



MongoDB Administrator Training

MongoDB Administrator Training

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1 Introduction

Warm Up (page 4) Activities to get the class started

MongoDB - The Company (page 5) About MongoDB, the company

MongoDB Overview (page 5) MongoDB philosophy and features

MongoDB Stores Documents (page 8) The structure of data in MongoDB

MongoDB Data Types (page 11) An overview of BSON data types in MongoDB

Lab: Installing and Configuring MongoDB (page 14) Install MongoDB and experiment with a few operations.

1.1 Warm Up

Introductions

- Who am I?
- My role at MongoDB
- My background and prior experience

Getting to Know You

- Who are you?
- What role do you play in your organization?
- What is your background?
- Do you have prior experience with MongoDB?

MongoDB Experience

- Who has never used MongoDB?
- Who has some experience?
- Who has worked with production MongoDB deployments?
- Who is more of a developer?
- Who is more of an operations person?

Logistics

1.2 MongoDB - The Company

10gen

- MongoDB was initially created in 2008 as part of a hosted application stack.
- The company was originally called 10gen.
- As part of their overarching plan to create the 10gen platform, the company built a database.
- Suddenly everybody said: “I like that! Give me that database!”

Origin of MongoDB

- 10gen became a database company.
- In 2013, the company rebranded as MongoDB, Inc.
- The founders have other startups to their credit: DoubleClick, ShopWiki, Gilt.
- The motivation for the database came from observing the following pattern with application development.
 - The user base grows.
 - The associated body of data grows.
 - Eventually the application outgrows the database.
 - Meeting performance requirements becomes difficult.

1.3 MongoDB Overview

Learning Objectives

Upon completing this module students should understand:

- MongoDB vs. relational databases and key/value stores
- Vertical vs. horizontal scaling
- The role of MongoDB in the development stack
- The structure of documents in MongoDB
- Array fields
- Embedded documents
- Fundamentals of BSON

MongoDB is a Document Database

Documents are associative arrays like:

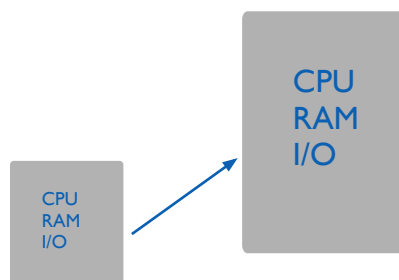
- Python dictionaries
- Ruby hashes
- PHP arrays
- JSON objects

An Example MongoDB Document

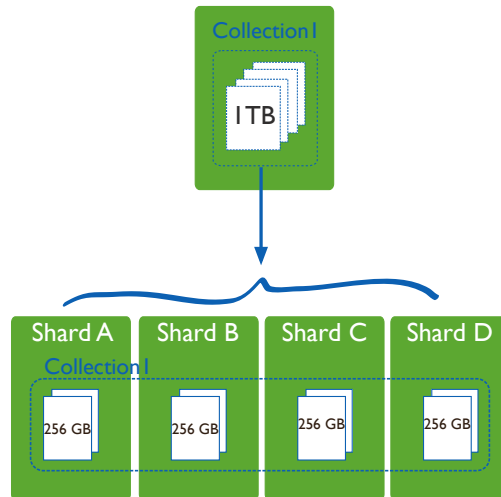
A MongoDB document expressed using JSON syntax.

```
{
  "_id" : "/apple-reports-second-quarter-revenue",
  "headline" : "Apple Reported Second Quarter Revenue Today",
  "date" : ISODate("2015-03-24T22:35:21.908Z"),
  "author" : {
    "name" : "Bob Walker",
    "title" : "Lead Business Editor"
  },
  "copy" : "Apple beat Wall St expectations by reporting ...",
  "tags" : [
    "AAPL", "Earnings", "Cupertino"
  ],
  "comments" : [
    { "name" : "Frank", "comment" : "Great Story" },
    { "name" : "Wendy", "comment" : "When can I buy an Apple Watch?" }
  ]
}
```

