a price: where platform-specific features of RenderWare Graphics are chosen, the code for each target platform will need to be changed when porting.

C vs. C++

One of the most common questions asked about RenderWare Graphics is the choice of programming language: C.

There are two reasons for choosing to write RenderWare Graphics in the C programming language. The first is that there is no standard for C++ libraries; RenderWare Graphics would have to be shipped as a separate set of libraries for each supported compiler, as well as each platform. Clearly, this would complicate product support.

Secondly, while C++ has many, many great features, most new platforms – particularly consoles – don't get a stable, mature C++ compiler until long after they get a good C compiler. In order for a new platform to be worked on as soon as possible, the fastest way to achieve this is to use a mixture of highly optimized C and assembly language.

That said, it is quite possible to mix C and C++. The Plugin mechanism lets you add space for '**this**' pointers to RenderWare Graphics objects with minimal fuss, and all RenderWare Graphics' header files have the requisite "extern 'C'" directives to allow the two languages to mix seamlessly.

Several of our licensees have also produced their own C++ wrapper classes to encapsulate RenderWare Graphics in order to develop in a 'pure' C++ environment.

1.2The RenderWare Graphics SDK

1.2.1 Libraries and Header Files

RenderWare Graphics is supplied as a number of libraries on the Software Development Kit (SDK). Applications will need to link against these libraries and **#include** the associated header files.

All RenderWare Graphics libraries are static.

Each platform is provided with its own headers and libraries. In addition, the SDK contains *null* libraries, which are used by exporters and other tools. These are provided with all platforms. The *null* libraries contain all the PC functionality, but do not perform any rendering.

A NULL target DLL is also provided that the art tools exporters make use of. This DLL contains almost all of the static NULL libraries.

Null Libraries

On Xbox, GameCube and PlayStation 2 *null* and *nullplatform* libraries are also built. For example, PlayStation 2 RenderWare Graphics SDK is supplied with *null* and *nullsky* libraries. These PC libraries are required for certain tools that process platform specific data. They can be used for the generation of texture dictionaries.

It should be noted that *nullplatform* libraries can not create pre-instanced and geometry data.

Debug, Metrics and Release Libraries

For each platform, separate *debug*, *metrics* and *release* builds of the RenderWare Graphics libraries are also provided. Debug, release and metrics libraries live in separate folders inside the *rwsdk/lib* folder. **RWDEBUG** and **RWMETRICS** preprocessor symbols must be used to indicate which build is being used.

It is crucial that you do not mix symbols and libraries between these builds. To illustrate, some API calls are implemented in release builds as macros. In debug builds these calls are really implemented as functions. This can mean that if you define the **RWDEBUG** preprocessor symbol, but link with the release build of the library you will get numerous "undefined symbol" link errors.

Compilers supported

Please see the appropriate platform specific top-level readme files supplied with the RenderWare Graphics SDK for information on the compilers supported by RenderWare Graphics.

SN Systems, Visual Studio IDE integration and Project Files

The RenderWare Graphics SDK provides full support for the SN Systems Visual Studio Integration features.

Project Build Target settings are included for all platforms supported via Visual Studio. Developers should ensure the correct Project Build Target is selected.

1.2.2 Examples

The SDK contains nearly 50 source code examples. Examples are small and designed to *illustrate* a particular technique or feature of the RenderWare Graphics API. They are intended as a means of education: we encourage you to look through the source code and play with them.

Tools & Viewers

Also included are tools and viewers for you to use during development. Of particular note is the RenderWare Visualizer viewer, which allows you to easily view RenderWare Graphics artwork on any target hardware.

Two other viewers are also available for viewing artwork: '**`wrldview`**', and **`'clmpview'`**. **`'wrldview'`** displays static models created for the Retained Mode API, and '**`clmpview`**' displays dynamic models.

RenderWare Graphics uses a single file format, using chunk-IDs, which is capable of storing any one or more RenderWare Graphics objects. The RenderWare Graphics Binary Stream format can be viewed using the '**`strview`**' applet supplied with the SDK.

A Microsoft Visual Studio 6 AppWizard is also supplied with RenderWare Graphics that can be used to generate an MFC framework-based clump or world viewer. This AppWizard can be incorporated into Microsoft Visual C++ and used in the same manner as the standard Microsoft AppWizards.

Please see the accompanying documentation describing how to build a RenderWare Graphics viewer.

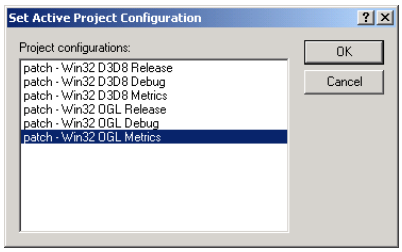
Building the Examples

The examples that are shipped on the SDK should not need compiling to run them. If you modify them, you will want to re-build the executables.

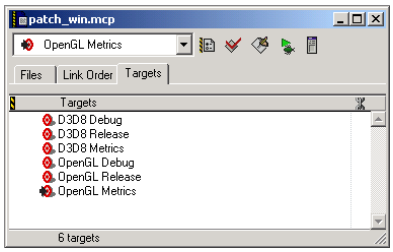
The Project files provided with the tools and examples are not necessarily set for your particular platform so make sure you select the correct build configuration prior to compilation. The two screen shots below show the Integrated Development Environments (IDEs) and the build targets that they offer. In Visual Studio, you will need to select the correct Project Configuration; in CodeWarrior, you must select the correct Target. Further, there are separate release, debug, and metrics builds. Unless you have good reason not to, it is suggested that you select:

- Win32 D3D8 Release project in Visual Studio for the PC
- Xbox Release in Visual Studio for Xbox.

- PS2 Release in CodeWarrior for the PlayStation 2
- GCN Release in CodeWarrior for GameCube



Visual Studio



CodeWarrior

1.2.3 Documentation

Documentation is provided in both online and PDF formats. The PDF format is intended for printing *only* and is not hyperlinked. The PDF files have been setup for double sided printing.

The following documentation is provided in the SDK:

- This User Guide
- API Reference
- Tutorials (PC only)
- White Papers
- Exporter Guides for artists and programmers
- Tools and Viewers documentation
- Examples document listing all examples with brief explanation
- **`readme_xxx.pdf`**

All the examples and tools have a related **`readme.txt`** file. It is highly recommended that you read these for information about any last-minute changes or features.

There is also the top-level SDK **`readme_xx.pdf`** file, where **`xxx`** is the platform name, which lists last-minute changes, fixes and known issues and can be found in the root of the SDK.

1.2.4 Artists Tools

The RenderWare Graphics installer can be used to install the artists' tools. These tools are exporter plugins for exporting 3D model data from packages such as 3ds max and Maya.

When installed, artists will find:

- The modeling package's RenderWare Graphics exporter plugin(s)
- Sample artwork demonstrating optimal modeling techniques
- Documentation covering how to create and export models successfully for RenderWare Graphics.

It is strongly recommended that programmers also read the documentation supplied with the artists tools. The installer adds links to these docs from the start menu.

1.2.5 Open Export Framework

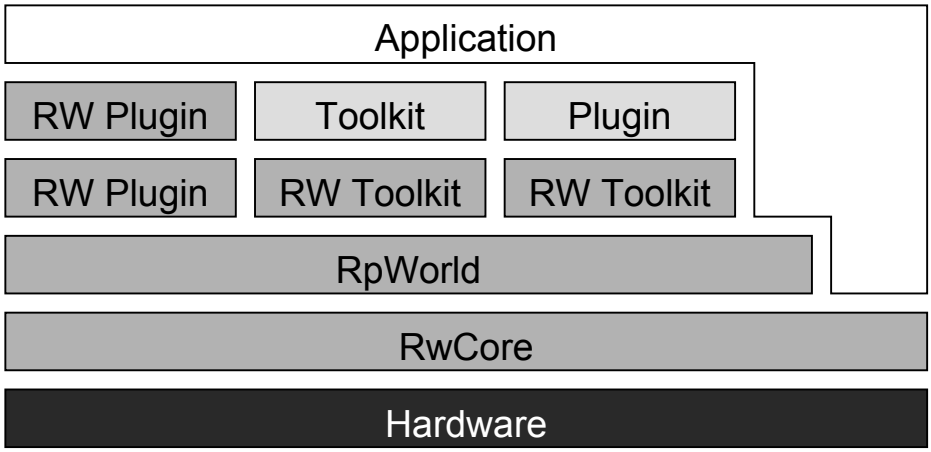
The RenderWare Graphics programmer installer can be used to install the Open Export SDK that gives you a powerful way of extending the exporters. Consisting of a series of modular libraries and custom code hooks, you could soon be introducing new common classes to the modelers, changing behaviors or creating new object handlers under our plugin architecture.

To get you started, we have provided the Getting Started section in the Open Export API Reference document. In addition, we have included six examples of what you can do with the SDK:

- **ExportObject** - An example of a custom object exporter optimizes the exported textures, by making sure that all texture sizes are beneath a certain threshold.
- **MaxSimple** - An example of how to write your own custom builder and export application. To demonstrate this we used a simplified 3dsmax exporter.
- **PostProcess** – An example demonstrates how to post process the entire list of exported RenderWare Graphics assets, and how to customize the stream process for streaming them out.
- **ScaleAnim** - This example adds support for animated scale to the RwExp layer.
- **TravAction** - Demonstrates the use of traverse actions together with traverse lists that filters out all nodes containing a certain name.
- **VertexFilter** - An example of a vertex filter which pre-lights a scene by applying per vertex operations.

1.3RenderWare Graphics Architecture

The diagram below shows how the RenderWare Graphics library fits into a typical application.



Abstracting the underlying hardware is the RenderWare Graphics Core Library. Above this is the world plugin. This is the largest and most widely used of the optional RenderWare Graphics modules. Various plugins provided with the SDK are shown adding functionality. Also shown are toolkits, both supplied with the SDK, and non-RenderWare Graphics Toolkits supplied by third parties. A third party plugin is also shown. Above these components is the application which uses the services (functions) exposed by the various components.

The gray boxes above that labeled **`RwCore`** are *optional*. Unlike monolithic 3D graphics libraries, most of the higher-level features can be omitted. Although it's not explicitly stated in the diagram, **`RpWorld`**, which provides the Retained Mode API, is itself just a Plugin.

1.3.1 The Core Library, Plugins and Toolkits

The RenderWare Graphics components can be broken down:

1. Core Library
2. Plugins
3. Toolkits

The first is the *Core Library*. The Core Library must always be linked into your application as it provides the glue that joins all the components together, as well as basic rendering functionality.

Plugins

These are the keys to RenderWare Graphics extensibility. Plugins can extend existing objects in both the Core Library and other Plugins – and add their own objects. This feature is what differentiates them from ordinary libraries. RenderWare Graphics' high-level APIs are all implemented as Plugins.

Supplied Plugins

The following Plugins are supplied as standard with all releases of the SDK:

PLUGIN	DESCRIPTION
RpADC	Address Control flag generation
RpAnisot	Anisotropy extension for extending textures
RpCollision	Collision-detection extensions
RpDMorph	Delta morphing and delta animation extensions
RpHAnim	Hierarchical animation plugin
RpLODAtomic	Level Of Detail extensions for RpWorld's "RpAtomic" object
RpLtMap	Render geometry using detailed static lighting information from lightmap textures.
RpMatFX	Multi-pass special effects, such as environmental mapping, bump mapping, 2-pass
RpMipmapKL	Texture mipmap "K" and "L" value extensions
RpMorph	Morph-target animation extensions
RpPatch	Bézier patch rendering engine
RpPrtStd	Particle animation plugin
RpPTank	Creation, management and rendering of user customizable particles
RpPVS	Fast visibility culling extension for RpWorld, using Potentially Visible Sets
RpRandom	Platform-neutral random number generator
RpSkin	Skinned model rendering extensions with multiple bone weights per vertex
RpSpline	Spline manipulation extensions
RpUserData	Provides functionality for storing user defined data with geometry
RpWorld	Provides RenderWare Graphics' Retained Mode API – specifically, the scene graph portion of it

Toolkits

A Toolkit is an ordinary library that just happens to make use of RenderWare Graphics features. A Toolkit usually provides conversion functions or other utilities.

Supplied Toolkits

The following Toolkits are supplied as standard with all releases of the SDK:

TOOLKIT	DESCRIPTION
Rt2d	Advanced 2D Graphics API utilizing underlying 3D graphics hardware
Rt2dAnim	Animation of 2D objects
RtAnim	Create, stream and play keyframe animation.
RtBary	Mapping points between the barycentric space and Cartesian space
RtBezPat	Bézier patch generation utility library
RtBMP	Microsoft® Windows® Bitmap image format handling
RtCharset	A bitmapped character library
RtCmpKey	Keyframe system supporting compressed matrix animation
RtGCond	Geometry Conditioning
RtIntersection	Polygon and line intersection testing functions
RtLtMap	Generation of lightmap textures - used with RpLtMap
RtMipK	Texture mipmap "K" value calculation functions
RtPick	Object-picking functions
RtPITexd	Platform independent texture dictionary streaming
RtPNG	Portable Network Graphics image format handling
RtQuat	Quaternion manipulation functions
RtRAS	Sun® Raster image format handling
RtRay	Ray-casting functions used for picking
RtSkinSplit	Skin & Geometry splitter for large bone count models
RtSlerp	Spherical Linear Interpolation functions
RtSplinePVS	Utility functions to allow PVS generation using spline paths
RtTIFF	Tag Image File Format image format handling
RtTile	Tiled rendering functions (used mainly for very high-resolution renderings)
RtTOC	Table Of Contents for a stream
RtVCAT	Vertex Cache Aware Tri-stripper
RtWing	Winged edge/half-edge
RtWorld	Utility functions to be used in conjunction with RpWorld
RtWorldImport	Utilities for creating RpWorld objects from foreign data formats

1.3.2 PowerPipe

PowerPipe provides a means of overloading the rendering subsystem either wholly or piecemeal. You can replace or even create entirely new rendering pipeline nodes and clusters.

1.3.3 Namespaces

All the RenderWare Graphics functions and objects carry two-letter prefixes to prevent naming clashes with your own code. This has been used to provide the best compromise between readability and name length.

The prefixes depend on whether the object in question is part of the Core Library, part of a Plug-in, or part of a Toolkit. They are:

PREFIX	DESCRIPTION
'Rw'	Indicates a function situated in the RenderWare Graphics Core Library ("**rwcore.h**" / "**rwcore.lib**"). These functions are always available as long as the core RenderWare Graphics library is linked to your application. *Examples:* **RwEngineStart()** **RwCameraCreate()**
'Rp'	Indicates a function situated in a Plugin library (e.g. **RpMorph**.) In most cases, the name of the Plugin follows the prefix, but this guideline is sometimes ignored to keep function names sensible. The appropriate Plugin must be attached if you intend to use these functions and linked to the appropriate header and library files. *Examples:* **RpMorphPluginAttach()** **RpPVSAtomicVisible()**
'Rt'	Indicates a Toolkit. Syntax is similar to that of Plugins, described above. Many Toolkits rely on one or more Plugins being attached, but Toolkits themselves do not need to be attached. *Examples:* **RtSlerpCreate()** **RtTileRender()**
'Rx'	Used by the PowerPipe API. *Examples:* **RxHeapFree()** **RxPipelineExecute()**
'Rs'	Source code to a simple (and very basic) platform abstraction layer used for all examples is provided. Major functions in this layer use an '**Rs**' prefix.
Exceptions	These include constants, such as **#define**s and **enum** values. These generally use the same prefixes as above, but entirely in lower case, followed by an all-caps name, such as: **rwRASTERTYPECAMERA**.

1.3.4 Just Graphics

This may seem obvious, but it is important to remember that RenderWare Graphics *only* provides multi-platform 3D graphics features. While some utilities are provided, such as an abstraction layer known as the '*Skeleton*', this code is not officially supported.

Most developers will create their own abstraction layers and write suitable plugins for RenderWare Graphics to provide a consistent programming interface across their supported platforms.

1.3.5 Objects

As RenderWare Graphics is written in C and assembler, it makes object-oriented design that little bit harder to implement. C++ classes might need to be written to wrap the RenderWare Graphics API.

One important issue to consider is the definition of an *object* in RenderWare Graphics.

In C++, objects are an explicit part of the language's design. RenderWare Graphics 'objects' are either intrinsic, such as **`int`** and **`char`**, or an ordinary C **`struct`**. These usually have a noun for a name – e.g. World, Clump, and Vector. The methods or member functions associated with these objects are ordinary C functions that live outside these structures, but with names that begin with the same name as the 'object'.

For instance, a hypothetical object called **`RwThing`** might have methods with names like **`RwThingGetProperty()`**.

RenderWare Graphics objects have been designed to operate in much the same way as C++ objects. The main difference is that there are no member selection operators to separate object names from their associated methods.

Objects & Properties

Transparent vs. Opaque Objects

RenderWare Graphics developers sometimes make a simple object *transparent*. This means that you will find complete documentation of the internals of said object in the API Reference and (usually) no property-access functions. The point of this is to reduce unnecessary function calling overheads: you are free to directly change the individual object elements.

This reveals the element of trust enshrined with RenderWare Graphics' design: where a data structure is not explicitly documented, it should be considered an *opaque* object. Usually, such objects will have no documentation for their individual members; so only their associated property access methods (using the traditional 'Get' and 'Set' convention) should be used.

The table below shows some examples of opaque objects and access to their members:

OBJECT	PROPERTY	'METHOD' NAME
`RwCamera`	`ViewWindow`	`RwCameraGetViewWindow()`
		`RwCameraSetViewWindow()`
`RpAtomic`	`Geometry`	`RpAtomicGetGeometry()`
		`RpAtomicSetGeometry()`

The objects name always forms the root of the function name. This pattern is followed consistently throughout the RenderWare Graphics API.

Obviously, the various header files document all members of a particular **`struct`**. In general, these members should not be modified in your code, but instead use the functions that are supplied in the library.

Of course, C doesn't automatically pass the object instance to the functions, so you still have to do this explicitly. Usually, the first parameter of a function will be a pointer to the object.

1.4Creating A Scene

1.4.1 Step-by-Step

To render scenes in RenderWare Graphics applications, a number of steps need to be performed:

1. Create assets in a modeling package.

   This includes the background scenery and all the characters, props and other animated models that will populate that scenery. Textures may need creating in a paint package.

2. Export assets in the RenderWare Graphics format.

   The RenderWare Graphics Retained Mode API supports two kinds of model: *static* models that live in *World* objects, and *dynamic models* that live in *Atomic* objects.

Backgrounds and other fixed scenery models are generally considered static; all other models are dynamic. To add dynamic scenery elements, you should use dynamic models and position them in the scene accordingly.

These objects are part of the high-level **`RpWorld`** Plugin that encapsulates our Retained Mode API. More on this powerful Plugin can be found in the two chapters: *Worlds & Static Models* and *Dynamic Models*.

3. Load assets into the RenderWare Graphics application.

   RenderWare Graphics includes a multi-platform file serialization API – **`RwStream`** – that is used for this purpose.

4. Position them using *frames*.

   Frames, described in the *Fundamental Types* chapter, are an essential feature of the RenderWare Graphics architecture. They are attached to objects so they can be positioned in *world space*. Frames also manage model hierarchies.

5. Create *lights*.

   RenderWare Graphics supports a number of lighting models, as well as both static and dynamic lights, and the standard light model can be overridden.

6. Create a *camera* object and orient it.

   RenderWare Graphics uses the standard virtual camera metaphor in the Retained Mode API. This API, and Cameras in general, can be found in the following chapters: *Cameras*; *Worlds & Static Models* and *Dynamic Models*.

7. Take a picture.

This process involves the actual rendering of the scene.

8. Update the scene.

   If you're producing real-time animation in 3D, you will need to update the models between renderings.

9. Repeat steps 7 and 8 until the user tells the application to quit.

   This is the rendering process in short. Aside from some of the terminology specific to RenderWare Graphics, this is much the same as in any other 3D graphics API.

1.4.2 Platform Abstraction

In order to be able to write our examples and other sample code just once, without the need to rewrite it for each target platform, the hardware abstraction layer called the '*Skeleton*' has been developed. Almost all the sample code supplied with the SDK will use this code as its foundation.

The Skeleton was developed for our sample code. It is not suitable for anything other than similarly simplistic test-beds and prototyping. It is absolutely, categorically *not* intended for use as the basis for a professional application. However, it does provide a convenient set of functions that can be used for rapid prototyping of games.

The Skeleton code is completely unsupported. The source code to it is provided to show you that (a) it can be done, and (b) so that all our tools and examples can be presented in a consistent way.

Put another way: *the Skeleton is provided as-is and with no guarantee for any suitability or fitness for purpose. You use it entirely at your own risk.*

File I/O

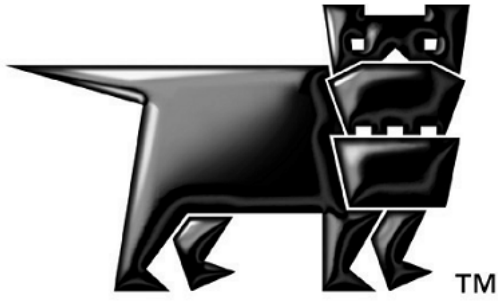
File handling is an important facet of RenderWare Graphics and for this reason, we provide a file system that can be overloaded. The **`RwOsGetFileInterface()`** can be used to obtain a structure containing the pointers to the file operation functions. The file pointers in this structure can be replaced by pointers to your own, which makes it easier to divert file-handling to the DVD, host machine and possibly even over a TCP/IP link.

Part A

Core Library

Chapter 2

Fundamental Types



2.1Introduction

This chapter covers many of the basic types that are exposed by RenderWare Graphics.

Some types are simple and *transparent*, meaning you can access them and their elements directly. Others may be *opaque* and you should use the API provided to manipulate them.

If your development is intended to run on multiple platforms then it is suggested that you use RenderWare Graphics' data types throughout your application. The Core Library implements a number of basic data types, such as **RwChar**, **RwUInt16** and so on, which means that you can rely on RenderWare Graphics to ensure that on the different platforms the sizes of these types are correct.

For example, you can rely on the **RwChar** to be the correct size on a particular platform to store characters as these are not guaranteed to be eight bits on all supported platforms.

2.2RenderWare Graphics & Objects

The first chapter explained that RenderWare Graphics is designed along object-oriented principles. As a result, the concept of objects plays an important part in understanding how the API works.

Before covering the basic data types then, it is worth looking at the ramifications of this design in a little more detail.

2.2.1 RenderWare Graphics Objects

C is not an object-oriented language, so one question frequently asked of the development team is *why use C?* This question was answered in the previous chapter, but it leaves open the question of *how* an object-oriented design is implemented.

By design, the API looks rather like a C++ based one, without all the extra punctuation. By necessity, the API supports a plugin mechanism which is used to extend the "objects". This extension mechanism is managed programmatically rather than as an intrinsic feature of the programming language.

For example, a look at the **RpWorld** plugin's API will reveal a number of base objects: **RwTexture**, **RpClump**, **RpWorld** and so on. Each of these objects is actually defined as a standard C **struct** datatype with their "methods" – functions – defined as ordinary functions separate from the data structure.

2.2.2 Object Instantiation

This is usually a two-stage process. The first is to define a variable of the object's type. For example:

```
RwTexture myTexture;
```

It is rare for developers to create automatic instances; allocation on the heap is far more common. This example therefore defines **myTexture** as an object of type **RwTexture**.

However, C does not support a constructor mechanism in the way C++ does, so **myTexture** has no valid data in it.

To reduce bugs caused by referencing uninitialized objects, RenderWare Graphics' API usually provides some form of default object creation function. In the case of Texture objects, the function is **RwTextureCreate()**, which generates a new Texture from the given Raster object and returns a pointer to the Texture on success.

```
RwTexture myTexture;
RwTexture * pmyTexture = RwTextureCreate();
```

Similar creator functions are provided for most RenderWare Graphics objects and it is advisable to use them where possible.

2.2.3 Object Destruction & Reference Counters

As in C++, RenderWare Graphics objects must *be destroyed when you are finished with them. This is particularly important if you are working on platforms with limited memory available. However, care is needed to ensure that you do not destroy objects that are still being referenced elsewhere in your code...*

Although the documentation for RenderWare Graphics talks about things like container objects, these just boil down to objects that contain lists of *pointers* to the objects they contain. The word pointer is emphasized here because it implies that an object can be referenced by more than one object.

For example, a Texture can be "contained" by multiple Materials (part of the World Plugin and a useful container object for Textures), but this just means these Materials would each contain a pointer to the same Texture.

So far, so obvious, but multiple references can be a problem when it comes to destroying objects. If a Texture is referenced by multiple objects, some method is needed to prevent it being destroyed before the other objects have finished with it.

To avoid this, RenderWare Graphics uses a fairly standard *reference counting* system.

For example, if a Texture is referenced by another object, the Texture's reference counter will be incremented using a call to the Texture's **...AddRef()** method. (**RwTextureAddRef()**) When the Texture is removed from that object, its counter is decremented. So if the Texture is referenced by, say, five other objects, its counter will be equal to five.

When the Texture is no longer needed by an object, it should be destroyed by calling the object's **...Destroy()** method. (For Textures, the full function name is **RwTextureDestroy()**.) This function will decrement the reference counter and, if it is zero, finally destroy the object referred to.

It is important to note that the reference counting system is *not* fully automatic. For example, you will need to call **...AddRef()** and **...Destroy()** methods directly if you add a reference to a RenderWare Graphics object to a structure of your own.

Destruction & Destruction Order

The order in which objects are destroyed is an important consideration.

RenderWare Graphics programming often involves the use of a number of container objects. A common bug can be brought about by deleting such containers *before* deleting the contained objects.

For example, take the Clump and Atomic objects. These are part of the scene graph API provided by the World Plugin (**RpWorld**). For now, it's important to know only that Clumps are container objects for Atomics.

A common cause of bugs is to destroy a Clump, then destroy each of its contained objects *by referencing through the Clump*. Obviously, the Clump no longer exists at this point, but many programmers assume that the pointer is still valid as no code has been executed to overwrite the data yet.

This is a bad assumption to make: some platforms, including Microsoft Windows, have background tasks running which can easily trigger the overwriting of such data. This is a common cause of intermittent bugs and crashes, so you should always destroy objects in the correct order.

2.3The Boolean Type

RenderWare Graphics supports one Boolean type:

TYPE	DESCRIPTION	RANGE	SIZE
RwBool	A standard Boolean type with the usual two states	**FALSE, TRUE**	32 bits

2.4Characters

TYPE	DESCRIPTION	RANGE	SIZE
RwChar	Character type, in either ANSI or Unicode format		8 bits (ANSI char) or 16 bits (Unicode)

RwChar is intended *solely* for storing individual characters and character strings (usually 8-bit for ANSI libraries and 16-bit for Unicode libraries).

You should never use **RwChar** * as pointers to memory as it is wrong to assume it will be equivalent to the C Language "char" type.

Use **RwInt8** * or **RwUInt8** * instead.

2.5Integer Types

RenderWare Graphics is intended to run on a number of platforms. To ensure consistent behavior, new types are defined to replace the base C Language ones. The RenderWare Graphics replacements are designed to behave as consistently as possible over all supported platforms.

RenderWare Graphics defines a number of integer types for specific bit widths, which are shown in the table on the following page.

These data types are designed to behave identically across all supported platforms. It therefore makes sense to use these instead of the standard C data types in your own applications.

Integer types:

TYPE	DESCRIPTION	RANGE
RwInt8	signed byte (8 bits)	-128 to +127
RwUInt8	unsigned byte (8 bits)	0 to 255
RwInt16	signed word (16 bits)	RwInt16MINVAL (-32768) to RwInt16MAXVAL (32767)
RwUInt16	unsigned word (16 bits)	RwUInt16MINVAL (0) to RwUInt16MAXVAL (65535)
RwInt32	signed long (32 bits)	RwInt32MINVAL (-2^{31}) to RwInt32MAXVAL ($2^{31}-1$)
RwUInt32	unsigned long (32 bits)	RwUInt32MINVAL (0) to RwUInt32MAXVAL ($2^{32}-1$)
RwInt64	64 bit, signed integers should only ever be used on platforms with native and compiler support for 64 bit data types. On other platforms, this data type is defined using a struct so no mathematical operations are available.	-2^{63} to $2^{63}-1$. No range defining macros are defined.
RwUInt64	64 bit, unsigned integers should only ever be used on platforms with native and compiler support for 64-bit data types. On other platforms, this data type is defined using a struct so no mathematical operations are available.	0 to $2^{64}-1$. No range defining macros are defined.
RwInt128	128 bit, signed integers should only ever be used on platforms with native and compiler support for 128 bit data types. On other platforms, this data type is defined using a struct so no mathematical operations are available.	-2^{127} to $2^{127}-1$. No range defining macros are defined.
RwUInt128	128 bit, unsigned integers should only ever be used on platforms with native and compiler support for 128 bit data types. On other platforms, this data type is defined using a struct so no mathematical operations are available.	0 to $2^{128}-1$. No range defining macros are defined.

2.6Real Types

RenderWare Graphics supports the following real number types:

TYPE	DESCRIPTION	RANGE	SIZE
RwReal	Usually equivalent to the C Language's single-precision "float" type.	RwRealMINVAL to RwRealMAXVAL	32 bits
RwFixed	16 bit integer, 16 bit fractional fixed point value. Rarely used, as true floating-point math is usually faster in current hardware.	RWFIX_MIN to RWFIX_MAX	32 bits

A common mistake is to forget to provide a trailing "f" on floating point constants. Some platforms have no double precision hardware support. If the "f" is omitted from an expression compiled for these platforms the expression will be assumed to be double precision and it will be emulated in software. This can dramatically reduce performance. It is recommended that you get into the habit of either using type prefixes:

```
RwReal g = 9.8f;
RwReal f = m * g;
```

or make use of type-casting in expressions, which is more portable:

```
RwReal g = 9.8;
RwReal f = m * (RwReal)g
```

2.7Vectors

RenderWare Graphics supports two and three dimensional vector types and arithmetic.

These types should be considered *opaque* as they can sometimes map directly onto underlying hardware vector processing units.

2.7.1 Two Dimensional Vectors

The 2D Vector type is **RwV2d**. It contains ***x*** and ***y*** coordinates.

The following functions are provided to manipulate 2D Vectors:

FUNCTION	OPERATION
RwV2dAssign()	Assignment (Copy) from a source vector to a target vector
RwV2dAdd()	Addition
RwV2dSub()	Subtraction
RwV2dLength()	Length
RwV2dNormalize()	Return a unit normal vector calculated from the original vector
RwV2dLineNormal()	Find a Unit Normal line between two vectors
RwV2dScale()	Scale
RwV2dDotProduct()	Calculate Dot Product
RwV2dPerp()	Calculate a 2D vector perpendicular to the given 2D vector

2.7.2 Three Dimensional Vectors

The 3D Vector type is **RwV3d**. It contains ***x***, ***y*** and ***z*** coordinates.

The table below shows the functions available to work with these vectors:

FUNCTION	OPERATION
RwV3dAssign()	Assignment (Copy) from a source vector to a target vector
RwV3dAdd()	Addition
RwV3dSub()	Subtraction
RwV3dLength()	Length
RwV3dNormalize()	Calculate unit normal vector from the original vector
RwV3dScale()	Scale
RwV3dIncrementScaled()	Multiplies the second 3D vector by the given scalar then adds the resulting vector to the first vector
RwV3dDotProduct()	Calculate Dot Product
RwV3dCrossProduct()	Calculate Cross Product
RwV3dNegate()	Negation
RwV3dTransformPoints()	Transform an array of points or vertices by the specified matrix
RwV3dTransformVectors()	Transform an array of vectors or normals by the specified matrix

2.8Coordinate Systems

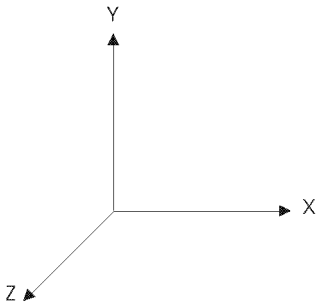
3D graphics programming requires understanding of a number of common coordinate systems, known as *spaces*. Some basic conventions need to be covered.

2.9Coordinate Systems

3D graphics programming requires understanding of a number of common coordinate systems, known as *spaces*. Some basic conventions need to be covered.

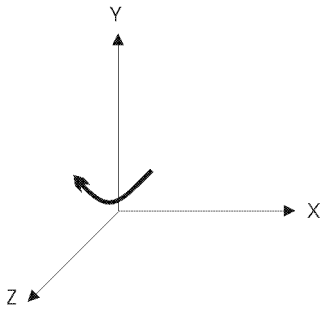
2.9.1 Right-handed Coordinates

RenderWare Graphics uses an orthogonal *right-handed coordinate system* for its 3D spaces.

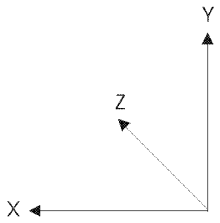


Typical right-handed coordinate system

The figure above displays the positive directions of **x**, **y**, and **z** axes with **z** pointing away from the screen.



*Rotate right-handed coordinate system about **y** axis*



RenderWare Graphics right-handed coordinate system

The RenderWare Graphics coordinate system is rotated about the **y** axis as and the figure on the right displays the positive directions of the **x**, **y** and **z** axes. The positive **z** axis points into the screen and the positive **x** axis points to the left.

As all the axes are rotated together the coordinate system is always right-handed.

Axis Naming Conventions

The three axes are defined in RenderWare Graphics by three vectors. By convention, the axis names used are:

AXIS	VECTOR REPRESENTATION
X	"Right"
Y	"Up"
Z	"At"

The vector is sometimes prefixed with the work *"look"*, as in *"look-at"*. This is commonly used when referring to the camera object which *"looks"* along the **z** axis.

The RenderWare Graphics' coordinate system is right-handed and the **x** axis is represented by the *right* vector. However, as the RenderWare Graphics coordinate system is rotated the **x** axis positive direction points to the left.

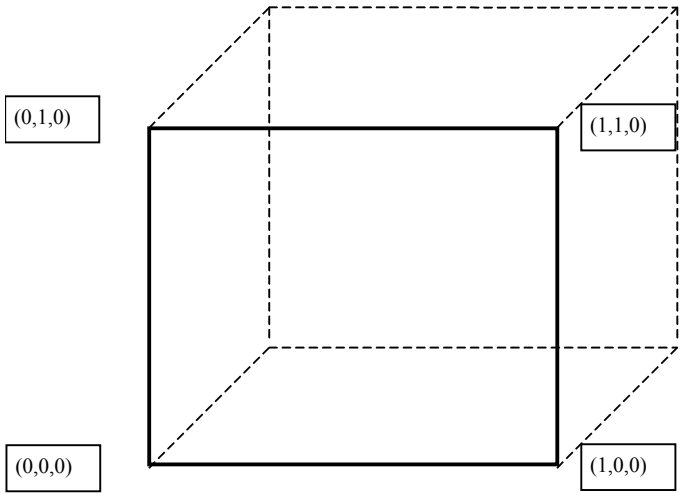
For example, the RenderWare Graphics camera faces into the screen, therefore we're effectively standing behind it. The camera's *right* vector points left as the RenderWare Graphics coordinate system has been rotated about the **y** axis so that **z** is pointing into the screen. Therefore moving the camera, by incrementing its **x** axis, results in the camera moving further to the left, along the positive **x** axis.

In 3D Graphics terminology, the **z** axis, represented by the *"at"* vector, is sometimes referred to as the *"front"* vector.

2.9.2 Object Space

Dynamic models in RenderWare Graphics are defined in terms of **Object Space**. This means that the vertices that define the model are relative to an arbitrary origin.

For example, the front face of a cube of unit size could be defined thus:



The origin in this case is the lower-left corner of the front face. However, the origin *could* be anywhere – even the center of the cube. This could be achieved by subtracting (0.5, 0.5, 0.5) from each vertex.

The location of the origin can be important, as it is easier to align models if their origins are on a shared edge or a corner rather than at some arbitrary point in the middle or outside the models.

2.9.3 World Space

Dynamic models, defined in Object Space, need to have a frame of reference so that they can be positioned relative to other models and scene graph objects. This frame of reference is **World Space**.

Objects positioned relative to this system are said to reside in *world space*. This coordinate system is used, for example, to specify the position of cameras and lights. Geometry can be positioned in world space using transformations described later.

A bounding box defines the World Space limits. This is either generated by a modeling package exporter when exporting World data, or explicitly by the developer when calling **`RpWorldCreate()`**.

Frames

The RenderWare Graphics object that allows us to position objects in World Space is called the **Frame** (**`RwFrame`**). Many RenderWare Graphics objects require a Frame to be attached before they can be positioned within a World.

2.9.4 Camera Space

Cameras, like many RenderWare Graphics objects, require a Frame to define their position and orientation. However, there is another system called Camera Space which defines the Camera's viewing coordinate system. A normalized Camera Frustum defines Camera Space as follows:

- for a parallel projection model the Camera Frustum space has side planes at $x = 0$, $x = 1$, $y = 0$ and $y = 1$
- for a Perspective Projection model, it has side planes at $x = 0$, $x = z$, $y = 0$ and $y = z$

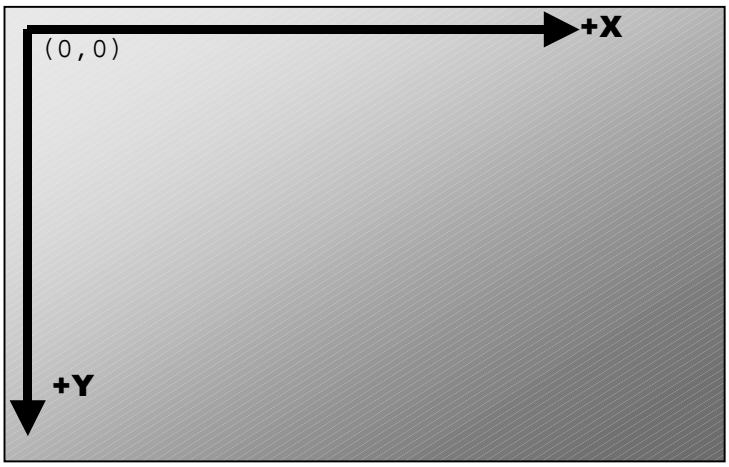
Camera Space is also a right-handed system with an origin at the Camera's position (given by the Frame's pos vector). The positive z axis of Camera Space is given by the view direction, which points in the direction of the Frame's *at* vector. The units of Camera Space z coordinates are the same as those for World Space.

RenderWare Graphics also recognizes a two-dimensional coordinate system.

2.9.5 Device Space

The device coordinate system defines a *device space*. Its units are those of the display (screen or window) to which the camera's image buffer is copied and as such, it has coordinates that only take discrete (or integer) values.

The origin of device space is located at the top-left of the display with the x-values running from left to right and the y-values running from top to bottom, as shown in the diagram:



Device space can also be considered to have a depth component that is used in the Z buffer.

2.10 Matrices

RenderWare Graphics defines a pseudo-4x4 homogeneous **Matrix** (**RwMatrix**) object to represent 3D transformations. The **Frame** object, see 2.11 below, makes heavy use of matrices. Matrices in RenderWare Graphics appear as shown below:

$$\begin{pmatrix} R_x & R_y & R_z & 0 \\ U_x & U_y & U_z & 0 \\ A_x & A_y & A_z & 0 \\ P_x & P_y & P_z & 1 \end{pmatrix}$$

The row vector *(R_x, R_y, R_z)* contains the components of the *look-right* vector, *(U_x, U_y, U_z)* are those of the *look-up* vector, *(A_x, A_y, A_z)* for the *look-at* vector and *(P_x, P_y, P_z)* are the components of the *pos* vector. The components of a matrix are available to the application programmer by using **RwMatrixGetRight()**, **RwMatrixGetUp()**, **RwMatrixGetAt()** and **RwMatrixGetPos()**.

2.10.1 Matrix Mathematics in RenderWare Graphics

Matrices are treated as quadruples of row vectors. Each row vector is a triple of real values. The vectors are the *right*, *up* and *at* vectors, which orient a Cartesian coordinate system, and the *pos* vector that positions this coordinate system with respect to a parent coordinate system. In conventional 4×4 matrix form, there is an implied last column of $(0,0,0,1)^T$. The equations for matrix multiplication can then be expanded as shown below.

$$\mathbf{C} = \mathbf{A} \times \mathbf{B}$$

$$\begin{pmatrix} R_x^A \cdot R_x^B + R_y^A \cdot U_x^B + R_z^A \cdot A_x^B & R_x^A \cdot R_y^B + R_y^A \cdot U_y^B + R_z^A \cdot A_y^B & R_x^A \cdot R_z^B + R_y^A \cdot U_z^B + R_z^A \cdot A_z^B & 0 \\ U_x^A \cdot R_x^B + U_y^A \cdot U_x^B + U_z^A \cdot A_x^B & U_x^A \cdot R_y^B + U_y^A \cdot U_y^B + U_z^A \cdot A_y^B & U_x^A \cdot R_z^B + U_y^A \cdot U_z^B + U_z^A \cdot A_z^B & 0 \\ A_x^A \cdot R_x^B + A_y^A \cdot U_x^B + A_z^A \cdot A_x^B & A_x^A \cdot R_y^B + A_y^A \cdot U_y^B + A_z^A \cdot A_y^B & A_x^A \cdot R_z^B + A_y^A \cdot U_z^B + A_z^A \cdot A_z^B & 0 \\ P_x^A \cdot R_x^B + P_y^A \cdot U_x^B + P_z^A \cdot A_x^B + P_x^B & P_x^A \cdot R_y^B + P_y^A \cdot U_y^B + P_z^A \cdot A_y^B + P_y^B & P_x^A \cdot R_z^B + P_y^A \cdot U_z^B + P_z^A \cdot A_z^B + P_z^B & 1 \end{pmatrix} =$$

$$\begin{pmatrix} R_x^A & R_y^A & R_z^A & 0 \\ U_x^A & U_y^A & U_z^A & 0 \\ A_x^A & A_y^A & A_z^A & 0 \\ P_x^A & P_y^A & P_z^A & 1 \end{pmatrix} \times \begin{pmatrix} R_x^B & R_y^B & R_z^B & 0 \\ U_x^B & U_y^B & U_z^B & 0 \\ A_x^B & A_y^B & A_z^B & 0 \\ P_x^B & P_y^B & P_z^B & 1 \end{pmatrix}$$

Matrix multiplication is *not* commutative so, the order of the arguments passed to **RwMatrixMultiply()** is significant. Transformation of a position is performed mathematically in the following manner:

$$\mathbf{v} = \mathbf{u} \times \mathbf{M}$$

$$\begin{pmatrix} u_x \cdot R_x + u_y \cdot U_x + u_z \cdot A_x + P_x \\ u_x \cdot R_y + u_y \cdot U_y + u_z \cdot A_y + P_y \\ u_x \cdot R_z + u_y \cdot U_z + u_z \cdot A_z + P_z \\ 1 \end{pmatrix}^T = \begin{pmatrix} u_x & u_y & u_z & 1 \end{pmatrix} \times \begin{pmatrix} R_x & R_y & R_z & 0 \\ U_x & U_y & U_z & 0 \\ A_x & A_y & A_z & 0 \\ P_x & P_y & P_z & 1 \end{pmatrix}$$

This is the operation performed by **`RwV3dTransformPoints()`**. This function is used to transform position vectors. There is also an **`RwV3dTransformVectors()`** function, which transforms vectors (e.g. normals). In this case, the matrix is assumed to contain a zero position vector and so does not contribute to the output vectors.

Put another way: a direction vector is *never* translated, but only rotated.

Using **`RwV3dTransformPoints()`** with normals, or **`RwV3dTransformVectors()`** with vertices will give strange results.

The order of matrix transformations has an effect on the visible orientation of Atomics, as discussed (see 2.11.3 below).

2.11 Frames

RwFrame objects contain two matrices. These are the *Local Transformation Matrix* (or LTM), and the *Modeling Matrix*. These two matrices can be retrieved using **RwFrameGetLTM()** and **RwFrameGetMatrix()**, respectively.

When transformations are performed on a frame (see next paragraph), it is the Modeling Matrix that is affected. (The LTM describes the total transformation from Object Space to World Space.) Unless the Frame belongs to a hierarchy, the Modeling and Local Transformation Matrices are identical. Otherwise, the Modeling Matrix is relative to the Frame's parent.

Frames can be transformed using **RwFrameTranslate()**, **RwFrameRotate()**, **RwFrameScale()** and **RwFrameTransform()**. Rotation and scaling is accrued in the top-left 3x3 sub-matrix, while translation is accumulated in the bottom row.