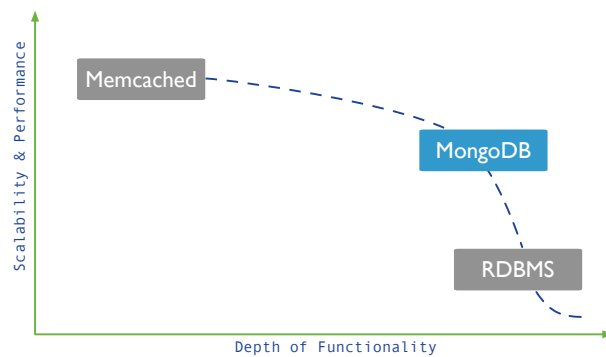
Vertical Scaling



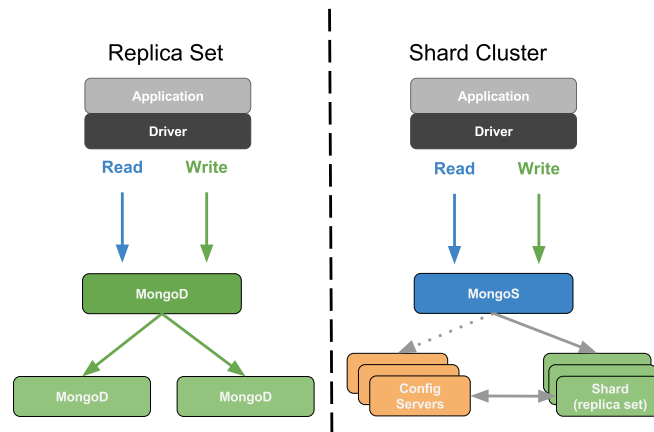
Scaling with MongoDB



Database Landscape



MongoDB Deployment Models



1.4 MongoDB Stores Documents

Learning Objectives

Upon completing this module, students should understand:

- JSON
- BSON basics
- That documents are organized into collections

JSON

- JavaScript Object Notation
- Objects are associative arrays.
- They are composed of key-value pairs.

A Simple JSON Object

```
{  
  "firstname" : "Thomas",  
  "lastname"  : "Smith",  
  "age"       : 29  
}
```

JSON Keys and Values

- Keys must be strings.
- Values may be any of the following:
 - string (e.g., "Thomas")
 - number (e.g., 29, 3.7)
 - true / false
 - null
 - array (e.g., [88.5, 91.3, 67.1])
 - object
- More detail at json.org¹.

Example Field Values

```
{  
  "headline" : "Apple Reported Second Quarter Revenue Today",  
  "date"      : ISODate("2015-03-24T22:35:21.908Z"),  
  "views"     : 1234,  
  "author"    : {  
    "name" : "Bob Walker",  
    "title" : "Lead Business Editor"  
  },  
  "tags" : [  
    "AAPL",  
    23,  
    { "name" : "city", "value" : "Cupertino" },  
    { "name" : "stockPrice", "value": NumberDecimal("143.51") },  
    [ "Electronics", "Computers" ]  
  ]  
}
```

¹ <http://json.org/>

BSON

- MongoDB stores data as Binary JSON (BSON).
- MongoDB drivers send and receive data in this format.
- They map BSON to native data structures.
- BSON provides support for all JSON data types and several others.
- BSON was designed to be lightweight, traversable and efficient.
- See bsonspec.org².

BSON Hello World

```
// JSON
{ "hello" : "world" }

// BSON
x16 x0 x0 x0      // document size
  x2              // type 2=string
  h e l l o x0    // name of the field, null terminated
  x6 x0 x0 x0     // size of the string value
  w o r l d x0    // string value, null terminated
x0               // end of document
```

A More Complex BSON Example

```
// JSON
{ "BSON" : [ "awesome", 5.05, 1986 ] }

// BSON
x31 x0 x0 x0      // document size
  x4              // type=4, array
  B S O N x0      // name of first element
  x26 x0 x0 x0    // size of the array, in bytes
    x2            // type=2, string
    x30 x0        // element name '0'
    x8 x0 x0 x0   // size of value for array element 0
    a w e s o m e x0 // string value for element 0
    x1            // type=1, double
    x31 x0        // element name '1'
    x33 x33 x33 x33 x33 x33 x14 x40 // double value for array element 1
    x10           // type=16, int32
    x32 x0        // element name '2'
    xc2 x7 x0 x0  // int32 value for array element 2
  x0
x0
```

² <http://bsonspec.org/#/specification>

Documents, Collections, and Databases

- Documents are stored in collections.
- Collections are contained in a database.
- Example:
 - Database: products
 - Collections: books, movies, music
- Each database-collection combination defines a namespace.
 - products.books
 - products.movies
 - products.music

The `_id` Field

- All documents must have an `_id` field.
- If no `_id` is specified when a document is inserted, MongoDB will add the `_id` field as an `ObjectId`.
- Most drivers will actually create the `ObjectId` if no `_id` is specified.
- Some restrictions:
 - The `_id` is immutable.
 - Can not be an array
 - The `_id` field must be unique to a collection
 - * acts as *Primary key* for replication.

1.5 MongoDB Data Types

Learning Objectives

By the end of this module, students should understand:

- What data types MongoDB supports
- Special consideration for some BSON types

What is BSON?

BSON is a binary serialization of JSON, used to store documents and make remote procedure calls in MongoDB. For more in-depth coverage of BSON, specifically refer to bsonspec.org³

Note: All official MongoDB drivers map BSON to native types and data structures

BSON types

MongoDB supports a wide range of BSON types. Each data type has a corresponding number and string alias that can be used with the `$type` operator to query documents by BSON type.

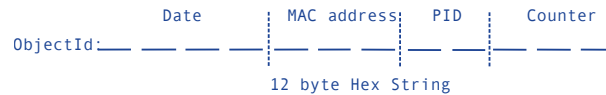
Double 1 “double”
String 2 “string”
Object 3 “object”
Array 4 “array”
Binary data 5 “binData”
ObjectId 7 “objectId”
Boolean 8 “bool”
Date 9 “date”
Null 10 “null”

BSON types continued

Regular Expression 11 “regex”
JavaScript 13 “javascript”
JavaScript (w/ scope) 15 “javascriptWithScope”
32-bit integer 16 “int”
Timestamp 17 “timestamp”
64-bit integer 18 “long”
Decimal128 19 “decimal”
Min key -1 “minKey”
Max key 127 “maxKey”

³ <http://bsonspec.org/>

ObjectId



```
> ObjectId()  
ObjectId("58dc309ce3f39998099d6275")
```

Timestamps

BSON has a special timestamp type for *internal* MongoDB use and is **not** associated with the regular Date type.

Date

BSON Date is a 64-bit integer that represents the number of milliseconds since the Unix epoch (Jan 1, 1970). This results in a representable date range of about 290 million years into the past and future.

- Official BSON spec refers to the BSON Date type as UTC datetime
- Signed data type. Negative values represent dates before 1970.

```
var today = ISODate() // using the ISODate constructor
```

Decimal

In MongoDB 3.4, support was added for 128-bit decimals.

- The **decimal** BSON type uses the decimal128 decimal-based floating-point numbering format.
- This supports 34 significant digits and an exponent range of **-6143** to **+6144**.
- Intended for applications that handle monetary and scientific data that requires exact precision.

How to use Decimal

For specific information about how your preferred driver supports decimal128, click [here](https://docs.mongodb.com/ecosystem/drivers/)⁴.

In the Mongo shell, we use the *NumberDecimal()* constructor.