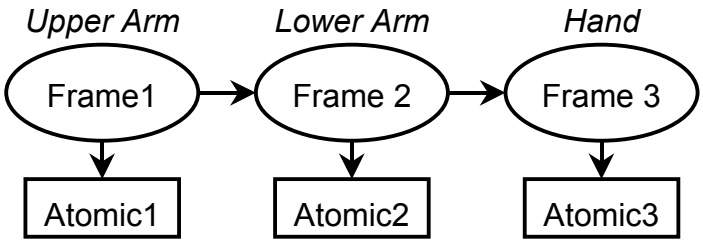
Given a transformation matrix, individual points and vectors (both of type **RwV3d**) can be transformed using **RwV3dTransformPoints()** and **RwV3dTransformVectors()**.

Hierarchical modeling is the process of building models that preserve the hierarchical structure of objects and allow the position and orientation of an object in the hierarchy to be specified relative to its parent.

2.11.1 Hierarchical Models & RenderWare Graphics

Hierarchical modeling explicitly models articulation, or joints, connecting objects. In RenderWare Graphics, these joints are represented by **frames** (**`RwFrame`**). These only define the hierarchy itself. The model data itself is sectioned, with each section stored in an **atomic** (**`RpAtomic`**). An atomic can be linked to a frame, with collections of atomics and frames thus forming a hierarchical model.

Consider, for example, the modeling of a robot arm consisting of an upper-arm, lower-arm and a hand represented by three atomics. We wish to model the arm so that movement of the upper-arm is transferred to the lower-arm and hand whilst movement of the lower-arm only affects the hand. Assume each atomic has its own frame (see API function **`RpAtomicSetFrame()`**). Then the required articulation can be achieved by attaching the lower-arm's frame as a child of the upper-arm's frame and, similarly, attaching the hand's frame as a child of the lower-arm's frame. The API function **`RwFrameAddChild`** is used to accomplish this.



The modeling matrix of each frame is now described relative to the Frame's parent Frame object and the corresponding LTM becomes the concatenation of all the modeling matrices up to the root Frame, in this case the Frame on the upper-arm's atomic.

For each case we have:

$LTM_1=MM_1$

$LTM_2=MM_2 \otimes LTM_1$

$LTM_3=MM_3 \otimes LTM_2$

(where *LTM* = local transformation matrix and *MM* = modeling matrix.)

Only the root Frame's modeling and local transformation matrices are identical.

The object hierarchy is shown schematically above. *Frame1* is the parent of *Frame2* (therefore, *Frame2* is the child of *Frame1*), while *Frame2* is the parent of *Frame3*. Note that the arrangement of the Atomics is determined entirely by the frame hierarchy. If these Atomics were all added to a single **Clump** object, the Clump would impose no organization. Because a Clump is designed as a container for Atomics, it can be assumed that the Clump must order its Atomics but, as you can see, this is not how it works.

To model the robot hand in more detail by adding some fingers:

- give the hand three fingers represented by three more Atomics.
- build the hand hierarchy by attaching all the fingers' Frames as children of the hand's Frame (see diagram above).

All the fingers' Frames *(frame4*, *frame5*, *frame6*) are child frames of the hand's frame and siblings of each other. In terms of the LTMs we have, for example:

$LTM_4 = MM_4 \otimes LTM_3$

This means the LTM of *frame4* is the concatenation of the modeling matrices of Frames *Frame1*, *Frame2*, *Frame3* and *Frame4* – this is the same for the other fingers. Movement of the hand is now automatically transferred to all the fingers.

It is recommended, though it is by no means required, that the hierarchy is encapsulated within a Clump which has its own Frame – see **`RpClumpSetFrame()`** – acting as the root of the Frame hierarchy. For example, *Frame1* would be attached to the Clump's frame (say, *Frame0*,) as a child of that Frame. Also, each of the Atomics must be added the Clump using **`RpClumpAddAtomic()`** for this organization to work correctly.

Frames and the Local Transformation Matrix

Frame objects contain a matrix called the **Local Transformation Matrix**, (usually abbreviated to "**LTM**"). This matrix is used when working with hierarchies of Frame objects.

Local Transformation Matrices are constructed by traversing the hierarchy from top to bottom. At each level in the hierarchy, the modeling matrix is pre-multiplied into the local transformation matrix from the level above to form the LTM for the current level. Because the LTM is used to post multiply vectors this means that the transformation stored in the lowest frame in the hierarchy affects the vertex first of all:

$$U = V \cdot M_n \cdot M_{n-1} \cdot \Lambda \cdot M_1 \cdot M_0$$

In this equation, the Local Transformation Matrix at the root of the hierarchy is M_0 and that at the bottom of the hierarchy is M_n, where there are $n+1$ levels in the hierarchy.

2.11.2 Traversing Frame Hierarchies

There are two methods for traversing an object hierarchy depending on whether it is Frames or the objects hanging from them. It is assumed that a hierarchy of Frames and Atomics assembled into a Clump where the Clump's Frame acts as the root of the hierarchy.

All Frames in the hierarchy may be iterated over using the **RwFrameForAllChildren()** iterator. Starting at the root Frame, this function will apply a user-defined callback to all first generation child Frames. Repeating **RwFrameForAllChildren()** on each callback will then iterate over all second generation, i.e. grandchild, frames, and so on. Also, for each Frame encountered a call to **RwFrameForAllObjects()** applies a callback to each object attached to the Frame.

RwFrameForAllChildren() will only take you down *one* level in a hierarchy. You must use your callback function to call **RwFrameForAllChildren()** again to go down the hierarchy another level, so your callback should be designed for recursion.

If the Frame hierarchy is not important, a call to the **RpClumpForAllAtomics()** iterator will iterate over all the Atomics registered with a Clump. The supplied user-defined callback function will be applied to each Atomic in turn.

2.11.3 Matrix Combination Flags in RenderWare Graphics

Matrix and frame transformation functions in RenderWare Graphics (for example, **RwFrameTransform()** and **RwMatrixRotate()**) take a parameter, **combineOp**. This parameter is used to control the order in which the transform is applied to the matrix or Frame.

The available combine operators are: *replace*, *pre-concatenate*, and *post-concatenate*.

- **rwCOMBINEREPLACE** assigns the new transformation to the matrix. The original contents of the matrix are entirely replaced by the new transform.

  RwMatrixTranslate(M, t, rwCOMBINEREPLACE) builds a new matrix containing only a translation, and stores this matrix in **M**. Any rotation component in the matrix **M** is overwritten with a 3x3 identity sub-matrix. This is true for all matrix-transforming functions where the **rwCOMBINEREPLACE** flag is used.

- **rwCOMBINEPRECONCAT** causes the transform matrix to be pre-concatenated onto the matrix. This has the effect of applying the transformation before the transformation already in the matrix. Put another way: this operator causes the transformation to be made in object space (or the coordinate space of the matrix).

- **rwCOMBINEPOSTCONCAT** instructs RenderWare Graphics to post-multiply the transformation into the matrix. The new transformation will take effect after the transform already in the matrix. In other words, the transformation takes place in world space.

Example

Consider a call made to **RwFrameScale()** with a Frame **F**, and a vector **S** encoding the scale. The effect of changing the combination operator will be looked at. Firstly, however, it should be pointed out that the function alters the modeling matrix in the frame.

A RenderWare Graphics application should never modify the LTM matrix directly, since the library is responsible for computing this matrix from the Modeling Matrix and the LTMs of the Frame hierarchy.

In this example the modeling matrix, denoted **M**, is stored in Frame **F**.

Notionally, the **RwFrameScale()** function computes a scale transformation matrix, **S**. This will be a 4x4 zero matrix with a diagonal encoding the elements from the scale vector, and 1:

$$\mathbf{S} = \begin{pmatrix} s_x & 0 & 0 & 0 \\ 0 & s_y & 0 & 0 \\ 0 & 0 & s_z & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

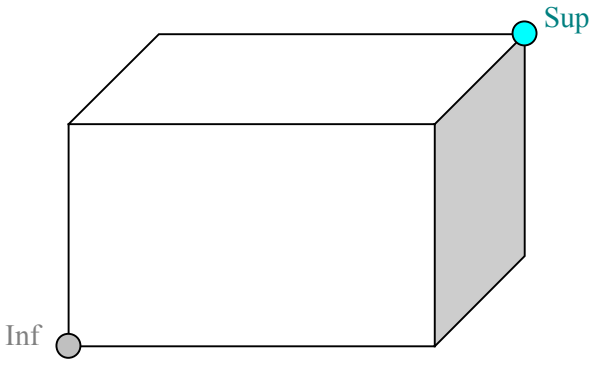
The table below illustrates the result of varying the combine operator on the matrix **M**.

OPERATOR	RESULTING MATRIX (M)
rwCOMBINEREPLACE	S
rwCOMBINEPRECONCAT	SM
rwCOMBINEPOSTCONCAT	MS

2.12 Bounding Boxes

The **Bounding Box** (**RwBBox**) object defines a bounding box using two points: **sup** (supremum) and **inf** (infimum). These two points define diametrically opposite corners of the box, such that for any axis, the value in the **inf** coordinate is never larger than the value in the **sup** coordinate.

The illustration below shows how this works in practice:



The resulting box therefore represents a 3D axis aligned cuboid volume.

Bounding boxes provide the basis for simple tests to determine whether specific coordinates in the coordinate space are bounded by the volume. The box may also be expanded to include another point within its volume, using the **RwBBoxAddPoint()** function.

Another test available is **RwBBoxContainsPoint()**, which can be used to check if a vertex is inside or outside a Bounding Box.

RwBBoxAddPoint() can also be used together with the **RwBBoxInitialize()** function. This takes a single vertex and initializes both the **inf** and **sup** elements to this point. **RwBBoxAddPoint()** can be called repeatedly to expand the Bounding Box to contain any arbitrary number of points. This technique is useful if the number of points involved is unknown.

If, on the other hand, you do have a fixed-length array of vertices, you can use the **RwBBoxCalculate()** function to perform a similar operation to the above. This function is usually the more efficient of the two systems.

2.13 Lines

RenderWare Graphics naturally supports a basic line type. This is called **RwLine** and it is defined by two **RwV3d** objects denoting the start and end vertices. The **RwLine** object is used typically as an intersection primitive. Do not confuse the **RwLine** object with an immediate mode line, which is a renderable object.

2.14 Rectangles

Rectangles are defined by the **`RwRect`** type. This type takes a positioning vector to locate the rectangle, as well as two parameters defining its width and height. As with lines above, the **`RwRect`** object is not renderable. Rectangles are typically used to define sub-regions of the screen.

2.15 Spheres

RenderWare Graphics defines the **RwSphere** type. This contains both a **center** and a **radius** as elements to define the location and size of the sphere.

Spheres are heavily used during Retained Mode rendering to determine which models are within the Camera Frustum. Using spheres for the initial tests makes for rapid culling. Once this coarse-level checking has been performed, the remaining models can then be tested and clipped more accurately.

Note that this object is not renderable, and is used primarily for intersection testing.

2.16 Colors

RenderWare Graphics defines two color representation types: **RwRGBA**, which is an integer-based primitive for describing colors, and **RwRGBAReal**, which defines colors using real numbers rather than integers.

The **RwRGBA** form is the most used as it corresponds closely with most of our supported platforms. This structure contains four **RwUInt8** elements, one for each of the Red, Green, Blue and Alpha components.

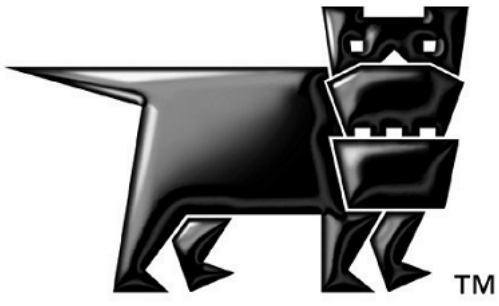
Although the **RwRGBA** format is fixed, the bitmap facilities offered by RenderWare Graphics are not and may differ widely in color element format. It is therefore possible that conversion may be needed when extracting or modifying individual pixels in a bitmap and such processing should thus be kept to a minimum.

See the chapter on *Rasters, Images and Textures* for information on these items and their colors.

RwRGBAReal defines four **RwReal** elements for **red**, **green**, **blue** and **alpha**. It is intended to be used in cases where high orders of accuracy are needed while processing colors. Values range from 0.0f to 1.0f.

Chapter 3

Initialization & Resource Management



3.1Introduction

RenderWare Graphics Core Library contains the base feature-set of the API. All other features are optional, provided in the form of either Plugins or Toolkits.

The Core Library's functionality is divided up into the following broad categories:

- Memory management
- OS-level file and memory management
- Plugin management
- Basic objects and intrinsic types, such as **RwInt32**, **RwBBox**, **RwMatrix**, **RwImage**, etc.
- 2D and 3D immediate modes
- PowerPipe extensible rendering pipeline
- Platform-Specific APIs (where applicable)
- Managing rendering time through the Lock and Unlock commands.

This chapter focuses on the memory management, plugin management and file management features of the core library.

3.2Basic Housekeeping

At the heart of RenderWare Graphics is the **RwEngine** object. This engine performs a number of housekeeping functions, including:

- Initialization and shut-down procedures
- Selecting the display device and video mode
- Querying the underlying hardware about its capabilities
- Updating metrics information (when linked to the Metrics libraries)
- Managing Plugins

All RenderWare Graphics applications have to initialize the engine before calling any other RenderWare Graphics functions. We'll look at this process next.

3.2.1 Initialization

Getting the RenderWare Graphics engine up and running is a three-step process:

1. Initialization of memory management and default file system interface
2. Setting the video mode
3. Plugins and starting RenderWare Graphics

and there are three functions you need to call:

1. **RwEngineInit()**
2. **RwEngineOpen()**
3. **RwEngineStart()**

These functions *must* be called in the above order and you cannot start rendering until after the **RwEngineStart()** call.

Why the three steps?

RenderWare Graphics has to make allowances for the many platforms it supports. Splitting the start-up process into three stages lets us open up such features as file and memory management, as well enabling the plugin architecture to operate properly.

Let's look at these steps in terms of what they're for...

Step 1 - Initialization of Memory Management and Default File System Interface

This first step concerns the API function **RwEngineInit()** and involves setting up the memory and file-handling subsystems.

Why Does the Engine need to be Initialized First?

RwEngineInit() must always be the first RenderWare Graphics function your application calls as all other functions assume the memory management facilities have been set up. For example, the plugin mechanism needs to access these memory functions, so they need to be set up before any Plugins are attached.

Similarly, the display device your application will use may also need some memory allocated for it. So again, we have to make sure the memory subsystem is ready first.

The Memory Functions

By default, RenderWare Graphics uses the standard ANSI memory functions, as implemented by the target platform's compiler, so any replacement functions must have identical prototypes to their ANSI counterparts.

In theory, the application can replace the default RenderWare Graphics handlers with its own at any time. In practice the application should change the memory handler only at this initialization stage, rather than later.

Changing the memory and file handling subsystems within the main loop of your application is possible, but not recommended as it can make debugging much more difficult.

Pointers to the functions are stored in the **RwMemoryFunctions** structure returned by **RwOsGetMemoryInterface()**. If necessary, the entries in this structure can be overwritten directly with your own function pointers, but this is not recommended as the change takes place immediately—if memory has already been allocated with the original functions, then it is likely that memory will be "lost" to your application.

Your application should create a new **RwMemoryFunctions** structure with pointers to your own functions, then pass a pointer to the structure to **RwEngineInit()**.

The File Functions

The file system is implemented in a similar way to the memory system, with a structure containing pointers to default POSIX functions used by default. Again, any replacement functions will need to share the same prototypes as the functions they will be replacing.

A file functions structure filled with the default functions can be retrieved using **RwOsGetFileInterface()**. To replace these default function pointers with your own, overwrite the entries in the structure. Your functions will then be used when accessing files.

Step 2 - Setting the Video Mode

At this stage, you will need to:

- Open the RenderWare Graphics Engine
- Determine which graphics subsystem the application should be using, as some platforms can support more than one
- Determine the video display mode the application should use.

Video hardware varies greatly from platform to platform, so this procedure requires some additional steps of its own.

Opening the RenderWare Graphics Engine

The RenderWare Graphics Engine can be opened using **RwEngineOpen()**.

Choosing the Graphics Subsystem

The RenderWare Graphics API represents a graphics device as a graphics *subsystem*.

The application must first determine how many graphics subsystems are available. This requires a call to **RwEngineGetNumSubSystems()**.

With this information, the application iterates through the available subsystems, checking each one for suitability. This is achieved by calling **RwEngineGetSubSystemInfo()** and interrogating the structure returned.

The following code fragment illustrates this process by printing out the identifying names of all graphics subsystems on a particular platform:

```
RwInt32 numSubSystems, i;
RwSubSystemInfo ssInfo;

numSubSystems = RwEngineGetNumSubSystems();

for(i=0; i<numSubSystems; i++)
{
    RwSubSystemInfo ssInfo;

    if( RwEngineGetSubSystemInfo(&ssInfo, i) )
    {
        printf("SubSystem %d: %s\n", i, ssInfo.name );
    }
}
```

(The **RwSubSystemInfo** structure contains only the **name** element.)

Once the subsystem has been chosen, the application must inform RenderWare Graphics of its choice by calling **RwEngineSetSubSystem()** with the requisite index number.

Setting the Video Mode

With the graphics subsystem selected, the application must now set the video mode. The first step is to determine how many video modes are supported, and what these modes are.

To determine the number of video modes supported, the application should call **RwEngineGetNumVideoModes()**, then iterate through the available modes by calling **RwEngineGetVideoModeInfo()**.

The code fragment below iterates through the available video modes and prints the information for each one to **stdio**.

```
RwInt32 numVideoModes, j;
RwVideoMode vmodeInfo;

numVideoModes = RwEngineGetNumVideoModes();

for(j=0; j<numVideoModes; j++)
{
    if( RwEngineGetVideoModeInfo(&vmodeInfo, j) )
    {
        printf("Video Mode %d: %dx%dx%d %s\n", j,
            vmodeInfo.width, vmodeInfo.height, vmodeInfo.depth,
            (vmodeInfo.flags & rwVIDEOMODEEXCLUSIVE)
            ? "(EXCLUSIVE)" : "" );
    }
}
```

The **RwVideoMode** object contains the following elements:

- *width* – the width, in pixels, of the video mode;
- *height* – the height, in pixels, of the video mode;
- *depth* – the number of bits per pixel supported by the video mode;
- *refRate* – approximate vertical refresh rate;
- *format* – pixel format of the display buffer. See also: **RwRasterFormat**.
- *flags* – contains one or more of the following flags:

  - **rwVIDEOMODEEXCLUSIVE** – if set, the video mode is full-screen rather than windowed.

    Windowed modes are only available on DirectX and OpenGL platforms.

  - **rwVIDEOMODEINTERLACE** – if set, the video mode is interlaced, with alternate fields being displayed each frame.

    Interlaced video modes are more common on platforms that use televisions for their video output.

  - **rwVIDEOMODEFFINTERLACE** – if set, the video mode is interlaced, but the signal is processed to reduce or eliminate the flickering normally associated with interlaced video modes.

    Interlaced video modes are more common on platforms that use televisions for their video output.

Owing to differences in hardware design, the flags shown above are not supported on all platforms. Detailed below are the platform-specific video mode flags. Please refer to the platform-specific documentation in the API Reference for additional information on any flags.

- **rwVIDEOMODE_XBOX_WIDESCREEN** – (Xbox specific) if set, wide screen is used. The application will also need to adjust the transform matrix to provide a 16:9 display aspect ratio rather than the more common 4:3 display aspect ratio.

- **rwVIDEOMODE_XBOX_PROGRESSIVE** – (Xbox specific) if set, progressive scan is used. Currently the supported progressive scan video modes are 480p and 720p HDTV modes.

- **rwVIDEOMODE_XBOX_FIELD –** (Xbox specific) field rendering is a special video mode where the back buffer size is assumed to be half the vertical height of the output display and the output format is defined to be interlaced. In this mode, the even lines of the display are rendered during one field and the odd lines are rendered during the next field. When using field rendering, the flicker filter is disabled. Field rendering can reduce the fill-rate and bandwidth requirements of a game substantially; however, since there is no flicker filter, display quality can also be degraded.

- **rwVIDEOMODE_XBOX_10X11PIXELASPECT –** (Xbox specific) if set, the frame buffer is centered on the display. On a television where the resolution is 704 pixels across, this would leave a 32 pixel black border on the left and a 32 pixel black border on the right.

  - **rwVIDEOMODE_PS2_FSAASHRINKBLIT** – (PlayStation 2 specific) if set, this video mode is full-screen anti-aliased by a scaled blit from the draw buffer to the display buffer.

– **RwVIDEOMODE_PS2_FSAAREADCIRCUIT** – (PlayStation 2 specific) if set, this video mode uses read circuit scan line blending for flicker reduction.

The video mode is set with a call to **RwEngineSetVideoMode()**, which requires the index number of the desired video mode.

Step 3 – Plugins and starting RenderWare Graphics

Plugins are one of the keys to RenderWare Graphics power. Before RenderWare Graphics can be started, plugins need to be attached. Plugins usually extend or add objects and provide new functionality. The Retained Mode API, for example, is exposed by the *RpWorld* plugin.

RenderWare Graphics is written in C, not C++, so object extensions must be handled explicitly. One of the most important procedures is *attaching* a plugin. This process performs the following steps:

- Linking a plugin with any existing RenderWare Graphics objects;
- Adding any extensions to those objects;
- Informing the RenderWare Graphics engine about any additional memory the extended objects will need.

Attaching must take place prior to starting the RenderWare Graphics engine with **RwEngineStart()**.

3.2.2 Shutting down RenderWare Graphics

Each of the three start-up functions has a matching shutdown function, which also needs to be called in the following order when the application terminates:

1. **RwEngineStop()**
2. **RwEngineClose()**
3. **RwEngineTerm()**

Each of these functions needs to be called in turn to close down and exit a RenderWare Graphics application.

Applications running on consoles, such as the PlayStation 2 or Xbox, do not need to concern themselves with exiting cleanly as console users just switch off the machine. But developers targeting multi-purpose platforms like Windows and MacOS will need to use these functions.

A good reason for shutting down is to trigger debugging functions, which notify the developer of any memory leaks. As these are often tied to the memory handling functions set up by **RwEngineInit()**, it may be necessary to perform a complete shutdown of RenderWare Graphics to trigger the leakage tests.

3.2.3 Changing Video Modes after Initialization

Changing video modes after the initialization steps described so far is tricky. To do so, you will need to partially shut down the RenderWare Graphics Engine by calling both **RwEngineStop()** and **RwEngineClose()**, then set your new video mode by calling **RwEngineOpen()** and **RwEngineInit()** to restart the RenderWare Graphics Engine.

This procedure requires the deletion and re-initialization of many active RenderWare Graphics bitmap objects, as hardware issues may require your graphics data to be in a different format for some display modes.

3.3Memory Management

RenderWare Graphics supports two memory management features, as well access to those of the underlying platform.

In this part of the chapter, we will take a look at these features, which are:

- The OS-level memory interface
- The Freelist memory management system
- The Resource Arena

3.3.1 The OS-level Memory Interface

As we've already seen, the RenderWare Graphics initialization function, **`RwEngineInit()`**, lets you set up the memory management subsystem used by the RenderWare Graphics API. This is a useful feature as you will be in a far better position to understand your application's memory usage patterns and can therefore replace the RenderWare Graphics memory manager with your own, more optimized one if you require.

To use these functions, your application should call the **`RwOsGetMemoryInterface()`** API function. This returns a pointer to an **`RwMemoryFunctions`** structure. The structure contains function pointers for OS-specific implementations of the ANSI C **`malloc()`**, **`free()`**, **`realloc()`** and **`calloc()`** functions.

RenderWare Graphics provides default implementations of the ANSI functions, which are named as follows:

- **`RwMalloc()`**
- **`RwFree()`**
- **`RwRealloc()`**
- **`RwCalloc()`**

These functions are mapped using macros. Where a specific platform's operating system provides its own, optimized forms of the ANSI functions, these will be substituted in the macros. In addition, debug versions of these functions will be substituted in the macros if a debug build is specified.

Your application can override these default functions by passing a structure populated with your own function pointers to **`RwEngineInit()`**. Your functions will obviously need to take the same parameters as the ANSI ones.

If you want to cut down on porting issues, it's worth using the **RwMemoryFunctions** structure to access the relevant memory allocation functions, rather than calling them directly. This also means your code can seamlessly switch to another memory-management system if you should decide to replace the default RenderWare Graphics functions with your own.

3.3.2 FreeLists

RenderWare Graphics provides two memory-management systems. The first of these is the **RwFreeList** object and is active by default.

A value of **rwENGINEINITNOFREELISTS** can be passed in the *flag* parameter for **RwEngineInit()**. This will tell RenderWare Graphics to use ANSI memory functions in place of the FreeList functions instead.

How FreeLists work

FreeLists are initialized with a block size – call it ***s*** – and a number – call it ***n*** – which specifies the minimum number of such blocks to allocate at a time. When you allocate your first object, the FreeList grabs enough memory to hold ***n*** blocks. You're free to allocate and free any of these blocks as often as you like.

If the FreeList is full and you try and allocate a new block, the FreeList grabs another (***s*** * ***n***) bytes of memory.

As you develop your application, you should monitor your usage of FreeLists to determine the best balance between speed and efficient memory usage.

Why FreeLists are useful

FreeList objects manage blocks of memory of the same size. Applications often spend most of their time creating and destroying groups of related objects. Grouping similar objects together under one FreeList object gives an economy of scale. Instead of allocating lots of small chunks of memory, the object allocates in bulk, grabbing another big chunk only if the previous chunk is completely filled. Because a FreeList knows all the objects it contains are the same size, it can allocate space for an object in a block much more quickly than the standard system heap allocators that must handle objects of mixed sizes.

FreeLists can also be useful for avoiding memory fragmentation, which can be particularly problematic on consoles that don't use virtual addressing systems. If you know how much space your game is likely to need for a certain type of object, setting aside this space early on and allocating into it at run time is often better than doing heap allocations at run time. Depending on the state of the heap and how long allocations stay before they are deallocated again, you can end up with memory with many small holes and no contiguous space large enough for allocations you may need later. Even though there may be enough memory in total, it is fragmented and therefore unusable. It is possible to "lose" megabytes of memory to this. RenderWare FreeLists provide a way of setting aside memory at startup for future allocations to help avoid this problem.

As an example, take a game that needs to instantiate groups of missiles. Each missile structure requires the same amount of space as that for any of the other missiles, so it makes sense to avoid multiple **`malloc()`** calls and use a single FreeList object to handle the missiles in batches instead. We might also know that the game will only ever have a maximum of 64 missiles in play at any one time so we can set aside enough space for all of them when we create the FreeList and be sure no more allocations for missiles will occur after then.

In code, our initialization for the missiles FreeList might look something like this...

```
RwBool
InitializeMissiles(void)
{
/* First, set up an RwFreeList structure for our missiles... */

   /* "TMissile" is our missile structure (wrapped into a typedef).
    * We want to allocate them in batches of 64 at a time.
    * We need them aligned to 4-byte boundaries,
    * ask for one block of these to be set aside now,
    * and provide space for the RwFreeList structure itself,
    * rather than mallocing it too. */
   RwFreeList *ok;

   ok = RwFreeListCreateAndPreallocateSpace(
      sizeof(TMissile), 64, 4, 1, &Globals.missilesList);

   return (ok != NULL);
}
```

Now, to use our FreeList mechanism, we can do something like this:

```
  ...

  /* Need a new missile... */

    TMissile *myMissile;
```

```
    myMissile = (TMissile *)RwFreeListAlloc( &Globals.missilesList
);

    if (myMissile)
    {
        /* Do something here with the missile. */
    }
```

And, when we're done with all our missiles, we can destroy our FreeList storage:

```
void
DestroyMissilesList(void)
{
    RwFreeListDestroy( &Globals.missilesList );
}
```

You can see that the FreeList allocation and destroy functions are similar to **malloc()** and **free()**, with the important difference that they result in far fewer calls to those low-level functions.

If you prefer that RwFreeLists don't allocate any memory until you start using them, you can pass 0 as the number of blocks to allocate on creation. Had we done this for our example above, the big block allocation would take place during the call to **RwFreeListAlloc()**. However, it is probably better to allocate space on start up to avoid heap fragmentation during run time, as mentioned above.

FreeList usage within RenderWare Graphics

FreeLists are used extensively by RenderWare Graphics for its internal memory management, particularly for managing groups of textures, cameras, clumps and other objects. These lists are not accessible directly by the application. However because the optimal number of objects to reserve space for is application specific, you can configure the sizes of the FreeLists RenderWare Graphics uses to suit your application. This should allow you to have no wasted space and no more allocations than absolutely necessary. See the RwFreeList overview in the API reference for a list of functions you may call to configure internal FreeList sizes, e.g. RwTextureSetFreeListCreateParams.

3.3.3 Resource Arenas

The *Resource Arena* is a cache and only one is supported in an application.

When rendering geometry, RenderWare Graphics will create a platform-specific version of that geometry—a process known as *instancing*—in the Resource Arena. RenderWare Graphics can then use the cached instance of the geometry directly rather than re-generate the platform-specific data for each rendering cycle. This is faster than re-instancing the geometry data every cycle.

This system is most efficient if the model geometry changes infrequently—a common situation in many 3D graphics applications.

There are some important points to understand:

- If you make your Resource Arena too small, your application will suffer from slowdown by a process known as *arena thrashing*. This occurs when objects that are being instanced require that another, previously instanced object, be kicked out to make room. This kicked out object will have to be re-instanced in the next rendering frame. This will result in another object being evicted from the cache, and so on.

- Conversely, making the Resource Arena too big makes less than efficient use of your platform's memory. On platforms like the PC, this is not such a big issue, but when it comes to consoles, every byte counts.

The answer, as with FreeLists, is to spend some time optimizing the parameters you use when setting up your Resource Arena.

The Resource Arena API

The **`RwResources`** object represents the Resource Arena. This object represents a list of **`RwResEntry`** structures, each describing a block of memory in the Resource Arena. The API itself is centered on the **`RwResources`** object.

A Resource Arena is always present when using RenderWare Graphics. The size of the arena is set during **`RwEngineInit()`**, which is passed in the **`resArenaSize`** parameter. The arena size can be set to zero if it is not needed.

Also present in this particular API is the equivalent *get* function – **`RwResourcesGetArenaSize()`** – which returns the size of the Resource Arena. This can be used together with **`RwResourcesGetArenaUsage()`** to determine the optimum Arena size. This last should be called just before a call to **`RwCameraShowRaster()`** to obtain meaningful results.

`RwResourcesGetArenaUsage()` returns the memory used by instancing and can return a value greater than the maximum value you set. If it does so, it means that *arena thrashing* is taking place – geometry is being instanced, thrown away then re-instanced again because there isn't enough space to store all the instanced data needed for the frame. You should increase the maximum size of the Arena to prevent this or, if memory is tight, reduce the complexity of your geometry to keep the size of the instanced data down.

`RwResourcesSetArenaSize()` now determines the size the Resource Arena, which is a single block of allocated memory. This will free the current resource arena heap, if one exists, and allocate a new heap.

3.3.4 Locking and Unlocking data

The process of instancing display data into platform-dependent form generally takes a lot of processing time. The Lock and Unlock functions that are part of most plugins allow the developer to control this process.

The Lock function tells RenderWare Graphics that the developer wants to access and change some data, like a geometry, texture or palette, and have it re-instanced so that it can be rendered efficiently. The Unlock function allows re-instancing, which is generally slow (though for some data, like vertex positions and colors, re-instancing is postponed until just before rendering).

Many Lock functions have flags to indicate precisely which data is being altered and thus avoid recalculating unchanged data.

So the Lock functions should be used judiciously and be avoided when possible.

3.4Summary

3.4.1 Starting The Engine

The initialization phase of your application needs to perform the following steps to start the RenderWare Graphics engine:

1. Call **RwEngineInit()**, passing an **RwMemoryFunctions** structure if required.

   The **rwENGINEINITNOFREELISTS** flag should also be specified if the FreeList mechanism is not required, pass the **resArenaSize** parameter for the Resource Arena size;

2. Enumerate the available graphics subsystems and use **RwEngineSetSubSystem()** to select the subsystem required by the application;

3. Enumerate the available video modes and use **RwEngineSetVideoMode()** to select the video mode required by the application;

4. Call **RwEngineOpen()**;

5. Attach any required plugins;

6. Call **RwEngineStart()**.

The RenderWare Graphics engine is now started and rendering can take place.

3.4.2 Shutting Down The Engine

When running on platforms that run multi-tasking operating systems such as Windows or MacOS, applications should exit gracefully. This is achieved by calling the following functions in the order shown:

1. **RwEngineStop()**

2. **RwEngineClose()**

   (At this point, it is possible to change the graphics subsystem and video mode and restart the engine.)

3. **RwEngineTerm()**

3.4.3 Memory Handling

Default Memory Handlers

RenderWare Graphics provides two default, general-purpose memory-management mechanisms, only one of which is available at any one time:

- FreeList memory management (default);
- ANSI-standard memory management functions—**`RwEngineInit()`** must be called with the **`rwENGINEINITNOFREELISTS`** flag set;

You can replace the memory-management functions by creating an **`RwMemoryFunctions`** structure with pointers to your own functions, then passing this structure to **`RwEngineInit()`**.

The Resource Arena

When rendering takes place, platform-specific instances of the geometry data are created in the Resource Arena, which acts as a cache. If the same geometry data is required later, the cached data in the Resource Arena will be used directly.

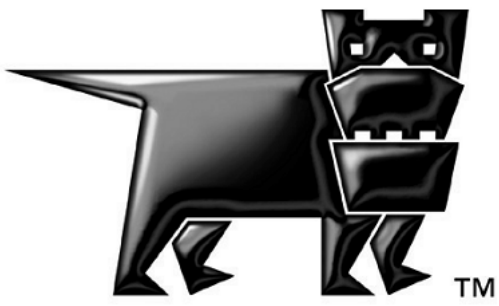
3.4.4 Plugins

Plugins extend existing RenderWare Graphics objects and/or create new ones. In order for this mechanism to work, the memory management system needs to be in place.

The plugin must also be *attached*, by calling its associated **`...PluginAttach()`** function prior to the call to **`RwEngineStart()`**.

Chapter 4

Plugin Creation & Usage



4.1Introduction

Plugins are an important feature of RenderWare Graphics. By providing a mechanism to extend and enhance the in-built objects of RenderWare Graphics, they give us the flexibility to consistently meet your needs in a fast-moving industry. The entire Retained Mode functionality for RenderWare Graphics is, in fact, provided as a plugin.

Toolkits

Toolkits don't extend any core objects or datatypes at all, and usually provide a set of utility functions.

In fact, a Toolkit is just a library that requires RenderWare Graphics to work. The RenderWare Graphics team uses the "Toolkit" term to differentiate a simple utility library from the more complex Plugins, which must be handled more carefully.

Plugins and Streaming

Streaming is covered in the *Serialization* chapter.

4.2Using Plugins

This part of the chapter focuses on how to use plugins and how they work.

4.2.1 Attaching Plugins

Plugins have to be registered with RenderWare Graphics Core Library. The reason for this is so that any object extensions have the chance to hook into the memory handler and allocate space for their additional data structures. For example, if you wanted a plugin to extend camera objects by 64 bytes, then RenderWare Graphics needs to be told this before any cameras are created.

Most RenderWare Graphics applications follow a start-up process along the following lines (some error checking has been removed for clarity):

```
  ...

/* Platform-specific initialization */

  ... some code ...


/* Initialize RenderWare Graphics Engine: */


   /* use default memory handler with Freelists
    * and set arena size */
  RwEngineInit(NULL, 0, resArenaSize);

  /* Attach Plugins */
  if (!RpWorldPluginAttach())
  {
        /* Something went wrong so, */
        /* either display an error message, */
        /* or just crash.*/

         return FALSE;
  }
```

Other plugins should be attached at the same point in the start-up sequence. After this, accessing a plugin's API is the same as calling any other function.

After all necessary plugins are attached, the RenderWare Graphics engine can be opened and started:

```
  ...code to choose display device, format and other parameters ...
```

```
RwEngineOpen(&openParams);


/* Start Engine */
RwEngineStart();  /* "We have ignition!" */
```

With the plugins attached, calling their functions is now possible:

```
...

/* Render World */
RpWorldRender();  /* Render the RpWorld object. */

...
```

As with toolkits, plugins also have to have associated libraries and header files that must be included in your build. Merely attaching them is not enough.

Dependencies

Plugins must be attached in the right order. If plugin B relies on plugin A being present then plugin A should be attached *before* plugin B.

For example, the World plugin (**RpWorld**) is required by a number of other plugins. **RpWorld** must therefore be attached first.

4.3Creating Your Own Plugins

4.3.1 Introduction

Your application is not limited to using the plugins supplied with the RenderWare Graphics SDK. Plugins can be written by any licensed developer.

In this part of the chapter, we will see how this is done.

4.3.2 Anatomy of a Plugin

A RenderWare Graphics plugin is divided in two parts.

The first part is the exposed API that users of the plugin will have access to. This API is the one other developers will use: it's the reason for writing the plugin.

The second part is not usually seen by the plugin's user and performs the housekeeping tasks: it performs any initialization and shut-down processes required by the plugin; it tells the core engine how much memory it needs for the new data structures, and also attaches itself to other plugin objects if needed.

For instance, when calling **`RpWorldPluginAttach()`** to attach the World plugin, it is the housekeeping functions that are called to create the extended objects and initialize any data structures.

4.3.3 The "Plugin" Example

Path: **`examples/plugin`**

This example defines both a plugin and a simple demo to exercise it.

The **`main.c`** file contains the demo program which exercises the plugin.

The plugin code is in **`physics.c`** and **`physics.h`**.

The **`physics.h`** exports the plugin's "public" API. As you can see from the plugin's API, the plugin extends the World plugin's **`RpClump`** object by adding some basic physical properties.

The base object name for this extension is "**`ClumpPhysics`**", so the public API uses an "**`RpClumpPhysics…()`**" prefix.

Defining the Plugin

Near the start of the **`physics.c`** file, we see the first requirement for a plugin, the Plugin *ID*:

```
#define rwID_EXAMPLE 0xff
```

This example uses an ID of 255, but most developers will produce more than one plugin and so will use ID numbers starting from 0 upwards.

The ID shown above is only part of the full Plugin ID. The complete ID is created using the **MAKECHUNKID** macro, which combines your Vendor ID with the Plugin ID number.

You can see this used in the **RpClumpPhysicsPluginAttach()** function.

This function is the one called by the application just after **RwEngineOpen()**. It performs the operations required to extend the core library and any other extensible objects.

Plugin & Vendor Ids

The maximum number of plugins possible is 256 per Vendor ID. If you need more than this, you should contact Criterion Software Ltd. for another Vendor ID.

(Contact devrels@csl.com for your Vendor ID.)

Extensible Objects

These are objects which have a function in their API ending with "**PluginAttach()**". Without this functionality, it is impossible to directly extend such an object.

Because of this, a number of the core library objects, such as **RwBBox**, are not directly extensible using the plugin mechanism. Instead, you will need to define a new, extensible container object with one of the inextensible objects as a member—a wrapper object—which you can then extend.

New structures

The next step is to define the new structures with which we will extend the core engine and any other extensible objects.

In this example, we are adding some new global variables (at the core library, or "global", level), and extending the World plugin's **RpClump** object (the "local" level) to support some basic physics variables. Hence, we now define two structures: **PhysicsGlobals** and **PhysicsLocals**.

The global-level structure defines storage for a caption, gravity and a minimum speed. The caption is there because it is easy to spot when debugging.

Global structures are added to the core RenderWare Graphics engine itself.

The *Local* structures in this plugin are attached to each **RpClump** object created by the application.

If we were extending other objects, such as Atomics, we'd also need to define Local structures for them along with associated copiers, constructors and destructors.

Data Access Macros

One of the original design goals for C++ was that all of its functionality could be implemented using standard C. The upshot of this is that you *can* do object-oriented programming in C. It's just nowhere near as elegant, natural or pretty.

An important issue is the need for some macros to make accessing the new "members" of extended objects as painless as possible. In the case of the Physics example, these macros are defined at the top of the **physics.c** code: **PHYSICSGLOBAL** and **PHYSICSLOCAL**.

These macros provide access to the base address of the new data structures within the **RpClump** object. By using these macros, it is possible to access the relevant structures directly without having to add the overhead of a function call. It also makes the code a lot more readable.

Registering the Plugin

While object creation and destruction is relatively trivial stuff for a C++ expert, this kind of thing requires a bit more work when using good, old-fashioned C. In particular, we *have* to explicitly define constructors, copiers and destructors because there are no defaults for these purposes.

Going back to the **physics.c** code, you'll find functions with words like "**constructor**", "**destructor**" and "**copier**" in their names. These functions are defined in the first half of the file and represent the housekeeping part of the plugin's API.

Just for completeness, we also define functions for serializing the data to and from RenderWare Graphics binary streams.

As you can see from the source code, we need to produce constructor and destructor functionality for both the global and local data structures, but only the local data structures need copiers as well.

Stream reading and writing functionality should only be provided if the base object also supports streaming. This can be determined by looking for a function name ending in "**…RegisterPluginStream()**". If it doesn't, you should create a new wrapper object containing the base object and provide full streaming support through this.

The stream support functionality needed is: **Read()**, **Write()** and **GetSize()** – the last allows the RenderWare Graphics binary stream functions to work out how much data will be read or written to the stream.

How do we tell RenderWare Graphics about these functions? This is why we need the plugin attachment process to attach a plugin and register it with the core library. Once registered in this way, RenderWare Graphics will automatically call the new functions as callbacks.

Take a look at the **RpClumpPhysicsPluginAttach()** function. A cursory glance shows that it is split into three very similar sections:

Registering the Global-Level Extensions

Here, we use the Core Library's **RwEngineRegisterPlugin()** function to add the new global variables to the engine and register the constructor and destructor functions for them.

The return value is the offset into the RenderWare Graphics engine's global data structure where the new variables will be stored.

This value is *very* important: it's needed by the data access macros (see *Data Access Macros* on page 85.)

Registering the Clump Object Extensions

This section uses the **RpClumpRegisterPlugin()** function – part of the World plugin's API. The main difference between this section and the global-level extensions section is the additional need to register a copier function which will be called when clumps are copied or cloned.

Registering the Clump's Binary Stream Extensions

Again, very similar except that functions that hook into the stream handler are registered instead of constructors, destructors or copiers.

Finishing Touches

The rest of the **physics.c** file consists of the remaining publicly-exposed API functions. These implement a Newtonian physics model using our new structures to store the state of each extended clump object.

In keeping with the object-oriented design philosophy behind RenderWare Graphics, these functions provide access to the new data members.

At this stage, we know how to create a simple plugin; now let's take a look at the other side of the coin and see the new plugin in action…

4.3.4 Using the Physics Plugin

The example plugin is used by the code found in **main.c**.

As with all of the other RenderWare Graphics Examples, the "**plugin**" example is built on top of a simple platform abstraction layer called "*The Skeleton*". This is spread through a number of files and is used to provide a platform-neutral framework for all our sample code.

For clarity, this chapter only discusses the relevant functions specific to the "**plugin**" example.

The full source code to the Skeleton is available for you to peruse and examine. It can be found in: **shared/skel/**

The `ClumpPhysics` Demo

The new plugin – called **RpClumpPhysics** – is used in a simple demo which drops some wooden buckyballs onto a simple surface. Each buckyball is stored in a clump which has been extended using the new plugin. The physics attributes are used to give each buckyball a random bounciness and initial speed.

At this point, you should build and run the demo and play with it for a bit. Stepping through functions with the debugger is also advised so you can get an idea of the program execution flow.

Most of the code is basic stuff: create a floor, create the buckyballs, initialize it all and then enter the main event loop.

"Buckyballs

A "buckyball" is a nickname given to any structure or object that looks like a C_{60} molecule. The molecule's fully qualified name is *Buckminsterfullerene* and was named after Richard Buckminster Fuller (1895-1983), an inventor, architect, engineer, mathematician, poet and cosmologist. His most famous invention was the geodesic dome, a structure similar to that of C_{60}.

Preparation

We have already learned that the first thing you need to do when using plugins is to make sure they're *attached*. The Skeleton used as a framework for this example application can make it difficult to see where this process takes place.

You'll find the plugin being attached within the aptly-named **AttachPlugins()** function. This function gets called by the Skeleton's event handler at the appropriate point during the startup phase and, as you can see, our plugin isn't the only one being attached.

Dependencies

You'll note that the World plugin, which provides RenderWare Graphics Retained Mode features, gets attached *before* our **RpClumpPhysics** plugin. This is because our new plugin has to extend the features of the **RpClump** object—an object that is only available when the World plugin is attached.