- Can be created with a string argument or a double
- Stored in the database as *NumberDecimal*("999.4999")

```
> NumberDecimal("999.4999")  
NumberDecimal("999.4999")  
> NumberDecimal(999.4999)  
NumberDecimal("999.4999")
```

⁴ <https://docs.mongodb.com/ecosystem/drivers/>

Decimal Considerations

- If upgrading an existing database to use **decimal128**, it is recommended a new field be added to reflect the new type. The old field may be deleted after verifying consistency
- If any fields contain **decimal128** data, they will not be compatible with previous versions of MongoDB. There is no support for downgrading datafiles containing decimals
- **decimal** types are not strictly equal to their **double** representations, so use the **NumberDecimal** constructor in queries.

1.6 Lab: Installing and Configuring MongoDB

Learning Objectives

Upon completing this exercise students should understand:

- How MongoDB is distributed
- How to install MongoDB
- Configuration steps for setting up a simple MongoDB deployment
- How to run MongoDB
- How to run the Mongo shell

Production Releases

64-bit production releases of MongoDB are available for the following platforms.

- Windows
- OSX
- Linux

Installing MongoDB

- Visit <https://docs.mongodb.com/manual/installation/>.
- Please install the Enterprise version of MongoDB.
- Click on the appropriate link, such as “Install on Windows” or “Install on OS X” and follow the instructions.
- Versions:
 - Even-numbered builds are production releases, e.g., 2.4.x, 2.6.x.
 - Odd-numbers indicate development releases, e.g., 2.5.x, 2.7.x.

Linux Setup

```
PATH=$PATH:<path to mongodb>/bin

sudo mkdir -p /data/db

sudo chmod -R 744 /data/db

sudo chown -R `whoami` /data/db
```

Install on Windows

- Download and run the .msi Windows installer from mongodb.org/downloads.
- By default, binaries will be placed in the following directory.

```
C:\Program Files\MongoDB\Server\<VERSION>\bin
```

- It is helpful to add the location of the MongoDB binaries to your path.
- To do this, from “System Properties” select “Advanced” then “Environment Variables”

Create a Data Directory on Windows

- Ensure there is a directory for your MongoDB data files.
- The default location is \data\db.
- Create a data directory with a command such as the following.

```
md \data\db
```

Launch a mongod

Explore the mongod command.

```
<path to mongodb>/bin/mongod --help
```

Launch a mongod with the MMAPv1 storage engine:

```
<path to mongodb>/bin/mongod --storageEngine mmapv1
```

Alternatively, launch with the WiredTiger storage engine (default).

```
<path to mongodb>/bin/mongod
```

Specify an alternate path for data files using the `--dbpath` option. (Make sure the directory already exists.) E.g.,

```
<path to mongodb>/bin/mongod --dbpath /test/mongodb/data/wt
```

The MMAPv1 Data Directory

```
ls /data/db
```

- The mongod.lock file
 - This prevents multiple mongods from using the same data directory simultaneously.
 - Each MongoDB database directory has one .lock.
 - The lock file contains the process id of the mongod that is using the directory.
- Data files
 - The names of the files correspond to available databases.
 - A single database may have multiple files.

The WiredTiger Data Directory

```
ls /data/db
```

- The mongod.lock file
 - Used in the same way as MMAPv1.
- Data files
 - Each collection and index stored in its own file.
 - Will fail to start if MMAPv1 files found

Import Exercise Data

```
unzip usb_drive.zip
cd usb_drive
mongoimport -d sample -c tweets twitter.json
mongoimport -d sample -c zips zips.json
mongoimport -d sample -c grades grades.json
cd dump
mongorestore -d sample city
mongorestore -d sample digg
```

Note: If there is an error importing data directly from a USB drive, please copy the sampledata.zip file to your local computer first.

Launch a Mongo Shell

Open another command shell. Then type the following to start the Mongo shell.

```
mongo
```

Display available commands.

```
help
```

Explore Databases

Display available databases.

```
show dbs
```

To use a particular database we can type the following.

```
use <database_name>
```

```
db
```

Exploring Collections

```
show collections
```

```
db.<COLLECTION>.help()
```

```
db.<COLLECTION>.find()
```

Admin Commands

- There are also a number of admin commands at our disposal.
- The following will shut down the mongod we are connected to through the Mongo shell.
- You can also just kill with Ctrl-C in the shell window from which you launched the mongod.

```
db.adminCommand( { shutdown : 1 } )
```

- Confirm that the mongod process has indeed stopped.
- Once you have, please restart it.

2 Storage

Introduction to Storage Engines (page 18) MongoDB storage engines

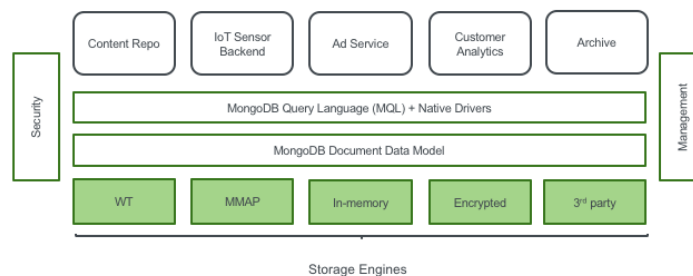
2.1 Introduction to Storage Engines

Learning Objectives

Upon completing this module, students should be familiar with:

- Available storage engines in MongoDB
- MongoDB journaling mechanics
- The default storage engine for MongoDB
- Common storage engine parameters
- The storage engine API

What is a Database Storage Engine?



How Storage Engines Affect Performance

- Writing and reading documents
- Concurrency
- Compression algorithms
- Index format and implementation
- On-disk format

Storage Engine Journaling

- Keep track of all changes made to data files
- Stage writes sequentially before they can be committed to the data files
- Crash recovery, writes from journal can be replayed to data files in the event of a failure

MongoDB Storage Engines

As of MongoDB 3.4, three storage engine options are available:

- WiredTiger (default)
 - with the option of on-disk/at rest encryption (Enterprise only)
- MMAPv1
- In-memory storage (Enterprise only)

Specifying a MongoDB Storage Engine

Use the `--storageEngine` parameter to specify which storage engine MongoDB should use. E.g.,

```
mongod --storageEngine mmapv1
```

Specifying a Location to Store Data Files

- Use the `dbpath` parameter

```
mongod --dbpath /data/db
```

- Other files are also stored here. E.g.,
 - `mongod.lock` file
 - `journal`
- See the MongoDB docs for a complete list of [storage options](http://docs.mongodb.org/manual/reference/program/mongod/#storage-options)⁵.

⁵ <http://docs.mongodb.org/manual/reference/program/mongod/#storage-options>

MMAPv1 Storage Engine

- MMAPv1 is MongoDB's original storage engine was the default up to MongoDB 3.0.
- specify the use of the MMAPv1 storage engine as follows:

```
mongod --storageEngine mmapv1
```

- MMAPv1 is based on memory-mapped files, which map data files on disk into virtual memory.
- As of MongoDB 3.0, MMAPv1 supports collection-level concurrency.

MMAPv1 Workloads

MMAPv1 excels at workloads where documents do not outgrow their original record size:

- High-volume inserts
- Read-only workloads
- In-place updates

Power of 2 Sizes Allocation Strategy

- MongoDB 3.0 uses allocation as the default record allocation strategy for MMAPv1.
- With this strategy, records include the document plus extra space, or padding.
- Each record has a size in bytes that is a power of 2 (e.g. 32, 64, 128, ... 2MB).
- For documents larger than 2MB, allocation is rounded up to the nearest multiple of 2MB.
- This strategy enables MongoDB to efficiently reuse freed records to reduce fragmentation.
- In addition, the added padding gives a document room to grow without requiring a move.
 - Saves the cost of moving a document
 - Results in fewer updates to indexes

Compression in MongoDB

- Compression can significantly reduce the amount of disk space / memory required.
- The tradeoff is that compression requires more CPU.
- MMAPv1 does not support compression.
- WiredTiger does.