It is important to bear this dependency issue in mind when developing your own plugins.

Exercising the Plugin

The demo consists of a bunch of buckyballs, dropped from a height onto a surface and allowed to bounce.

The code which sets up the World itself sets up the lighting, the camera and the floor. You can see this being done in the **`CreateScene()`** function. See the two chapters, *Worlds & Static Models* and *Dynamic Models*, for more information on scene creation.

The interesting bit begins when the buckyballs are initialized:

The ClumpPhysics plugin is used to add storage space to each of the buckyballs for some basic physical attributes relating to speed and "bounciness" – elasticity in technical terms.

This initialization process takes place in the **`InitClumps()`** function found in the **`main.c`** file. Look at the section following the "**`/* Initialize user plugin data... */`**" comment and you'll see the new ClumpPhysics plugin in use.

In this case, we're using the exposed property get/set functions we saw in **`physics.c`**, setting most of the attributes using a random number generator. (The *Active* flag we added to the clump object is used to keep a note on which of the buckyballs is still bouncing.)

Once the initialization phase is completed, the demo starts the main update cycle. The physics calculations are handled in **`UpdateClumpDynamics()`**. Here, the basic Newtonian Laws of Motion are applied to make the buckyballs behave in a manner approximating reality.

4.4Plugin Design

4.4.1 Introduction

The Physics example we have looked at is pretty simple. Most real-world plugins won't be so trivial as to contain the plugin code within the test-bed itself: full plugins are usually created as standalone libraries that are linked into your application like any other library.

In this section, we will look at some design issues that you'll likely come across when designing your own extensions.

4.4.2 Extension vs. Derivation

The **RpClumpPhysics** plugin extends an existing object. This is great for small-scale additions, but this design does have a serious drawback: *all* **RpClump** objects will have these extra data structures attached.

This means that the buckyballs are not the only ones affected: the floor itself is also a clump and, therefore, it too has the storage space allocated for our **RpClumpPhysics** extensions. While this kind of overhead is acceptable for such basic examples as *ClumpPhysics*, clearly this is going to be a problem if memory is tight—as is the case on a number of our supported platforms.

The trick, then, is to find some way of optimizing the design such that only objects that actually need the additional data will have it available. By far the most efficient way of doing this with RenderWare Graphics is to create a plugin that creates a new object instead of just extending an existing one.

This is the equivalent of C++'s derivation mechanism and most of the plugins supplied with RenderWare Graphics derive new objects rather than extending existing ones.

One notable exception is **RpWorld**'s extensions to the **RwCamera** object. It adds new functions that retain the "**RwCamera**" prefix, rather than using "**RpCamera**".

4.4.3 Deriving new objects

The process of creating derived objects is not very different from what you've seen already.

The first step is to decide how to link the new object to its parent object so that the two can be used to share data efficiently. Thanks to the design of the C programming language, three options are available to the developer:

1. The object can be extended

2. A container object can be created

3. An extended container object can be created—a combination of options 1 and 2.

Object Extensions

This technique is the one used by the ClumpPhysics example, covered earlier in this chapter.

The base object is extended by adding a pointer to it which connects that object to the extended data. Multiple pointers can be used if there are multiple derivations. In addition, you could add a second pointer so that a child object can access its parent. This gives you increased flexibility for such things as iterator functions, without sacrificing too much valuable memory.

The drawback is the overhead of forcing all instances of the parent object to have a pointer that may not always be used.

Container Objects

This technique involves creating a master object through which accesses to the base and derived objects are made. It would usually be a simple construct such as a pair of linked lists. The **`RpAtomic`** object found in the World plugin is an example of this technique.

Container objects have advantages where you need to derive a large number of interrelated objects from a single base object with a one-to-many relationship: the use of a separate linking object removes the need to store a large number of pointers in the base object.

The disadvantage with this technique is that all access to the interesting objects must be made via this link object to maintain integrity. The linking mechanism must therefore be designed carefully to keep access time overheads as low as possible.

Extended Container Objects

This option sometimes makes sense when the base object has a wildly variable number of derived objects. The disadvantage is that access to the derived objects through the list will be relatively slow. In addition, the links can be tricky to maintain when there are a large number of interdependent objects.

4.4.4 Plugins & C++

RenderWare Graphics plugin mechanism can make life a lot easier if you're using C++ as your primary development language.

As an example, let's assume you're writing a wrapper class for RenderWare Graphics clump (**RpClump**) object. Ignoring constructor/destructor methods and other side-issues, your class might look something like this:

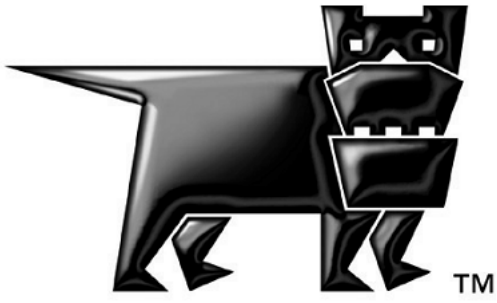
```
class CClump
{
  ...

  // private data

  ...

  private:
        RpClump *myClump;
        RwInt32 someData;

  ...
}
```

A problem arises when you need to pass the clump data to one of the RenderWare Graphics iterator functions, such as **RpWorldForAllClumps()**. These functions trigger a callback which expects an **RpClump** parameter, not your **CClump** class. So how does the callback used by the iterator function get a reference to the wrapper class?

The answer is to extend the clump object, using the plugin mechanism, and add a pointer which your wrapper class then initializes with a pointer to itself. Now your callback function can get at the rest of the class' data, (usually by calling a plugin-supplied access function).

Chapter 5

The Camera



5.1Introduction

Wander into any movie studio's sound stages and you'll see a common set-up: static sets, props and actors, all lit by a lighting rig and performing in front of one or more cameras.

RenderWare Graphics defines equivalents for most of these elements:

- static sets (static models) are covered in the chapter *Worlds & Static Models*;
- dynamic elements, such as props and actors, are covered by the chapter on *Dynamic Models*;
- lighting is covered in the chapter on *Lights*;
- …and the Camera is covered here.

5.1.1 The `Camera` Example

Computer software has the useful ability to be interactive and can therefore be used to great effect as an educational tool in its own right. With this in mind, our RenderWare Graphics Demos Team has created a number of educational examples that demonstrate particular features of the SDK and let you play with them to see how they work and interact. The '**`camera`**' example is one such, and provides an interactive illustration of the Camera object's features.

This Example will be referred to frequently to highlight the many properties of the Camera object. In the second part of this chapter, the source code will be discussed, to understand, how it all fits together.

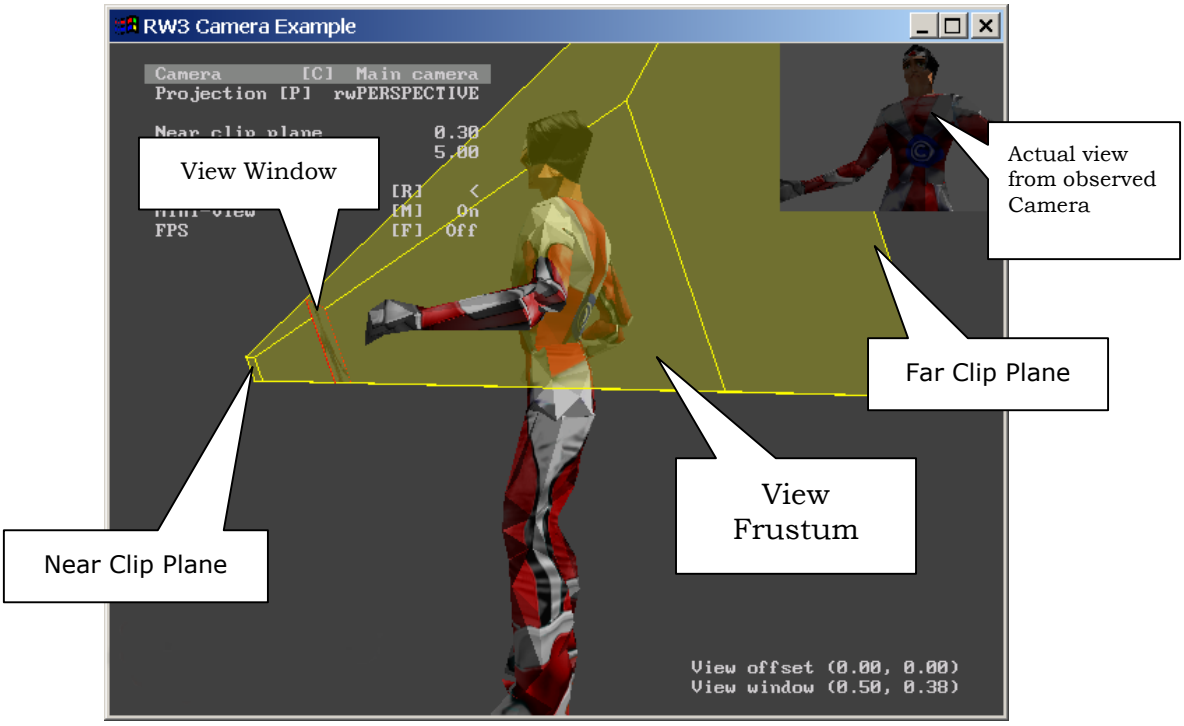
The Camera Example is in the **`examples/camera/`** folder. (Open up the text file to view the user interface instructions as these vary from platform to platform.)

5.2 The RenderWare Graphics Camera object

The RenderWare Graphics **Camera** (**RwCamera**) object is part of the Core Library. It is the target of all 3D rendering operations and therefore plays an important part in any 3D graphics application built on RenderWare Graphics.

5.2.1 Camera Properties

The screenshot below is taken from the '**camera**' Example and it has been annotated to show the primary features of the Camera object:



Other Camera properties, such as projection modes, frame buffers, and fog handling, will be covered later.

5.2.2 The View Frustum

The highlighted volume in the diagram on the previous page represents the volume in front of the Camera within which a renderable object is considered visible. This is the **View Frustum**, defined by the **near clip plane**, the **far clip plane** and the four planes passing through the **Viewpoint** and the edges of the **View Window**. RenderWare Graphics uses the bounding sphere of the object to determine whether it intersects or lies within the view frustum. This course-grain visibility test is then used to determine whether or not to draw the object, and whether the object is clipped or unclipped. Clipping is a fine-grain visibility test.

If a model does not have a valid bounding sphere, the RenderWare Graphics engine may produce unexpected results.

The Clipping Planes

Two clip planes define the near and far extents of the view frustum.

The **far clip plane** defines the point along the Camera Space Z axis, beyond which objects will not be rendered.

The far clip plane is responsible for the infamous 'pop-up' found in older 3D games, whereby model geometry suddenly appears on the horizon as if from nowhere. If a platform has enough 3D graphics processing power, this plane can be pushed back so far that the 'pop-up' simply isn't visible.

The **near clip plane** defines the point along the Camera Space Z axis, nearer than which, objects will not be rendered. It is parallel to the far clip plane and on the opposite side of the view frustum. Again, this is just a point along the Z-axis running through the center of the camera object and into Camera Space.

The near clip plane controls clipping of polygons close to the camera object. Without it, even models behind the camera might be considered visible by the engine and be rendered to the camera's frame buffer.

Pushing the Near Clip Plane away from the Camera improves Z Buffer resolution. When feasible, the Near Clip Plane should be positioned as far away from the Camera as possible without introducing visible clipping artifacts. The distance at which this will occur depends on the zoom factor currently applied to the Camera. As a rule of thumb, dividing the distance of the far clip plane from the camera by the distance of the near clip plane from the camera should ideally result in a value of less than 1000.

The Viewpoint

When the Camera is set to the more usual Perspective view the View Frustum defines a section through a pyramid. The apex of this pyramid is the **Viewpoint**.

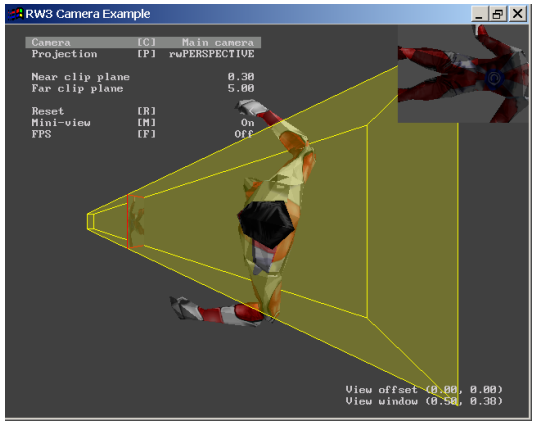
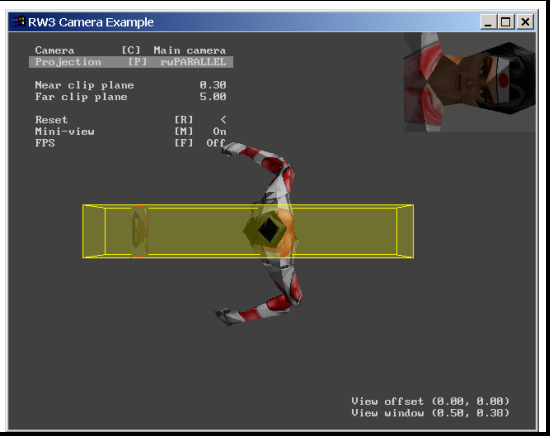
The Viewpoint is the center of projection when using a camera set to Perspective mode. It is, literally, the 'point of view' – the eye – in the scene.

Projection Modes

RenderWare Graphics provides two Projection Modes: **Perspective** and **Parallel**. Perspective projection is the most generally used and is the projection system assumed throughout most of this chapter. That said, Parallel projection mode, while not so frequently used in apps, does lend itself to a number of more specialist rendering tasks.

Perspective projection makes objects that are more distant (from the camera) appear smaller on the screen as they do in real life. The angular field of view may be controlled by calling the **`RwCameraSetViewWindow()`** function, as described in the API Reference Manual.

Parallel projection mode, which can be selected using the **`RwCameraSetProjection()`** function, changes the View Frustum to a *View Cuboid*.

PERSPECTIVE PROJECTION	PARALLEL PROJECTION
	

As you can see from the screenshots above, the main difference between Perspective and Parallel projection modes is that the latter does not scale vertices in the Z axis – no matter how far away a model is, it won't get any smaller.

This mode is most often used for orthographic views or for projecting shadows from area light sources, but it can also be used to duplicate some popular 2D graphics rendering techniques, such as parallax scrolling. This has the advantage of using the 3D acceleration hardware features available on your target platform.

5.2.3 The View Window

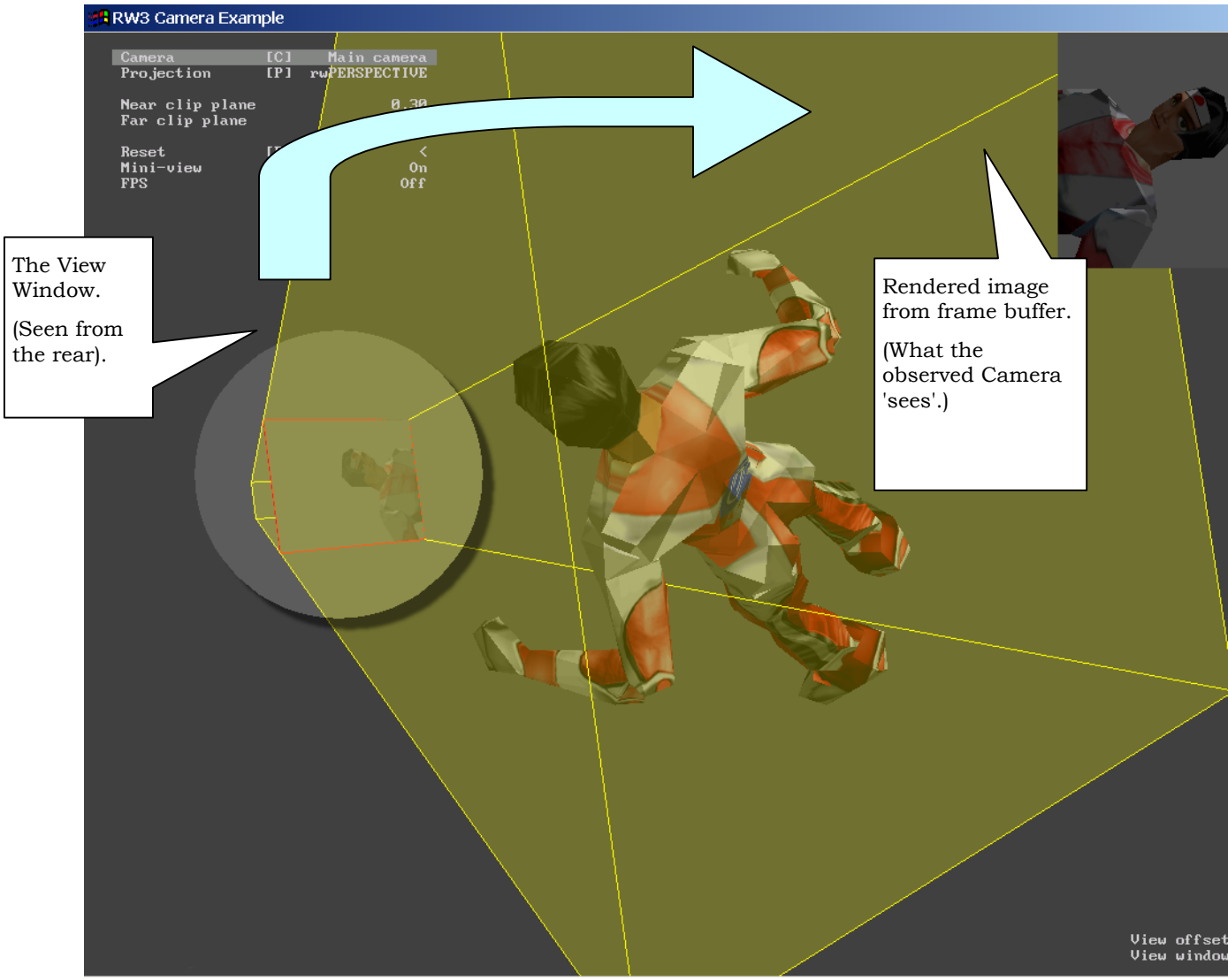
Earlier, the Viewpoint was described as being a virtual 'eye' looking into a scene. If we continue with this analogy, the **View Window** becomes a virtual 'retina'. Where the analogy falls down is that the View Window is *in front* of the Viewpoint.

Let's go back to the '**`camera`**' Example.

With the '**camera**' Example running, you can move the model around and see its image rendered into the view window. This is shown inside a red outline close to the near clip plane.

This View Window represents the frame buffer – our virtual retina – upon which the actual scene is rendered. The picture below shows this happening.

A useful feature of the '**camera**' Example is that it displays the view from the observed Camera inset at the top-right corner of the screen. (Because of our view of the Camera object, the image shown in the View Window appears to be reversed because it is facing away from us.)



It is the contents of the frame buffer the View Window represents which the end-user gets to see.

View Windows & Aspect Ratio

Aspect ratio is defined by a combination of the View Window's dimensions and those of the frame buffer Raster.

While you can set the View Window to any arbitrary dimensions, the resulting image must still fit into the supplied frame buffer. Therefore, RenderWare Graphics scales the output so that it always fits into the frame buffer Raster.

This opens up a useful feature of the Camera: by manipulating the dimensions of the View Window and frame buffer Raster, we can:

- Zoom into a scene by decreasing the dimensions of the View Window;
- Zoom out of a scene by increasing the dimensions of the View Window;
- Duplicate an anamorphic lens by adjusting the dimensions of both the View Window *and* the frame buffer and Z buffer Rasters.

This last feature can be used to implement a typical requirement for a console game: support for anamorphic wide screen displays: Setting the View Window to a 16:9 aspect ratio, but keeping the frame buffer's dimensions to the traditional 4:3 TV standard achieves this. The rendered scenes will be squashed to fit into the frame buffer's smaller width. The resulting frame buffer can then be displayed on a wide screen TV using its anamorphic (i.e. 'stretched') setting. The result is that the squeezed frame buffer image becomes stretched across the entire width of the wide screen TV's display, restoring it to its intended aspect ratio.

The advantages of this technique are two-fold:

1. It saves memory. By removing the need for a wide screen frame buffer, we save on precious video RAM.
2. The lower memory overhead typically results in faster performance as system bus bandwidth requirements are reduced.

This technique can also be used to produce distortion effects.

The View Window is defined as being always one unit away from the Viewpoint mentioned briefly above.

The Camera View Window API

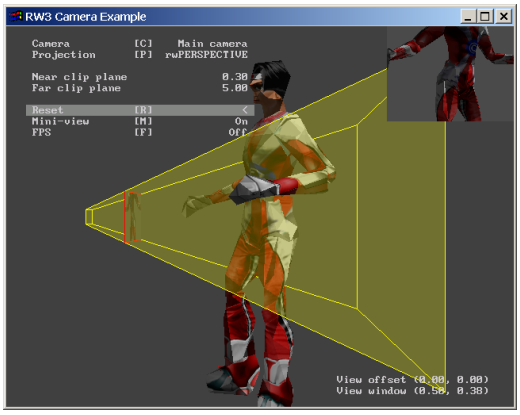
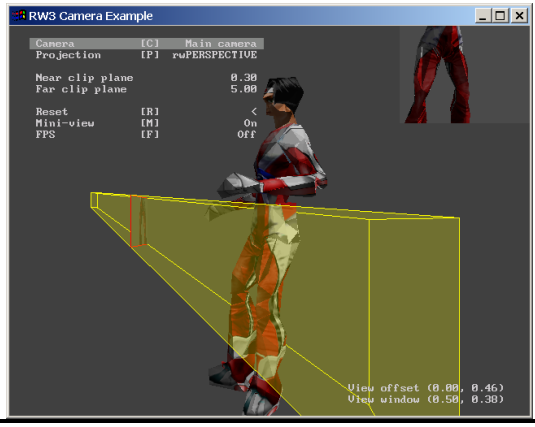
The View Window is set using an **`RwV2d`** vector set to *half* the required dimensions in each axis. The function call is **`RwCameraSetViewWindow()`**. The property retrieval function is **`RwCameraGetViewWindow()`**. Again, the returned **`RwV2d`** vector is set to half the actual dimensions.

The Raster object, used to provide the frame buffer and the Z buffer for Cameras, is covered in the *Rasters, Images & Textures* chapter.

5.2.4 The View Offset

The View Offset is used to shear the Camera's view frustum. This is done by specifying an X and Y (Camera Space) offset for the frustum's apex – the point defining the center of the far end of the frustum.

The screenshot below, left, shows an un-offset View Frustum. The screenshot to the right shows the View Frustum with a View Offset of 0.46 in the Y axis:

NO OFFSET	OFFSET IN Y AXIS
	

Notice how the Viewpoint – the apex of the View Frustum – is offset vertically relative to its original position. The result is the shearing of the View Frustum so that the View Window renders the lower portion of the model instead of the middle portion.

This feature can be explored in the '**camera**' example (see the associated **readme.txt** file for the user interface functions needed to manipulate the View Offset).

The offsets are absolute values, so repeated calls to **RwCameraSetViewOffset()** will not be accumulated.

This function has advantages for such activities as supporting stereoscopic display devices and tiled rendering to a high resolution output device.

Camera View Offset API

Two functions are supplied for this feature: **RwCameraSetViewOffset()** and **RwCameraGetViewOffset()**. Both take an **RwV2d** vector to set or store the offset.

5.2.5 Fog

Fog effects in RenderWare Graphics are tightly coupled to the Camera model.

A number of different fog models are supported by RenderWare Graphics: *Linear*, *Exponential*, *Exponential²* and *Table*. However, some of these fog types are only supported on a sub-set of platforms.

Basic Fog Controls

Fogging starts at the distance set by **`RwCameraSetFogDistance()`** for Linear and Table fog types. Also, for the same fog types, the full fog effect is achieved at the far clip plane.

Fog Distance should never be set to zero.

Most of the fog handling is done through the **`RwRenderState`** API, so let's take a quick look at what's available...

Fog Render State

Fog is controlled through both the **`RwCamera`** and **`RwRenderState`** APIs. The Render State API provides the following fog control functionality:

- **`rwRENDERSTATEFOGENABLE`**
  Turns on fogging. All polygons rendered from this point onwards will be modified by fog processing. Clear this flag to disable fogging.

- **`rwRENDERSTATEFOGCOLOR`**
  The target **`color`** for fogging. The denser the fog around a particular polygon, the closer the polygon's color will be to this target color.

- **`rwRENDERSTATEFOGTYPE`**
  The type of **`fogging`** to use. The fog types defined are:

  - **`rwFOGTYPELINEAR`**
    Selects the Linear fogging type.

  - **`rwFOGTYPEEXPONENTIAL`**
    Selects the first Exponential fog type. This is available on most of our supported platforms. If the fog effect is represented by *f* then the function is:

    $$f = 1 \;/\; e^{(d * \text{density})}$$

    (where *d* is the distance from the Camera's View Point.)

  - **`rwFOGTYPEEXPONENTIAL2`**
    Selects the second Exponential fog type. This is using a higher exponent in the formula to make the fog get denser faster. The formula is as above except that the exponent – *(d * density)* – is further raised to the power of two.

- **`rwRENDERSTATEFOGDENSITY`**
  Select the density of Exponential and Exponential² fogging. The higher the value, the denser the fog.

- **rwRENDERSTATEFOGTABLE**
  This is the *Table* form of fogging. The parameter is a 256-entry fog table placed between fog distance and far clip plane. The table format is not fixed, so check your platform-specific documentation to see what format to use if this fog type is supported.

Note that Render States can return **FALSE** for a number of reasons. Check the platform-specific information in the API Reference to ensure that a particular fog type is supported for a particular platform.

The Render State API, consisting of the two **RwRenderStateSet()** and **RwRenderStateGet()** functions should be used to set the fogging as appropriate.

The Render State represents the RenderWare Graphics state machine and is a shared resource. This means, when a particular render state is set, it stays set until it is cleared again, either by your own code, or by code elsewhere in RenderWare Graphics.

RenderWare Graphics makes heavy use of its rendering engine. Check the Render State flags if you find effects being applied inappropriately – like fog being applied to displaying text.

5.3The Camera View Matrix

This matrix transforms world space coordinates to camera clip space. The camera's clip space is bounded by the near and far clip planes, and side planes defined as follows:

x = 0, x = z, y = 0 and y = z for a Perspective projection model;

x = 0, x = 1, y = 0 and y = 1 for a Parallel projection model.

Camera View Matrix API

The **View Matrix** is accessed through the **`RwCameraGetViewMatrix()`** function.

5.4Rasters & Cameras

In order to be useful, a Camera object has a couple of optional buffers attached to it that are used to store the resulting rendered image. These provide storage for both a Z Buffer and the frame buffer itself. In RenderWare Graphics, the Raster object is used for both of these buffers.

Rasters are a key feature of RenderWare Graphics and are covered in much greater detail in the *Rasters, Images & Textures* chapter.

The Raster types *must* be **rwRASTERTYPEZBUFFER**, for the Z-buffer, and of type **rwRASTERTYPECAMERA** for the frame buffer.

The frame buffer Raster holds the rendered image. Since RenderWare Graphics provides a double-buffered model, this image is stored off-screen and is displayed when rendering is completed by the **RwCameraShowRaster()** function.

Z Buffer Accuracy

This can vary quite dramatically from platform to platform and application to application.

The Z buffer range is effectively dictated by both the spacing of the near and far clip planes, *and* the definition of the Z buffer Raster. This last might use anything from an array of 8-bit bytes to a map constructed from IEEE-standard double-precision floating-point values.

Clearly, this means you need to take care when setting up the view frustum as placing the near and far clip planes too far apart may result in rounding errors and related problems.

5.5Creating a Camera

The process of constructing a RenderWare Graphics camera is typically as follows:

- Create and allocate a Raster of type **rwRASTERTYPECAMERA**
- Create and allocate another Raster of type **rwRASTERTYPEZBUFFER**
- Create a Camera object using **RwCameraCreate()**
- Attach the two Rasters to the Camera object using **RwCameraSetRaster()** and **RwCameraSetZRaster()**
- Create a Frame object and attach it to the Camera object using **RwCameraSetFrame()**. The Frame allows for the control of the position and orientation of the Camera.
- Finally, if you're using the **RpWorld** Retained Mode API, you will need to 'add' the Camera to the World. (See the two Retained Mode API chapters, *Worlds & Static Models* and *Dynamic Models* for more on this.)

At this point, the Camera is ready to use.

5.5.1 Orienting and Positioning a Camera in Scene Space

A quick skim through the *Fundamental Types* chapter reminds us that the Frame object is a container for the matrices used to position and orient objects in a virtual space.

Cameras use frames to define:

- Where they are positioned
- Which direction they are facing

The Camera will *always* face along the Frame's *look-at* vector. The *look-up* vector always points at the top of the View Window.

One oddity is that, because the Camera is facing away from us, its *look-right* vector is invariably pointing to the left from the user's point of view.

Transformations

Frames attached to Cameras behave just like Frames attached to anything else. Transformations are performed by using the **RwFrame** API and are used to position and orient a Camera.

Frame Origin

When attached to a Camera, the Frame's origin will be coincident with the Viewpoint. Note that this means the View Window will *always* be located exactly one unit along the *look-at* vector.

5.6Rendering to a Camera

3D graphics rendering takes place between an **RwCameraBeginUpdate() / RwCameraEndUpdate()** pair. *All* rendering *must* take place between these two functions, although you can have more than one Begin/End pair operation before displaying the rendered image using **RwCameraShowRaster()**.

As many RenderWare Graphics applications use the Retained Mode (**RpWorld**) Plugin, a typical render cycle may look like this:

```
if ( RwCameraBeginUpdate(mainCamera) )
```

This line prepares the Camera for rendering, pushing its frame buffer Raster onto the *context stack*. The top-most Raster on this stack is used as the target for rendering. (Rasters are covered in more detail in the *Rasters, Images and Textures* chapter.)

*The context stack is described in more detail in the "*Immediate Mode*" chapter.*

At this point, Frame objects marked as 'dirty' will also have their Local Transformation Matrices (LTM) resynchronized. Any hierarchies hanging off the Frames are also updated. This ensures any rendered objects attached to the Frames are positioned and oriented correctly.

```
{
  RpWorldRender(gameWorld); /* Render the main game world */
```

We'll cover the **RpWorld** Retained Mode API in detail in later chapters. For now, suffice to say that this function will render an entire scene.

```
  /* Now render any UI overlays, such as HUDs, high score */
  … some more rendering code…
```

At this stage, you may want to add some special effects, such as lens flare or other visual gloss. Many such effects are often best achieved using the Immediate Mode APIs.

```
  RwCameraEndUpdate(mainCamera);
  /* End of rendering cycle. */
```

At this point, RenderWare Graphics will pop the Camera's Raster off the context stack. It also cleans up after itself and performs any necessary housekeeping.

We do not, however, have a visible result: the rendering has taken place, but because RenderWare Graphics uses double buffering, we need to swap the buffers over so we can see the results of our toil...

```
  /* Display the results of the rendering. */
  RwCameraShowRaster(mainCamera, (void *)win32Handle,
  rwRASTERFLIPWAITVSYNC);
}
```

This function performs the buffer-swap needed to display our rendered scene. The parameters are, in order: the Camera object, a platform-specific parameter (in this case, a HWND container as the Win32 SDK is being used in this example), and finally, a flag can be specified to tell RenderWare Graphics to wait for the vertical blanking interrupt. (This last should only be used in a full-screen application.)

We can now update our scene ready for the next rendering cycle.

Destroying a Camera

Camera objects need to be explicitly destroyed when you are finished with them. Because the Camera contains references to other objects, these also need to be destroyed explicitly as **`RwCameraDestroy()`** will *not* destroy these for you.

So:

1. Obtain pointers to any Rasters attached to the Camera – use **`RwCameraGetRaster()`** and **`RwCameraGetZRaster()`** for this.

2. Destroy these Rasters using **`RwRasterDestroy()`**.

3. Use **`RwCameraGetFrame()`** to extract the Frame object and destroy that also.

4. Destroy the Camera object itself using **`RwCameraDestroy()`**.

5.7Sub-Rasters

Sub-Rasters can be used with Cameras to provide the following:

- Split-screen views, often seen in multi-player games
- Picture-in-picture and other inset effects, such as rear-view mirrors in driving games

These effects are achieved by sharing a single Raster across multiple Camera objects.

For full details on how Sub-Rasters work, see the *Rasters, Images & Textures* chapter.

5.8Other Features

Clearing the Buffers

This process should be performed at the beginning of each frame unless your scene rendering is refreshing each pixel in the buffer every cycle anyway.

The function for this procedure is **`RwCameraClear()`**. Refer to the API Reference Manual for more details.

Cloning a Camera

RenderWare Graphics provides the **`RwCameraClone()`** function for this purpose.

As with most other 'clone' operations in RenderWare Graphics, this means both the source Camera and the target Camera objects will *share* the Frame, frame buffer Raster and Z-buffer Raster. Also, if the source Camera had been added to a World (**`RpWorld)`** object, the cloned Camera will also be in that World.

5.9World Plugin Extensions

About the Extensions

The World Plugin adds a number of additional functions to the Core Library's Camera API. These are described here.

5.9.1 Automatic & Manual Culling

When rendering scenes using the World Plugin (**RpWorld**) API, the Plugin will automatically cull any Atomics and World Sectors that are located outside the Camera's view frustum. It will also cull any dynamic Lights whose spheres of influence are inapplicable within the view frustum.

However, this only applies to model data that has been explicitly 'added' to the World object. If you need to render an object, such as an Atomic, explicitly – and this is sometimes desirable – then you will need to perform the culling yourself.

This can be achieved using the **RwCameraFrustumTestSphere()** function, which will test a Bounding Sphere (**RwSphere**) object passed to it and tell you whether it is inside, outside or intersecting the specified Camera's view frustum. The values it will return are: **rwSPHEREINSIDE**, **rwSPHEREOUTSIDE** and **rwSPHEREBOUNDARY** respectively.

5.9.2 Clump Cameras

An **RpClump** is a container for dynamic objects that are associated with a frame hierarchy, and are described in more detail in a later chapter. It is possible to add Cameras to a Clump using the function **RpClumpAddCamera()**. Such Cameras are streamed with the Clump, and their location within the frame hierarchy preserved. This mechanism is used whenever Cameras are exported from the modeling packages.

5.9.3 Iterators

A number of useful iterator functions are provided to access model data that falls either within or outside the Camera's view frustum. The iterators cover a number of object types.

In all cases, the iterators can rely Bounding Spheres to perform their tests.

World Sectors

These represent static model geometry. One iterator is supplied: **RwCameraForAllSectorsInFrustum()**. This will iterate through all World Sectors that are either partially or entirely within the view frustum, calling a specified callback function for each one it finds.

The World Sector functions include a number of iterators for locating objects that lie within them, such as Atomics and Lights.

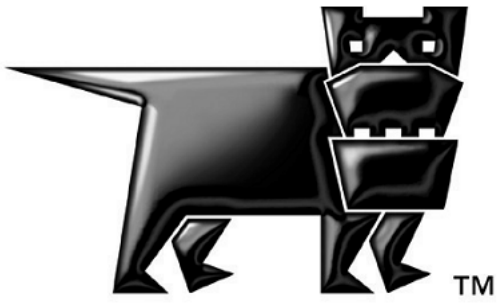
Clumps

Clumps represent dynamic objects and a frustum iterator is supplied: **`RwCameraForAllClumpsInFrustum()`**. Like the World Sector form described above, this function will iterate through all Clumps that contain Atomics either partially or entirely within the view frustum. For each such Clump, it will call the specified callback function.

The callback function is of type **`RpClumpCallBack()`**.

Chapter 6

Rasters, Images and Textures



6.1Introduction

This chapter discusses bitmaps, images, rasters and textures and explains when and where they are used. These objects can all be found in the Core Library:

- **RwImage**
- **RwRaster**
- **RwTexDictionary**
- **RwTexture**

In addition, platform independent texture dictionaries are explained here, and these require the use of the **RtPITexD** toolkit.

6.2Bitmaps & Textures

Bitmaps play a major part in any 3D graphics engine. They form the basis for texture maps.

6.2.1 Bitmaps

RenderWare Graphics' Core Library supports two different types of bitmap objects: **Images** and **Rasters**.

While the APIs for these objects are superficially similar, there is one very important difference. The **Image** (**`RwImage`**) object is platform independent; the **Raster** (**`RwRaster`**) is not.

The reason for this duality is to give you the most flexibility without sacrificing power. Images can be easily processed and manipulated, but cannot be displayed until they have been converted to Rasters. Rasters have minimal manipulation and processing facilities, but are highly optimized for the underlying hardware.

6.2.2 Images

Images provide a platform-independent object for manipulating bitmap data.

Images are used to load bitmaps from disk or other media storage prior to conversion to a platform-optimized Raster object, which can then be manipulated.

6.2.3 Rasters

Rasters provide a platform dependent form of image and are used to hold image data. Rasters are frequently found inside other RenderWare Graphics objects. Of particular note are the **Camera** (**`RwCamera`**) and **Texture** (**`RwTexture`**) objects. For more information about cameras see the chapter on *The Camera*.

Rasters are the *only* form of bitmap that RenderWare Graphics can actually render to a display device. Image objects are normally used as intermediaries.

6.2.4 Textures

A texture is a bitmap that is stretched across a polygon. Textures use Rasters to store the actual bitmap data. The Rasters are also used to store mipmaps.

It is the Raster itself that supports mipmapping, not the Texture object.

6.3The Image Object

Images represent a platform-independent bitmap.

They can support most common image formats and this makes them ideally suited as intermediaries.

For example, when you load a bitmap, such as a PNG or BMP, from disk, it ends up in an Image object.

6.3.1 Image Dimensions

Image objects can have any width or height. Dimensions are limited only by available memory. The color depth can be four, eight or thirty-two bits per pixel.

Images do not support packed pixel formats. This means that the bitmap actually stores only one pixel per byte, even if only four of the bits in each byte are significant.

6.3.2 Stride

An Image is associated with a *stride*. A stride defines the physical number of bytes needed to get from one pixel in the bitmap to the one directly below.

The stride allows a bitmap to be defined as a portion of a larger bitmap. This kind of usage is popular as it reduces loading times by combining smaller images into one larger one.

6.3.3 Palettes

Four-bit and eight-bit Image depths require palettes.

Palettes consist of:

- 16 entries for 4-bit formats
- Up to 256 entries for 8-bit formats.

Each entry is an RGBA value defining a color.

6.3.4 Gamma Correction

Image objects also support a gamma correction value. This value defines the gamma curve of the device upon which the bitmap is to be displayed. Changing this value and applying the gamma correction enables you to adjust the gamma of the bitmap.

What is Gamma Correction?

This process exists to make graphics appear as close to the original as possible, regardless of any differences or gamut limitations in the display device used. Gamma correction is similar to the "contrast" control on a television set or monitor.

When applied, the RGB values are multiplied by the gamma correction value to increase or decrease the effective level of an image's pixels.

Consumer video devices, such as televisions, have a higher native gamma than dedicated computer monitors. This means that graphics drawn on a monitor will tend to look brighter on a television set. This may not be what the graphics artist intended, hence the provision for gamma correction.

6.3.5 Creating Images

Image objects can be created either by allocating memory for the data and assigning that data to an Image, or by reading the object from a RenderWare Graphics Binary Stream.

Creating Images by Assigning Data to an Image

Initialization is fairly straightforward: a call to **`RwImageCreate()`** is made, supplying width, height and depth values.

This gives a dummy image object with all its members except those that point at the actual bitmap data. To include these **`RwImageAllocatePixels()`** is used. This looks at the width, depth and height of the image and calculates the memory required to store this Image.

If your Image uses a palette format then space also needs to be allocated for the palette. **`RwImageAllocatePixels()`** will handle this for us automatically by looking up the settings in the Image object.

For example, a depth of 8 bits will result in the creation of a 256-entry palette.

Loading Images

Image objects are most commonly loaded. They act as containers for bitmaps loaded from a disk or CD. Usually, bitmaps are drawn by an artist and then loaded into the game ready-made.

Bitmap files include standard formats, for example, Windows Bitmap (**`.BMP`**), Portable Network Graphics (**`.PNG`**).

RenderWare Graphics doesn't support any of these formats and **`RwImageRead()`** routine does not support *any* standard formats by default.

RenderWare Graphics does, however, have four toolkits, which add support for four popular file formats: **`RtPNG`**, **`RtRAS`**, **`RtTIFF`** and **`RtBMP`**. These provide a single callback function, which the RenderWare Graphics Image Streaming API uses to handle a particular file extension.

More information about these Toolkits is in the table below:

FORMAT	EXTENSION	TOOLKIT	SUPPORTED FEATURES
Microsoft® Windows® Bitmap format	**.bmp**	**RtBMP**	Palette-based, 24-bit RGB and grayscale. No Alpha support.
Portable Network Graphics	**.png**	**RtPNG**	8-bit palette-based and various RGBA formats. Alpha is supported.
Sun Microsystems® "Raster" format	**.ras**	**RtRAS**	Palette-based formats, 32-bit BGR and RGB formats supported. No Alpha support.
Aldus Corporation Tagged Image File Format	**.tif** **.tiff**	**RtTIFF**	Palette-based (8-bit), grayscale (8-bit), RGB (24-bit) and RGBA (32-bit). Supports Stripped, LZW and both big endian and little endian formats. Win32 and PlayStation®2 platforms only.

This open architecture means that you can write your own image format handler to handle any image file format and add it to RenderWare Graphics Toolkits and include that Toolkit in your application.

The "**imgformt**" example shows you how to do this by implementing a minimal Targa Image File (**.tga**) file format handler.

Bitmaps & RenderWare Graphics Binary Streams

It is worth pointing out that Image objects do *not* make any use of the RenderWare Graphics Binary Stream system. The only bitmap object that supports this API is the Raster.

6.3.6 Example: Reading a BMP file

This section will show you the procedure involved with reading a Microsoft Windows Bitmap format file, usually stored with the "**.BMP**" file extension.

Writing Images is essentially identical to that for reading except **RwImageWrite()** is used instead of **RwImageRead()**, so the following example can be easily applied to both processes.

Registering an image file format

To start with, the image format needs to be chosen and then linked to the appropriate Toolkit and registering it with the **RwImageRegisterImageFormat()** function. This allows RenderWare Graphics' Image streaming functions to access image file formats transparently.

For this example the Windows Bitmap (**.bmp**) file format will be used:

1. Add the appropriate header – **rtbmp.h** – and ensure our application is linked with the associated Toolkit library. (For Win32 developers, this library is "**rtbmp.lib**".)

2. Register the **RtBMP** Toolkit's supplied callback functions with the Core Library so it knows which functions to call in order to read or write BMP-format images using the **RwImageRegisterImageFormat()** function. This takes a string containing the associated filename extension, a pointer to the image reading function and another pointer to the image write function.

   In this instance, the registration code would look like this:

```
RwImageRegisterImageFormat("bmp", RtBMPImageRead,
                           RtBMPImageWrite);
```

Any number of additional image formats can be registered in this way. When reading or writing Images, RenderWare Graphics will look up the supplied filename extension against the registered extensions in its database and call the appropriate callback functions.

Search Paths

Before an image can be read we have to ensure RenderWare Graphics knows where to look for it. For this purpose, RenderWare Graphics' Core Library provides the **RwImageSetPath()** function. This accepts a string containing one or more search paths separated by semicolons. RenderWare Graphics will use this to find the Image filename supplied to the read function.

For obvious reasons, the **RwImageWrite()** function requires an absolute, fully qualified path, filename and extension. It makes no reference to the search path.

6.3.7 Reading the Image

It is now possible to read or write an Image object using the **RwImageRead()** and **RwImageWrite()** functions.

These work by passing a filename to the function and, if successful, it will return a pointer to an **RwImage** object with your image in it. If you pass a filename without a path, RenderWare Graphics will use the search paths to attempt to locate the file.

Two important points to note are:

1. If you haven't registered the image file format you're trying to read or write the function call will fail.
2. The **RwImageRead()** function requires the file extension so RenderWare Graphics can work out which registered reader function to use.

For example, a "**BMP**"-format image file is being read, we would perform the registration process just detailed, then call the **RwImageRead()** function to perform the Image reading, as below.

```
{
  …

  /* BMP Registration must have been done prior to this point. */

  myImage = RwImageRead("myimage.bmp");

  if (!myImage)
  {
       /* Failed to read the image. Handle error condition. */
  }

  …

}
```

Assuming all went well, a pointer to a ready-to-use Image object should be stored in **myImage**.

Any image processing or manipulation can be performed on our Image.

Masked Images

RenderWare Graphics can use Image alpha channels as masks when available. (The "A" in RGBA formats represents the alpha/mask data). Masks are covered later in this chapter.