WiredTiger Storage Engine

- The WiredTiger storage engine excels at all workloads, especially write-heavy and update-heavy workloads.
- Notable features of the WiredTiger storage engine that do not exist in the MMAPv1 storage engine include:
 - Compression
 - Document-level concurrency
- Default storage engine since MongoDB 3.2.
- For older versions, specify the use of the WiredTiger storage engine as follows.

```
mongod --storageEngine wiredTiger
```

WiredTiger Compression Options

- `snappy` (default): less CPU usage than `zlib`, less reduction in data size
- `zlib`: greater CPU usage than `snappy`, greater reduction in data size
- no compression

Configuring Compression in WiredTiger

Use the `wiredTigerCollectionBlockCompressor` parameter. E.g.,

```
mongod --storageEngine wiredTiger
       --wiredTigerCollectionBlockCompressor zlib
```

Configuring Memory Usage in WiredTiger

Use the `wiredTigerCacheSize` parameter to designate the amount of RAM for the cache used by the WT storage engine.

- By default, this value is set to the maximum of:
 - 50% of physical RAM minus 1GB or 256 MB (for MongoDB 3.4+)
 - 60% of physical RAM minus 1GB or 1GB (for MongoDB 3.2)
- Additionally, MongoDB uses memory for connections, aggregations, sorts, ...
- The rest of the memory is used by the File System Cache, which is also needed by WT for optimal performance.

Journaling in MMAPv1 vs. WiredTiger

- MMAPv1 uses write-ahead journaling to ensure consistency and durability between fsyncs.
- WiredTiger uses a write-ahead log in combination with checkpoints to ensure durability.
- Regardless of storage engine, always use journaling in production.

MMAPv1 Journaling Mechanics

- Journal files in <DATA-DIR>/journal are append only
- 1GB per journal file
- Once MongoDB applies all write operations from a journal file to the database data files, it deletes the journal file (or re-uses it)
- Usually only a few journal files in the <DATA-DIR>/journal directory

MMAPv1 Journaling Mechanics (Continued)

- Data is flushed from the shared view to data files every 60 seconds (configurable)
- The operating system may force a flush at a higher frequency than 60 seconds if the system is low on free memory
- Once a journal file contains only flushed writes, it is no longer needed for recovery and can be deleted or re-used

WiredTiger Journaling Mechanics

- WiredTiger will commit a checkpoint to disk every 60 seconds or when there are 2 gigabytes of data to write.
- Between and during checkpoints the data files are always valid.
- The WiredTiger journal persists all data modifications between checkpoints.
- If MongoDB exits between checkpoints, it uses the journal to replay all data modified since the last checkpoint.
- By default, WiredTiger journal is compressed using snappy.

Storage Engine API

MongoDB 3.0 introduced a storage engine API:

- Abstracted storage engine functionality in the code base
- Easier for MongoDB to develop future storage engines
- Easier for third parties to develop their own MongoDB storage engines

Conclusion

- MongoDB 3.0 introduces pluggable storage engines.
- Current options include:
 - MMAPv1 (default)
 - WiredTiger
- WiredTiger introduces the following to MongoDB:
 - Compression
 - Document-level concurrency

3 CRUD

Creating and Deleting Documents (page 24) Inserting documents into collections, deleting documents, and dropping collections

Reading Documents (page 29) The find() command, query documents, dot notation, and cursors

Query Operators (page 36) MongoDB query operators including: comparison, logical, element, and array operators

Lab: Finding Documents (page 40) Exercises for querying documents in MongoDB

Updating Documents (page 40) Using update methods and associated operators to mutate existing documents

Lab: Updating Documents (page 49) Exercises for updating documents in MongoDB

3.1 Creating and Deleting Documents

Learning Objectives

Upon completing this module students should understand:

- How to insert documents into MongoDB collections.
- `_id` fields:
- How to delete documents from a collection
- How to remove a collection from a database
- How to remove a database from a MongoDB deployment

Creating New Documents

- Create documents using `insertOne()` and `insertMany()`.
- For example:

```
// Specify the collection name
db.<COLLECTION>.insertOne( { "name" : "Mongo" } )

// For example
db.people.insertOne( { "name" : "Mongo" } )
```

Example: Inserting a Document

Experiment with the following commands.

```
use sample

db.movies.insertOne( { "title" : "Jaws" } )

db.movies.find()
```

Implicit `_id` Assignment

- We did not specify an `_id` in the document we inserted.
- If you do not assign one, MongoDB will create one automatically.
- The value will be of type `ObjectId`.