6.3.8 Image Processing

The **RwImage** API supports a number of basic image manipulation functions. These cover such processes as re-sampling, copying, gamma correction, masking (for basic alpha channel effects) and resizing.

Creating an Image object

Sometimes, you'll need to create an empty Image object, which is to be populated with data and bitmaps later in its life-cycle. This process can be a one- or two-stage process, depending on what the object is to be used for.

To instantiate the Image object itself:

1. Call the **RwImageCreate()** function and pass it the dimensions you need and it will return an Image object that is almost, but not entirely, complete.

2. Allocate the memory for the bitmap and the palette (if this is a palletized Image). This is achieved using **RwImageAllocatePixels()**. This will look at the dimensions of the Image object and use these data to work out how much memory the Image will need. It will also allocate memory for the palette if one is required.

The reason for this two-step process is to allow multiple Image objects to share a single bitmap. This is a useful feature as you can, for instance, have a number of sprites stored within a single bitmap. To make access to each of these sprites easier, you can define multiple Images which share the same physical bitmap and point at individual sprites.

You can therefore set the bitmap data pointer in an Image object directly using **RwImageSetPixels()**.

Re-sampling

There are two re-sampling functions. Both take an original Image object and produce another Image of a different width and/or height. The main difference between them is that the first function creates and allocates a new re-sampled Image object for you, while the second does not:

- **RwImageCreateResample()** function allocates and creates a new Image for the re-sampled bitmap.
- **RwImageResample()** requires that you supply a valid **RwImage** object for both the source and the destination. You will need to use both **RwImageCreate()** and **RwImageAllocatePixels()** to create the Image objects.

  RwImageCreateResample() also differs in that it allows you to specify a palletized image as the source. However, the result is always an Image of 32-bit depth.

  Re-sampling actually re-scales the source image to fit the new dimensions. RenderWare Graphics always uses the CPU to perform this operation.

Accessing and modifying Image properties

RenderWare Graphics' Image API provides **get** functions to access Width, Height, Depth and other properties. These are **RwImageGet[PROPERTY]()** form. For example:

RwImageGetHeight(), **RwImageGetDepth()**, **RwImageGetStride()**

Most of these have equivalent **Set** forms. The only exceptions being Width, Height and Depth. These are set through the **RwImageResize()** function which takes all three as parameters.

Copying

RwImageCopy() will copy a source Image into a destination Image. Both Image objects must already be created (using **RwImageCreate()**), and bitmap memory allocated (using **RwImageAllocatePixels()**), as this copying function will not create the destination Image for you.

Alpha Channel Masks

All Image objects have storage for alpha channel information, either directly in the bitmap (32-bit formats), or in the palette table (4-bit and 8-bit formats). While some image file formats support alpha channels directly, many others do not so the **RwImage** API includes functionality to get around this and allows you to transfer alpha channel data from one Image to another.

In particular, functions are provided for loading masks stored in a separate file (**RwImageReadMaskedImage()**); creating masks from pixel data (**RwImageMakeMask()**); and applying a mask stored in one Image to another (**RwImageApplyMask()**).

At the time of writing, RenderWare Graphics supports two image file formats that can handle alpha channel data:

- the Portable Network Graphics format (**.PNG**), supported by the "**RtPNG**" Toolkit
- the TIFF format (**.TIFF**), supported by "**RtTIFF**".

These can read a 32-bit RGBA PNG-format or TIFF-format file complete with alpha channel. A single Image is returned.

6.3.9 Raster Conversion

So far, Rasters haven't been covered in detail. The **RwImage** API also provides functionality to convert a Raster to an Image object and vice versa. The function that performs this magic is **RwImageSetFromRaster()**. This function will take a Raster and convert it into an Image of the same dimensions. The target Image must be valid, initialized to the right dimensions and allocated enough memory for the pixel data.

A complementary function, **RwRasterSetFromImage()** also exists to perform the reverse conversion. This is covered in more detail in the section on Rasters.

Palletized bitmaps can be more efficient on some platforms. RGBA formats may work better on others. You should refer to platform-specific documentation to determine which bitmap formats are best suited to your target platform.

6.3.10 Destroying Images

Any RenderWare Graphics image objects you have explicitly created must be destroyed.

Images should be destroyed using the **RwImageDestroy()** function. If the bitmap and palette data were allocated using the **RwImageAllocatePixels()** function, the destructor function will also free this memory. Otherwise, you will need to free it yourself.

6.4The Raster Object

Images must be first converted into a platform-dependent format if they are to be rendered. This platform-dependent format is known as the *Raster* (**RwRaster**).

Rasters also provide the foundation for RenderWare Graphics' virtual camera as well as its texture-mapping features. This makes the Raster one of the most important objects in RenderWare Graphics.

6.4.1 Basic Properties

Like Images, Rasters represent bitmaps. Therefore, they contain all the basic features of a bitmap: width, height, depth, palette data (if applicable) and the bitmap data itself. As with Images, Rasters can also support alpha channel data, if, the platform supports it.

The main difference between Rasters and Images is the lack of control available to you over format and other basic properties. There's a good reason for this:

Rasters will support only the formats most suited to the underlying platform, ***and nothing else****.*

This platform-dependence is a very important aspect. A few points regarding platform-dependence are below:

- Just because you managed to get a 16-bit Raster on one platform, there is no guarantee that you will be able to get that same format on another platform. In fact, there is nothing to prevent Rasters using such non-RGB formats as DYUV or similar.
- Another related point is that some platforms may only support Rasters with dimensions that are a power of 2 or some other arbitrary limitation.
- Never rely on being able to obtain a particular Raster format.

In fact, it is quite possible for later versions of RenderWare Graphics to switch to another Raster format for a particular task.

Developers should also note that RenderWare Graphics treats PC and Apple Macintosh graphics cards as separate platforms in their own right. Rasters are optimized for specific hardware, not specific operating systems.

Creating Rasters

Rasters are created using the **RwRasterCreate()** function. This takes the usual width, height and depth settings. It also takes a *flags* value that determines what the Raster is to be used for.

Rasters are primarily defined by their purpose. For example, a Raster can be used as storage for texture data so setting the **rwRASTERTYPETEXTURE** flag would produce a Raster with additional storage space for mip-levels (on platforms that support mipmaps).

An important point to note is that the width, height and depth values are limited to those supported by the underlying platform. For instance, some platforms may require that all Rasters have dimensions that are exact multiples of two.

In short: be prepared to have this function fail if you attempt to create an unsupported Raster format.

It is common for developers to leave the depth setting to zero as this lets RenderWare Graphics choose the best depth for the platform and means the function call is more likely to succeed.

Creating Rasters from Images

Bitmaps are often loaded from a file on disk. As Rasters cannot be read directly from any of the popular file formats – only Image objects can do this – this means that bitmaps intended for use as Rasters will need to be read as Image objects first.

The **RwRaster** API provides the **RwRasterSetFromImage()** function for this purpose. As with many other RenderWare Graphics conversion functions, a valid, initialized **RwRaster** object needs to be provided as a destination. The function will not allocate a new Raster.

RwImageFindRasterFormat()

This function accepts an Image and a hint flag telling it what the Image data is to be used for. It uses this information to determine the best available Raster pixel format for the Image.

Creating Mipmap Rasters

Rasters can contain multiple bitmaps – known as mipmaps. This is a popular system used for texturing 3D models. A mipmap stores a base bitmap and zero or more re-scaled versions of the same bitmap. The rendering engine can choose to upload a smaller bitmap if the texture is being viewed from a distance, as the smaller bitmap's lower detail won't be noticed.

This has the advantage of reducing the memory bandwidth required to render the texture and, over a whole scene, this technique can dramatically increase efficiency. (Another use for mipmaps is to reduce the effects of aliasing.)

Creating Mipmap Rasters can be done in two ways:

1. Manually, by reading individual Image files for each mipmap level.

2. Automatically, by specifying the base image and telling RenderWare Graphics to create the remaining mipmap levels itself.

To *enable* mipmapping, create a Raster including the **rwRASTERFORMATMIPMAP** flag.

1. Choose to lock the Raster at each mipmap in turn.
2. Call **RwRasterSetFromImage()** with the requisite Image to store the mipmaps.
3. Unlock the Raster.
4. Repeat the lock/unlock process for each of the levels until the Raster is ready.

If the flag **rwRASTERFORMATAUTOMIPMAP** is also used at the Raster's creation, you can:

1. Lock the Raster.
2. Then, read in the base Image bitmap using **RwRasterSetFromImage()**.
3. Unlock the Raster.

RenderWare Graphics will generate the remaining mipmaps for you using a simple re-scale algorithm. This issue is covered in more detail in the Textures section, later in this chapter.

Accessing Raster Properties

There is only one "set" function in the **RwRaster** functions in the API Reference. This is a conversion function.

The reasons for this were covered in the *Basic Properties* section earlier: Rasters are designed primarily as "look but don't touch" objects. Changing their properties is likely to impact on performance, so the **RwRaster** functions are designed to avoid that by not providing property-setting functions in the first place!

Pixels and palette data can be accessed. The only problem with this is that the data may be compressed or in some strange format so the Raster bitmap data may not be easily manipulated.

To get at the data the Raster needs to be locked. This process is also used to tell RenderWare Graphics if you intend to read and/or write to the data. If you write data into the Raster, RenderWare Graphics may need to re-generate mipmaps if the Raster is of type **rwRASTERFORMATAUTOMIPMAP** (this should be avoided wherever possible).

While most of the basic properties – width, height, depth, stride, etc. – are the same as their **RwImage** equivalents, the following four need more explanation:

1. NumLevels

This property defines the number of MIP-levels defined in a Raster when a Texture object is using it. Such Rasters can contain multiple bitmaps.

The function to access this property is **RwRasterGetNumLevels()**.

2. Format

   The Format of a Raster is usually dictated by the underlying hardware – particularly its bit-depth. The Format property can be used to query the actual bit-depth and format of the Raster palette.

   For instance, a 16-bit Raster using a 1555 form for ARGB will return **rwRASTERFORMAT1555**.

   A current list of valid formats can be found in the API Reference. See the entry for **RwRasterGetFormat()**.

3. CurrentContext

   The current Context is a pointer to the Raster used as the target for 2D rendering by RenderWare Graphics' rendering engine.

   The Context mechanism uses a stack, consisting of two functions **RwRasterPushContext()** and **RwRasterPopContext()**.

4. Parent

   There is a special kind of Raster, called a *sub-Raster*, which is simply a Raster that shares another Rasters bitmap data. The sub-Raster must therefore keep track of which Raster its actual bitmap data is stored in, hence the "Parent" property.

   Sub-Rasters come into their own when used with Camera objects. For instance, split-screen rendering is usually achieved by using sub-Rasters. This is covered in the chapter on *The Camera*.

   The **RwRasterSubRaster()** function is used to create these. **RwRasterGetParent()** will return the parent Raster containing the actual bitmap data.

6.4.2 The Raster as a Display Device

While Rasters can be used as sprites and textures, a Raster also represents the display device itself. This means that Rasters spend most of their time being rendered onto other Rasters.

RenderWare Graphics' rendering engine uses double buffering. This means that rendering takes place off-screen and you don't see anything updated until you explicitly swap the buffers over. (Most hardware supports this by simply flipping memory addresses, although some older devices require a physical blit operation instead.)

When 3D graphics are rendered to the virtual camera object, this is actually rendering to a Raster. This is why, once the rendering cycle is completed, the **RwRasterShowRaster()** function needs to be called in order to see anything. This performs the buffer swap needed for double-buffering to work.

The **RwRasterShowRaster()** function also takes a flag which lets you tell RenderWare Graphics to wait for the vertical blank interrupt ("Vsync" or "VBI") before performing the switch.

Rasters used as targets for 3D rendering are always attached to Camera objects. This means they *must* have the **rwRASTERTYPECAMERA** Raster type.

6.4.3 Rendering Rasters

Rendering Rasters is a 2D render process and therefore involves an **RwRasterPushContext()** / **RwRasterPopContext()** function pair. All 2D rendering must be topped and tailed by these two functions.

In other words, the code should be structured something like this:

```
...

if (RwRasterPushContext(DestRaster))
{
     /* Do any rendering of Rasters here.*/
     RwRasterPopContext();   /* Done with our 2D rendering. */
}

...
```

There are three functions provided for Raster rendering.

1. **RwRasterRender()**, this performs a simple blit operation, copying the Raster to the target Raster – the Context – and taking the alpha channel transparency into account while doing so.

2. **RwRasterRenderFast()**, performs a faster blit operation, but takes no account of the alpha channel. This makes it considerably faster on most platforms.

3. **RwRasterRenderScaled()**, this operates much like **RwRasterRender()** while also taking an **RwRect** parameter defining the target rectangle to blit to. The Raster will be scaled during the blit operation to match the target rectangle. (The original data is not changed; the scaling takes place during the blit itself.)

In all three cases, the Z-buffer is ignored.

If you need this functionality, you should use Textures and the Immediate Mode APIs.

6.4.4 Accessing Rasters

Rasters do not support many processing functions. Two bitmap clearing functions exist:

- **RwRasterClear()** - clears the entire bitmap array
- **RwRasterClearRect()** - clears a defined rectangle within the bitmap.

A Raster might be using a non-standard format, so, Rasters need to be *locked* before any major processing is performed.

Locking is done using the **RwRasterLock()** function. The function takes both a MIP-level and *lock mode*. The MIP-level specifies the MIP-map level desired from the Raster. (0 is the highest resolution – the level displayed when the texture is close to the Camera.) The lock mode enables you to tell RenderWare Graphics what you intend to do with the Raster:

- **rwRASTERLOCKREAD**
- **rwRASTERLOCKWRITE**
- **rwRASTERLOCKREADWRITE**
- **rwRASTERLOCKNOFETCH**. This mode lets you tell RenderWare Graphics that you intend to overwrite all the bitmap data without reading any of it. This can speed things up considerably on some platforms.

Once locked, the Raster can have its pixels accessed and manipulated.

Of course, if the Raster is in some non-standard format, it makes more sense to convert it to a more useful one. Usually, this is achieved by converting the Raster to an Image using **RwImageSetFromRaster()**.

This is a procedure often used for creating screen dumps, avoiding the need to point cameras at screens in order to create screenshots for packaging. In such cases, you simply lock the Camera Raster and convert it into a known Image format before either storing it somewhere in memory, or writing it to disk using one of the Image format Toolkits.

RwRasterUnlock() will reverse the locking process.

If your Raster has a palette, you will need to use the **RwRasterLockPalette()** and **RwRasterUnlockPalette()** functions as well if you need access to it.

RwRasterGetFormat() will tell you if you have a paletted Raster.

6.4.5 Reading Rasters from disk

Rasters can be read and written to disk using the **RwRasterRead()** and **RwRasterReadMaskedRaster()** functions. Both will read an Image from disk (using the **RwImage** API) and convert that Image to a Raster of type **rwRASTERTYPENORMAL**.

These functions are most often used to read data such as sprites or UI elements.

6.5Textures & Rasters

RenderWare Graphics has a *Texture* (**RwTexture**) object. This is, as you would expect, used to provide the texture handling features in RenderWare Graphics.

Textures are actually thin wrappers for Rasters, which means Textures shouldn't be considered as entirely autonomous entities. For instance, we have already seen that mipmap features are actually handled at the Raster level.

The number of mipmap levels is returned by **RwRasterGetNumLevels()**.

Rasters that are to be used as mipmaps should have either the **rwRASTERFORMATMIPMAP** or **rwRASTERFORMATAUTOMIPMAP** Raster Type.

In this section, we'll take a close look at RenderWare Graphics' Textures and how they relate to Rasters.

6.5.1 Introducing Textures

Textures add some additional properties to the Raster:

- Filtering

  This determines how mipmaps are to be used (if at all) and rendered. A number of Filter Modes are provided and are listed in the *Mipmaps* section, below.

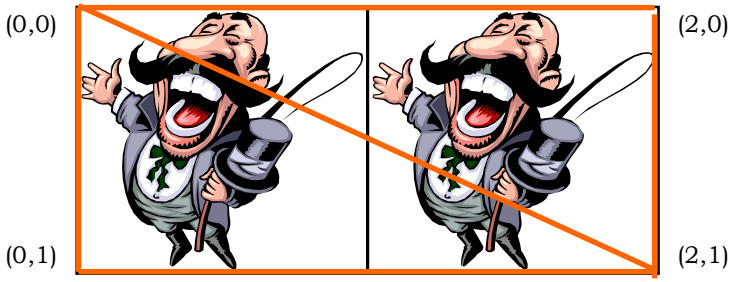
- Addressing modes

  This determines how the texture is mapped to the polygons. "Texture Space" is always defined as running between 0 and 1, so that for any given Texture, the Texture's own U and V coordinates will be as follows:

This Texture Space is mapped onto polygons during rendering by mapping the Texture's own U and V coordinates to those linked to each Material and/or Vertex. Thus, rendering the Texture with the U and V coordinates shown below would result in the Texture being drawn actual size:

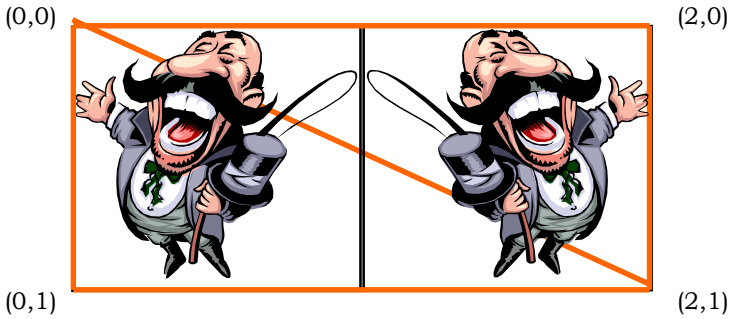
But you can use the U and V mapping to stretch or shrink the Texture in one or two axes, or even to tile it or produce mirrored reflections of it depending on the Addressing Mode. The diagrams below show some options available:

Here, the Texture is stretched across a wide polygon (built using two triangles). Stretching is simply a matter of stretching the polygons while retaining the same U/V mapping.



This is the same texture rendered using a tiled addressing mode called "**rwTEXTUREADDRESSWRAP**". Note the right-most U coordinates are set to 2, which is exactly twice the size of Texture Space, hence the Texture is repeated exactly once.

Other addressing modes let you modify this tiling behavior. For instance, if the addressing mode were set to **rwTEXTUREADDRESSMIRROR**, the result might look like this:



You can use the **texadrss** example to experiment with different addressing modes and see their effects.

The full list of addressing modes is listed in the *Addressing Modes* section, below.

Mipmaps

These are simply individual bitmaps, which are used to make up a texture. In RenderWare Graphics' case, all mipmaps for a particular Texture object are stored in a single Raster.

The purpose of mipmaps is to allow a Texture to use different bitmaps according to its distance from the virtual camera. This technique allows smaller, less-detailed bitmaps to be used when a model – and, hence, its Textures – are a long way from the camera.

Mipmaps are divided into *MIP levels*. Level 0 is the default and is always present in a Raster, which means that it is also always present in a Texture. Level 0 is usually the largest of the bitmaps with each additional MIP level half the size of the previous one.

Mipmaps are enabled or disabled explicitly on a per-texture basis using the **RwTextureSetMipmapping()** function.

During the rendering process, RenderWare Graphics will use the Texture's Filtering settings to determine which MIP level(s) should be used. These are detailed below.

Filtering

Filtering is the process used to determine how – and *if* – the Texture object selects and displays individual MIP levels.

It is usual for the MIP levels to be blended smoothly from one to the other across the level threshold rather than simply switching between two states and the last two Filters listed below can be used to support this where available.

FILTER	EFFECT
rwFILTERNEAREST	No MIP mapping. Point-sampled textures.
rwFILTERLINEAR	No MIP mapping. Bilinear interpolated textures.
rwFILTERMIPNEAREST	Point-sampled MIP mapped textures. Individual mipmaps are drawn using point-sampling and will simply flip from one image to the next as the level changes over distance.
rwFILTERMIPLINEAR	Bilinear interpolated MIP mapped textures. Mipmaps are drawn using bilinear interpolation. They still flip from one image to the next as the level changes over distance.
rwFILTERLINEARMIPNEAREST	Mipmaps are interpolated between levels so giving a smooth blend from step to step rather than simply flipping from one image to the next at the threshold. Mipmaps are drawn using point-sampling.
rwFILTERLINEARMIPLINEAR	Tri-linear interpolated textures. Interpolation works in three dimensions, running through U, V and MIP level axes. Gives the best visual results but can be expensive on some hardware.

The first two of these Filter types are for Textures that are not MIP mapped and therefore only have their MIP-level 0 bitmap defined. The remaining Filter types are mipmap blend modes, listed in order of complexity and visual quality, from least to best.

An ideal world would have every Texture mapped using the best quality Filtering – in this case, tri-linear interpolation. But this Filter can require a lot of processing power, so you will need to balance your mix of Filter modes.

SDK-Examples: "MIPMAP"

This Example demonstrates mipmap filters available on your platform.

Some filters may be unsupported on certain platforms. Attempting to use unsupported Filters may result in an error condition being returned from the **RwTextureSetFilterMode()** function.

Addressing Modes

Addressing modes define the process used to determine a particular texel color. These modes define how the indexing along the texture map's U and V axes behaves when the edge of the texture map is reached.

The addressing modes defined by RenderWare Graphics are:

ADDRESSING MODE	EFFECT
rwTEXTUREADDRESSWRAP	This mode is the default. When the edge of a texture map is reached, RenderWare Graphics wraps back to the opposite edge. The result is that the texture map is tiled.
rwTEXTUREADDRESSMIRROR	This is similar to the default mode except that alternate tiles are mirror images of the original.
rwTEXTUREADDRESSCLAMP	This mode clamps the U and V indices at the edges so that the edge-most pixel is repeated across the remainder of the surface. It is sometimes used for one-off decals.
rwTEXTUREADDRESSBORDER	This mode is similar to the Clamp mode. However, this mode applies the BORDERCOLOR Render State color to the polygon where the U and V indices fall outside the bitmap's range.

examples\texadrss

This Example demonstrates all the Addressing Modes available on your platform.

Addressing Modes can be varied by U/V axis. There are *three* API functions available to set the Addressing Mode for a Texture:

RwTextureSetAddressing() applies an Addressing Mode across both U and V axes so that behavior in both directions is the same. The appropriate property interrogator is **RwTextureGetAddressing()**.

RwTextureSetAddressingU() applies an Addressing Mode across the U axis only. The appropriate property interrogator is **RwTextureGetAddressingU()**.

RwTextureSetAddressingV() applies an Addressing Mode across the V axis only. The appropriate property interrogator is **RwTextureGetAddressingV()**.

A couple of important notes:

Firstly, if you are using different Addressing Modes across each axis, the **RwTextureGetAddressing()** function will return **rwTEXTUREADDRESSNATEXTUREADDRESS**.

Secondly, some Addressing Modes may be unsupported on particular platforms and will cause **RwTextureSetAddressing()**, **RwTextureSetAddressingU()** and **RwTextureSetAddressingV()** to return an error condition.

6.5.2 Loading Textures

Textures are loaded using the **RwTextureRead()** function.

This function makes use of the **RwImage** API, so you must register any image file format readers with **RwImageRegisterImageFormat()** before attempting to load Textures.

It is important to note that **RwTextureRead()** will also perform some additional operations:

- A search is made in the default Texture Dictionary (**RwTexDictionary**) for an existing Texture with the same filename stored in its "name" property. If no such Texture is found, the function attempts to load it as expected. However, if a matching Texture *is* located, the function simply returns a pointer to this Texture.
- On the first attempt to read a Texture, the function will, if the data was read successfully, store the filename in the Texture's "name" property.
- The function also adds the Texture to the default Texture Dictionary if it is not already in there.

That last point is important: it means Textures will only ever be loaded once, unless you explicitly change the Texture's "name" property.

Texture Dictionaries are covered a little later on.

Platform Specific Information

RenderWare Graphics uses the platform's conventions for pixel and texel centers. These may vary per platform. For an example, look at the **imshadow** example.

Mipmap Generation

During the load process, mipmaps can be generated automatically or additional mipmaps images can be read and added to the Texture. The first step is to tell RenderWare Graphics whether we want mipmaps generated at all. This is done through a call to **RwTextureSetMipmapping()**.

If you want mipmaps to be generated for your Textures, you need to call **RwTextureSetAutoMipmapping()**. This lets you choose:

1. To let RenderWare Graphics generate all mipmaps levels automatically from a single bitmap loaded from disk.

   Call **RwTextureRead()** with the filename of the bitmap to load. RenderWare Graphics will then generate the MIP-levels itself by re-sampling the original image as required for each level.

2. To load all the individual mipmaps directly from disk.

   Individual images are named something like: "**image_m?.ext**", where "**image**" is the name of your image, "**?**" is a number between 1 and 9 inclusive and "**ext**" is the three-letter extension of the image file format used.

The Third Way: Generating mipmaps yourself

This system can be overridden by supplying the **RwTextureSetMipmapGenerationCallBack()** function with a pointer to a function that will be called to generate each MIP layer. (See the API Reference for the callback's prototype.)

Your callback function will be given a pointer to the destination Raster and the source Image: what it does with them is up to you.

This naming system is restricted by the ISO 9660 filename convention. ISO 9660 dictates an 8.3 format, which limits image filenames to a maximum of five useful characters on most platforms.

RwTextureSetMipmapping() and **RwTextureSetAutoMipmapping()** affect *only* the loading of Textures using the **RwTextureRead()** functionality. These settings will have no effect whatsoever on automatic Texture loading by Clumps, Worlds and other RenderWare Graphics objects.

Accessing mipmaps

Individual mipmaps can be accessed at the Raster level using the **RwRaster** API's **RwRasterLock()** and **RwRasterUnlock()** functions, as well as their palette equivalents. These were described in more detail in the section on Rasters.

6.5.3 Texture Dictionaries

It is often convenient to group Textures together using some form of simple database to make it easier to manage them. For this purpose, RenderWare Graphics provides the Texture Dictionary (**RwTexDictionary**) object.

Texture Dictionaries are collections of Textures. The Textures are indexed via their "name" property. (API functions: **RwTextureGetName()** to retrieve; **RwTextureSetName()** to set.)

Names are associated with both Textures and their Masks and, to keep object sizes constant, names are limited to a maximum of thirty-two characters in length.

The 32-character limit for Texture names may appear to contradict the earlier point about the ISO-9660 filename convention.

In fact, Texture names are not directly linked to filenames and can therefore provide a more convenient means of accessing Textures. You can use the **RwTextureSetName()**, **RwTextureGetName()** and the two Mask name equivalents; **RwTextureSetMaskName()** and **RwTextureGetMaskName()**, to manipulate and change Texture names directly.

Streaming Texture Dictionaries

In the section about loading Textures, RenderWare Graphics automatically maintains a default Texture Dictionary (**RwTexDictionary**) object was mentioned. This prevents RenderWare Graphics from making unnecessary reads from a disk or CD as it can check to see if the Texture is already loaded and just return a pointer to that if so.

Reading a Texture Dictionary from a binary stream is a very quick way of getting all Textures and Rasters into memory. It eliminates the need to load each individual Texture from its own file and perform the conversion of the bitmap from an Image to a device-dependent Raster.

If textures are being loaded individually, the time needed to locate and read each one from the storage media—usually a CD or DVD disk—the seek time alone slows the loading process down dramatically.

Generation of mipmaps can be particularly expensive on CPU time and system resources, so this should be kept to a minimum. This is why the Texture Dictionary mechanism was created: you can create them just once for a particular platform, store all the Textures into a Texture Dictionary object then stream said object out for re-use in your application.

examples\texdict

This SDK example exercises the Texture Dictionary API and shows how to construct, write and then read a Texture Dictionary.

It can be found in the **examples** folder.

6.5.4 Using Texture Dictionaries

When you write a Texture Dictionary to a binary stream, the result is a file containing all your Textures with their associated Rasters ready for use.

The API functions to use Texture Dictionaries with RenderWare Graphics Binary Streams are the standard three: **RwTexDictionaryStreamGetSize()**, **RwTexDictionaryStreamRead()** and **RwTexDictionaryStreamWrite()**.

Using Texture Dictionaries

It is possible to create your own Texture Dictionaries rather than using the default one created by RenderWare Graphics. This lets you have, for example, a separate Texture Dictionary for each level in a game. Multiple Texture Dictionaries can also be loaded into memory.

To get a pointer to the active Texture Dictionary, use **RwTexDictionaryGetCurrent()**. Which can also access the default database created by RenderWare Graphics.

To set the current active database **RwTexDictionarySetCurrent()** function needs to be called. Pass NULL if you do not want RenderWare Graphics to use a Texture Dictionary at all. (This can also be used to disable the default database created by RenderWare Graphics.)

Platform dependent texture dictionaries for PS2, Xbox and GCN can be generated on the PC using **nullsky**, **nullxbox** or **nullgcn** libraries. They do not have to be generated on the target platform.

Other API features are:

- Adding and removing Textures from the database is achieved through the **RwTexDictionaryAddTexture()** and **RwTexDictionaryRemoveTexture()** functions.
- To locate a Texture in the database by name, use **RwTexDictionaryFindNamedTexture()**.
- An iterator function, **RwTexDictionaryForAllTextures(),** uses the standard RenderWare Graphics callback mechanism to give you access to all Textures within the Texture Dictionary.

6.5.5 Platform independent texture dictionaries

The convenience of platform specific (PS) texture dictionaries to improve texture load performance has been explored in the previous sections. However, since RenderWare Graphics is a multi-platform solution, it may be that original artwork needs to exist for multiple platforms. For a final product, it makes sense to create PS texture dictionaries, but during development, a single set of artwork, compatible across all targeted platforms would be of more use. Platform independent (PI) texture dictionaries provide a solution.

The API functions to use PI texture dictionaries with RenderWare Graphics Binary Streams are the standard three:
RtPITexDictionaryStreamGetSize(),
RtPITexDictionaryStreamRead() and
RtPITexDictionaryStreamWrite().

These are exposed in the **RtPITexD** toolkit.

6.5.6 Using PI texture dictionaries

Whereas PS texture dictionaries save **RwTexture** data, PI texture dictionaries save **RwImage** data along with some texture addressing and filtering flags.

In order to stream out a PI texture dictionary, a PS texture dictionary should exist in memory.

All mip levels of every texture in the PS texture dictionary is streamed as a separate **RwImage** in the PI texture dictionary. This avoids the need to regenerate mip levels when the PI texture dictionary is streamed back in.

Gamma correction is also removed when a PI texture is written, and reapplied when it is read, to avoid cumulative gamma corrections.

In addition, any plugin extension data associated with each **RwTexture** is also streamed with the PI texture dictionary.

When a PI texture dictionary is streamed in, a PS texture dictionary is created that can subsequently be used on the target platform.

6.5.7 Non-fixed hardware issues with texture dictionaries

For non-fixed hardware platforms that RenderWare Graphics' supports, such as PC and Macintosh, platform *specific* texture dictionaries may not be the best method of distributing final artwork with a product.

This is because the format of the platform specific textures will nearly always be dependent on the capabilities of the video card on which the product is being used on, which can significantly vary from one computer to another.

Hence, one solution is to distribute platform *independent* texture dictionaries (and possibly other associated source artwork) and generate platform specific versions at application specified times. For example, this may be at installation time, load time, or when the user changes some video settings. The application should be aware of what situations require a rebuild of the PS texture dictionary.

6.5.8 Textures & Binary Streams

While Textures can be read directly from disk or stored in Texture Dictionaries, they can also be streamed to and from RenderWare Graphics Binary Streams.

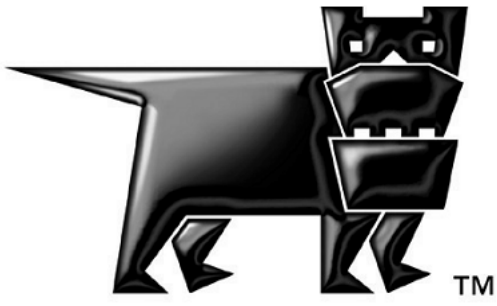
Once opened using the standard **RwStream** API the **RwTextureStreamRead()** and **RwTextureStreamWrite()** functions can be used to read and write Texture objects to the stream.

It is important to note that Textures are *not* serialized with their Raster data. Instead, writing a Texture object results in a data stream containing the Texture's settings and properties along with the filename from which the Texture's Raster was created. Therefore a reference to the filenames needs to be made by opening each one using the Image object API and performing the conversion into a Raster for the Texture to use.

Because of this, most developers will prefer to use the Texture Dictionary mechanism as it provides a much neater way of performing this task.

Chapter 7

Immediate Mode



7.1Introduction

Immediate Mode contains 2D and 3D graphics functionality. The API functions can be found in the Core Library. There are two Immediate Mode APIs **RwIm2D** and **RwIm3D**. They provide low-level control over the underlying hardware through a multi-platform API.

A quick glance at the API Reference reveals that both the Immediate Mode APIs are based around the rapid manipulation and rendering of *primitives*. Primitives are built up of lines or filled triangles. *All* other polygons are built up of combinations of triangles. The line-drawing features are typically used for very specialized effects, such as wire frame rendering or GUI features.

7.1.1 Properties & Render States

Before Immediate Mode features are looked at in more detail, there are some very important points to note that apply to both these 2D and 3D APIs. In particular, the properties of any and all RenderWare Graphics primitives are specified and defined by the developer.

These properties include:

- Color
- Position
- Render State
- Texture Coordinates

Colors are specified on a per-vertex basis for most rendering tasks. For example, a line drawn with a red vertex at the start and a blue vertex at the end will be drawn with the color blending smoothly from red to blue along the line.

Positioning vertices requires performing transformation operations on said vertices. RenderWare Graphics includes **RwV2d**, **RwV3d** and **RwMatrix** data types as well as the API to manipulate them.

Perhaps the most important property of the two Immediate Modes is the *Render State*. The Render State is a collective term for a group of settings that define how primitives are to be rendered. It is accessed through the **RwRenderStateSet()** and **RwRenderStateGet()** functions. It manages issues such as texturing, fogging and alpha blending.

The Render State system has its own API and this will be covered in more detail later in this chapter.

7.22D Immediate Mode

This mode forms the basis of RenderWare Graphics' rendering engine.

There are relatively few functions to grasp because the 2D Immediate Mode API performs line and triangle rendering. These basic shapes, known as *primitives*, form the basis of the Immediate Mode APIs.

Lines and triangles are built up using vertices stored as **`RwIm2DVertex`** objects. The properties of this object will be examined shortly, but first, fundamental concepts behind 2D Immediate Mode will be covered.

7.2.1 Basic Concepts

Coordinates

RenderWare Graphics' 2D Immediate Mode API works in screen space, also known as device space. This means that you work directly with display device coordinates and, in turn, this means the output is resolution and platform dependent.

The **`RwIm2DVertex`** object stores coordinates as **`RwReal`** types, making them floating point values rather than integers. This makes it easier to handle features, such as anti-aliasing, which require sub-pixel precision in order to work.

Coordinates can also be defined in terms of the *camera space*. This is of use mainly for layering rendered imagery over a previous rendering. (For example, layering an effect over a model rendered by a Retained Mode plugin.) Camera Space rendering takes place in a 3D co-ordinate system with the origin and orientation defined by the current Camera position and orientation.

Rt2d Toolkit

This resolution-dependency is what separates 2D Immediate Mode from the Rt2d Toolkit. The Rt2d Toolkit provides a higher-level 2D graphics API that is resolution independent. It also makes heavy use of the 3D graphics facilities in RenderWare Graphics to support a number of powerful hardware-accelerated features, including rotation, translation and alpha blending.

Clipping

The 2D Immediate Mode API does not make any attempt at clipping. If you attempt to draw using invalid coordinates, the results will be undefined and a crash is quite possible. You should make full use of debug builds when testing Immediate Mode applications.

Z-Buffers

The output of 2D Immediate Mode can make use of Z-buffers. This lets you position your 2D renderings along the Z-axis. In theory, a Z-axis is taken to point 'into' the screen.

However, in practice, hardware implementations of Z-buffers vary greatly from platform to platform. For instance, some may define the range of Z coordinates as running between 0 and 1 with values specified in floating point. Others may use integers running from 0 to –32768.

The upshot of this is that the RenderWare Graphics Z-buffer may work differently from platform to platform.

Near & Far Z

A common requirement for 2D graphics is the need to place the rendered imagery at either the closest or furthest point along the Z-axis. These limits are defined by the underlying hardware, which dictates the resolution of the Z-buffer.

Two functions are provided to support these requirements: **RwIm2DGetFarScreenZ()** and **RwIm2DGetNearScreenZ()**. These will return the minimum and maximum possible Z coordinates for the active Raster as a **RwReal** value. You should ensure any Z values are clipped to this range.

Perspective Projection

Camera space is a space with the origin at the camera, looking along the camera's at vector, with the up vector roughly upwards. This is completely separate from screen coordinates, which are computed by performing a perspective projection.

If you have a coordinate in world space, use the camera view matrix to transform it into camera space. Then, if **outx/outy/outz** are the elements of the camera space vertex, project to screen space using:

```
X = outX * recipZ * W + offX
Y = outY * recipZ * H + offY
Z = recipZ * Z + offZ
```

where **recipZ = 1/outZ**, **W/H** are the width/height of the camera raster, **offX** and **offY** are raster offsets (pull them from the camera's raster) and **Z** and **offZ** are computed from the near/far clip planes. Use **camera->zScale** and **camera->zShift** for **Z** and **offZ** respectively.

This is the technique used by the non-hardware T&L version of RenderWare Graphics.

Vertices

While the result of working with 2D Immediate Mode is primitives rendered on a display, your code will actually work directly with vertices, so let's take a look at these now.

The vertex is the main data type for RenderWare Graphics' Immediate Mode APIs. There are two such types, one each for 2D and 3D Modes.

The 2D Immediate Mode form is **RwIm2DVertex**. As with its **RwIm3DVertex** counterpart, this data type's physical format is platform-dependent, so you shouldn't try to access it directly. Instead, the API provides a complete set of functions to prepare and manipulate the vertex. Note: These functions are implemented as C Macros in most cases to provide optimum performance.

7.2.2 Initializing an RwIm2DVertex object

As mentioned earlier, this object is defined in a platform-specific way. This prevents us from documenting its structure. Initializing such objects is therefore performed entirely through the API.

An **RwIm2DVertex** object contains the following properties:

- Red, Green, Blue and Alpha components
- Camera-space coordinates (X, Y and Z)
- Reciprocal of Camera's Z coordinate
- Screen-space coordinates (X, Y and Z)
- U and V coordinates

Setting & Retrieving Coordinates

2D Immediate Mode vertices are usually in screen space and this means the **RwIm2DVertex** objects are also known as "device vertices". Since this vertex object is not exposed as a structure, you need to use the API functions, **RwIm2DVertexSetScreenX()**, **RwIm2DVertexSetScreenY()** and **RwIm2DVertexSetScreenZ()**, to set these coordinates programmatically. These functions have counterparts that can be used to retrieve these same values: **RwIm2DVertexGetScreenX()**, **RwIm2DVertexGetScreenY()** and **RwIm2DVertexGetScreenZ()**.

It is also possible to specify coordinates in terms of camera space – the functions are: **RwIm2DVertexSetCameraX()**, **RwIm2DVertexSetCameraY()**, **RwIm2DVertexGetCameraX()** and **RwIm2DVertexGetCameraY()**.

Reciprocal Camera Z, Texture Coordinates & Platform Dependence

The underlying platform's hardware has a great impact on the vertex object. Often, the **RwIm2DVertex** (and its 3D Immediate Mode counterpart) are simply wrappers for a hardware-specific data type.

This means that even the format of the colors can change. For instance, some platforms require colors to be specified in floating point form while others prefer integer values. This is why, if you look at the API Reference entries for the two Immediate Mode APIs, you'll find color setting functions that accept both formats. This gives you the option of either sticking to one color format – the functions will convert where necessary – or changing the format from platform to platform if you prefer that level of control.

In order for some rendering techniques, including Gouraud shading and perspective-correct texture mapping, to work correctly, you *may* need to specify the reciprocal camera-space Z coordinate of a vector and/or the actual camera-space Z coordinate itself.

This is an important facet of Immediate Mode programming: some functions simply don't exist on some platforms; on others, different functions may be required to achieve the same effects.

In the case of the reciprocal of Camera Z, the function (if available) to obtain this is **RwIm2DVertexGetRecipCameraZ()**. (There is an equivalent **RwIm2DVertexSetRecipCameraZ()** function too if the former is available.)

The reciprocal camera Z value is generally required to enforce perspective-correct texture mapping. Texture coordinates can therefore also be specified if your primitive(s) are to be so rendered. Currently, the vertex object will only support one texture – multi-texturing is planned – so setting the U and V coordinates is a matter of calling the appropriate **RwIm2DVertexSetU()** and **RwIm2DVertexSetV()** functions respectively.

The API Reference is rebuilt specifically for each platform so it will only contain the relevant platform-specific entries. Other platforms have different builds of the API Reference with different platform-specific entries as appropriate.

7.2.3 Primitives

RenderWare Graphics supports two major types of primitive: Lines and Triangles. These are in turn split into subtypes. Lines are split into *line lists* and *poly-lines*.

Line Lists

These are lists of vertex pairs defining the start and endpoints of lines. This data format is ideal for rendering groups of unconnected lines.

Poly-lines

This is a list consisting of one start point, followed by any number of endpoints. The Immediate Mode rendering engine will start at the first point, draw a line to the first endpoint and draw another from the end of that line to the next endpoint in the list. This primitive is ideal for sequences of connected lines.

Except for the first line, the poly-line primitive type does not require two vertices to be processed per line. This means it needs the least data to work and is therefore the most efficient of the line primitives. If possible, use this primitive type when working with lines.

Rendering individual lines can be done using **`RwIm2DRenderLine()`**. This function allows you to draw individual lines between arbitrary vertices. (See the API Reference for more details.)

It should be noted, however, that drawing individual lines in this way is not recommended as it can be slow.

RenderWare Graphics also supports a number of triangle primitives:

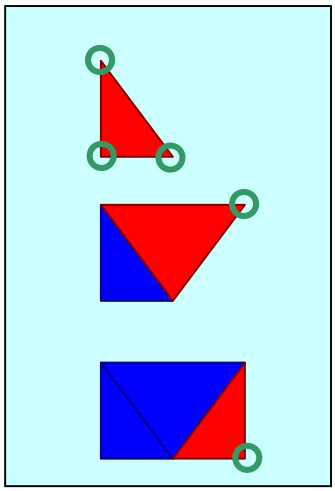
Triangle Lists ("Tri-List")

These are similar to the *Line Lists* mentioned earlier. They consist of triplets of vertices defining individual triangles. This implies that triangles in a tri-list are entirely independent of each other.

Triangle Strips ("Tri-Strip")

These define strips of adjacent triangles, each sharing an edge with another. This form requires fewer vertices than the Triangle Lists type as, after the first triangle is defined, only one additional vertex is needed to define each subsequent triangle. This has significant performance benefits on most platforms.

The diagram to the right demonstrates the advantage of tri-strips. Once the first three vertices (shown as rings in the diagram) have defined the first triangle, only one additional vertex is required to add each new triangle to the strip.

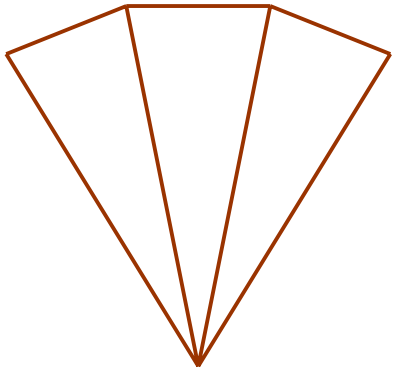


In the diagram, the second step shows a fourth vertex defining the second triangle (shown in red) and in the third step, we have just five vertices defining three triangles.

Obviously, this format is more efficient as you add more triangles.

Triangle Fans ("Tri-fan")

These are similar in concept to triangle strips, relying on contiguous triangles to reduce the number of vertices that need to moved around and processed.



As you can see from the example to the right, a triangle fan requires that all triangles share a vertex and are contiguous. This form has much the same advantages as triangle strips.

Both the strip and fan forms are popular with transform and lighting processing hardware, so RenderWare Graphics is biased somewhat in their favor on most supported platforms.

The triangle fan and triangle strip primitives are not built on the fly by RenderWare Graphics' rendering engine. The RenderWare Graphics modeler exporter plugins allow you to export geometry optimized for triangle strips and/or fans.

7.2.4 Triangle Winding Order

Throughout RenderWare Graphics, the ordering of the vertices defining a triangle – the *winding order* – also define its visibility. RenderWare Graphics' use of a right-handed coordinate system means triangles with vertices defined in clockwise order (relative to the camera) have a normal pointing *away* from the camera and are therefore not visible, so they will not be drawn.

In summary: visible Triangles must have vertices defined in anti-clockwise order, relative to the camera, as the normal to the Triangle is pointing towards the camera.

7.2.5 Primitives vs. Indexed Primitives

2D Immediate Mode can work directly with arrays of primitives, which are in any case just arrays of vertices. It can also work with arrays of *indices* to such arrays of vertices. This second technique is particularly important as it opens up more efficient use of system memory. In particular, it lets you re-use vertices rather than having define duplicates.

The SDK includes a number of Examples, including the **`im2d`** Example. This illustrates 2D Immediate Mode by rendering a number of different primitives, including indexed and non-indexed forms.

7.2.6 Example 1: Rendering A Line.

This code fragment renders a single, simple, opaque red line:

```
RwIm2DVertex vertex[2];

// Set up the vertices...
RwIm2DVertexSetScreenX(&vertex[0], 20.0f );
RwIm2DVertexSetScreenY(&vertex[0], 20.0f );
RwIm2DVertexSetScreenZ(&vertex[0], 3276.0f );
RwIm2DVertexSetRecipCameraZ(&vertex[0], (1.0f/6.0f) );

RwIm2DVertexSetScreenX(&vertex[1], 620.0f );
RwIm2DVertexSetScreenY(&vertex[1], 460.0f );
RwIm2DVertexSetScreenZ(&vertex[1], 3276.0f );
RwIm2DVertexSetRecipCameraZ(&vertex[1], 1.0f/6.0f );

// Opaque red...
RwIm2DVertexSetIntRGBA(&vertex[0], 255, 0, 0, 255);

// ...and the same for the second vertex.
RwIm2DVertexSetIntRGBA(&vertex[1], 255, 0, 0, 255);

// Texturing off...
RwRenderStateSet(rwRENDERSTATETEXTURERASTER, NULL);

// Flat shading on...
RwRenderStateSet(rwRENDERSTATESHADEMODE, (void
*)rwSHADEMODEFLAT);

// Alpha-transparency off...
RwRenderStateSet(rwRENDERSTATEVERTEXALPHAENABLE, (void
*)FALSE);

//Render line...
RwIm2DRenderLine(vertex, 2, 0, 1);
```

Release Builds

There appear to be a lot of function calls involved in this code, but the overhead is not as bad as it first appears.

The RenderWare Graphics libraries are supplied in three *builds*: Release, Metrics and Debug.

Release builds redefine many trivial functions as macros. The upshot is that almost all property setting and access functions, such as those above, are inlined.

Example 2: Rendering A Triangle.

This code fragment renders a simple, yellow, flat shaded triangle:

```
RwIm2DVertex vertex[3];

//Set up the vertices...
RwIm2DVertexSetScreenX(&vertex[0], 20.0f );
RwIm2DVertexSetScreenY(&vertex[0], 20.0f );
RwIm2DVertexSetScreenZ(&vertex[0], 3276.0f );
RwIm2DVertexSetRecipCameraZ(&vertex[0], (1.0f/6.0f) );

RwIm2DVertexSetScreenX(&vertex[1], 20.0f );
RwIm2DVertexSetScreenY(&vertex[1], 40.0f );
RwIm2DVertexSetScreenZ(&vertex[1], 3276.0f );
RwIm2DVertexSetRecipCameraZ(&vertex[1], (1.0f/6.0f) );

RwIm2DVertexSetScreenX(&vertex[2], 40.0f );
RwIm2DVertexSetScreenY(&vertex[2], 40.0f );
RwIm2DVertexSetScreenZ(&vertex[2], 3276.0f );
RwIm2DVertexSetRecipCameraZ(&vertex[2], (1.0f/6.0f) );

// Opaque yellow...
RwIm2DVertexSetIntRGBA(&vertex[0], 255, 255, 0, 255);

// Opaque yellow...
RwIm2DVertexSetIntRGBA(&vertex[1], 255, 255, 0, 255);

// ...and, once again, opaque yellow...
RwIm2DVertexSetIntRGBA(&vertex[2], 255, 255, 0, 255);

// Texturing off...
RwRenderStateSet(rwRENDERSTATETEXTURERASTER, NULL);

// Flat shading mode...
RwRenderStateSet(rwRENDERSTATESHADEMODE, (void
*)rwSHADEMODEFLAT);

// Alpha-transparency off...
RwRenderStateSet(rwRENDERSTATEVERTEXALPHAENABLE, (void
*)FALSE);

// Render triangle...
RwIm2DRenderTriangle(vertex, 3, 0, 1, 2);
```

As you can see from the examples above, there is an overhead involved in setting up the **RenderState** data. Because of this, it makes sense to group all your primitives by **RenderState** to speed up the rendering process.

7.33D Immediate Mode

3D Immediate Mode provides low-level 3D rendering facilities. It is designed around the same concepts as its 2D counterpart, including the concepts of *vertex lists*, *index lists* and *primitives*. In addition, it makes heavy use of RenderWare Graphics' *Render State* API to control the rendering process.

7.3.1 Preparation for Rendering

Vertices & Indices

3D Immediate Mode has its own vertex object: **RwIm3DVertex**. This holds coordinates defined using either *world space* (also known as 'scene space'), or in *object space*. This distinction is covered in more detail later.

As with the 2D Immediate Mode's own vertex object, **RwIm3DVertex** is also an opaque, platform-dependent type. Access is entirely through the API.

In fact, there isn't all that much to say about the 3D vertex object: aside from the extra dimension, it's relatively straightforward and the API is similar to that for 2D Immediate Mode's own **RwIm2DVertex** object.

Where the 3D Immediate Mode API does differ slightly from the 2D one is that setting coordinates is done through a single function call: **RwIm3DVertexSetPos()**. This takes the X, Y and Z coordinates as well as a pointer to the **RwIm3DVertex** where they are to be stored. A retrieval function, **RwIm3DVertexGetPos()**, is also provided.

As with the 2D Immediate Mode, 3D Immediate Mode expects vertices to be stored in arrays. These arrays can be referenced either directly or using an index array. The latter has the expected advantage of requiring fewer vertices, but can cause problems if your model geometry is to be adjusted in real-time.

Unlike its 2D counterpart, the 3D Immediate Mode API provides clipping.

Transforming Space

To determine how a particular vertex maps to the display device, the 3D Immediate Mode API provides a function that takes an array of 3D vertices and transforms them to camera space (which is much the same thing as device space).

The function that performs this feat is the **RwIm3DTransform()** function. This takes four parameters, the third of which is an optional parameter specifying an additional transformation matrix to be applied.

This transformation matrix should be set when working with vertex arrays, which use object space. The matrix will be used to map the object to world space and then to camera/device space.

The **RwIm3DTransform()** function normally produces two new arrays, one of camera space vertices and – for those vertices that lie within the camera frustum – an array of device space (device-dependent) vertices.

Access to these intermediate data representations should be performed very carefully. They are platform-dependent, some hardware accelerators may store these new arrays in strange formats – or even not at all.

Additional Vertex Properties

As well as the usual three coordinates, each 3D Immediate Mode vertex can store RGBA values. These are set using the **RwIm3DVertexSetRGBA()** function. (The function accepts 8-bit unsigned integers, so floating point RGBA formats will need to be converted first.)

The remaining two properties are U and V coordinates for texturing. The functions for setting these are **RwIm3DVertexSetU()** and **RwIm3DVertexSetV()** respectively. Both functions take an **RwReal** value for the texture coordinates.

The 'impick' Example

This example lets you pick and drag vertices in wireframe 3D Immediate Mode models. The commented code therefore illustrates a wide variety of Immediate Mode programming techniques.

Lighting

Lights are not supported in 3D Immediate Mode. You can simulate them by manipulating the vertex colors in accordance with a custom lighting model.

7.3.2 Rendering

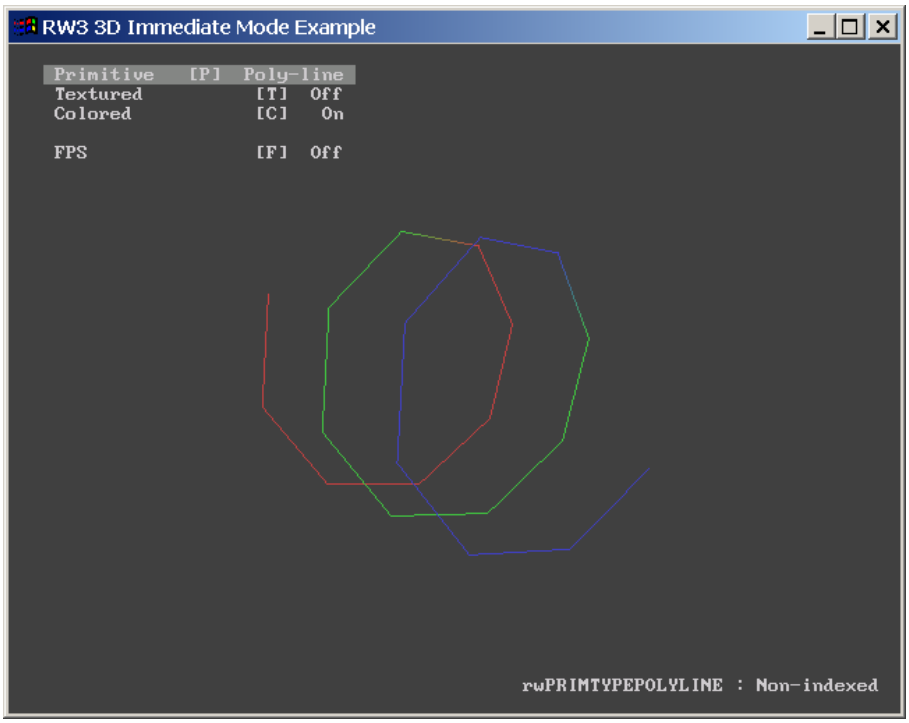
Rendering in 3D Immediate Mode requires following this sequence:

1. Transform the primitives into camera space
2. Perform any rendering with the primitives
3. Terminate pipeline execution

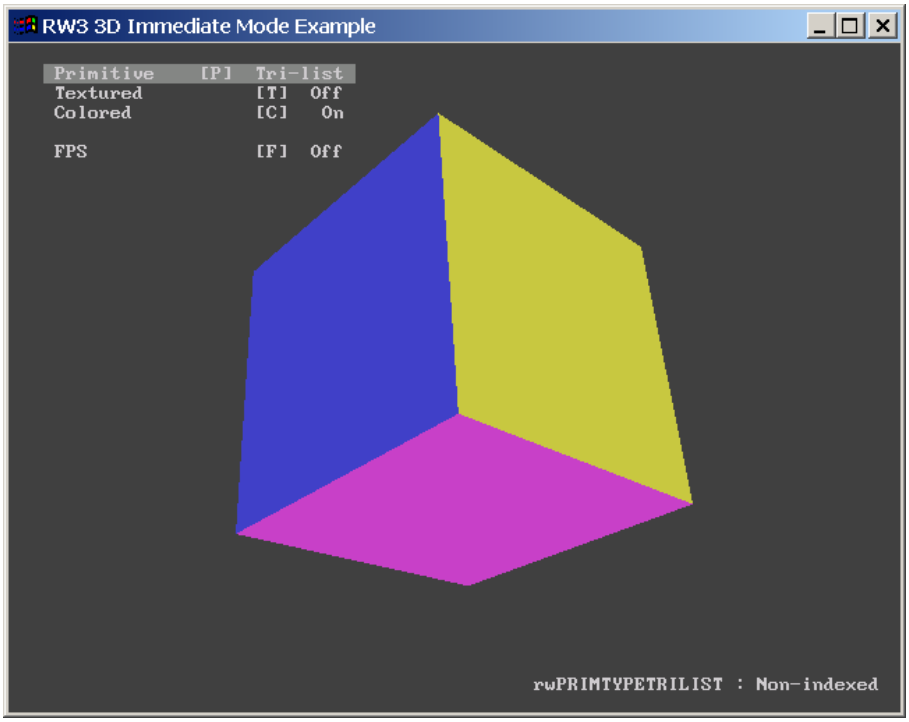
The primitives supported by 3D Immediate Mode are simply extensions of those found in the 2D mode: line lists, polylines, triangle lists, triangle strips and triangle fans. Again, the same trade-offs apply.

The screenshots below illustrate some of the primitives in action. All are from the **im3d** Example.

This first shot is the polyline form in action. (The code used to display this is contained within the **polyline.c** source file.)



The next shot shows the triangle list primitive. (The code that exercises this primitive can be found in **trilist.c**.)



We recommend you take a look through and modify the code that makes up this Example as it illustrates the salient features of this particular API.

Render States

3D Immediate Mode rendering makes heavy use of render state settings. More on these in 7.4 Render States. As with the 2D Immediate Mode API, the most efficient way to handle render states is to group primitives with the same state and render them in batches, switching render states between each batch.

Rendering primitives

Two rendering functions are available for this: **`RwIm3DRenderPrimitive()`**, which renders non-indexed primitive types, and its counterpart **`RwIm3DRenderIndexedPrimitive()`**, which renders indexed ones.

For instance, the following line…

```
RwIm3DRenderIndexedPrimitive(rwPRIMTYPETRILIST, myIndices, 8);
```

…would be used to render an indexed triangle list. The relevant array indices are stored in the **`myIndices`** array, and there are 8 such indices to render.

Remember that the **`RwIm3DTransform()`** function has already taken this array and transformed it into camera-space vertices. The PowerPipe Transform node caches these internally. It is these converted vertices that are referenced during any rendering.

If your target platform allows it, it may be possible to access these converted vertex arrays using RenderWare Graphics' platform-specific API. The exact functionality available will likely vary from platform to platform.

7.3.3 Closing the pipeline

Once rendering of your array of primitives is complete, you must call **RwIm3DEnd()** to close and flush the rendering pipeline.

7.3.4 3D Immediate Mode & PowerPipe

3D Immediate Mode rendering makes use of RenderWare Graphics' PowerPipe rendering technology. When you transform an array of vertices with **RwIm3DTransform()**, you are actually firing up PowerPipe and calling its default pipeline.

Many of our platforms are provided only with generic transform and render nodes. These nodes do **not** support all of the primitives. For instance, the generic transform node will expand triangle fans into ordinary triangle lists.

The transform node also does not support unindexed primitives and will create indices for them, so you should use indexed rendering wherever possible.

However, all PowerPipe nodes can be overridden by your own, so two functions are provided to give you direct access to the Transform and Rendering nodes. They are, respectively, **RwIm3DGetTransformPipeline()** and **RwIm3DGetRenderPipeline()**.

Should you wish to revert to the generic nodes, you can obtain pointers to the generic transform and render nodes using **RwIm3DGetGenericTransformPipeline()** and **RwIm3DgetGenericRenderPipeline()**.

On platforms that support Transform & Lighting in hardware, overloading the generic node will cause a software pipeline to be used. This will have a negative impact on performance so you may need to write your own hardware T&L node.

Once the pipeline is fired up, it transforms and renders the supplied vertices.

It's important to understand that the only way to transform some more vertices at this stage is to close down the pipeline using **RwIm3DEnd()** and restart it with **RwIm3DTransform()**. This is not the obstacle it appears, as you will usually render batches of primitives sorted by Render State anyway. It is not possible to nest Transform/End sequences.

As you can see, efficient management of this process is the key to getting maximum performance out of RenderWare Graphics' 3D Immediate Mode.

Uses for 3D Immediate Mode

RenderWare Graphics provides a very rich Retained Mode API, which would lead many to suspect 3D Immediate Mode of being of relatively little use. Nothing could be further from the truth!

3D Immediate Mode is ideally suited to the rendering of program-generated data. For example, particle system explosions and other scenery effects are often added to a scene using this API.

Other techniques include producing pseudo-3D imagery, such as that seen in some real-time strategy games. (Although produced long before RenderWare Graphics was released, Cavedog's "Total Annihilation" series is a good example of pseudo-3D.)

An important use is for rendering of scientific data or mathematical models that don't map easily to traditional modeling paradigms. One of our developers has taken advantage of this aspect of 3D Immediate Mode to create a groovy multicolor lava lamp simulator using a marching cube algorithm.

7.3.5 Platform Specific Information

Some platforms do their vertex transforms in hardware and cannot provide access to the transformed vertices. You should refer to the platform-specific documentation to see what functionality is available in this regard.

Similarly, texture coordinates may have restrictions imposed by their underlying hardware. Again, you should refer to the platform-specific documentation to see if this applies to your target platform.

7.3.6 Camera-space and Z-buffer depth equations

The mapping functions that convert from camera space to screen depth space are provided here for information:

Perspective Camera:

$$Z(z) = Z_{\min} + \left(\frac{Z_{\max} - Z_{\min}}{R_{\max} - R_{\min}} \right) (z - R_{\min}) \frac{R_{\max}}{z}$$

Parallel Camera:

$$Z(z) = Z_{\min} + \left(\frac{Z_{\max} - Z_{\min}}{R_{\max} - R_{\min}} \right) (z - R_{\min})$$

Where:

- ***Z(z)*** is the Z-buffer value corresponding to a camera space ***z***-coordinate ***z***.
- Z_{max}, Z_{min} are the maximum and minimum Z-buffer values, respectively. They correspond to the Z-buffer values given by $\mathbf{Z}(\mathbf{R}_{max})$ and $\mathbf{Z}(\mathbf{R}_{min})$. Their values may be queried using the API functions **`RwIm2DGetFarScreenZ()`** and **`RwIm2DGetNearScreenZ()`**.
- R_{min}, R_{max} are the distances to the far and near clip planes, respectively. Their values may be queried using the API functions **`RwCameraGetFarClipPlane()`** and **`RwCameraGetNearClipPlane()`**.

7.3.7 Rt2D

This Toolkit provides a 2D graphics API. Its power is such that it could justifiably be considered a kind of Retained Mode API for 2D graphics.

Unlike 2D Immediate Mode, which deals solely with the most basic rendering chores, the 2D Toolkit also supports features such as resolution-independence, scaleable fonts, paths, textured polygons, anti-aliasing, alpha blending effects, free rotation and scaling, clipping, rendering to any arbitrary Camera object, and more.

Its power is derived from RenderWare Graphics' 3D graphics capabilities. This means it can make full use of any 3D graphics acceleration hardware to produce great 2D imagery.

So why use 2D Immediate Mode?

2D Immediate Mode is a thin API. This makes it much better suited to fast, simple 2D operations of the type often required to create a user interface. Icons, debugging messages, quick bitmap font routines, side-panels, simple sprites and so forth are generally easier to produce using the 2D Immediate Mode API.

7.4Render States

Briefly, the Render State object is a basic state machine. It is an opaque object, with two API functions provided to access its properties: **RwRenderStateSet()** and **RwRenderStateGet()**.

7.4.1 Key Features

- Render States are a *shared* hardware resource.

  There is only one Render State structure and it is shared throughout RenderWare Graphics. Therefore, 2D Immediate Mode shares this with both the 2D and 3D Retained Mode APIs – **Rt2D** and **RpWorld**, respectively.

- There is no multi-platform default setting for the Render State structure.

  This is because some platforms may not support all the Render State settings, or support them in different ways. Instead, the default setting for the Render State varies from platform to platform.

- The application is responsible for ensuring any required state(s) are set correctly.

  Some high-level portions of the RenderWare Graphics API, such as **RpWorld**, may change the Render State settings if they need to. You should not assume that a particular Render State has been left untouched by, say, a call to **RpWorldRender()**.

- Some Render State settings are unsupported on certain platforms.

  RenderWare Graphics does not provide any software emulation as such, so if a platform does not support a particular Render State feature, setting it will have no effect.

7.4.2 API

The Render State API (**RwRenderState**) differs from most other APIs in that there is only one Set/Get pair of functions. They are **RwRenderStateSet()** and **RwRenderStateGet()** respectively.

Both functions take two parameters: an enumerated type and a void pointer. The enum or 'render state specifier' determines which render state the function is to set or get. The void pointer holds the data. So the void pointer is used as an arbitrary 32-bit value whose contents depend on the value of the render state specifier. The programmer is responsible for checking the type of this parameter as the compiler will not check the type of void pointers. (Types cast to void in these function calls include **RwRaster ***, **RwBool**, and other enumerated types.)

Currently, the following render states are supported:

- **rwRENDERSTATETEXTURERASTER**
  Use this render state to set the Raster object to texture with.

  For example:

  ```
  RwRaster * myRaster;
  RwRasterCreate( myRaster );
  RwRenderStateSet( rwRENDERSTATETEXTURERASTER,
                                          (void *)myRaster);
  ```

- **rwRENDERSTATETEXTUREADDRESS**
  Use this render state to tell RenderWare Graphics how to handle the texture coordinate space. The options are: **rwTEXTUREADDRESSWRAP**, **rwTEXTUREADDRESSCLAMP**, **rwTEXTUREADDRESSMIRROR** or **rwTEXTUREADDRESSBORDER**.

  The values to pass as the void pointer are those described in the API Reference under **RwTextureGetAddressing()**.

  This render state will set both U and V handling to the same operation. The following two enumerated values can be used to set the U and V spaces individually so you can have different behavior for each:

  - **rwRENDERSTATETEXTUREADDRESSU**,

  - **rwRENDERSTATETEXTUREADDRESSV**,

  Example 1: Set both U and V coordinate spaces to Clamp mode:

  ```
  RwRenderStateSet( rwRENDERSTATETEXTUREADDRESS, (void *)
  rwTEXTUREADDRESSCLAMP);
  ```

  Example 2: Set V coordinate space to Wrap mode:

  ```
  RwRenderStateSet( rwRENDERSTATETEXTUREADDRESSV, (void *)
  rwTEXTUREADDRESSWRAP);
  ```

- **rwRENDERSTATETEXTUREPERSPECTIVE**
  Pass **TRUE** or **FALSE** in the void pointer. **TRUE** enables perspective correction.

- **rwRENDERSTATEZTESTENABLE**
  Pass **TRUE** or **FALSE** in the void pointer. **TRUE** enables Z-buffer tests.

- **rwRENDERSTATESHADEMODE**
  Can be set to either **rwSHADEMODEFLAT** or **rwSHADEMODEGOURAUD**.

- **rwRENDERSTATEZWRITEENABLE**
  Pass **TRUE** or **FALSE** in the void pointer. **TRUE** enables Z-buffer writes.

- **rwRENDERSTATETEXTUREFILTER**
  Texture filtering method. The values you can pass are as follows:

  - **rwFILTERNEAREST,**
  - **rwFILTERLINEAR,**
  - **rwFILTERMIPNEAREST,**
  - **rwFILTERMIPLINEAR,**
  - **rwFILTERLINEARMIPNEAREST,**
  - **rwFILTERLINEARMIPLINEAR**

  See the *Rasters, Images and Textures* chapter for more detailed information on these.

- **rwRENDERSTATESRCBLEND**
  Used to set the source blending factor.

- **rwRENDERSTATEDESTBLEND**
  Used to set the destination blending factor.

- **rwRENDERSTATEVERTEXALPHAENABLE**
  Pass **TRUE** or **FALSE** in the void pointer. **TRUE** enables vertex alpha transparency.

- **rwRENDERSTATEBORDERCOLOR**
  Border color for texturing with borders. The argument should be RGBA components packed into an **RwRGBA** value and cast to a void pointer.

- **rwRENDERSTATEFOGENABLE**
  Pass **TRUE** or **FALSE** in the void pointer. **TRUE** enables fogging effects. (All polygons rendered from this point on until this is set to **FALSE** will be affected.)

- **rwRENDERSTATEFOGCOLOR**
  Color used for fogging. The argument should be RGBA components packed into an **RwRGB** value cast to a void pointer.

- **rwRENDERSTATEFOGTYPE**
  Select the type of fogging to use. Valid arguments are:

  - **rwFOGTYPELINEAR,**
  - **rwFOGTYPEEXPONENTIAL,**
  - **rwFOGTYPEEXPONENTIAL2**

  The precise algorithms used vary from platform to platform, but are broadly similar. Read the documentation supplied with your target platform for more details on how fogging is implemented.

On current platforms, linear fog will be faster than exponential forms.

Not all platforms support all three fogging formats.

- **rwRENDERSTATEFOGDENSITY**
  Defines the density of exp and exp2 fogging. The density should be an **RwReal** value cast to a void pointer. See the platform-specific documentation for the range(s) allowed.

In *all* cases, the **RwRenderStateGet()** and **RwRenderStateSet()** functions will return FALSE if a particular render state is unsupported.

7.4.3 Blending

The Render State structure includes two blending settings, **rwRENDERSTATESRCBLEND** and **rwRENDERSTATEDESTBLEND**. These functions are used to control the blending of the rendered imagery with the data already extant in the target Raster.

The components of the final pixel color value in the frame buffer are obtained according to the formula:

$$C_{Out}^{(i)} = B_{Src}^{(i)} C_{Src}^{(i)} + B_{Dest}^{(i)} C_{Dest}^{(i)} \quad (\text{for } i = \text{R, G, B, A})$$

B_{Src} : source blend factor

C_{Src} : source color

B_{Dest} : destination blend factor

C_{Dest} : destination color (frame buffer)

Several options are available for the source and destination blend factors, but there are some platform specific restrictions.The following are available for all platforms:

rwBLENDZERO	(0, 0, 0, 0)
rwBLENDONE	(1, 1, 1, 1)
rwBLENDSRCALPHA	(A_s, A_s, A_s, A_s)
rwBLENDINVSRCALPHA	(1-A_s, 1-A_s, 1-A_s, 1-A_s)
rwBLENDDESTALPHA	(A_d, A_d, A_d, A_d)
rwBLENDINVDESTALPHA	(1-A_d, 1-A_d, 1-A_d, 1-A_d)

A_s and A_d are the source and destination alpha values respectively. On PlayStation 2, certain combinations of these factors for source and destination cannot be used together due to the underlying blend equation. See the API reference for more details. Note also that the DESTALPHA modes are only valid when the frame buffer actually contains an alpha channel.

The following color blend factors are supported in any combination in RenderWare Graphics for Xbox and D3D8 but have more limited availability on other platforms:-

rwBLENDSRCCOLOR	(R_s, G_s, B_s, A_s)
rwBLENDINVSRCCOLOR	(1-R_s, 1-G_s, 1-B_s, 1-A_s)
rwBLENDDESTCOLOR	(R_d, G_d, B_d, A_d)
rwBLENDINVDESTCOLOR	(1-R_d, 1-G_d, 1-B_d, 1-A_d)

PlayStation 2 does not support them at all. OpenGL and GameCube only support DESTCOLOR factors for SRCBLEND and SRCCOLOR factors for DESTBLEND.

One further mode is supported for Xbox and D3D8:

- **rwBLENDSRCALPHASAT** (f, f, f, 1), where f = min(A_s, 1- A_d)

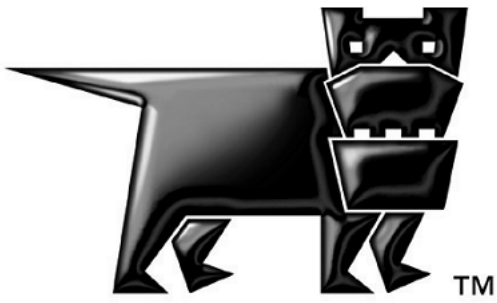
7.4.4 Sorting Alpha Primitives

Current versions of RenderWare Graphics do not support sorting of alpha primitives for you. It is therefore necessary to perform such processing explicitly in your application. This issue is explored in one of our FAQs.

7.4.5

Chapter 8

Serialization



8.1Introduction

RenderWare Graphics supports both a low-level file I/O API and a high-level streaming API which is used for serialization of objects.

This chapter covers the low-level file I/O API, which is similar in design to most ANSI-based operating system APIs. However, the main focus is on the streaming API.

8.2File I/O API

The low-level file I/O API deals with file-level access to storage devices. It exposes a file I/O interface based on the standard ANSI interface included with most C compilers.

The interface is exposed through the **RwFileFunctions** structure, a pointer to which can be obtained through a call to **RwOsGetFileInterface()**. This structure contains pointers to the file I/O functions and a default set is installed by default by RenderWare Graphics upon initialization.

The default functions implement the functionality either by using the platform's C compiler's default implementation (if available), or by passing the file I/O requests to a platform's underlying operating system.

The following table lists the **RwFileFunctions** element names, its associated ANSI file I/O function, and its purpose. Due to the popularity of the ANSI file I/O interface, it is assumed developers are familiar with these functions and their usage.

STRUCTURE ENTRY	ANSI NAME	PURPOSE
rwfexist	**fexist()**	Returns TRUE if the file exists
rwfopen	**fopen ()**	Opens a file for reading/writing
rwfclose	**fclose ()**	Closes an opened file
rwfread	**fread ()**	Reads data from a file
rwfwrite	**fwrite ()**	Writes data to a file
rwfgets()	**fgets ()**	Reads a null-terminated string from a file
rwfputs()	**fputs ()**	Writes a null-terminated string to a file
rwfeof()	**feof ()**	Returns TRUE if the end of the file has been passed
rwfseek()	**fseek ()**	Moves the file pointer to the specified point in the file
rwfflush()	**fflush ()**	Flushes any data written to a file from the internal cache
rwftell()	**ftell ()**	Returns the current position of the file pointer in a file

The application can replace the default functions by overwriting the entries in the **RwFileFunctions** structure with pointers to custom functions.

The replacements must use the relevant function prototype. For this purpose, suitable prototype **typedef**s have been defined. These **typedef**s are highlighted in bold within the function prototypes given in the table below.

ANSI NAME	PROTOTYPE
fexist()	RwBool (***rwFnFexist**)(const RwChar *name);
fopen()	void *(***rwFnFopen**)(const RwChar *name, const RwChar *access);
fclose()	int (***rwFnFclose**)(void *fptr);
fread()	size_t (***rwFnFread**)(void *addr, size_t size, size_t count, void *fptr);
fwrite()	size_t (***rwFnFwrite**)(const void *addr, size_t size, size_t count, void *fptr);
fgets()	RwChar *(***rwFnFgets**)(RwChar *buffer, int maxLen, void *fptr);
fputs()	int (***rwFnFputs**)(const RwChar *buffer, void *fptr);
feof()	int (***rwFnFeof**)(void *fptr);
fseek()	int (***rwFnFseek**)(void *fptr, long offset, int origin);
fflush()	int (***rwFnFflush**)(void *fptr);
ftell()	int (***rwFnFtell**)(void *fptr);

8.3RenderWare Binary Streams

RenderWare Graphics supports the concept of *binary streams*.

A binary stream is a data format which allows data to be streamed to files or through a network connection. Only the former is supported explicitly.

The binary stream mechanism is also used to support serialization of objects and this API relies on the low-level file I/O API described earlier, in section 1.2.

8.3.1 Binary Stream Structure

The binary stream format is used when serializing all serializable objects. For example, static worlds (**`RpWorld`**) can be serialized to a binary stream and so can dynamic models (**`RpClump`**).

Binary streams are normally written to, or read from, files. Such files can contain one *or more* serializable objects, so a system of *chunk IDs*—also known as *object type IDs*—is used to identify the specific entities within the stream.

For example, the RenderWare Graphics SDK comes with a number of demonstrations and examples. Most of these load model geometry and other related data from individual files with an extension of either "**`.dff`**" for dynamic models, or "**`.bsp`**" for static models. Both of these file extensions are used purely to remind the programmer what is in each file. Both file types are fundamentally the same: both are binary streams and accessed using the same binary stream API.

Note that from RenderWare Graphics 3.5, some file types are now considered "legacy": **`.dff`** and **`.bsp`** are among these. The default file type for *new* RenderWare Graphics binary streams is **`.rws`**. These **`.rws`** files encapsulate the data that the legacy file types would have contained and group related binary data together into a single container. The binary streaming methods remain unchanged however. See *8.3.4 RWS files* for more information on **`.rws`** files.

The meaning of "legacy" file types is that in the future, RenderWare Graphics exporters *may* not export to these file types. However, the binary format of these files continue to be supported, and RenderWare Graphics 3.5 will continue to read them. There is no need to re-export existing DFF/BSP/etc. artwork as RWS files.

Although the examples provided with the SDK use individual files for each dynamic model or world, an application could keep all its data in a single binary stream if needed. This is one such use for an **`.rws`** file.

The Header

When an object is serialized, the data is preceded by a *chunk header*, represented by the **`RwChunkHeaderInfo`** structure:

- **length** – length of the chunk data in bytes
- **type** – chunk ID, which can either be one of the following or a custom application-created ID:
  - **rwID_ATOMIC** - an atomic (type **RpAtomic**).
  - **rwID_CAMERA** - a camera (type **RwCamera**).
  - **rwID_CLUMP** - a clump (type **RpClump**).
  - **rwID_GEOMETRY** - a geometry (type **RpGeometry**).
  - **rwID_IMAGE** - an image (type **RwImage**).
  - **rwID_LIGHT** - a light (type **RpLight**).
  - **rwID_MATERIAL** - a material (type **RpMaterial**).
  - **rwID_MATRIX** - a matrix (type **RwMatrix**).
  - **rwID_TEXDICTIONARY** - a texture dictionary (type **RwTexDictionary**).
  - **rwID_TEXTURE** - a texture (type **RwTexture**).
  - **rwID_WORLD** - a world (type **RpWorld**).
- **version** – version of the chunk data

Chunk Types

The key to the streaming mechanism is in the **type** element. This element denotes the type of object stored in the chunk referred to by the chunk header. When a plugin is attached, it registers its supported object type IDs with the streaming API.

The type ID should be created using the **MAKECHUNKID** macro. This macro is also used to create plugin IDs, but plugins rarely implement more than one serializable object, so the plugin ID can also be used as the object type ID.

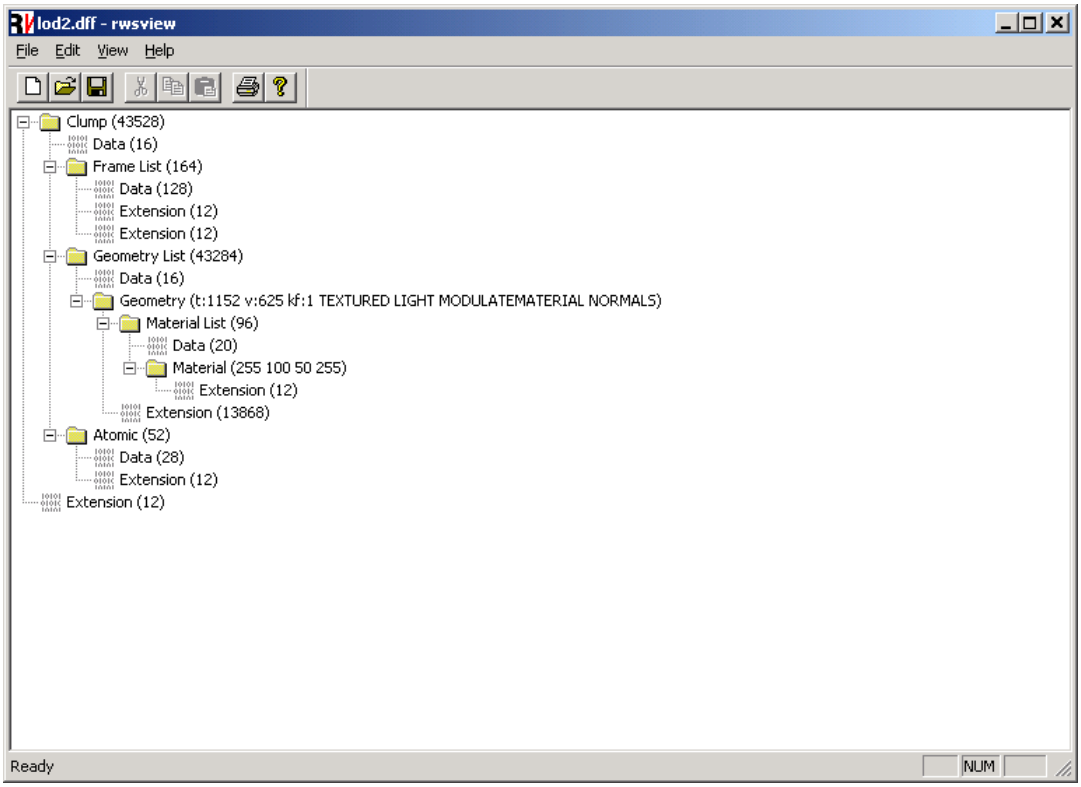
If a custom plugin does implement more than one object, you should ensure that the additional object IDs are unique. If you need more than 256 unique IDs, you should contact Criterion Software Ltd. to obtain additional Vendor IDs, each of which can be used to create a further 256 unique IDs.

Complex Chunks

Chunks can contain other chunks, so a complete stream can be parsed as a tree-like hierarchy. Such chunks are known as *complex chunks*.

The **strview** applet, which can be located in **[SDK-ROOT]/tool/strview**, illustrates this aspect of RenderWare Graphics' binary streams by displaying the structure of any valid stream as a hierarchical view. An example of the stream viewer in action can be seen in the screenshot on the next page.

Complex chunks are handled transparently by callbacks which are registered with the streaming API. In the screenshot below, the structure of a typical **RpClump** container object is clearly visible, with its list of **RwFrame** objects, **RpGeometry** objects and **RpAtomic** objects.



The stream viewer applet

8.3.2 Serializing Objects

Although there is a trend towards originating 3D graphics data algorithmically, most 3D graphics data is streamed into memory from a storage device. Given RenderWare Graphics' target market, this is usually either a CD, DVD or hard disk.

The streaming of extended or derived object data requires the creation of additional functions. We saw these in the **Plugin** example (see the *Plugins: Creation & Usage* chapter), but didn't see them in action.

Look for **TestPluginStream()** in the ClumpPhysics example's **main.c** file. This function, which is predicated on a build-time **#define** called **TESTSTREAM**, was included in this source code so you can see how the RenderWare Graphics Binary Stream facility is used.

You may want to activate it, by defining the **TESTSTREAM** constant, and step through the code in your debugger to watch what it does.

Registering the Stream Functions

If you look at the source code, you'll notice that none of the three stream functions created for the new plugin appear to be called directly. This is because these functions are called directly by the clump object's own stream functions.

Objects that support extension via the plugin mechanism *and* support for binary streams have *two* registration functions. Respectively, these are:

- **Rp[PLUGIN-NAME]RegisterPlugin()**
- **Rp[PLUGIN-NAME]RegisterPluginStream()**

In the ClumpPhysics plugin example, both functions are called in the **RpClumpPhysicsPluginAttach()** function. The second of the two registration functions, **RpClumpRegisterPluginStream()**, is the one that tells the clump object about our own stream functions.

The **RpClumpRegisterPluginStream()** function accepts three function pointers. Respectively, these are for reading, writing and returning the size of the additional data our functions will place into the stream.

It is important to note that **RpClumpRegisterPluginStream()** is part of the **RpClump** plugin, not the ClumpPhysics plugin. All plugins that need to support extension of their binary streams must implement their own registration function to allow this. For example, the ClumpPhysics plugin would need to implement an **RpClumpPhysicsRegisterPluginStream()** function.

Determining the Size of a Chunk

A stream chunk is not assumed to be fixed in size.

One reason for this is that plugins may extend existing chunk types rather than utilizing their own. Another issue is that some platforms work better if data is padded to a certain minimum block size. (This is often the case on consoles which make heavy use of caches and other hardware tricks.)

Every chunk type needs to have its own chunk size function. This function will call the chunk size functions for any extensions within that chunk so, if another plugin extends the same chunk, it too must implement a chunk size function.

This gives RenderWare Graphics a means by which it can determine the full size of a chunk: adding up the results of all the chunk size functions implemented for a chunk type gives the total size of the complex chunk.

Reading and Writing

Writing platform independent data to a stream is not as straightforward as it sounds. RenderWare Graphics' multi-platform nature means we have to take into account such things as packing sizes, default datatype sizes and even the *endian-ness* of the data. Otherwise, data written out on one platform may not be readable on another.

Endian-ness

Depending on the processor used at the heart of your target platform, data can be stored in one of two formats: *big-endian* or *little-endian*. This defines the byte-order of datatypes larger than a single byte when these are stored in RAM.

The table below uses hexadecimal notation to show the difference between the two forms when storing the hexadecimal 4-byte number "0x12345678":

BIG-ENDIAN	LITTLE-ENDIAN
0x12 0x34 0x56 0x78	0x78 0x56 0x34 0x12

As you can see, all the endian-ness means is which order bytes are stored. Little-endian format places the least significant byte ("LSB") first, while big-endian format places the most significant byte ("MSB") first.

This means you cannot simply throw your data structures at the stream as there's no guarantee that the raw bytes will be read back correctly on another platform. The solution is to standardize on some basic datatypes and make sure the endian-ness of the streamed data is consistent across all platforms.

In RenderWare Graphics, we've chosen little-endian format as our standard. This was picked mainly because we use PCs to develop on and these use little-endian format. This standard is used for all streams, regardless of platform, so streams written on a big-endian platform will be converted to little-endian form. On platforms that use little-endian format, no endian-ness conversion takes place.

The table below shows which of our key platforms uses which storage format:

PLATFORM	CPU	STORAGE FORMAT
Sony PlayStation 2	MIPS-based core	Little-endian
Microsoft Xbox	Intel Pentium III	Little-endian
PC (Direct3D / OpenGL)	Various x86-compatible CPUs	Little-endian
MacOS (OpenGL)	Motorola / IBM PowerPC	Big-endian
NINTENDO GAMECUBE	Motorola / IBM PowerPC	Big-endian

Endian-ness Conversion

The endian-ness of individual platforms makes it impossible to create data streams that are cross-platform compatible without some conversion work. The **RwMem** part of the core library API provides such conversion functions.

Some of the streaming functions—see the next section—perform these conversions internally. However, you *must* use the conversion functions described here if your application uses only the basic **RwStreamRead()**/**RwStreamWrite()** functions.

An important point to note is that none of the **RwMem** conversion functions will change the physical size of the data being converted, so a "**Float32**" occupies the same number of bytes as an **RwReal** value. This makes calculating the size of the data to be read or written easier.

The functions are:

- **RwMemFloat32ToReal()**

  Used when reading from the stream: this function reverses the conversion process performed by **RwMemRealToFloat32()** and gives you back your original array of **RwReal** values. The **RwMemNative32()** function should be called first.

- **RwMemLittleEndian32()**
  RwMemLittleEndian16()

  Used when writing to the stream: this function converts the integer data you've pointed it at and converts the data to little-endian format if necessary. (On platforms that natively use little-endian format, this function has no effect.)

- **RwMemNative32()**
  RwMemNative16()

  Used when reading from the stream: this function converts the little-endian data read in from the stream into the native endian-ness of the platform. (As with its counterpart, this function has no effect if the platform uses little-endian format.)

- **RwMemRealToFloat32()**

  Used when writing to the stream: this function converts an array of **RwReal**s to a standard 32-bit floating point format for streaming. The appropriate **RwMemLittleEndian32()** function should be called after this.

Reading & Writing to a Stream

Once the data has been converted, the **RwStream** API is used to write the individual data elements to the stream. When reading data, the process is reversed.

Endian-ness Conversion

Endian-ness conversion must be performed explicitly if using the **RwStreamRead()**/**RwStreamWrite()** functions. However, when using the streaming functions that know about their type—such as **RwStreamReadInt32()** or **RwStreamWriteReal()**—you do not need to perform explicit endian-ness conversion: these functions perform the conversion internally. It is usual for developers to avoid using **RwStreamRead()**/**RwStreamWrite()** wherever possible.

The following two tables list the read and write functions respectively.

Stream Reading Functions

These functions read data from a binary stream. Those functions with an explicit datatype as part of their name will perform any endian-ness conversions internally, if necessary.

READ FUNCTION	PURPOSE
RwStreamRead()	Reads the specified number of bytes from the specified stream into the given data buffer. This function requires explicit endian-ness conversion.
RwStreamReadChunkHeaderInfo()	Reads the Chunk Header information and stores it into the **RwChunkHeaderInfo** structure provided. (Intended mainly for diagnostics.)
RwStreamReadInt16()	Reads an array of 16-bit **RwInt16** values from the stream into the specified buffer.
RwStreamReadInt32()	Reads an array of 32-bit **RwInt32** values from the stream into the specified buffer.
RwStreamReadReal()	Used to read an array of **RwReal** data values from the stream into the specified buffer.
RwStreamSkip()	Used to skip the specified number of bytes in the given stream.

Stream Writing Functions

These functions write data to a binary stream. Those functions with an explicit datatype as part of their name will perform any endian-ness conversions internally, if necessary.

WRITE FUNCTION	PURPOSE
RwStreamWrite()	Writes the specified number of bytes to the specified stream from the given data buffer. This function requires explicit endian-ness conversion.
RwStreamWriteChunkHeader()	Used to write a chunk header to the specified stream. This function would typically be used by an application wishing to write application specific data to a file.
RwStreamWriteInt16()	Writes an array of 16-bit **RwInt16** values to the stream from the specified buffer.
RwStreamWriteInt32()	Writes an array of 32-bit **RwInt32** values to the stream from the specified buffer.
RwStreamWriteReal()	Used to write an array of **RwReal** values to the stream from the specified buffer.

8.3.3 Explicit Streaming Functions

In many cases, RenderWare Graphics' supplied plugins implement and expose streaming functions to serialize their objects explicitly. The **RpClumpStreamRead()** function is an example of such a function.

When developing custom plugins and objects, it is worth considering exposing similar, high-level functions. This makes it easier for developers using the plugin to stream the plugin's data without having to explicitly parse its individual components—a task which becomes a chore if the plugin is a complex one.

Another, very important, advantage of implementing high-level functions in this way is so that the function can perform any required pre- or post-processing transparently. This avoids the need for developers to remember to perform such processes explicitly.

In most cases, you will have already implemented the necessary low-level functionality needed to implement high-level functions, so adding them to your plugin's API is usually trivial.

Using Explicit Streaming Functions

In the previous section, *8.3.2 Serializing Objects*, we looked at serialization from within a plugin. This is important to know, but what if your application needs to read or write an object to a stream directly?

Although it is not entirely necessary for it to do so, it is good practice for your plugin to implement high-level stream-read and stream-write functions. The application to which the plugin is attached should be responsible for managing the streams.

This is best illustrated with an example.

Reading a Clump Object

The clump (**RpClump**) object, part of the World plugin (**RpWorld**), is a complex object, containing additional objects such as frames (**RwFrame**) and atomics (**RpAtomic**).

All this complexity is handled by callback functions set up by the plugin itself when it is attached to your application. This makes reading a clump object very simple.

First, we need to declare our stream and clump objects:

```
RwStream *stream;
RpClump *newClump;
```

Next, we open our binary stream:

```
stream = RwStreamOpen(rwSTREAMFILENAME, rwSTREAMREAD,
                      "myclump.rws");
```

(Remember, the **.rws** filename extension is purely a reminder that this is a RenderWare Graphics binary stream.)

Now we can check that the stream was opened and locate our clump object within the stream:

```
if( stream )
{
    if( RwStreamFindChunk(stream, rwID_CLUMP, NULL, NULL) )
```

The **RwStreamFindChunk()** function call above locates the first occurrence of a chunk with a chunk ID of **rwID_CLUMP**. An **.rws** file may contain more than one clump, so it may be necessary to identify each clump unless the developer is aware of the exact contents of the file. One method by which the identification may take place is by using a table of contents (TOC). See *8.3.4 RWS files* for information about TOCs in **.rws** files.

With the correct chunk located, the application can now read the clump data.

```
        {
            newClump = RpClumpStreamRead(stream);
        }
```

Finally, we should close the stream as we no longer need to read anything else from it.

```
        RwStreamClose(stream, NULL);
    }
```

Writing a Clump Object

This process is rare within a game, but applications written as part of a tool-chain, such as an exporter for a modeling package, will need to perform this operation frequently.

Writing an object is very similar to reading one. Again, we'll use a clump object for our example, which will assume that **myClump** contains a valid clump object for writing.

First, we need to declare our stream object:

```
RwStream *stream;
```

Next, we need to open a stream for writing. This uses the same function as for reading, but with a different flag. (These flags are covered in section 8.3.5, *Stream Types*.)

```
stream = RwStreamOpen(rwSTREAMFILENAME, rwSTREAMWRITE,
"myclump.rws");
```

At this point we should check that the stream was opened:

```
if( stream )
    {
```

Now the data can be written to the stream:

```
        RpClumpStreamWrite( myClump, stream );
    }
```

Finally, the stream should be closed:

```
RwStreamClose(stream, NULL);
```

Designing an Explicit Streaming API

It is not a requirement that a plugin exposes a high-level streaming API as there are a number of different ways in which a plugin can be implemented.

Two examples of plugins that may not need such an API are:

- *Plugins that extend existing objects* – if a plugin extends an existing object, there is usually no need for a high-level API. This is because streaming the original object will automatically cause RenderWare Graphics' streaming API to call the appropriate callbacks for the extended data.

- *Plugins that implement objects that do not need to be streamed* – for instance, a plugin designed for run-time diagnostics may not need to serialize its objects at all.

  If there is nothing to be gained by allowing your plugin to stream its objects, don't implement a streaming API for it. However, if you decide your plugin does need to support explicit serialization of its objects, you will need to use the **`RwStreamRead()`** and **`RwStreamWrite()`** functions—as outlined in *8.3.2 Serializing Objects*.

Chunk Headers

Any object that supports streaming must explicitly write a header chunk by calling **`RwStreamWriteChunkHeader()`** with both the chunk ID (discussed in *8.3.1 Binary Stream Structure*) and the size of the object's data.

It is important to note that reading the object data from a stream does not require the reading of the chunk header as the call to **`RwStreamFindChunk()`**—made by the calling application—performs this process.

8.3.4 RWS files

RWS files, identified by the **.rws** extension, extend the concept of RenderWare Graphics' binary streams to group related streams together into a single stream. An **.rws** file is designed to contain any number of clumps, worlds, texture dictionaries, etc. For example, it would be common to find a world and it's textures together in an **.rws** file.

There are no specific streaming functions for **.rws** files. The developer should just use the standard RenderWare Graphics read/write streaming functions described in this chapter on a single stream.

The default export option in the RenderWare Graphics exporters for 3dsmax and Maya are to save **.rws** files. The Visualizer viewer also is capable of reading **.rws** files.

Given broad uses of grouping related streams together, a single **.rws** file may contain many objects. Hence, **.rws** files usually contain another type of object at their head called an **RtTOC**, or Table of Contents (TOC), to keep track of what the **.rws** file contains.

Table of Contents Creation

Given an existing stream containing many chunks, a TOC may be created using **RtTOCCreate()** that parses this stream constructing an entry per chunk. This TOC may then be prefixed to the original stream using **RtTOCStreamWrite()**.

The entries in the TOC contain the ID of the chunk and a byte offset from the beginning of the stream to the entry's *chunk header*. This convention is used so that if a TOC entry's offset is used to skip through a stream, the usual RenderWare Graphics stream reading conventions can then be used to read the required chunk, as if the stream had been read sequentially.

The TOC entries also contain a GUID that uniquely identifies the chunk. A GUID is automatically created by the RenderWare Graphics exporters for each new asset created in a supported modeling package. One such use of the GUID is to identify a unique chunk in an RWS file that contains many chunks of the same ID.

Using a Table of Contents

There are several uses and usage approaches for the TOC in an **.rws** file.

The first is to quickly scan what an **.rws** file contains.

1. Open the **.rws** file for reading using **RwStreamOpen()** and the **rwSTREAMREAD** flag.
2. Find the TOC using **RwStreamFindChunk()** with the **rwID_TOC** ID.
3. Read the **RtTOC** using **RtTOCStreamRead()**.
4. Close the stream using **RwStreamClose()**.

RtTOCGetNumEntries() can be used to query how many entries there are in the TOC. **RtTOCGetEntry()** can be used to obtain an entry in the TOC, identified by it's zero-based index. The use of this entry is then application specific. For example, an ordered list of the chunk types can be obtained by simply looping through all TOC entries enumerating their ID.

The second use for a TOC is to read entries from the stream. The application should be aware of whether the entries are to be read sequentially or non-sequentially.

For a sequential read, the TOC need only be used to predetermine the chunk ID of the next entry. A single RWS load function would only be needed to cater for all chunk types, rather than individual load functions per chunk type.

For a non-sequential read, the TOC can be used to skip regions of the stream to gain access to a specific chunk without having to perform a search using **RwStreamFindChunk()**. The usefulness of this becomes apparent when an **.rws** file contains multiple instances of the same chunk ID, e.g. two (**rwID_WORLD**) worlds, as you can preprocess the TOC entry without having to perform expensive stream operations.

The byte offset of the TOC entry's chunk header is relative to the *beginning* of the stream. Hence, before that offset can be used in **RwStreamSkip()**, the stream position must be reset to the beginning. To do this, the stream must be closed and then re-opened.

After a skip has been performed, the chunk should be read in the same manner as if it had been read sequentially from the stream. This is because the offset is to the chunk's header, as mentioned earlier.

Whatever the TOC may be used for, it should be destroyed with **RtTOCDestroy** once finished with.

8.3.5 Stream Types

RenderWare binary streams are not limited to file-based streams.

The **RwStreamOpen()** function therefore has two flag parameters. The first defines the type of stream to use and the possible flags are listed in the table below:

FLAG	PURPOSE
rwSTREAMFILE	The stream is to a disk file that has been set up by the user. The access mode should match that used when the file was opened. The type-specific argument should be set to the file's pointer (usually of type **FILE ***).
rwSTREAMFILENAME	The stream is to a disk file that has *not* been set up by the user. The type-specific argument should be set to the desired filename.
rwSTREAMMEMORY	The stream is to a chunk of memory. If access type is **rwSTREAMAPPEND** then the chunk of memory must have been created using **RwMalloc** as RenderWare may subsequently try to use **RwRealloc** to gain more memory. The type specific argument should be a pointer to the memory chunk (**RwMemory ***) giving the position and size of the chunk to use.

The second flag parameter determines how the stream is opened:

FLAG	PURPOSE
rwSTREAMREAD	Opens a stream for reading only.
rwSTREAMWRITE	Opens a stream for writing only. If the stream is of type **rwSTREAMFILE** or **rwSTREAMFILENAME** the file size will be reduced to zero when the stream is opened.
rwSTREAMAPPEND	Opens a stream to which data will be appended.

8.4 Summary

RenderWare Graphics supports both a low-level file I/O API and a high-level streaming API.

8.4.1 File I/O API

Low-level access to files on disk is accessed through the **RwFileFunctions** structure. This structure, which can be overwritten with custom functions, exposes an ANSI-compliant set of file I/O functions:

8.4.2 RenderWare Binary Streams

Binary streams can contain simple objects, or complex ones. Complex objects can contain other objects—including other complex objects—so a stream's structure can be viewed as a tree.

The Stream Viewer application, **strview.exe**, can be used to examine binary streams. It can be found in the **[SDK-ROOT]/tool/strview/** folder.

Stream Types

RenderWare binary streams are usually file-based, but memory-based streams are also supported.

Chunk IDs

All objects are stored in *chunks*, which are the building-blocks of RenderWare binary stream. A chunk for a particular object is identified by its *chunk ID*.

Chunk IDs are generated using the **MAKECHUNKID()** macro, which takes your vendor ID (used to log-in to the developer support website) and an object ID—between 0 and 255—which identifies the object itself. This is the same mechanism used for plugin IDs, so care should be taken not to confuse the two.

Serializing Objects

Object serialization is the responsibility of the plugin within which the object resides.

Serializable objects *must* implement the three callback functions necessary for **RwRegisterPluginStream()**. These functions are:

- a chunk read function;
- a chunk write function;

- a function that returns the size of the chunk.

The developer can choose to implement an object as either:

- a container object, (e.g. **RpClump** and **RpWorld**)
- an extension to another object, (e.g. **RpMatFX**)
- a stand-alone object (e.g. **RpLight**).

Container objects should expose a high-level serialization API, as should stand-alone objects. Objects that extend an existing object rarely need to expose a high-level serialization API, unless the object can also be used as a stand-alone object.

In all cases, callback functions for serialization are necessary if the object is to support serialization at all.

Registering the Stream Functions

Plugin objects that support both the RenderWare Graphics binary stream API and extension via the plugin mechanism must call *two* plugin registration functions.

The first function will be either one of two choices:

- **RwRegisterPlugin()**, which registers the plugin with the core directly and is used *only* if the plugin does not extend other objects itself, or
- **...RegisterPlugin()**, which belongs to the API of the object which the plugin is to extend.

The second function, **...RegisterPluginStream()**, belongs to the API of the plugin that contains the object to be extended. It registers the serialization callback functions with that base object, so that it knows how to load the extended data.

Endian-ness

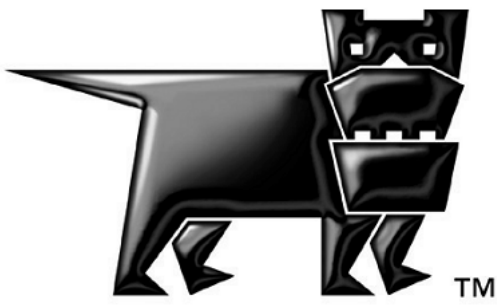
Data in a stream uses a little-endian storage format, so conversion functions—supplied by the **RwMem** API—must be used to ensure all the streamed data is in the right format.

RWS files

The concept of the RenderWare Graphics binary stream can be extended to RWS files that may contain all art assets packaged together. To keep track of the contents of an RWS file, a Table of Contents is attached to the beginning of the file.

Chapter 9

Debugging and Error Handling



9.1 RenderWare Graphics Errors

RenderWare Graphics functions return error codes using the **RwError** API. This is a simple, minimal impact, general-purpose error reporting mechanism that has minimal impact on application performance even if heavily used.

The API has two functions, **RwErrorSet()** and **RwErrorGet()**, which are used to set or retrieve error codes respectively.

By convention, most RenderWare Graphics functions will return:

- a pointer to an object if successful;
- NULL to represent failure.

Should an API function fail, developers can check what the error code of the last function was using **RwErrorGet()**.

Error codes take the form of an integer matching an enumerated value, such as **E_RW_INVRASTERSIZE**, ("Invalid Raster Size").

Error code enumerations can be found in the appropriate **[SDK-ROOT]/rwsdk/include/** folder corresponding to the build target. The files have one of two extensions:

- **.def** – for common error codes and those used by the core library;
- **.rpe** – for error codes used by specific plugins and toolkits.

9.2RenderWare Graphics Builds

RenderWare Graphics libraries are supplied in three different builds: *Release*, *Metrics* and *Debug*.

Release Build, as its name implies, is for release builds of your applications. It has no debugging information or unnecessary hooks; it's a lean, mean rendering machine.

Metrics Build is a modified version of the Release Build, exposing hooks in the rendering engine that can be queried with **`RwEngineGetMetrics()`**. The metrics structure accumulates values since the last call to either **`RwCameraShowRaster()`** or **`RwRasterShowRaster()`**, and is most useful when examined immediately before calls to these functions.

The format of the data structure returned by this function will vary by platform – on Sony's PlayStation 2, for instance, it will cover aspects such as DMA and Vector Unit utilization.

Finally, we come to the **Debug Build**. This set of libraries has been built with debug message logging enabled, so that a log file (with a file extension of **`.log`**) is created while running. This log file lists assert messages, errors, bad arguments and similar reports generated by the RenderWare Graphics API.

The log file is generated through the **`RwDebug`** object, which we'll look at shortly.

9.3The Debug Object

When using a Debug Build of RenderWare Graphics, the **RwDebug** object becomes active. In the other library builds, the object does nothing.

This object maintains a simple debugging information reporting system, with output being handled by a Debug Stream Handler function. The default function simply diverts the messages to a file called "**rwdebug.log**", or, in the case of some console platforms, it sends the data across a network or other target/host link.

This handler can be replaced by your own function with the **RwDebugSetHandler()** function. This function controls output for all RenderWare Graphics messages, including those emitted by **assert** and trace (covered in 9.4) messages. These messages are all disabled in release and metrics builds.

An important, but often missed, point to understand is that a Debug Build of RenderWare Graphics is designed to behave *exactly* as if it were a Release Build. The only difference is the activation of the **RwDebug** API and the logging of any asserts and errors raised while running.

This is an intentional design feature. Our view is that if an application is going to crash in Release Build, it should also crash in Debug Build. This may sound extreme, but it has the advantage of dramatically reducing unpleasant surprises when you're ready to build a release. In particular, it avoids the problem of bugs that cannot be repeated in a debug build.

It is also important to note that overuse of the **RwDebug** functionality is very likely to affect performance, particularly if the output is being streamed to a file. For example, we do not advise placing long, descriptive messages in the stream for functions likely to be frequently called within the inner loop of a rendering cycle.

9.3.1 The Default Debug Stream Handler

As we saw earlier, the default Debug Stream Handler outputs to a log file named "**rwdebug.log**". This file is either stored in the current working directory, or, on platforms where this isn't possible, is transmitted to the host (development) computer.

If you have replaced the default debug stream handler with your own functionality, then passing NULL to **RwDebugSetHandler()** will re-instate it.

9.3.2 Sending a Message to the Debug Stream

The Debug Stream is not limited to RenderWare Graphics' own functions: you can send your own messages to the stream using **RwDebugSendMessage()**. These messages will be chronologically ordered with any other messages, including those resulting from **assert**s and the trace message mechanism.

The function takes the following parameters:

Type – Signifies whether this message is an Assert, an Error message, an informational Message, or a simple Trace ("where am I?") message. These are defined as **rwDEBUGASSERT**, **rwDEBUGERROR**, **rwDEBUGMESSAGE** and **rwDEBUGTRACE** respectively.

Filename – The filename from where the message was sent. Usually, this is the source file containing the function sending the message and can be obtained using the ANSI C compiler directive **__FILE__**.

Line – The line number where this particular call to **RwDebugSendMessage()** is taking place. Again, this is usually obtained using the ANSI C compiler directive **__LINE__**.

Function Name – The name of the function from whence the message was sent.

Message – The message itself.

These are the arguments passed to **RwDebugSendMessage()**. Most of this information is combined before passing to the Debug Stream Handler itself. The stream handler only receives two parameters: the Type and a Message. The Message is a single string, usually containing the information outlined above.

9.4Tracing RenderWare Graphics Activity

RenderWare Graphics' functions can be made to output simple Trace messages using the **RwDebugSendMessage()** mechanism.

Trace messages are simple, informational "I Am Here" messages which can be used during debugging to track the flow of execution of your application. They are specified by passing **rwDEBUGTRACE** as the *Type* parameter to **RwDebugSendMessage()**.

To enable these Trace messages, use:

```
RwDebugSetTraceState(TRUE);
```

Passing FALSE will disable them.

All of RenderWare Graphics public API will output Trace messages when the Trace State is TRUE. (This can impact performance, so the default Trace State is FALSE.) Messages are output both on entry to and on exit from each function.

The text below is an extract from an example Debug log with Trace enabled:

```
...
D:/rel/rwsdk/world/baclump.c(1740): TRACE: RpClumpForAllAtomics:
Enter
d:/rel/rwsdk/plugin/morph/rpmorph.c(1151): TRACE:
RpMorphAtomicAddTime: Enter
d:/rel/rwsdk/plugin/morph/rpmorph.c(1203): TRACE:
RpMorphAtomicAddTime: Exit
D:/rel/rwsdk/world/baclump.c(1763): TRACE: RpClumpForAllAtomics: Exit
D:/rel/rwsdk/src/bacamera.c(1580): TRACE: RwCameraClear: Enter
D:/rel/rwsdk/src/bacamera.c(1592): TRACE: RwCameraClear: Exit
D:/rel/rwsdk/src/bacamera.c(957): TRACE: RwCameraBeginUpdate: Enter
D:/rel/rwsdk/src/bacamera.c(961): TRACE: RwCameraBeginUpdate: Exit
D:/rel/rwsdk/world/baworobj.c(331): TRACE: WorldCameraBeginUpdate:
Enter
D:/rel/rwsdk/world/baworobj.c(342): TRACE: WorldCameraBeginUpdate:
Exit
D:/rel/rwsdk/src/bacamera.c(776): TRACE: CameraBeginUpdate: Enter
D:/rel/rwsdk/src/bacamera.c(810): TRACE: CameraBeginUpdate: Exit
D:/rel/rwsdk/world/baworld.c(1874): TRACE: RpWorldRender: Enter
D:/rel/rwsdk/world/baworld.c(1885): TRACE: RpWorldRender: Exit
D:/rel/rwsdk/src/bacamera.c(1118): TRACE: RwCameraGetRaster: Enter
D:/rel/rwsdk/src/bacamera.c(1123): TRACE: RwCameraGetRaster: Exit
D:/rel/rwsdk/src/baraster.c(347): TRACE: RwRasterGetWidth: Enter
D:/rel/rwsdk/src/baraster.c(351): TRACE: RwRasterGetWidth: Exit
D:/rel/rwsdk/src/bacamera.c(1118): TRACE: RwCameraGetRaster: Enter
D:/rel/rwsdk/src/bacamera.c(1123): TRACE: RwCameraGetRaster: Exit
D:/rel/rwsdk/src/baraster.c(371): TRACE: RwRasterGetHeight: Enter
D:/rel/rwsdk/src/baraster.c(375): TRACE: RwRasterGetHeight: Exit
```

```
d:/rel/rwsdk/tool/charse/rtcharse.c(943): TRACE: RtCharsetGetDesc:
Enter
d:/rel/rwsdk/tool/charse/rtcharse.c(953): TRACE: RtCharsetGetDesc:
Exit
...
```

9.5Replacing The Stream Handler

We saw earlier that the Debug Stream Handler can be replaced by your own code. This is achieved through a standard callback mechanism.

The callback function prototype is defined by a **typedef** named **RwDebugHandler**. Your callback function's prototype must match this.

Secondly, either your main program or your handler will need to open or create any files it intends to use. Disabling the default handler will close the "**rwdebug.log**" file it uses automatically, so your new handler cannot make the assumption that it is still open for writing.

To replace the default RenderWare Graphics handler with your own, you should call **RwDebugSetHandler()**, passing a pointer to your replacement callback function as the parameter.

9.5.1 Example

The following code replaces the existing handler with a dummy handler that outputs the supplied text only if it is an **rwDEBUGTRACE** type.

(This example assumes your program's global data is stored in a structure called **GlobalData** and that this structure has an entry named **debugFile** representing a FILE * type.)

```
static void
MyDebugHandler(RwDebugType type, const RwChar * debugText)
{
  /* First check if output file is available... */
  if ( !GlobalData.debugFile )
  {
     /*
      * output file not initialized, better create it...
      */

     GlobalData.debugFile) = RwFopen(RWSTRING("bug_out.txt"),
  RWSTRING("at"));

  }

  /* Output message if it's the right type... */

  if ( (GlobalData.debugFile) && (rwDEBUGTRACE == type) )
  {
     RwFwrite(debugText, (rwstrlen(debugText) * sizeof (RwChar)), 1,
         RWSRCGLOBAL(debugFile));
     RwFwrite(cr, (rwstrlen(cr) * sizeof (RwChar)), 1,
```

```
            RWSRCGLOBAL(debugFile));
        RwFflush(RWSRCGLOBAL(debugFile));

    }

    return;
}
```

This example handler is for illustration purposes only and has little error checking of its own. Naturally you will want to remedy this in production code.

Setting the above handler in your RenderWare Graphics application would be achieved by adding the following line to your code after the Engine has been initialized:

```
RwDebugSetHandler(MyDebugHandler);
```

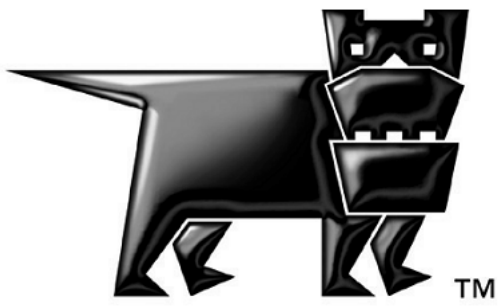
We can reset the default debug handler by passing NULL to the above function, therefore there is no need to store the returned function pointer unless you are using multiple handlers.

Part B

World Library

Chapter 10

World and Static Models



10.1 Introduction

This chapter explains scenes and static models, which are represented by **RpWorld** and **RpWorldSector**. These objects are part of the **World** plugin (**RpWorld**) which provides RenderWare Graphics' Retained Mode API.

This Plugin provides the following objects:

RpAtomic; **RpClump; RpGeometry**; **RpInterpolator**; **RpLight**; **RpMaterial; RpMorphTarget**; **RpWorld** and **RpWorldSector**. It also adds some extensions to the Core Library's **RwCamera** API.

These objects can be further extended through the plugin mechanism.

10.2 Scenes & Static Models

10.2.1 Scenes

A typical scene will consist of:

- Static models – the 'scenery'
- Dynamic models – objects that can be moved or animated
- Dynamic lights
- Cameras – one or more depending on the number of views required

This chapter is primarily concerned with static models. Separate chapters are devoted to dynamic models (Atomics), Lights and Cameras.

10.2.2 RpWorld Object

The **RpWorld** object is a container for scenes. It links the dynamic and static components and provides a cohesive world space in which they can exist.

A World is bounded by a single box, which is internally subdivided into static sectors (**RpWorldSector** objects). Each of these defines a cuboid volume within the scene, and encloses a section of the static scenery.

The sectors are created by dividing up the static scenery using a binary space partition (BSP) tree and this sectorization process is usually performed at the exporter stage using the functions supplied by the **RtWorldImport** Toolkit. This structure is used to speed up the rendering process.

Dynamic objects such as Atomics, Lights and Cameras can be added to a World and this allows links to be maintained between the objects and any World Sectors to which they are relevant. When dynamic objects are moved around, the World plugin will decide which World Sector(s) they should be linked to, based on their location. This makes the rendering process more efficient since:

- Only World Sectors that are visible from the Camera need be rendered.
- Dynamic objects that lie entirely within non-visible sectors can be eliminated.
- Only the dynamic lights affecting visible sectors need be considered in lighting calculations.

10.2.3 RpWorldSector Object

A World Sector is the static counterpart to the Geometry object, which is used for dynamic models.

A World Sector performs two tasks:

1. Contains all Vertices, Triangles, Materials and other data that define the scenery within the World Sector's space.

2. Maintains links with Atomics, Cameras and Lights that have been positioned within the World Sector.

The data for the static scenery is usually divided up across multiple World Sectors to increase the rendering engine's efficiency. This division is in the form of a binary space partitioning ('BSP') tree.

Binary Space Partitioning

The World is sectorized by recursively slicing the geometry along axis-aligned planes to produce a BSP tree. The resulting box regions are sectors. Geometry cannot always be cleanly divided and sectors often overlap slightly.

RenderWare Graphics uses a modified form of BSP, known as a *K Dimensional Tree* (KD-tree). The difference between the two forms is that KD-trees are always axis-aligned.

Normals & Bounding Boxes

Normals and bounding boxes are encountered when creating import and conversion tools for World and World Sector objects.

- Normals

  These are required for lighting calculations. During the world creation process, the normals are stored as **`RwV3d`** for full floating-point precision, but in the final World Sectors they are compressed to triples of type **`RwInt8`**.

- Bounding Box

  World Sectors have bounding boxes (**`RwBBox`**). Since models can rarely be cut into neat, straight lines, the bounding boxes of neighboring World Sectors often overlap.

10.3 Iterator Functions

A number of simple iterator functions are provided to access the contents of both **RpWorld** and **RpWorldSector** objects:

10.3.1 RpWorld Iterators

There are four **RpWorld** iterators:

1. **RpWorldForAllClumps()**

   This function takes a callback (type **RpClumpCallBack()**), which is called for each Clump within the specified **RpWorld** object. This function will only locate Clumps that have been added to the World using **RpWorldAddClump()**.

2. **RpWorldForAllLights()**

   This function takes a callback (type **RpLightCallBack()**), which is called for each Light within the specified **RpWorld** object. This function will only locate Lights that have been added to the World using **RpWorldAddLight()**.

3. **RpWorldForAllMaterials()**

   This function takes a callback (type **RpMaterialCallBack()**), which is called for each Material object within the specified **RpWorld** object. This function iterates *only* through Materials contained within World Sectors. Materials define how a model's surface should be rendered and are covered in more detail in the *Dynamic Models* chapter.

4. **RpWorldForAllWorldSectors()**

   This function takes a callback (type **RpWorldSectorCallBack()**), which is called for each World Sector within the specified **RpWorld** object.

This function is one of the most often-used iterators and it is often used together with **RpWorldSectorForAllAtomics()**.

10.3.2 RpWorldSector Iterators

There are three **RpWorldSector** iterators:

1. **RpWorldSectorForAllAtomics()**

   This function takes a callback (type **RpAtomicCallBack()**), which is called for each Atomic within the specified **RpWorldSector** object. This function will only locate Atomics that have been added to the World either explicitly, using **RpWorldAddAtomic()**, or implicitly using **RpWorldAddClump()**. It is often used in conjunction with **RpWorldForAllWorldSectors()** to access all Atomics with in a World.

2. **RpWorldSectorForAllLights()**

   This function takes a callback (type **RpLightCallBack()**), which is called for each Light within the specified **RpWorldSector** object. This function will only locate Lights that have been added to the World using **RpWorldAddLight()**.

3. **RpWorldSectorForAllMeshes()**

   This function takes a callback (type **RpMeshCallBack()**), which is called for each Mesh within the specified **RpWorldSector** object. This function will only locate Meshes that are part of the static model data.

10.3.3 Collision Detection

Originally, the **RpWorld** API contained some basic collision detection functionality. This has now been moved into a separate RenderWare Graphics Plugin: **RpCollision**.

10.4 Modeling Tools

The RenderWare Graphics modeling package exporters supplied with the SDK can be used to export static models. Artists should read the associated documentation installed with these exporters for details on how they work.

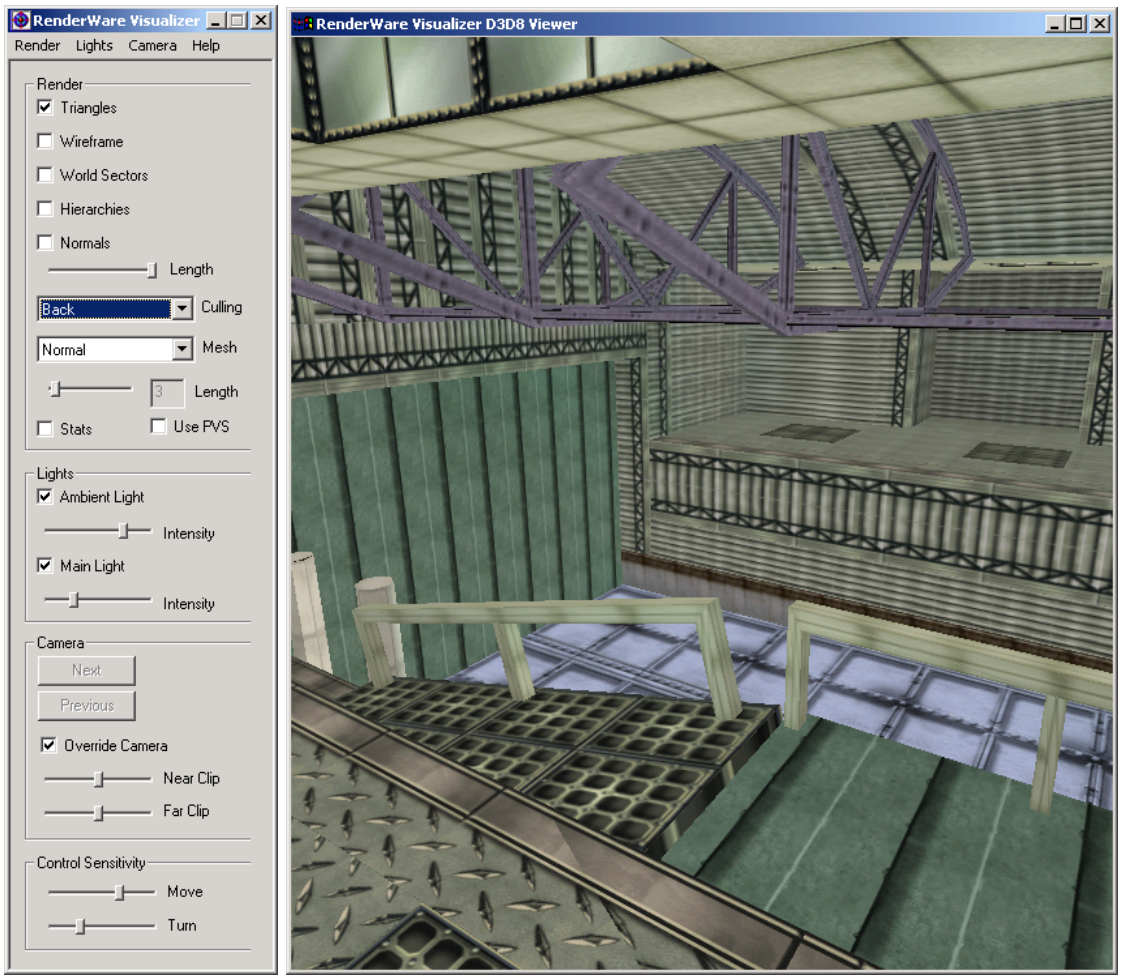
Developers are also advised to read these documents, as exporters for particular modelers may not necessarily support all features.

Exported files can be read by applications.

10.4.1 Viewers

The static models exported by artists can be tested using the RenderWare Visualizer viewer supplied with the RenderWare Graphics SDK. Using the RenderWare Visualizer is covered in the *RenderWare Visualizer Viewers* document.

The screenshot below shows this viewer displaying a static model of a building's interior.



This viewer can display most serialized RenderWare Graphics objects including those supported directly by the World Plugin.

10.5 Creating Worlds

10.5.1 Creating Worlds from Foreign Data

This process is essentially the same as that performed by the RenderWare Graphics modeling package exporters, the main difference is that such modeling packages usually supply their own API to assist in the process. The exporters take the model data, in the format the modeling package exposes it, and converts it into RenderWare Graphics Worlds, Clumps, Atomics, Morph Targets, Skinning data, etc.

The source code for these exporters is provided to give some insight into how to write your own converter tools.

Creating Worlds

The SDK contains the **World Import** Toolkit (**RtWorldImport**). This Toolkit provides API functions for creating an **RtWorldImport** object.

A **RtWorldImport** object is a fully exposed, un-optimized, uncompressed format of a world. It is suitable for easy creation of a new World and its static model data. The model data is exposed in the form of RenderWare Graphics Vertices, Triangles, Materials, Normals etc.

The **RtWorldImport** object can then be converted by the World Import Toolkit into an optimized, compressed **RpWorld** structure, and written to disk. The toolkit provides controls for how this process is performed. In addition, an optional callback is available to provide progress information as the compression and optimization processing may take some time.

This process is illustrated by the **world** SDK-Example supplied with the SDK. This creates a "buckyball" static model given the raw data and uses the model to create a valid **RpWorld** object.

First, locate the **world** project files and open the **world.c** source file in your preferred editor. The first part of the file contains model data, stored in a bunch of ordinary arrays.

The first function in the source code is **CreateWorldImport()**.

The steps involved are explained below:

1. Create an **RtWorldImport** object by calling **RtWorldImportCreate()**.

   This is the very first thing the **CreateWorldImport()** function does. Once it's defined all the variables it needs, we see the following code:

```
worldImport = RtWorldImportCreate();
if( worldImport == NULL )
   {
       return NULL;
```

```
}
```

2. Interrogate the modeling tool to find the number of triangles and vertices in the model to be exported then call **RtWorldImportAddNumTriangles()** and **RtWorldImportAddNumVertices()** to create memory for your data.

   The **world** Example is working with its own arbitrary, hand-typed data rather than from a modeling package's internal data structures, but the procedure remains the same...

```
/*
 * Allocate the memory to store the world's vertices and
   triangles...
 */
RtWorldImportAddNumVertices(worldImport, NOV);
   RtWorldImportAddNumTriangles(worldImport, NOT);
```

   NOV - defines the number of vertices; **NOT** – defines the number of triangles

3. Call **RtWorldImportGetVertices()** and **RtWorldImportGetTriangles()** to obtain pointers to the vertex and triangle arrays.

4. The **world** example has to first generate some Textures and some Materials to put them in, so the vertices and triangles get added later:

```
vertices = RtWorldImportGetVertices(worldImport);
triangles = RtWorldImportGetTriangles(worldImport);
```

   These lines appear immediately after the two loops that generate the texture U/V coordinates for each vertex. If you are working with a modeling package's own data, you may be able to take these coordinates straight out of an existing data structure.

5. Iterate over the vertex array, copying the required data from your modeler data into the **RtWorldImport** object's vertices.

   In the Example, this copying takes place in the middle of two long **for…** loops, which also define surface normals. The code looks like this fragment, taken from the first (pentagons) loop:

```
/*
 * Initialize the vertices with a world-space vertex
   position,
 * a normal, texture coordinates and a material...
 */
vertices->OC = VertexList[PentagonList[i]];
vertices->normal = normal;
vertices->texCoords = uvPentagon[0];
vertices->matIndex = pentagonMatIndex;
vertices++;
…etc.
```

6. Similarly, iterate through the triangles and store these in the triangle array.

   The same **for…** loops also have code like this for the triangles:

```
/*
 * Initialize the triangles with indices into the vertex list
 * and a material...
 */
   triangles->vertIndex[0] = j;
   triangles->vertIndex[1] = j + 2;
   triangles->vertIndex[2] = j + 1;
   triangles->matIndex = pentagonMatIndex;
   triangles++;
   …etc.
```

   This is only a small fragment of the triangle copying code; refer to the source code to see the full code.

7. Use the **RtWorldImportAddMaterial()** and **RtWorldImportForAllMaterials()** functions to manage adding Materials to the **RtWorldImport** object. The return value from **RtWorldImportAddMaterial()** is the Material index. Materials are linked to triangles, so Material indices need to be copied to the appropriate elements in the **RtWorldImport** triangles array.

   The **world** Example actually performs this before the vertex copying steps. The programmer creates a standard **RpMaterial** object and populates it with the Texture loaded earlier…

```
hexagonMaterial = RpMaterialCreate();
RpMaterialSetTexture(hexagonMaterial, hexagonTexture);
```

   Now the Material is added to the World Import data structure…

```
hexagonMatIndex = RtWorldImportAddMaterial(worldImport,
hexagonMaterial);
```

   And the process is repeated for the pentagons. (Buckyballs are built out of hexagons and pentagons)…

```
pentagonMaterial = RpMaterialCreate();
RpMaterialSetTexture(pentagonMaterial, pentagonTexture);
pentagonMatIndex = RtWorldImportAddMaterial(worldImport,
pentagonMaterial);
```

   The following two steps are optional and the **world** Example only performs Step 8 as the model takes very little time to convert.

8. You can now optionally establish a callback procedure to handle the messages sent by the converter to advise on progress. To do this, you can use the **RtWorldImportSetProgressCallback()** function to specify the function that your exporter provides. The API Reference lists the messages that are sent.

9. Modify the parameters used to control the export process, using **RtWorldImportParametersInit()**.

   This is done in the **CreateWorld()** function which is also in the same source file. The relevant code is reproduced below:

```
static RtWorldImportParameters params;
RtWorldImportParametersInit(&params);

    params.flags = rpWORLDTEXTURED | rpWORLDNORMALS |
    rpWORLDLIGHT;
    params.conditionGeometry = FALSE;
    params.calcNormals = FALSE;
```

10. Call **RtWorldImportCreateWorld()** to perform the conversion of the **RtWorldImport** object into an optimized, compressed **RpWorld** object.

    A single line of code performs this task in the Example:

```
world = RtWorldImportCreateWorld(worldImport, &params);
```

    This will build your world with the default scheme, one that tries to balance the world and reduce splits to geometry and materials.

    The default scheme works by examining a number of candidate partitions for each axis, the default is 20. To change this value, to 50 in the example below, the following code should be called before **RtWorldImportCreateWorld()**:

```
RwInt32 maxClosestCheck = 50; /* required value */
RtWorldImportSetStandardBuildPartitionSelector(
             rwBUILDPARTITIONSELECTOR_DEFAULT,
             (void*)&maxClosestCheck);
```

    RtWorldImport provides the mechanisms necessary to create a world that is partitioned in a way that is specific to your own requirements and there are a diverse set of functions that let you partition the world as controllably as you want. Details of these are in the white paper "BSP trees".

The **params** structure is defined as follows:

PARAMETER	PURPOSE
WorldSectorMaxSize (**RwReal**)	Defines the maximum size of World Sector. This is generally a trade-off between storage space and speed.
MaxWorldSectorPolygons (**RwInt32**)	Maximum number of polygons in a World Sector.
TerminatorCheck (**RwBool**)	Set to **TRUE** to check the world for validity during the build process
CalcNormals (**RwBool**)	Set to **TRUE** to recalculate all normals.
MaxOverlapPercent (**RwReal**)	Maximum amount by which World Sectors are allowed to overlap.
ConditionGeometry (**RwBool**)	Set to **TRUE** to perform welding and other optimizations. (See the geometry conditioning white paper.)
UserSpecifiedBBox (**RwBool**)	Set to **TRUE** if you want to specify a minimum Bounding Box for the World.
UserBBox (**RwBool**)	Minimum Bounding Box (See above).
FixTJunctions (**RwBool**)	Set to **TRUE** to enable fixing of T-junctions created during World generation.
Flags (**RwInt32**)	Flags to be used for the World. These are: **rpWORLDLIGHT** **rpWORLDNORMALS** **rpWORLDTRISTRIP** **rpWORLDTEXTURED** **rpWORLDMODULATEMATERIALCOLOR** **rpWORLDPRELIT**

Finally, the **RpWorld** object can be serialized.

Converting custom formats

You can use a custom file format for your models, or have legacy objects for which the original modeling tool files have become lost or incompatible with newer tools. In such cases, it is more convenient to write a format converter and the **world** Example explained earlier in this chapter.

RenderWare Graphics separates static and dynamic geometry into Worlds and Atomics/Clumps. It would therefore make little sense to convert a legacy car model into an **RpWorld** object, or a complex building into an **RpAtomic**. RenderWare Graphics can perform intelligent scene management with an **RpWorld**, and can efficiently animate dynamic **RpAtomics**.

Creating an Empty World

It is sometimes useful to create a "blank" World object that contains no scenery data. Such usage is common in viewer utilities and many of the viewers supplied with the RenderWare Graphics SDK do use empty Worlds.

These Worlds contain only an empty World Sector that fills the entire world space and can be easily created using the **RpWorldCreate()** function. This takes a bounding box (**RwBBox**) parameter, which defines the extents of the single World Sector. You will find this function used frequently in the many SDK Examples supplied on the CD.

Creation Flags

A World's model data can be handled in a number of different ways. For instance, you might want to avoid lighting it dynamically using Lights and just use pre-lit vertices. Or, you may want to tell the rendering pipeline that the data is organized as triangle strips so it can run faster on the target platform.

It is not normal to change these flags once the World has been created or loaded. Doing so may have a detrimental effect on performance.

These and other settings are made using the **RpWorldSetFlags()** function. This exposes the following flags:

- **rpWORLDTEXTURED**

  The World has textures applied. Texture coordinates are specified on a per vertex basis.

  If reading the World data from a stream, you will need to either set up the search path for the Textures using **RwImageSetPath()**, or load a Texture Dictionary containing said Textures first.

- **rpWORLDPRELIT**

  The World has prelit colors.

  The modeling package exporters provide full support for prelights. See the Artists Guides supplied with the exporters for details.

- **rpWORLDNORMALS**

  The World has vertex normals.

  Normals are a requirement if you intend to have dynamic Light objects that affect the scenery. The **rpWORLDLIGHT** flag should also be set in such cases.

- **rpWORLDLIGHT**

  Dynamic Light objects will light the World.

Setting this flag tells RenderWare Graphics to allow dynamic Lights to affect the static geometry. As this form of lighting requires additional processing, you should take care when using this.

Dynamic Lights also need normals for the lighting calculations, so you should also set the **rpWORLDNORMALS** flag as well.

Using dynamic Lights does not preclude the use of prelights, but you may need to set the **rpWORLDMODULATEMATERIALCOLOR** flag if you intend to mix the two forms to best effect.

- **rpWORLDTRISTRIP**

  World's static geometry can be rendered as triangle strips.

  This is a hint to the rendering pipeline that the model data is optimized as triangle strips. Triangle strips are an option available on the RenderWare Graphics modeling package exporters.

- **rpWORLDMODULATEMATERIALCOLOR**

  This flag tells the rendering pipeline to take (a) lighting, (b) prelights and (c) Material colors into account when rendering the model data. This usually gives the most accurate rendering results, but can be expensive in terms of processing power.

10.5.2 What is Pre-lighting?

The distinction between static and dynamic models is not the only such division. RenderWare Graphics also supports both dynamic and static lights.

Static lighting doesn't actually involve a separate object, as the data is stored directly in the vertex data as arrays of **RwRGBA** color values. During the rendering cycle, the pipeline will simply combine this vertex prelight data with the Material for that vertex and extrapolate across the surface of the triangles.

Prelights are defined by the artist in their modeling package. The artist can position supported lighting types at the appropriate locations in their model. Artists must then tag all static lights using a "prelight" tag (the exact method for doing this varies from modeling package to modeling package).

At the export stage, the artist selects the appropriate option in the RenderWare Graphics exporter's options dialog box and the exporter then sets up the vertex lighting arrays and writes them out with the rest of the model data.

The nature of the pre-lighting processing means only some of the modeling package's full complement of lights can be used for this purpose. See the artist documentation for modeler-specific details.

Creating Prelights using the World Import Toolkit

The World Import Toolkit exposes the **RtWorldImportVertex** object. This is defined as follows:

```
typedef struct RtWorldImportVertexTAG
{
    RwV3d OC;              /* World space vertex position */
    RwV3d normal;          /* World space vertex normal */
    RwRGBA preLitCol;      /* Vertex Pre-light color */
    RwTexCoords texCoords; /* Vertex texture coordinates */
    RwInt32 clipFlags;     /* Internal use only */
    RwInt32 matIndex;      /* Vertex material index */
} RtWorldImportVertex;
```

As you can see, setting the prelight color is simply a case of modifying the **preLitCol** element.

Static Lights

Static model prelights work a little differently compared to its dynamic model variant. RenderWare Graphics assumes static models are *completely* static – including any prelight data – so prelight colors cannot be manipulated directly.

If you need lights that flicker, or any similar such effects, you will need to use either dynamic lights or Atomics placed over the static model.

10.6 Rendering

10.6.1 How to Render Worlds

Rendering a World object will render its contents. This means that, usually, rendering a complete scene can be achieved with a single call to **RpWorldRender()**.

The Rendering Process

When you call **RpWorldRender()**, the BSP tree is searched and the visible World Sectors are rendered in turn.

The following points should be taken into consideration:

- When each World Sector is rendered, each Atomic and Light in that sector is rendered before the next visible World Sector is processed.
- Rendering is performed either back-to-front, or front-to-back depending on which is faster on that particular platform.
- Local dynamic Light objects may only affect some World Sectors. Use the bounding-box-to-sphere intersection collision detection functions to identify these.

Rendering World Sectors

World Sectors are rendered automatically by calls to **RpWorldRender()**. It is not possible to explicitly render a specific World Sector object.

Render Callback

It is possible to hook into the World Sector rendering process by providing a callback function to **RpWorldSetSectorRenderCallBack()**. This callback function, of type **RpWorldSectorCallBackRender()**, will then be triggered prior to rendering each sector.

This allows you to include your own optimization techniques. The **RpPVS** visibility culling Plugin uses this hook.

10.6.2 Instancing

A static geometry in RenderWare Graphics has two representations: a platform-independent (PI) representation (also known as platform neutral) and a platform-specific (PS) representation (also known as native data) optimized for the underlying hardware. The process of converting from platform neutral data to native data is called instancing. This process normally happens only during the first rendering of the world.

Native data is not actually stored within the geometry itself. Instead, it is allocated space in the *Resource Arena*. This is a cache that *only* stores native data. The caching metaphor is particularly apt since existing native data can be thrown out if there isn't enough space left to create new instances of other geometries that need to be rendered. This can result in a problem known as *arena thrashing*, whereby performance is crippled by the need to re-instance the geometry every frame.

The Resource Arena's size is set during the start-up phase by calling the **RwEngineInit()** function. Exactly what size you should set is heavily dependent on your application, so you will need to experiment to get a good balance between speed and efficiency. The ideal is as small as possible without arena thrashing ever occurring during application execution.

10.6.3 Pre-instancing Static Geometry

One optimization of the above instancing scheme can be performed if it is known that the platform independent (PI) representation will not be used at run-time, and that is to use solely pre-instanced platform specific (PS) representation, rather than creating it at run-time. This has the advantages that no CPU cycles are used to instance data on their first rendering, which gives a minor performance improvement, but also means that space is not required for storage of the platform neutral data. In the case of static geometry this is strongly recommended.

The **RpWorldInstance()** function is used to generate a persistent copy of the native data, so at that time both representations of the world exist. The PI representation exists as before and the PS representation both exist outside the resource arena. When rendering occurs the platform specific representation is always used and the resource arena is now not used by the world during rendering.

The platform specific data generated should be considered opaque and highly volatile as the format is subject to change between versions.

Worlds with pre-instanced geometry are serialized slightly differently from those without. If the world is serialized, the function for writing the geometry to the stream **RpWorldStreamWrite()** does not export platform neutral data when persistent native data is present, and consequently when the world is loaded into memory with **RpGeometryStreamRead()** the PI data is lost. This is where the memory saving occurs.

As the instancing process has already been performed and is not performed at run-time, the resource arena is never used, and the resource arena size may be reduced accordingly. The resource arena may be eliminated altogether if no instancing occurs, which would require any dynamic geometry to be pre-instanced too, *see the Dynamic Models chapter of this guide*.

This does mean that features which use the PI data will no longer work and functions to get PI data will return failure codes. For instance static PVS creation should be undertaken before pre-instancing. Collision detection is not possible, though a lower resolution collision geometry, which is never rendered could be used to test for collisions.

The only exceptions to this is that the number of vertices in the geometry is and the number of triangles in the geometry are preserved and can be read using **RpGeometryGetNumVertices()** and **RpGeometryGetNumTriangles()** respectively. These are stored mainly so that sensible metrics can be observed with PS data, and the actual PI triangle data itself is not present.

Using RpWorldInstance()

Firstly the availability of pre-instancing of worlds varies from platform to platform, and so please check the platform specific documentation for your platform to determine if this feature is supported for your platform.

To pre-instance a world, it is required that the world plugin is attached.

Also the correct rendering pipelines must be attached to the world and any materials it uses before the **RpWorldInstance()** function is called. These rendering pipelines may introduce PS data which is required to give the desired effect during rendering

The **RpWorldInstance()** function must be called within the **RwCameraBeginUpdate()** and **RwCameraEndUpdate()** pair of calls within the rendering loop, as the render pipelines must be executed to ensure that all the relevant data is created. In practice the **RpWorldInstance()** function is similar to the **RpWorldRender()** function but that the PS data is not created in the resource arena but allocated from the heap, ensuring that the data is persistent. Clipping and culling are never performed so that all instanced data is generated even if not inside the camera's view frustum.

Save the world to disk using serialization functions as described below and use this as the asset for loading from the game disk. If loading of the PS data fails, it is sensible during development to automatically fallback to loading a platform independent version of the asset, and flag it for pre-instancing in the render loop. Then save the new pre-instanced version over the top of the one that failed to load. This will cope with any changes to the binary format of pre-instanced data caused by updating your version of RenderWare Graphics.

Pre-instancing should not be attempted when PVS is enabled.

10.7 Serialization

The **RpWorld** object supports serialization through the standard RenderWare Graphics Binary Stream system.

Filename Extensions

The "**.BSP**" file extension is not obligatory. RenderWare Graphics has only one file format as such: the RenderWare Graphics Binary Stream. Different extensions are used as a memory aid.

The functions provided by the **RpWorld** API for this purpose are:

- **RpWorldStreamGetSize()**

  This returns the size, in bytes, of the binary stream representation of the given **RpWorld** object excluding dynamic objects.

The size returned by this function is **not** the same as the size of an actual **RpWorld** object.

- **RpWorldStreamRead()**

  Reads an **RpWorld** object, and all the **RpWorldSector** objects it contains, from the specified RenderWare Graphics binary stream.

- **RpWorldStreamWrite()**

  Writes an **RpWorld** object, all the **RpWorldSector** objects it contains, to the specified RenderWare Graphics binary stream.

- **RpWorldSetStreamAlwaysCallBack()**

  You provide a callback function, which will be called after any **RpWorldStreamRead()** operations. This function is designed to allow plugins that extend **RpWorld** to initialize structures based on data read from the stream.

  The callback is called after *all* World Sectors have been read.

  There is also an equivalent function for **RpWorldSector** objects, named **RpWorldSectorSetStreamAlwaysCallBack()**. This exists for similar reasons to the **RpWorld** function, but is called after each World Sector is read.

It is important to remember that only the static model data is referenced when serializing **RpWorld** objects. Dynamic models *must* be written separately by explicit calls to the appropriate ...**StreamRead/Write()** functions.

10.7.1 Writing

The **world** SDK Example includes the code needed to serialize the World object it creates. This code is near the end of the **world.c** file. (The code fragments below show only the relevant code for clarity.)

First, open a RenderWare Graphics binary stream...

```
RwStream *stream;
RwChar *path;

path = RsPathnameCreate(RWSTRING ("./world.bsp"));
stream = RwStreamOpen(rwSTREAMFILENAME, rwSTREAMWRITE, path);
```

...the stream needs to be writeable, hence the **rwSTREAMWRITE** flag...

```
RsPathnameDestroy(path);

if( stream )
{
    RpWorldStreamWrite(world, stream);
```

...now the **RpWorldStreamWrite()** function to write the **RpWorld**'s static model data to the stream.

It is important to note that this function *only* writes static model data – the World Sectors – to the stream. No dynamic model data is written.

At this point, all that is left is to close the stream thus:

```
    RwStreamClose(stream, NULL);
}
```

These steps should result in a file on disk with the name specified in the **RwStreamOpen()**. (In the code fragment above, the file would be named "**world.bsp**".)

Dragging this file onto the "**clmpview**" viewer or the "**RenderWare Visualizer**" viewer should also display the buckyball.

Note that the textures are not saved with the World data as they are treated separately. In most cases, they are already on the disk as either individually-serialized Textures (rare) or stored together in groups as a Texture Dictionary.

10.7.2 Reading

The most common use of static models is as scenery. Normally, you will want to read such models from a RenderWare Graphics binary stream and render the resulting **RpWorld** object.

The process is:

1. Ensure the path to any Texture images has been set using **RwImageSetPath()**.

2. Open a RenderWare Graphics binary stream using the standard **RwStreamOpen()** API.

3. Read the **RpWorld** object from the stream.

4. Close the stream.

5. Render the object.

10.8 Destruction

C does not provide intrinsic support for object destructors, which means that any objects created in a program *must* be destroyed explicitly.

Any objects associated with a World - the Atomics, Lights, Cameras and static scenery - will need to be destroyed and it is important that this is done in the correct order, as follows:

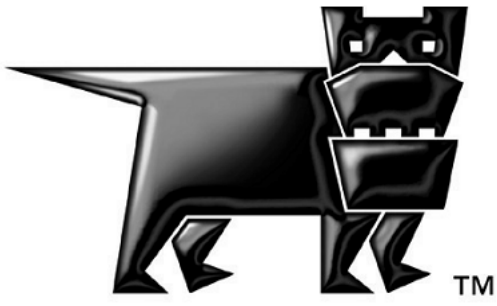
1. Remove and destroy any Clumps. These may contain collections of Atomics, Lights, and Cameras that are automatically removed from a World and destroyed during this process.

2. Remove and destroy any remaining Atomics, Lights, and Cameras that were added individually to the World.

3. Finally destroy the World itself. This automatically destroys the World Sectors and the static geometry they contain.

Chapter 11

Dynamic Models



11.1 Introduction

RenderWare Graphics' Retained Mode API distinguishes between two types of model: *static* and *dynamic*. For example, in a theater, static models are the "scenery" and dynamic models are the "actors". A racing game would therefore use a static model for the racing track and dynamic models for the cars.

RenderWare Graphics assumes that a dynamic model is likely to be manipulated *in real time* by the application. For example, they may be moved around a world by animating the position and rotation of their frames, or their vertex colors or vertex normals could be changed to adjust the appearance of the object.

Most real-time 3D graphics programming will make use of dynamic models.

11.2 The World Plugin

RenderWare Graphics' Retained Mode API is contained within the *world plugin* (**RpWorld**). This plugin defines many new object types. In this chapter, however, we are interested in the three primary dynamic model objects: the *clump* (**RpClump**), the *atomic* (**RpAtomic**) and the *geometry* (**RpGeometry**). Of these new objects, only the geometry object actually stores vertex and polygon information. The clump and atomic object are used to help manage the geometry.

11.2.1 The Geometry Object

The geometry object contains the vertices, triangle indices, texture coordinates and all other necessary components needed to create a model. It represents a model, or, a part of one, and is the actual object that is rendered.

The geometry, however, has no linkage for a *frame* (**RwFrame**) object, which is required for positioning within a scene.

(Frames are covered in detail in the *Fundamental Types* chapter.)

11.2.2 The Atomic Object

An atomic contains pointers to a geometry object and a frame object. It also contains a bounding sphere. This helps RenderWare Graphics determine quickly whether the atomic (strictly the geometry it points to) is visible.

The atomic object provides the link between the geometry and a frame, which allows a geometry to be located within the scene.

It is important to realize the difference between the atomic and the geometry. The atomic is a container for geometry. The geometry defines the data.

11.2.3 The Clump Object

Models tend to be quite complex and it is common for them to be broken down into smaller separate parts, particularly with hierarchical models. In RenderWare Graphics, a complete model is constructed from more than one geometry object. This means that multiple atomics need to be kept track of to manage complex models.

A clump is a container for dynamic objects that are associated with a frame hierarchy. This usually just means atomics, but a clump might also contain cameras and lights. A clump is a convenient place to store, say, a football player's hierarchical model data together in one place. A clump can:

1. Add and remove atomics using **`RpClumpAddAtomic()`** and **`RpClumpRemoveAtomic()`**.

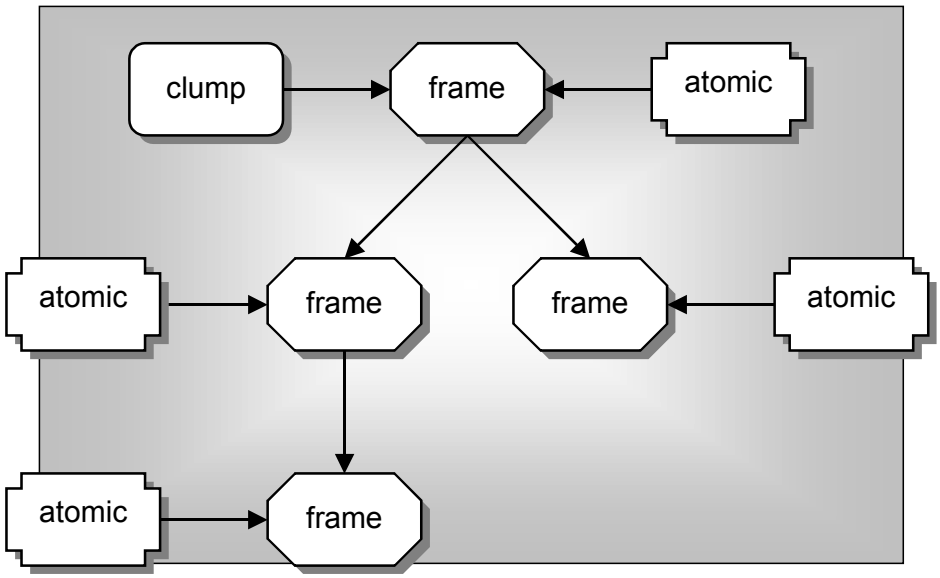
2. Render atomics in a clump using **`RpClumpRender()`**.

3. Get and Set frames in a clump using **`RpClumpGetFrame()`** and **`RpClumpSetFrame()`**.

4. Load and save clumps.

We can attach a frame to a clump and link that frame to the top frame in the model's hierarchy. This way, transforming the clump's frame will transform the clump *and* the hierarchical model it contains. Be careful to avoid falling into the trap of thinking that the clump defines the relationship between atomics it holds. In fact, the hierarchical relationship is determined completely by the frame hierarchy.

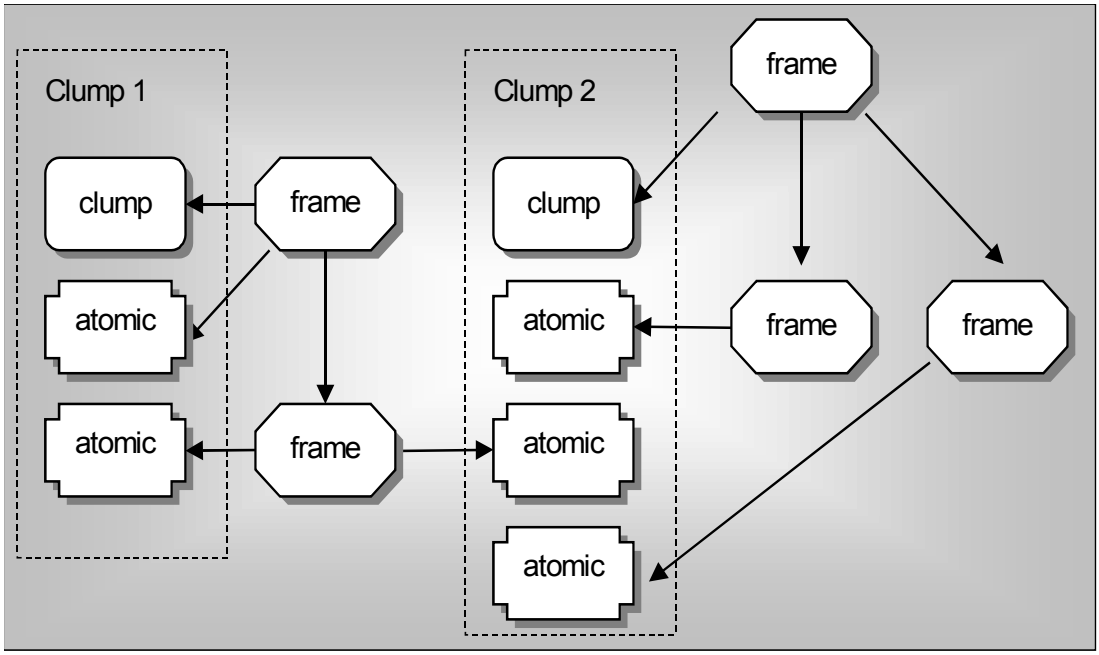
A Typical Clump Hierarchy of Atomics



In the figure above, a relationship between clumps, atomics and frames is shown. A single clump contains four atomics. The clump and first atomic share their frame. This frame is itself a parent of a hierarchy of frames and the clump points at the root frame for convenience. The frames in the tree are used by the remaining three atomics. Any changes made to clump's frame since it's the root frame, in this example, will affect all atomics.

Frames are parents of atomics, clumps and other objects, for example, camera and lights and more information on frames can be found in the *Fundamental Types* chapter.

A Complicated Clump Hierarchy of Atomics



The figure above illustrates a more complicated clump hierarchy of atomics.

The figure above shows a clump containing atomics, although the objects could just as easily be lights or cameras. Clumps and atomics can be attached to frames. A clump's frame can be the parent of an atomic's frame or a frame can be the parent of multiple atomics and multiple clumps.

Why Use Clumps?

It is not written in stone that atomics must be grouped in clumps. If you prefer to manage atomics yourself, you are perfectly free to do so; clumps were designed merely as a convenient container object.

That said, it can be useful to group atomics of a certain type together, even if they are not otherwise related. For instance, you may want to keep track of all atomics that use a particular Material so that you can get at them easily, or you may have atomics that have special attributes – e.g., they represent collectable items in a game. Again, clumps can be used for this. Attaching a frame to a clump is only required if you intend to render it using **`RpClumpRender()`**. You do not need to set up a frame otherwise.

The main reason for using clumps is to make use of their iterator functions, which usually make managing hierarchies and arbitrary groups of atomics easier.

".DFF" Files

Files with the extension DFF are considered to be legacy file types from RenderWare Graphics 3.5. These files were generally used to store clumps, but could actually contain anything that could be streamed through the RenderWare Graphics Binary Stream API. By definitions, a DFF would contain a single clump.

RWS files are the default binary stream file type now. These files may contain many clumps. See the *Serialization* chapter for more details on RWS files.

11.2.4 Clump Destruction

`RpClumpDestroy()` destroys all atomics (and other objects) in the clump, and all the frames in the hierarchy of the clump, but will not destroy the frames of the atomics in the clump if those frames are not in the clump hierarchy.

11.3 Creation of Dynamic Models

11.3.1 Model Creation Overview

Clumps, atomics and dynamic model geometry must be created before they can be used in a RenderWare Graphics application. Although these objects can be created dynamically at run time, it is more common to create them offline. Typically, one of the supported modeling packages will be used for this process. The steps involved in exporting dynamic models from modeling package to a file that can be read by a RenderWare Graphics application are described in the documentation supplied with the appropriate exporter plugins. This documentation is supplied with the Art Tools and covers the model creation and export processes.

The end result of the export process is, by default, an "**`.RWS`**" file of the kind we looked at briefly in the previous section. By convention, these files may contain any number of clump objects. The RenderWare Graphics streaming API can be used to find a clump in this RWS file. This clump will contain one or more atomics and frames.

You can test whether the export process worked by clicking *RenderWare→View* in 3ds max or Maya to launch the RenderWare Visualizer.

11.4 Modeling Tools

Most developers will be working with models built in a professional modeling package by an artist. To this end, RenderWare Graphics is supplied with a set of exporters for popular modeling packages, as well as some tools to view and test the output from these exporters.

11.4.1 Exporters

Our modeling package exporters are available for the following:

- Discreet 3ds max - support for versions 4 and 5.
- Alias|Wavefront Maya - support for versions 3 and 4.

Exporters for the other packages have broadly similar functionality, although the user interfaces and supported features do vary from package to package.

We do not support other modeling packages directly, but we have provided a number of RenderWare Graphics Toolkits to make it much easier to develop your own exporters and tools.

A separate set of Artists' Tools documentation is supplied with the SDK. Select the appropriate option in the installer to have it copied to your computer from the CD-ROM.

11.4.2 Viewers

The RenderWare Graphics SDK comes with three viewer applets. The viewers are RenderWare Visualizer, **`wrldview`** and **`clmpview`**. RenderWare Visualizer allows you to easily view RenderWare Graphics artwork on any target hardware. **`wrldview`** and **`clmpview`** deal with static and dynamic model data respectively, using the legacy file types **`.BSP`** and **`.DFF`**.

The meaning of “legacy” file types is that in the future, RenderWare Graphics exporters *may* not export to these file types. However, the binary format of these files continue to be supported, and RenderWare Graphics 3.5 will continue to read them. There is no need to re-export existing DFF/BSP/etc. artwork as RWS files.

All viewers will accept files for viewing on the target platform. The Win32 builds for **`wrldview`** and **`clmpview`** are drag-and-drop enabled for legacy file types. You can drop a **`.BSP`** (for **`wrldview`**) or **`.DFF`** file (for **`clmpview`**) onto the window to view the file.

These viewers are a useful means of testing your artists' exported models to ensure they look the way they're supposed to and contain valid data.

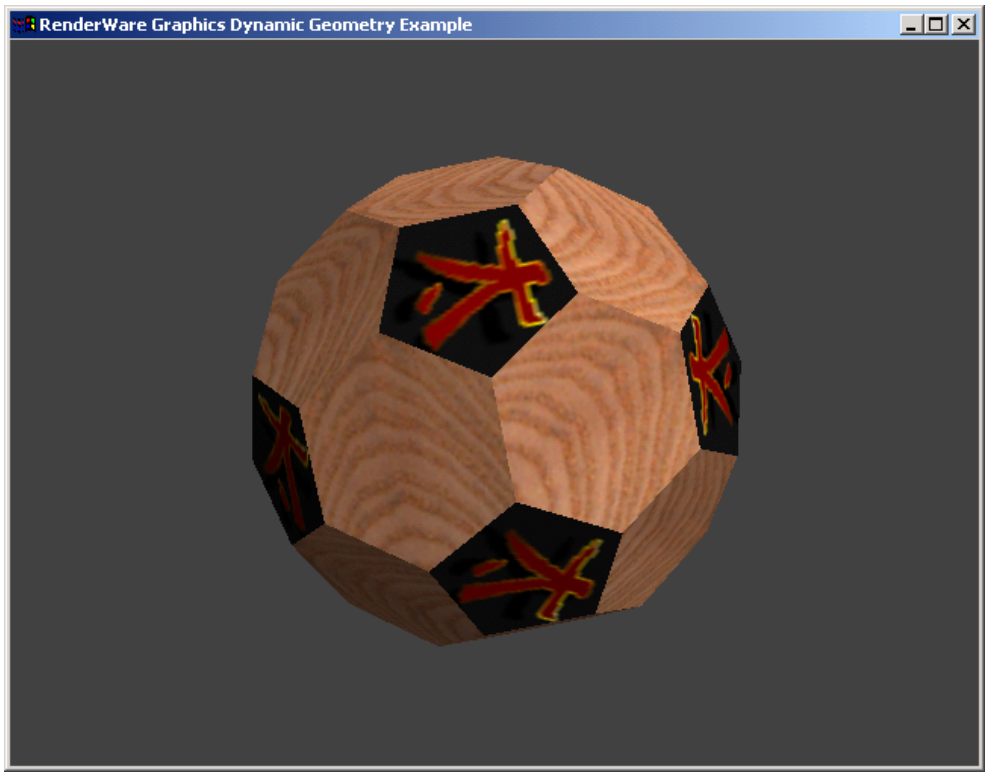
11.4.3 Procedural Model Creation

Creating models during the execution of your game (procedural generation) is rare. Normally, you will only ever need to load models exported from a modeling package. However, it is always useful to understand *why* an object works as it does or needs to be used in a particular way. Also, it is important to realize that the exporters supplied with the RenderWare Graphics SDK are regular RenderWare Graphics applications that make calls into the API. To this end, this section will walk you through the "**geometry**" SDK example. This example shows you how to build a clump using the API function calls.

For simplicity, we will ignore the rendering process of the example, and concentrate on the clump creation code.

Overview

The code in the **example/geometry** the **geometry.c** source file concerns itself with the construction of a simple buckyball object, as shown in the screen shot below. The "buckyball" is a "truncated icosahedron". The model is built from interconnected hexagons and pentagons.



buckyball

11.4.4 Vertices & Triangles

The first stage in model creation is to define the data.

All 3D geometry is defined in terms of vertices. These vertices are linked together to form polygons. The RenderWare Graphics geometry object supports only triangles, which is why the RenderWare Graphics' geometry objects are defined in terms of **triangle** (**RpTriangle**) objects.

The first section of the **geometry.c** source file therefore consists of long lists of coordinates (vertices) and array indices, which define our buckyball object. The first list defines 60 vertices:

```
static RwV3d BuckyBallVertexList[60] =
{
    {   0.00f,  145.60f,   30.00f },
    {   0.00f,  145.60f,  -30.00f },
```

This list of vertices is indexed by subsequent arrays that use these vertices to define pentagons and hexagons in terms of triangles:

```
static RwUInt16 BuckyBallPentagonList[5*NOP] =
{
     0,  2,  4,  6,  8,
```

and:

```
static RwUInt16 BuckyBallHexagonList[6*NOH] =
{
     0,  1, 20, 21,  3,  2,
```

Note that at this point in the example we are not defining the polygons (triangles) that RenderWare Graphics will use, merely defining data that we shall later use.

Object Space

The vertices that make up the buckyball model are defined in *object space*. This means they are relative to the origin of the object itself and have no relationship with the world coordinate system. The result, in this case, is that the origin of the buckyball model is in the center of the model.

11.4.5 Textures & Materials

Textures

The **geometry.c** source file contains one long function: **CreateBuckyBall()**. This function processes the data and creates the objects.

The first step is to load in the *textures* that will decorate the buckyball.

First, the programmer sets the search path for the texture data. This is done using the Skeleton's **RsPathnameCreate()** function to create a valid, platform-dependent path. This path is then fed to the **RwImageSetPath()** function so that RenderWare Graphics knows where to search for the texture map files. RenderWare Graphics will use the path name(s) to determine where on the file system to look for images. (This is similar in concept to the PATH variable found in many CLI-based operating systems.) In RenderWare Graphics, multiple locations can be specified, by separating the paths by semi-colons.

Next comes the actual creation of the texture objects with the **RwTextureRead()** function. The calls to **RwTextureSetFilterMode()** tells RenderWare Graphics that these textures are to use the "linear" filter mode. The filter mode that is set for each triangle is used by the rendering hardware to control how to texture map the surface. A linear filter mode helps "soften" the texture.

In the code below, we load two textures from disk. These textures will be used to texture map the pentagon polygons, and the hexagon polygons respectively.

```
/*
* Create the bucky-ball textures...
*/
  path = RsPathnameCreate(RWSTRING("./textures/"));
  RwImageSetPath(path);
  RsPathnameDestroy(path);

  pentagonTexture = RwTextureRead(RWSTRING("dai"), NULL);
  RwTextureSetFilterMode(pentagonTexture, rwFILTERLINEAR);

  hexagonTexture = RwTextureRead(RWSTRING("whiteash"), NULL);
  RwTextureSetFilterMode(hexagonTexture, rwFILTERLINEAR);
```

Textures are no use on their own. They need to be linked to the model data in some way so that RenderWare Graphics knows when and how they should be rendered.

Materials

Textures require two links with the model data. The first are the texture coordinates (*U* and *V*) defining where the texture is applied. Texture coordinates are stored on a per-vertex basis.

For RenderWare Graphics' Retained Mode API, the remaining link is the **material** (**RpMaterial**) object and we can see that, indeed, the textures are being added to two such material objects just after they are loaded:

```
/*
 * ...and materials...
 */
pentagonMaterial = RpMaterialCreate();
RpMaterialSetTexture(pentagonMaterial, pentagonTexture);

hexagonMaterial = RpMaterialCreate();
RpMaterialSetTexture(hexagonMaterial, hexagonTexture);
```

A buckyball is made up of pentagons and hexagons and the example's designer has decided to define two material objects, one each for the pentagons and hexagons. Pentagons will therefore all share one material (and its texture), while hexagons will share the other.

With the textures now added to a material object, the texture coordinates need calculating for use later. These are calculated in the two subsequent **for…** loops. (This is documented in the function's source code.)

Material Color

To use material colors the **rpGEOMETRYMODULATEMATERIALCOLOR** flag needs to be set (see **RpGeometryFlag**). If a model is exported with material color 255, 255, 255, 255 the **rpGEOMETRYMODULATEMATERIALCOLOR** flag is not set and the material color will *not* be used.

Using the RenderWare Graphics exporters (3ds max or Maya), if all the materials used are colored white, then the **rpGEOMETRYMODULATEMATERIALCOLOR** flag is set to OFF, otherwise the flag is set to ON.

For worlds and patches, the flags **rpWORLDMODULATEMATERIALCOLOR** and **rpPATCHMESHMODULATEMATERIALCOLOR** are used respectively. They are applied in the same way as **rpGEOMETRYMODULATEMATERIALCOLOR**.

11.4.6 Surface Properties & Geometry

The instantiation of the actual geometry object is trivial, although it is worth noting the flags parameter. The full set of available flags is as follows:

- **rpGEOMETRYTRISTRIP**

  This geometry's meshes can be rendered as strips of triangles. This is an optimization technique available on a number of platforms.

Sony PlayStation2 Optimization Tip

Tri-strips are practically mandatory on this platform due to the hardware's design.

- **rpGEOMETRYTEXTURED**

  This geometry has textures applied. Including this flag means the renderer will expect texture objects to be used.

- **rpGEOMETRYPRELIT**

  This geometry has pre-calculated lighting data.

- **rpGEOMETRYNORMALS**

  This geometry has normals. If your model is never going to be lit by RenderWare Graphics' dynamic *light* (**RpLight**) objects, you can save on system resources by not storing normals. This is particularly useful for pre-lit models.

- **rpGEOMETRYLIGHT**

  This geometry will be lit by dynamic light objects.

- **rpGEOMETRYMODULATEMATERIALCOLOR**

  Modulate material color with vertex colors (pre-lit + lit), allowing prelight vertex colors and dynamic lighting to be blended with the underlying material color.

Also defined in this part of the source code is the **surface property** (**RwSurfaceProperty**) data for the model.

Surface properties define how surfaces reflect light. The three components, as you can see from the code, are *ambient*, *specular* and *diffuse*. Respectively, they determine how much ambient light is reflected by the object, how smooth and shiny the surface is, and how the light is spread over the surface.

Surface properties are stored in material objects. Currently in RenderWare Graphics, the lighting does not compute a specular contribution.

11.4.7 Morph Targets

Geometry objects are essentially containers, similar to atomics. Their design is such that geometry will contain *all* the necessary data for a model, or portion of a model. One of the objects the geometry contains is the *morph target* (**RpMorphTarget**) object.

RenderWare Graphics' Retained Mode Plugin, **RpWorld**, is intended to provide scene graph facilities with *support* for animation plugins. The morph target object plays a part in this by supporting morph-target (also known as "keyframe-interpolated") animation. While it is possible to perform morph-target animation directly with **RpWorld**, most will use the Morph plugin (**RpMorph**) to perform this kind of animation.

For morph-target animation to work, all geometry objects have *at least* one morph target object. If there was no keyframe-interpolated animation sequence exported from the modeling package then the geometry object will contain exactly one morph target object.

The morph target and geometry objects divide the model data between them. The triangle objects, which only reference vertices, are stored in the geometry object. The actual vertex positions and normals themselves are stored in the morph target(s). The prelight and UV texture coordinates for each vertex live in the geometry object.

Why?

Morph Targets exist because only the vertices need to be manipulated, not the model topology itself.

11.4.8 Pentagons & Hexagons

After retrieving the necessary pointers to the data structures, the **`geometry.c`** then proceeds to set up the data for the pentagons. The **`for…`** loop runs through each pentagon in the **`BuckyBallPentagonList`** array.

The loop is divided into three parts:

1. Calculate the normal for the pentagon;

2. Initialize the vertex, normal and texture coordinates for each vertex in the polygon;

3. Assign the vertices to the triangles, which will define the pentagon, and assign the Material object to these triangles.

These processes are performed in the next **`for…`** loop for the hexagons as well and the result of all this processing is an almost-complete geometry.

Triangle Winding Order

It is important that triangles are defined in a specific order. During rendering, RenderWare Graphics looks at the vertices of a Triangle and will only render those with coordinates arranged in a *counter-clockwise* sequence relative to the camera. If the sequence is clockwise, the triangle is assumed to be facing *away* from the virtual camera and is not rendered (culled).

11.4.9 Bounding Spheres & Transformations

In this example, we want to condition the geometry such that it has an origin at the center of the model, and has a known physical size. The next steps perform these tasks.

The next section of code finishes off the construction of the geometry object. It is worth closer inspection…

```
if( normalize )
```

(The calling function sets this to **TRUE**.)

```
{
    /*
     * Center and scale to unit size...
     */
    RwSphere boundingSphere;
    RwMatrix *matrix;
    RwV3d temp;

    RpMorphTargetCalcBoundingSphere(morphTarget,
    &boundingSphere);
```

This function calculates a sphere that is just big enough to contain the entire buckyball model. The RenderWare Graphics core library and the world plugin both use bounding spheres heavily. In particular, the bounding sphere is used to determine whether the object is within the camera object's view frustum.

Also, if you are making use of the static geometry functionality provided by **RpWorld**, the sphere is used to check which world sector(s) the model resides in.

RwSphere is a simple exposed data-type. You can find its definition in the API Reference.

Continuing with the bounding sphere calculations:

```
matrix = RwMatrixCreate();

RwV3dScale(&temp, &boundingSphere.center, (RwReal)-1.0f);
RwMatrixTranslate(matrix, &temp, rwCOMBINEREPLACE);

temp.x = temp.y = temp.z = (RwReal)1.0f /
boundingSphere.radius;
RwMatrixScale(matrix, &temp, rwCOMBINEPOSTCONCAT);
```

At this point, we have a **matrix** that contains two operations:

1. A translation that positions the object coordinate system origin at the center of the buckyball;

2. A scaling operation that will shrink our buckyball model to a unit size.

This means that we now have a matrix that can be used to translate and rescale our buckyball model ready for viewing.

This scaling is being done because the vertex list was calculated with paper and pen, rather than a 3D-modeling package.

The next step is to apply the transformation matrix to our geometry object and then to destroy the matrix itself as we no longer need it. The call into **RpGeometryTransform()** will compute and set the bounding sphere for all morph targets on our behalf.

```
/*
 * This will re-calculate and set the new bounding sphere
 * and also unlock the geometry...
 */
        RpGeometryTransform(geometry, matrix);

        RwMatrixDestroy(matrix);
    }
```

If you take a look at the code branch that is taken if normalize is not set, then you can see what code is necessary to compute and set bounding spheres:

```
RwSphere boundingSphere;

RpMorphTargetCalcBoundingSphere(morphTarget, &boundingSphere);
RpMorphTargetSetBoundingSphere(morphTarget, &boundingSphere);
```

Note that each separate morph target in a model requires a bounding sphere to be calculated and set. In this example, the code assumes (correctly) that there is only a single morph target.

Locking, Unlocking

Geometry objects are created in a *locked* state. Geometry objects have to be locked while they are having their actual content changed. (They can be translated and transformed using frames without locking them.)

Unlocking the geometry will usually result in RenderWare Graphics creating new **mesh** (**RpMesh**) objects if the model data has been fundamentally changed. Mesh objects are covered in detail later in this chapter.

11.4.10 Atomics and Clumps

We've only created a geometry object so far.

The next few lines of code put the geometry in a clump.

```
/*
 * That's it...stick it in a single-atomic clump and return..
 */
    clump = RpClumpCreate();
    frame = RwFrameCreate();
    RpClumpSetFrame(clump, frame);
```

At this point, we have an empty clump object with a frame. Clumps need frames so that they can be moved around.

Now for the atomic...

```
atomic = RpAtomicCreate();
frame = RwFrameCreate();
RpAtomicSetFrame(atomic, frame);
```

This code has been used to create an empty atomic object with its own frame.

```
RpAtomicSetGeometry(atomic, geometry, 0);
```

This line links the geometry to the atomic. Atomics can only contain one geometry, so for a more complex model, multiple atomics would be needed, each with their own geometry.

The third parameter to **RpAtomicSetGeometry** is a flag which should only be set to **TRUE** if you want to retain the bounding sphere from a previous geometry object stored in the atomic. This is an unusual situation, and possibly, one you will never encounter.

```
RpClumpAddAtomic(clump, atomic);
```

This links the atomic with the clump, so now we have our clump, atomic and geometry all nicely packaged. One final step remains:

```
RwFrameAddChild(RpClumpGetFrame(clump), frame);
```

This line links the clump's frame to that of the atomic.

Without this, moving the clump around will have no effect whatsoever on the model itself; frames must be linked hierarchically like this for transformations to grow correctly.

This point is an important one. Clumps do not actually manage hierarchies themselves; they're just dumb containers that make it easier to manage complex models.

Our clump has been now completed and the only thing left to do is to return it to the calling function.

```
return clump;
```

11.5 Objects in more detail

In this section, we'll examine some of the objects we've encountered and look at them in more detail.

11.5.1 Reference Counting

Many RenderWare Graphics objects use a reference counting system to avoid being destroyed prematurely. This involves objects maintaining a counter that is incremented whenever a reference is made to said object and the counter decremented when a reference is removed.

RenderWare Graphics provides an **…AddRef()** function for each object which supports a reference counter. This function must be called when adding a reference to an object.

To delete an object, use the equivalent **…Destroy()** function. This function will only destroy the object if the reference count is at zero, otherwise it just decrements the count.

All objects defined by the World plugin *must* be destroyed explicitly after use.

For example, you cannot simply destroy an **RpWorld** object on the assumption that it will automatically destroy all objects it contains as the results of this are undefined.

Instead, you must iterate through all the contained objects, call the appropriate **RpWorldRemove…()** method on each, destroy it (if required) using the object's own **…Destroy()** method, and repeat for the remaining objects in the World.

While this sounds overly complicated, it does allow objects to be reused more easily. In the end, the benefits outweigh the costs.

11.5.2 Texture coordinates

By default, RenderWare Graphics' 3D Immediate Mode and Retained Mode supports only one (U,V) pair per vertex. A geometry does, however, have the ability to store up to 8 sets of UV pairs. If you need more than this, which is highly unlikely, the plugin mechanism can be used to extend the geometry structure.

A textured geometry must be created by passing in the appropriate flags to **RpGeometryCreate**. For a single texture, use **rpGEOMETRYTEXTURED**. For more textures, use **rpGEOMETRYTEXCOORDSETS(n)** where n is the number of required texture coordinate sets. After the geometry is created, the storage for each set of texture coordinates specified can be access by calling the **RpGeometryGetVertexTexCoords()** API. This returns a pointer to an array of texture coordinate pairs, **RwTexCoord**. There is no equivalent “set” function.

Whenever the geometry is locked, you have write access to the contents of this array. (Note however that the geometry must be locked in a mode that supports access to texture coordinates, i.e. **rpGEOMETRYLOCKTEXCOORDS**, **rpGEOMETRYLOCKTEXCOORDSn**, **rpGEOMETRYLOCKTEXCOORDSALL**, or **rpGEOMETRYLOCKALL**). At all times, you have read access to this array.

How you use texture coordinates (**RwTexCoords**) is heavily influenced by the target platform as well as the modeling package. For instance, ranges might be different from platform to platform because some consoles place limits according to their specific chipset designs.

11.5.3 Prelighting

This is a form of static lighting and full details are given in the *Worlds & Static Models* chapter.

In brief, prelighting involves pre-calculating the lighting values of vertices at design-time and storing the colors in the geometry. No further calculation is then required for the rendering.

The major problem with this technique is that the lighting isn't "real" in any sense: if you position another model nearby, the prelit model will not cast any light or shadow upon it.

As we saw in the example earlier, a simple flag setting can be used to determine if an atomic should be affected by dynamic lighting. This applies equally to prelit and unlit models.

It should be noted that if the models are animated or transformed then prelighting data may no longer be valid. RenderWare Graphics will continue to use this data however.

11.5.4 Surface properties

These are stored in material objects.

Surface properties (**RwSurfaceProperties**) are used in dynamic lighting calculations and basically describe how lighting reflects from the surface of a model: whether it's shiny and just leaves a bright spot of color, or whether it's matte and spreads the light around a bit more.

This mechanism is becoming superseded by PowerPipe API provided by RenderWare Graphics. This API gives more control over the rendering process.

11.5.5 Meshes

The mesh (**RpMesh**) object is elusive. It hides inside the geometry object and is only barely exposed.

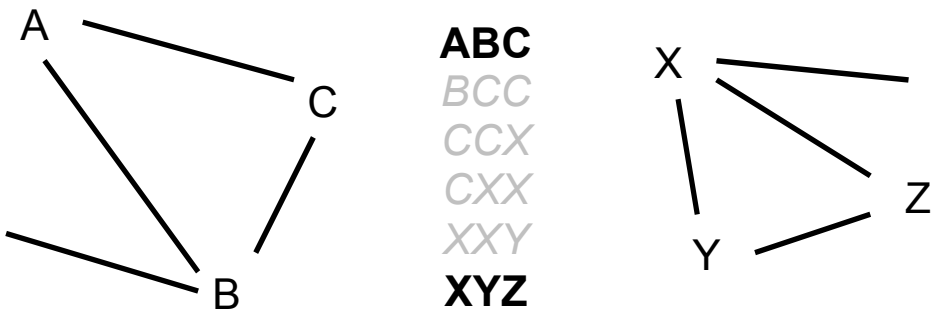
This object is actually an internal, optimized representation of the model topology. It is the reason why geometry objects have to be locked and unlocked. When the model is unlocked by the application, RenderWare Graphics will take the model data and convert it into one or more mesh objects.

Each mesh contains a group of triangles sharing the same material object. This minimizes render state changes required during rendering since RenderWare Graphics will render each mesh to completion before rendering the next.

The mesh is stored as triangle lists, triangle fans or triangle strips. The API function **RpMeshSetTristripMethod()** lets you supply a callback function to perform the tri-stripping according to your own requirements.

The choice between using tri-lists and tri-strips can be made using the **RpGeometrySetFlags()** function. If **rpGEOMETRYTRISTRIP** is set, triangle strips will be used, otherwise triangle lists will be used. At this time, you cannot construct meshes that use triangle fans to represent the object.

Note that triangle strips may result in the creation of degenerate triangles, as shown in the diagram below.



In this example, there are two geometrically partitioned sections of the strip, the ends of which are shown: one on the left and one on the right. Since the triangle strip has to be continuous, four additional degenerate triangles are created, the vertices of which are listed in gray. Each new degenerate triangle introduces a duplicated vertex. RenderWare Graphics relies on graphics hardware being accurate enough to know that a zero-area triangle cannot cover any pixel. This is certainly true on PlayStation2.

11.6 Atomics, Clumps & Transformations

Frames are important when dealing with atomics and clumps. They define the links that join hierarchical model elements together. They also give the atomics – and therefore, their contained geometry objects – a sense of place by giving them storage for position and orientation.

The clump, atomic and frame objects have already been covered in some detail. This section will look at them in the context of Dynamic Models.

11.6.1 Worlds

In order to render a clump or an atomic, we usually need to *add* the object to a world. Doing this gives RenderWare Graphics a frame of reference to work with and lets RenderWare Graphics work out whether the object is visible.

For more information on the world object, read the *World & Static Models* chapter.

One important point to note is that RenderWare Graphics relies on the bounding sphere defined for each atomic to determine (a) whether it is within the World, and (b) whether it should be rendered. A common mistake when creating atomics is to forget the calculation of the bounding sphere and this will often result in their not being rendered, no matter what you try and do with them!

11.6.2 Cloning

Clumps and atomics cannot be copied directly, but they can be cloned. The functions for this are **`RpClumpClone()`** and **`RpAtomicClone()`**.

What is Cloning?

The cloning process will copy the interpolator, bounding sphere, render callback and a reference to (i.e. *pointers* to) the geometry object. The fact that pointers are copied means that a cloned object will share the exact same geometry object as the original. Changes made to the geometry affect *all* clones that reference it.

Cloned atomics will have no attached frame: you'll need to create and add one yourself.

Cloned clumps will copy the entire frame hierarchy.

The **`RpClumpClone`** version naturally calls **`RpAtomicClone`** for all atomics contained in the original clump.

11.6.3 Iterator functions

General Iterators

RenderWare Graphics supplies iterator functions for accessing atomics within clumps, materials within geometry objects, and so on. It is extremely common for these iterator functions to be used together.

- **RpClumpForAllAtomics()**

  This iterator will call your supplied callback function on each atomic the clump contains. You can pass a (void *) data pointer to your callback through the iterator function to support user data. A simple use of this iterator function would be to visit every atomic that a clump contained, and increment a variable for each. This is a simple way to determine how many atomics the clump contains. It is common for a clump to contain just a single atomic. In this scenario, using the callback mechanism is the only way to get from the clump to the atomic. This can be inconvenient, although it is easy for an application to extend the clump object to contain a pointer to the (single) atomic.

- **RpAtomicForAllWorldSectors()**

  We learned earlier that atomics, when added to worlds, are linked to world sectors so that RenderWare Graphics can work out which atomics can be ignored during the rendering process.

  This function will iterate through all the world sectors with which the atomic intersects, calling your supplied callback function. An example use of this iterator would be to examine which world sectors the atomic spans. Other iterator functions can get from a world sector to any lights that it contains, and so these functions can locate lights that affect the atomic.

- **RpWorldForAllClumps()**

  This iterator will call your supplied callback function on each clump the world contains. You can pass a (void *) data pointer to your callback through the iterator function to support user data. If in your game you wanted to fade out every dynamic object, at the end of a level, say, you could use this function to visit every clump. Other callback functions could then be used to modify every material that each clump used.

- **RpWorldSectorForAllAtomics()**

  This iterator will call your supplied callback function on each atomic intersecting the specified world sector. You can pass a (void *) data pointer to your callback through the iterator function to support user data.

- **RpGeometryForAllMaterials()**

  This iterator will call your supplied callback function on each material object within the specified geometry. You can pass a (void *) data pointer to your callback through the iterator function to support user data. This function is typically used by an application as it gets access to the texture that each material holds.

- **RpGeometryForAllMeshes()**

  This iterator will call your supplied callback function on each mesh object within the specified geometry. You can pass a (void *) data pointer to your callback through the iterator function to support user data.

- **RwCameraForAllClumpsInFrustum()**

  This iterator will call each clump's registered callback function on all clumps that can be seen by the specified camera object. You can pass a (void *) data pointer to your callback through the iterator function to support user data.

  The clump's callback function is specified by the **RpClumpSetCallBack()** function. You will need to set this to an appropriate callback of your own for all clumps that you need to intercept.

Intersection test iterator

The atomic object supports some collision-detection functionality in the form of the following iterator:

- **RpAtomicForAllIntersections()**

  Requires a callback defined as type **RpIntersectionCallBackAtomic()**.

  This callback function is triggered for each intersection found between the atomic and the requested collision type, defined as an **RpIntersectionType** enumeration.

RpIntersection defined

The collision type mentioned above is an enumeration that identifies the type of collision primitive to test for. The types currently supported are:

- **rpINTERSECTLINE:** Line intersections.
- **rpINTERSECTPOINT:** Point intersections.
- **rpINTERSECTSPHERE:** Sphere intersections.
- **rpINTERSECTBOX:** Box intersection.
- **rpINTERSECTATOMIC:** Atomic intersections

Atomic Rendering Callback

It is possible to set a rendering callback for individual atomics. This callback, **RpAtomicCallBackRender()**, will be triggered when the atomic is about to be rendered, either by the **RpWorldRender()** function, or directly via **RpAtomicRender()**. This callback can be used, for example, to handle animations on a per-atomic basis.

The callback is set using **RpAtomicSetRenderCallBack()**.

Using atomic render callbacks can produce some very powerful techniques. Typically an application will want to store away the atomic render callback that is currently being used (with **RpAtomicGetRenderCallBack()**). This gives the application a way to continue with the atomic rendering. In RenderWare Graphics, this technique is called *chaining function calls*, or *hooking functions*. One example use might be if the application wanted to perform some high level culling. The application would store the current atomic render function and selectively call the stored function pointer if it wanted the atomic to be drawn. It might make the decision based on the distance of the atomic from the viewer or some other parameter. (In fact, this technique is exactly how the PVS plugin is implemented.)

11.6.4 Sorting Geometry objects by Material

RpGeometrySortByMaterial() is used to create a modified clone of the specified geometry object. The modification involves sorting vertices by material and duplicating them along material boundaries where necessary.

If the source geometry contains any RenderWare Graphics plugin extensions, the application must provide an **RpGeometrySortByMaterialCallBack()** callback function to update the extended data as appropriate. The callback will receive pointers to:

- the original geometry;
- the new geometry;
- a mapping array that links every vertex in the new geometry with that of the corresponding vertex in the source geometry using vertex indices, and…

- the length of the mapping array, the number of vertices in the new geometry.

On completion, each material's mesh references an independent set of vertices within the larger vertex array of the geometry. No vertices are shared between materials. The new geometry is returned in an unlocked state.

11.6.5 Animation

RenderWare Graphics supports a number of animation techniques. The World plugin itself supports only a subset of these directly: other plugins need to be attached to use the others.

In this section, we'll look at the forms of animation available directly to the World plugin.

Frame-based

We have already seen how frames affect the position and orientation of their associated atomic or clump. It is worth reiterating that hierarchies of frames can also be animated, either in whole or in part, by simply applying transformations and rotations to the individual frames.

Using this technique, it is possible to animate hierarchical models procedurally by simply adjusting the appropriate frame objects.

Vertex-based

Vertex-based animation is usually best left to the morph target plugin (**`RpMorph`**). This plugin uses keyframes, defined in terms of morph target objects, with linear interpolation between these simple animations of an atomic.

The API does expose some functionality that will let you access the vertex data directly. A number of animation techniques can be applied using this API, such as UV morphing, procedural vertex animations etc.

However, there are some important notes that you need to read before you attempt such animation:

- Geometry objects *must* be locked before you change any vertices.
- Geometry objects *must* be unlocked after you've made your changes.
- This lock-unlock cycle can be very slow. RenderWare Graphics may have to convert and/or re-instance the model data during the cycle and this can drastically impact performance.

- The *only* time the lock-unlock cycle is not needed is when changing material data. The only exception to this is for PC targets, when you want to change the material color and the modulate flag is set; this requires the geometry prelight to be locked.

11.6.6 Skinned Models

"Skinning" is a form of model representation that applies weights to vertices and uses these weights to morph vertices. The technique is particularly applicable to organic character models such as humans, animals and others with flexible skin. This form of model representation is provided by the skin plugin (**`RpSkin`**).

11.7 Optimization

A RenderWare Graphics Toolkit, **RtWorld**, exists to provide a number of functions for world objects.

Usually, the modeling package's RenderWare Graphics exporter plugin will use these when writing models out in RenderWare Graphics format. However, you can also use the functionality yourself in your own tools and utilities.

The function of interest to us at this point is:

- **RtGeometryCalculateVertexNormals()**

  This function is used to calculate a normal vector for each vertex defining the specified geometry. The geometry must have been created with the **rpGEOMETRYNORMALS** flag so that the data array holding the vertex normals is available.

  A vertex normal is calculated by averaging the face normals of all connecting polygons that share the vertex, weighted by the angle subtended by each polygon at the vertex. If the vertex is not shared, a normal equal to the face normal is used. The resulting vertex normals are set to unit length.

  Note that the geometry is unlocked after the vertex normals have been calculated.

11.8 Rendering

11.8.1 How to Render Dynamic Objects

There are two ways to render a dynamic object: directly or indirectly. In either case, the functions described need to be called between **`RwCameraBeginUpdate()`** and **`RwCameraEndUpdate()`** pair.

Rendering Atomics and Clumps directly

Assuming you have a camera to render into, you can render directly using either **`RpAtomicRender()`** or **`RpClumpRender()`**. You don't need to create a world object first, although rendering without one is rare.

If you do have a world, some platforms will apply dynamic lighting to your model, regardless of whether you added it to the world object. See the platform-specific documentation supplied with the SDK for more details on this.

RenderWare Graphics assumes *you* have handled visibility calculations when rendering directly, so it will attempt to render the model regardless of whether it is actually visible. Although rendering the model when it isn't visible will not cause any crashes, this can be a common cause of inefficient rendering and generally strange behavior.

Render CallBack issues

It is important to realize that rendering models with these functions will trigger any attached render callbacks regardless of visibility. If your callback functions are being called, but you cannot see the model on screen, this is probably the reason.

RpWorldRender()

This function is among the most powerful, most useful functions within the RenderWare Graphics API.

A glance at the API Reference for **`RpWorld`** will reveal functions for adding clumps, atomics, lights and even cameras to a specified world object. When these functions are used, they add references to the specified object to any World Sectors within which they are located or intersect.

Local & Global Lights

There are two kinds of dynamic lights: *local* lights, which need to have a frame attached to them, and *global* lights, which do not.

Local lights include spotlights and point lights. These need a frame object to define position and orientation. These lights are added to a world sector in the same way as an atomic, camera or clump. This allows the rendering engine to determine which world sector(s) are affected by the light. The number of world sector(s) affected by a Local light depends upon their radius of effect.

Global lights include ambient and directional lights, which are assumed to affect the entire world. These should still be added to a world, but on some platforms, they will affect *all* worlds, regardless of whether they have been added to them or not.

The **RpWorldRender()** function can then be used to render an entire scene with a single function call.

It first determines where the target camera is so it can then iterate through all visible world sector objects within the world and render them. As it renders each world sector, it checks it for any references to atomics, clumps and so forth and renders any it finds.

This makes rendering a lot easier as you can just add clumps and atomics to a world and not have to worry about render order, frustum testing, culling, visibility etc: the **RpWorldRender()** function will do this for you.

There is an exception to this: models with transparent materials often need a second rendering cycle for those materials on some platforms to ensure that models are rendered in the right order. Z sorting on the fly is not done by RenderWare Graphics.

*See the "**alphasrt**" example to see how this situation is handled.*

11.8.2 Instancing

A model in RenderWare Graphics has *two* representations: the platform-independent geometry/morph target data you get to play with and apply for collision detection, and an internal, platform-dependent "instanced" form optimized for the underlying hardware. This instantiation process usually happens once, on first rendering the model. RenderWare Graphics performs best when the vertices of your models stay put so it doesn't have to convert them to the platform-specific internal form again.

Changing vertices is possible, but you have to lock the geometry first and inform RenderWare Graphics how – or if – the data is about to change using the lock flags. You are then free to change the vertices within the constraints you set yourself. Once you've done that, you must unlock the geometry. At this point, the platform-specific data is in a kind of limbo: only when – or, indeed, if – it is rendered will RenderWare Graphics' instantiation process kick in to convert your changed vertices into the platform-specific form needed to keep things running fast.

Instanced data is not actually stored within the geometry itself. Instead, it is allocated space in the *Resource Arena*. This is a cache that *only* stores instanced data. Some platforms may store portions of instanced data in dedicated hardware video memory for efficiency.

The caching metaphor is particularly apt since existing instanced data can be thrown out if there isn't enough space left to create new instances. This can result in a problem known as *arena thrashing*, whereby performance is crippled by the need to repeatedly re-instance the same geometry data during a rendering cycle because there isn't enough space to store a full scene's instanced data.

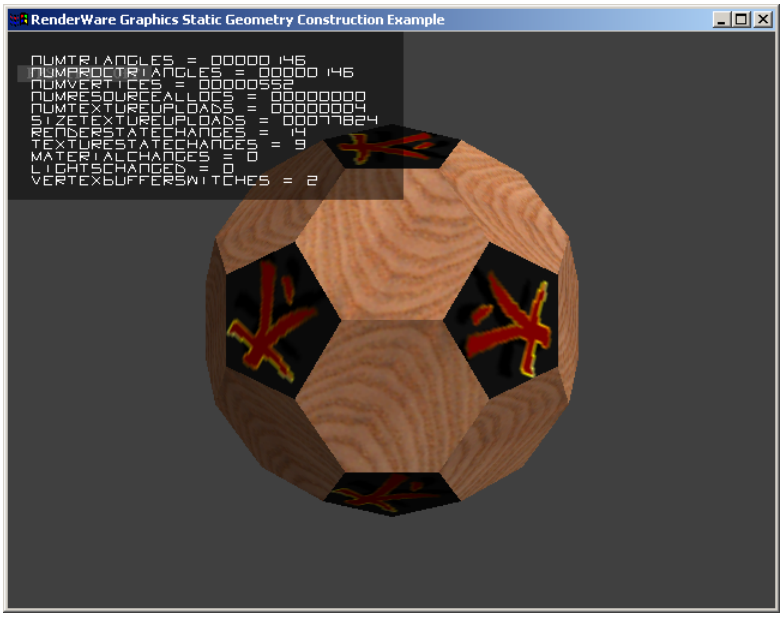
The Resource Arena's size is set during the start-up phase by calling the **RwEngineInit()** function. Exactly what size you should set is heavily dependent on your application, so you will need to experiment to get a good balance between speed and efficiency.

Optimizing with a Metrics Build

Determining the best Resource Arena size requires knowing how it is being used. The *metrics* build of the RenderWare Graphics libraries can help you decide on the best trade-off between speed and hardware resources by displaying resource usage on your target platform.

The **RwMetrics** structure varies from platform to platform so you should see the platform-specific documentation for more details on what is supported on your target hardware.

This screenshot shows the Win32, Direct3D metrics build in use in the "**world**" example.



11.8.3 Pre-instancing Dynamic Geometry

One optimization of the above instancing scheme can be performed if it is known that the platform independent (PI) representation will not be used at run-time, and that is to use solely pre-instanced platform specific (PS) representation, rather than creating it at run-time. This has the advantages that no CPU cycles are used to instance data on their first rendering, which gives a minor performance improvement, but also means that space is not required for storage of the platform independent copy of the data.

The **RpAtomicInstance()** function is used to generate a persistent copy of the platform specific data, so at that time, two representations of the atomic exist. The platform independent data and the platform specific data both exist outside the resource arena. When rendering occurs the platform specific representation is always used and the resource arena is now not used by the atomic during rendering.

The platform specific data generated should be considered opaque and highly volatile as the format is subject to change between versions.

Atomics with pre-instanced geometry are serialized slightly differently from those without. If the atomic is serialized, the function for writing the geometry to the stream **RpGeometryStreamWrite()** is called internally from **RpAtomicStreamWrite()**. **RpGeometryStreamWrite()** does not export PI data when persistent PS data is present, and consequently when the atomic is loaded into memory with **RpAtomicStreamRead()** or **RpGeometryStreamRead()** only the PI data is lost. This is where the memory saving occurs.

As the instancing process has already been performed offline, and is not performed at run-time, the resource arena is never used, and the resource arena size may be reduced accordingly. The resource arena may be eliminated altogether if no instancing occurs, which would require any static geometry to be pre-instanced too, see the *Worlds and Static Models Chapter* of this guide.

This does mean that features which use the PI data will no longer work and functions to get PI data will return failure codes. For instance **RpMorph** and **RpDMorph** will not function, and static PVS creation should be undertaken before pre-instancing. Collision detection is not possible, though a lower resolution collision atomic which is never rendered could be used to test for collisions.

The only exceptions to this is that the number of vertices in the geometry, and the number of triangles in the geometry, are preserved and can be read using **RpGeometryGetNumVertices()** and **RpGeometryGetNumTriangles()** respectively. These are stored mainly so that sensible metrics can be observed with PS data, and the actual PI triangle data itself is not present.

Using RpAtomicInstance()

Firstly the availability of pre-instancing of atomics varies from platform to platform, and so please check the platform specific documentation for your platform to determine if this feature is supported for your platform.

To pre-instance an atomic, it is required that the world plugin is attached.

Also the correct rendering pipelines are attached to the atomic and materials before the **RpAtomicInstance()** function is called. Those rendering pipelines may introduce PS data which is required to give the desired effect during rendering.

The **RpAtomicInstance()** function must be called within the **RwCameraBeginUpdate()** and **RwCameraEndUpdate()** pair of calls within the rendering loop, as the render pipelines must be executed to ensure that all the relevant data is created. In practice the **RpAtomicInstance()** function is similar to the **RpAtomicRender()** function but that the PS data is not created in the resource arena but allocated from the heap, ensuring that the data is persistent. Clipping and culling are never performed so that all instanced data is generated even if not inside the camera's view frustum.

Save the atomic and use this as the asset for loading from the game disk. If loading of the PS data fails, it is sensible during development to automatically fallback to loading a platform independent version of the asset, and flag it for pre-instancing in the render loop. Then save the new pre-instanced version over the top of the one that failed to load. This will cope with any changes to the binary format of pre-instanced data caused by updating your version of RenderWare Graphics.

11.8.4 Converting Model Data to RenderWare Graphics

RenderWare Graphics' reliance on its own data format means you may have data that needs to be converted. This is not a particularly difficult task as a number of utility functions are provided to assist in the conversion process.

Usually, you will want to feed in the data in one format and have valid clump or atomic data produced as a result. This is explained below.

Conversion Overview

The steps necessary to create an atomic or clump are roughly similar. No intermediate data type is necessary, and the exporter can create atomics directly.

The steps involved are:

1. Create an atomic by calling **`RpAtomicCreate()`**.

2. Create a geometry object by calling **`RpGeometryCreate().`**

   This function requires the number of vertices and triangles needed by the model, as well as a set of flags.

   The number of vertices and triangles can be obtained from the source data or, if developing an exporter for a modeling package, a suitable conversion API function.

   The flags should also be set up as required. For the purposes of simplicity, it is assumed that the geometry contains normals, texture coordinates and lighting values.

3. Obtain the default morph target object (which has an index of zero) from the geometry using **`RpGeometryGetMorphTarget()`**. This is where the vertices and normals are stored.

4. The UV coordinates are shared across all key-frames and can be found in the geometry object itself, so get a pointer to them using **`RpGeometryGetVertexTexCoords()`**. There is a one-to-one relationship between these and the vertex array in any related morph targets.

5. Obtain the vertex and normal arrays from the morph target using **`RpMorphTargetGetVertices()`**, and **`RpMorphTargetGetVertexNormals()`** respectively.

6. Iterate over the vertices in your model, copying vertex, normal and texture co-ordinate data from the model into the geometry arrays.

7. Create all the material objects that your model requires, taking care to read any textures necessary from disk and setting material colors correctly. (255 indicates a full intensity color RGB component and also a fully opaque (non-alpha) material.)

You may wish to build a Texture Dictionary object if the Null driver supports your target platform's bitmap formats. Alternatively, you may build a Platform Independent Texture Dictionary that can be used on any target platform. See the *Rasters, Images and Textures* chapter in this guide.

8. Iterate over the triangles in your model, setting the vertex indices and materials for all triangles in the geometry. You will need to use **`RpGeometryGetTriangles()`** to obtain the start address in memory where triangles are stored, and the various triangle object API functions to prepare and store them.

9. Calculate and set a bounding sphere for your morph target, using the API calls **`RpMorphTargetCalcBoundingSphere()`** and **`RpMorphTargetSetBoundingSphere()`**. (This step is often forgotten, but it is absolutely essential.)

10. Unlock the geometry.

11. Attach the geometry to the atomic with **`RpAtomicSetGeometry()`**.

Take a look at the **`geometry`** example in **`examples`** folder to see the above construction process in action on hand-made model data.

Null Libraries

The Null Libraries supplied on the SDK are specifically designed for conversion work. For instance, we use them to build our modeling package exporters.

These libraries are almost identical to the standard Release ones, with the exception that all actual rendering functionality is removed or diverted to a null driver. This is because conversion programs rarely need to render their output to the display while the conversion is taking place.

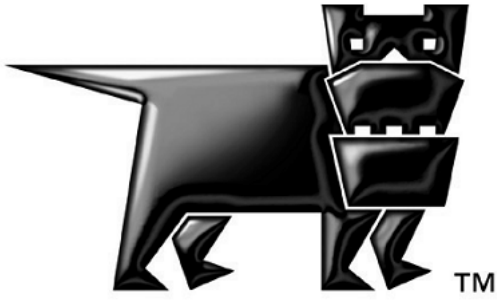
In addition, it means that functionality or output formats that may not otherwise be supported on a particular platform can be included.

Null libraries for each platform are also supplied with the SDK (for example, nullxbox). These are PC libraries used for building certain tools that process platform specific data. They can be used to build platform specific texture dictionaries.

It should be noted that Null platform libraries can not create pre-instanced world and geometry data.

Chapter 12

Lights



12.1 Introduction

RenderWare Graphics has two kinds of lighting models: *dynamic* and *static*. This chapter covers static lighting using RpLight. Static lighting can also be achieved using RpLtMap.

The dynamic lighting model is the closest in behavior to real-world lighting, with lights being independent from the model geometry.

Five light types are supported by the dynamic lighting model:

- ambient
- point
- directional
- spot
- soft spot

Static lighting—not to be confused with static geometry—is less flexible, but requires far fewer resources to use. This lighting model is tied to model geometry and is implemented in one of two ways, depending on whether the geometry itself is static or dynamic.

12.1.1 Other Documentation

- See the API Reference Lighting section for more information about lights and lightmaps.
  Modules→Lighting
- Lightmaps user guide chapter

12.2 Dynamic Lights

Dynamic lights represent the most flexible light model in RenderWare Graphics. They can:

- be fully controlled and manipulated at run-time
- be positioned at will and oriented in any direction
- selectively illuminate both static and dynamic models
- support a number of light types
- make use of hardware transform and lighting features

Dynamic lights have one *important* disadvantage: the processing power needed to implement them. On platforms with no hardware transform and lighting support, dynamic lights will eat up a substantial proportion of processing time, effectively limiting the number of dynamic lights your application can use.

Another disadvantage is that hardware transform and lighting stages on different platforms generally make use of different algorithms. The result is that the same settings for a particular light can produce varied results across different platforms. RenderWare Graphics therefore supports both *reference* and *platform-specific* forms of dynamic lighting.

The reference set supports all five light types. The platform-specific models usually support the same light types, but use the light types defined in the underlying hardware to perform the illumination calculations. This means the platform-specific lighting models are unlikely to give the same results across different platforms.

The reference set light types are designed to produce very similar results across all supported platforms. On some platforms, they may be wholly or partially implemented using hardware lighting facilities. In other cases, the light types are implemented in software.

Platform-specific dynamic lighting is provided mainly to enable access to all the light types available on the platform's hardware.

There are no platform-specific APIs for static lighting.

12.2.1 Dynamic Lights Representation

Objects

RenderWare Graphics dynamic lighting models are controlled through two objects: **RpLight** and **RpMaterial**.

The first object, **RpLight**, provides control over the light source itself. By linking this to an **RwFrame**, the light can be positioned within an **RpWorld** and, if necessary, oriented towards its target. In addition, the **RpLight** object exposes a number of functions, which allow the developer to modify the light's properties.

Effective lighting requires consideration of both the light itself and the materials of the models it is illuminating.

The **RpMaterial** object defines materials that are applied to models and therefore defines how models reflect light. This object is covered in detail in the *Dynamic Models* chapter, so this chapter will only touch upon the features that directly apply to dynamic lights.

Dynamic Lighting Models

A dynamic light is created using the **RpLightCreate()** function. This function takes a constant defining the light types to be used when processing the dynamic light.

The table on the following page lists the constants and describes the reference light types. These are always available, regardless of the platform.

Platform-specific lighting models

Platform-specific light types are documented in the relevant section of the API Reference and usually map directly onto light types implemented in the platform's hardware.

On the PlayStation 2 platform, all lighting models, including the reference models listed in the table below, are implemented using custom VU code.

Reference Dynamic Light Types

NAME	LIGHTING TYPES
rpLIGHTAMBIENT	Ambient light type. This type provides lighting from all directions. The light source is omnipresent. Cannot be positioned or oriented.
rpLIGHTDIRECTIONAL	Directional light type. This model simulates a light source at infinite distance from the world. Cannot be positioned, but can be oriented.
rpLIGHTPOINT	Point light type. This type simulates a point source of lighting. The light is emitted from this source in a sphere. Cannot be oriented, but can be positioned.
rpLIGHTSPOT	Spot light type. This light type simulate spotlight sources, which emit a cone of light from a specific source in a particular direction, resulting in a spot of light on the target. Can be positioned and oriented.
rpLIGHTSOFTSPOT	Soft spot light type. As **rpLIGHTSPOT**. The "soft spot" type adds a soft edge so that the light falls off smoothly at the edge of the spot. Can be positioned and oriented.

12.2.2 Creating a dynamic light

The following code fragment creates an **RpLight** object named **myLight**. It contains a dynamic light using the soft spot light (**rpLIGHTSOFTSPOT**) reference light type:

```
RpLight *myLight;
myLight = RpLightCreate( rpLIGHTSOFTSPOT );
```

At this point, **myLight** has been created, but has not yet been initialized.

Initialization

The initialization necessary for a particular light depends on the light types it is using. For instance, the ambient reference light type (**rpLIGHTAMBIENT**) needs only a color to be set.

In most cases however, the first step will be to attach a frame object to the **RpLight** object, so it can be positioned and/or oriented within a world. Of all the reference light types, only the ambient light type can be used without a frame.

Position & Orientation

Assuming the **myFrame** frame object contains a valid, initialized **RwFrame** object, the following code fragment would attach it to the light:

```
RpLightSetFrame( myLight, myFrame );
```

Attaching a frame to a light allows you to move and orient the light as required. The features of the **RwFrame** object also mean this light could easily be included in an **RwFrame** hierarchy along with model geometry.

Color

The next step is to set the color of the light. The **RpLightSetColor()** function performs this task. It takes an **RwRGBAReal** value defining the RGB and Alpha components.

Assuming that **lightColor** has been initialized to the required color, our initialization continues:

```
RpLightSetColor( myLight, &lightColor );
```

Sphere of illumination

Aside from those using the ambient and directional light types, most lights affect models within a finite *sphere of illumination*. This sphere is defined by the light object's *radius*, an **RwReal** value. This can be set thus:

```
RpLightSetRadius( myLight, 5.0f );
```

This radius defines the distance over which the lighting model acts, with the light falling off over distance according to the formula:

$$\text{intensity} = \max\left(\frac{\text{radius} - \text{distance}}{\text{radius}}, 0\right)$$

When the distance is zero, the light's intensity is at its highest. The intensity is zero when the distance traveled is equal to the radius.

Cone Angle

Spotlights also have a *cone angle* property, which defines the angle of the light cone. A wide angle results in a wide spot of light; a narrow angle gives a smaller spot of light.

The cone angle is an **RwReal** value and may be set as follows:

```
/* 0.785 is equivalent to PI / 4, about 45 degrees */
RpLightSetConeAngle( myLight, 0.785f );
```

Adding the light to a world

At this stage, the light is ready. All that remains is to add it to an **RpWorld** object. The fragment below assumes that the world object has been initialized:

```
RpWorldAddLight( myWorld, myLight );
```

The application is now free to move and orient the light within the world as well as modify its other properties.

Dynamic Lights & World Sectors

When a dynamic light is added to a world, the **RpWorldAddLight()** function positions the light within a world sector object.

The light's sphere of illumination is used to determine which world sectors the light affects. As such, a light may be referenced by more than one world sector.

Light object flags

Light objects also include a *flags* property. Currently, this can be used to inform the rendering engine which geometry types the light will affect: static and/or dynamic.

Two flags are defined: **rpLIGHTLIGHTATOMICS** and **rpLIGHTLIGHTWORLD**. The former, if enabled, means the light will affect dynamic models. The latter, if enabled, means the light will affect static models. The flags should be logically **OR**ed together if both are needed.

The function to set or reset the flags is **RpLightSetFlags()**. An example of its use appears below. The example sets the light created earlier to illuminate both static and dynamic models:

```
RpLightSetFlags( myLight, rpLIGHTLIGHTATOMICS | rpLIGHTLIGHTWORLD);
```

Dynamic Lights, Geometry & Materials

It is possible to modify the behavior of lighting at the **RpGeometry** level by manipulating the geometry flags. This lets applications enable or disable lighting for individual atomics. The flags are exposed by the **RpGeometry** object through the **RpGeometrySetFlags()** function.

It is important to understand that these flags are specific to the geometry object, not an atomic. The geometry will always be illuminated according to these flag settings.

There are two geometry flags relevant to lighting, as shown in the table below:

FLAG	DESCRIPTION
rpGEOMETRYLIGHT	If set, dynamic lights will illuminate the geometry. If cleared, dynamic lights will not illuminate the geometry.
rpGEOMETRYMODULATEMATERIALCOLOR	If set, the geometry will reflect illumination appropriately by combining both dynamic and static lighting to render the correct colors. If cleared, the geometry will not be lit at all. Instead, the geometry will be rendered using its material object's own color property alone.

Iterator functions

The **RpLight** object exposes an iterator function, **RpLightForAllWorldSectors()**, which will call a user-supplied callback function for each world sector the light affects.

12.2.3 Clump Lights & Streaming

An **RpClump** is a container for dynamic objects that are associated with a Frame hierarchy, and this includes dynamic Lights. Lights can be added to Clumps using the **RpClumpAddLight()** function.

- They will be automatically streamed with the Clump and their position within the Frame hierarchy of the Clump preserved.
- They will be automatically destroyed with the Clump when **RpClumpDestroy()** is called.
- They will be added to and removed from Worlds with the Clump when the functions **RpWorldAddClump()** and **RpWorldRemoveClump()** are used.

This mechanism is used whenever dynamic Lights are exported from one of the modeling packages. The artist is able to set up and position Lights within a world. Once exported within a Clump, the positions are stored in the Frame hierarchy.

12.2.4 Platform-Specific Lighting Models

Many platforms support hardware acceleration for lighting. However this support is not identical across platforms. Such hardware often provides its own implementation of lighting and this means lights can produce different results on different platforms, even though they are initialized with the same values.

The reference light types provide a means of ensuring consistent lighting across supported platforms, but their performance will vary from platform to platform.

RenderWare Graphics therefore exposes any platform-specific lighting models using the same API—only the lighting type constant changes.

Platform-specific lighting types are available for Nintendo GameCube, Microsoft DirectX (both Windows and Xbox) and OpenGL. The Sony PlayStation 2 supports the reference lighting models in hardware.

The RenderWare Graphics API for PlayStation 2 uses VU code to perform all rendering, so the reference lighting models are all accelerated.

12.3 Static Lights using RpLight

Regardless of whether they are supported in hardware or software, dynamic lights require substantial processing. So, it is wise to avoid using too many dynamic lights.

Static lights—also known as *prelights*—provide a form of lighting that avoids high processing overheads. They are a much simpler, faster, alternative to dynamic lights. The trade-off is that static lights are very limited in their abilities.

Static lighting can be applied to:

- *Static models* – i.e. worlds. The data is stored in **RpWorldSector** objects.
- *Dynamic models* – i.e. atomics, clumps, etc. The data is stored in **RpGeometry** objects.

The first usage is by far the most common as RenderWare Graphics modeling package exporter tools support static lighting features directly. Artists tag model geometry and apply lighting to it. When the model is exported, the RenderWare Graphics exporter encodes vertex lighting data right into the geometry.

The exact tagging mechanism used varies from package to package. See the art tools documentation for full details.

At run-time, all that is needed is to load and render the geometry. The static lighting is applied automatically when the relevant **RpWorld** object is rendered.

For dynamic models, there is currently no support for exporting static lighting data directly from the modeling package. Exporters will allocate the necessary space for an array of **RwRGBA** values, but initialization of these values must be performed explicitly, either in a custom tool, in a modified build of the exporter, or at run-time.

Static lighting is decreasing in importance as modern graphics hardware transform and light engines are reducing the need for processing dynamic lighting in the CPU.

12.3.1 Creating Static Lights

Static models

Static lighting is stored as fixed vertex lighting values. In static models—i.e. **RpWorldSector** data—these values are completely fixed and not exposed by the RenderWare Graphics API. This is a requirement of the static model rendering optimizations of RenderWare Graphics.

Developers building their own tools or creating static models from scratch will find that the **RtWorld** and **RtWorldImport** toolkits support creation of static lighting data as well as the model geometry itself.

Dynamic models

For dynamic models, static lighting is stored within **RpGeometry** objects. The data is represented by an array of **RwRGBA** values, which can be retrieved using **RpGeometryGetPreLightColors()**.

The array only exists if the geometry has been created using the **rpGEOMETRYPRELIT** flag. Space for the prelight array must be explicitly allocated if you are creating geometry objects, as setting the flag will not perform this procedure automatically.

The prelighting colors reside within the geometry's topology, at one color per vertex, and are therefore shared between all morph targets.

12.3.2 Static Lighting Techniques

Static lights are very fast, using a negligible amount of processing power regardless of how many such lights are used. However, limitations in their design means that they are most often used in tandem with dynamic lights.

Some common techniques are covered next, illustrating how the illusion of full lighting can be created without using too many dynamic lights.

Interactive static lighting

One of the most important limitations of static lighting models is that static lights do not actually cast any light. The process creates the *illusion* that light is striking the model. Static lighting affects *only* the vertices of the world sector or geometry objects in which the lighting information resides.

As a result, a dynamic model passing through a statically-lit world will not be illuminated by static lighting.

If you need to create the effect of static lights casting lights on other models, you will need to use a dynamic light as well. In most cases, the dynamic light can be a temporary creation, used only when the light would be visible to the camera and an object is near enough to it.

Modifying static lights on static models

There are occasions when static lights need to be disabled or modified in some way at run-time. This is trivial when working with statically-lit dynamic models, but the most common use for static lights is to light static models.

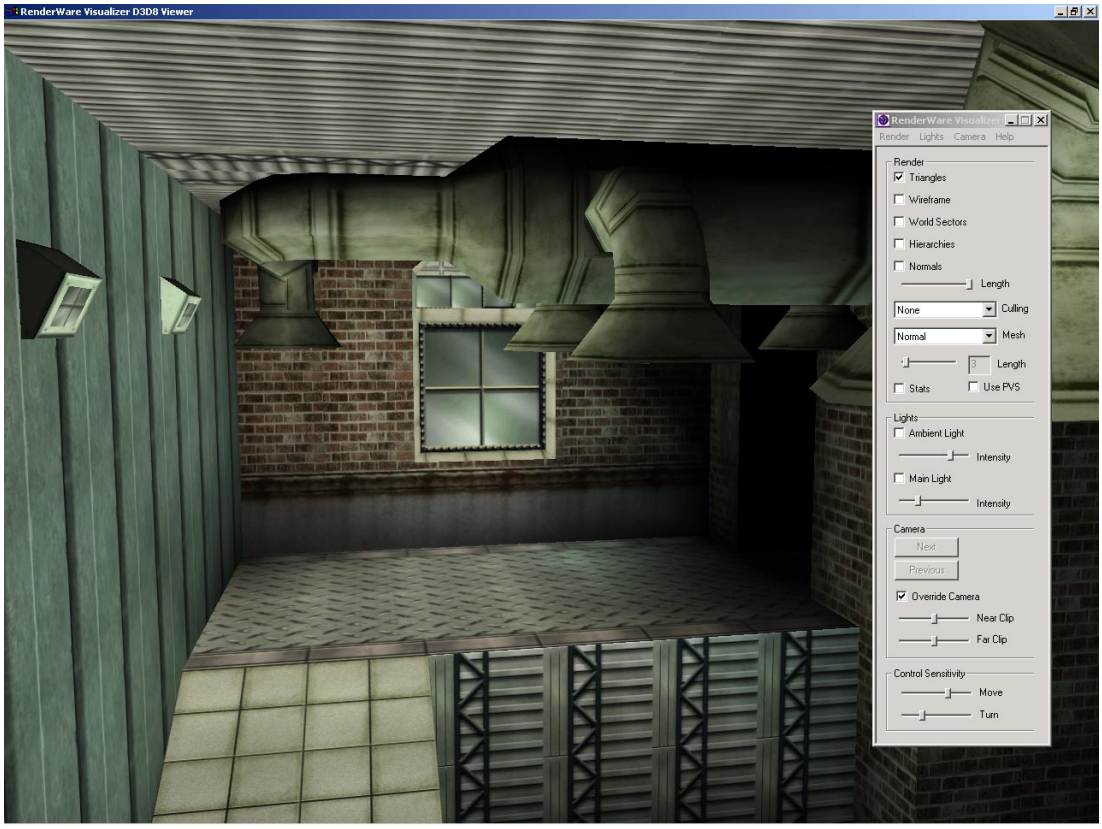
The fixed nature of static lights in static models means modification is impossible so the effect must be achieved by using dynamic models for areas where the static lights need to be modifiable.

Static lights in dynamic models

Static lighting in geometry objects can be modified at run-time to simulate glowing or pulsating lights and other similar lighting effects.

12.4 Related Examples

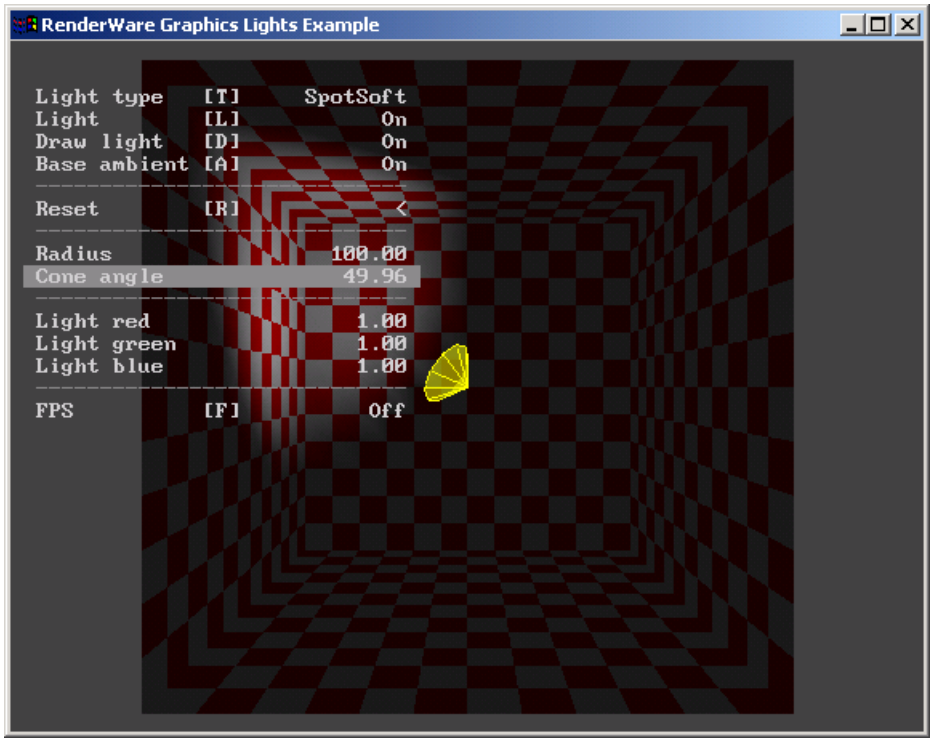
Static lights are not demonstrated by any one specific example. However, a model which has been exported from a modeling package with static lighting can be found in the **texdict** example. The model can be found in **models/dungeon.bsp**. RenderWare Visualizer can be used to view the model.



RenderWare Visualizer showing a model with static lighting

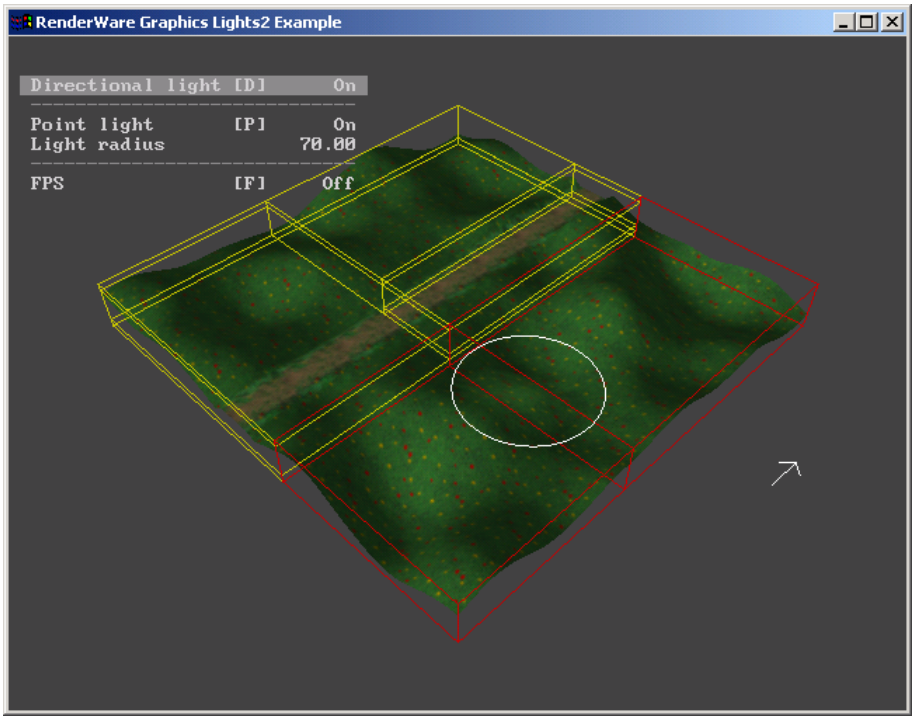
The SDK includes two examples covering dynamic lights: **lights** and **lights2**.

The **lights** example illustrates the different light types available for dynamic lights. Use the menu options to choose different types and combinations.



The **lights** example

The **lights2** example illustrates how lights interact with world sectors. When run, you will see a small landscape overlaid by wire-frame representations of the world sectors into which it has been divided.



The **lights2** example

Move the dynamic light around the scene to see how RenderWare Graphics links the light to world sectors according to the radius of its sphere of illumination.

The world sectors shown in the **lights2** example were created deliberately to show this effect; in normal usage, such a simple landscape would not make use of more than one world sector.

12.5 Summary

12.5.1 Dynamic Lights

Properties table

The table below lists the main properties of the reference dynamic lighting models. Additional properties may be added for platform-specific dynamic lighting models.

PROPERTY	AMB.	DIR.	POINT	SPOT	SOFTSPOT
`Color`	✓	✓	✓	✓	✓
`Flags`	✓	✓	✓	✓	✓
`Frame`		✓	✓	✓	✓
`Radius`			✓	✓	✓
`ConeAngle`				✓	✓

Dynamic Lighting: Main Features

- Five *reference* light types:
    - **`rpLIGHTAMBIENT`** – ambient
    - **`rpLIGHTDIRECTIONAL`** – directional
    - **`rpLIGHTPOINT`** – point-source
    - **`rpLIGHTSPOT`** – spot
    - **`rpLIGHTSOFTSPOT`** – soft-edged spot
- *Platform-specific* light types are provided where necessary for access to hardware lighting.
- Ambient lights do not require frames.
- Directional, point lights, spot lights and soft spot lights always require frames.
- All lights must be added to a world using **`RpWorldAddLight()`** if they are to affect the geometry within that world.
- All lights can selectively illuminate both static and dynamic geometry.
- The default light settings are intended to be "safe" on all supported platforms, but of little use in practice: you should explicitly set *all* of a dynamic light's properties on creation.

12.5.2 Static Lights

Static Lights: Main Features

- Also known as *prelights* or *prelighting*.
- A statically-lit model is known as a *prelit* model.
- Cheaper in terms of processing power.
- Prelit static models can be readily exported from modeling packages.
- Prelit dynamic models must have their prelight data initialized by the developer either in a custom tool, or at run-time.
- Prelights are not real lights. They are fixed vertex illumination levels and have no effect on nearby models.
- Prelights in static models cannot be changed or modified in any way whatsoever. They are not exposed.
- A pointer to the prelight data in dynamic models can be retrieved using **`RpGeometryGetPreLightColors()`**.

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