Example: Assigning `_ids`

Experiment with the following commands.

```
db.movies.insertOne( { "_id" : "Jaws", "year" : 1975 } )

db.movies.find()
```

Inserts will fail if...

- There is already a document in the collection with that `_id`.
- You try to assign an array to the `_id`.
- The argument is not a well-formed document.

Example: Inserts will fail if...

```
// fails because _id can't have an array value
db.movies.insertOne( { "_id" : [ "Star Wars",
                                "The Empire Strikes Back",
                                "Return of the Jedi" ] } )

// succeeds
db.movies.insertOne( { "_id" : "Star Wars" } )

// fails because of duplicate id
db.movies.insertOne( { "_id" : "Star Wars" } )

// malformed document
db.movies.insertOne( { "Star Wars" } )
```

insertMany()

- You may bulk insert using an array of documents.
- Use `insertMany()` instead of `insertOne()`

Ordered insertMany()

- For ordered inserts MongoDB will stop processing inserts upon encountering an error.
- Meaning that only inserts occurring before an error will complete.
- The default setting for `db.<COLLECTION>.insertMany` is an ordered insert.
- See the next exercise for an example.

Example: Ordered insertMany()

Experiment with the following operation.

```
db.movies.insertMany( [ { "_id" : "Batman", "year" : 1989 },
                        { "_id" : "Home Alone", "year" : 1990 },
                        { "_id" : "Ghostbusters", "year" : 1984 },
                        { "_id" : "Ghostbusters", "year" : 1984 } ] )
db.movies.find()
```

Unordered insertMany()

- Pass `{ ordered : false }` to `insertMany()` to perform unordered inserts.
- If any given insert fails, MongoDB will still attempt all of the others.
- The inserts may be executed in a different order than you specified.
- The next exercise is very similar to the previous one.
- However, we are using `{ ordered : false }`.
- One insert will fail, but all the rest will succeed.

Example: Unordered insertMany()

Experiment with the following insert.

```
db.movies.insertMany( [ { "_id" : "Jaws", "year" : 1975 },
                        { "_id" : "Titanic", "year" : 1997 },
                        { "_id" : "The Lion King", "year" : 1994 } ],
                      { ordered : false } )
db.movies.find()
```

The Shell is a JavaScript Interpreter

- Sometimes it is convenient to create test data using a little JavaScript.
- The mongo shell is a fully-functional JavaScript interpreter. You may:
 - Define functions
 - Use loops
 - Assign variables
 - Perform inserts

Exercise: Creating Data in the Shell

Experiment with the following commands.

```
for (i=1; i<=10000; i++) {  
  db.stuff.insert( { "a" : i } )  
}  
  
db.stuff.find()
```

Deleting Documents

You may delete documents from a MongoDB deployment in several ways.

- Use `deleteOne()` and `deleteMany()` to delete documents matching a specific set of conditions.
- Drop an entire collection.
- Drop a database.

Using `deleteOne()`

- Delete a document from a collection using `deleteOne()`
- This command has one required parameter, a query document.
- The first document in the collection matching the query document will be deleted.

Using deleteMany()

- Delete multiple documents from a collection using deleteMany().
- This command has one required parameter, a query document.
- All documents in the collection matching the query document will be deleted.
- Pass an empty document to delete all documents.

Example: Deleting Documents

Experiment with removing documents. Do a find() after each deleteMany() command below.

```
for (i=1; i<=20; i++) { db.testcol.insertOne( { _id : i, a : i } ) }

db.testcol.deleteMany( { a : 1 } ) // Delete the first document

// $lt is a query operator that enables us to select documents that
// are less than some value. More on operators soon.
db.testcol.deleteMany( { a : { $lt : 5 } } ) // Remove three more

db.testcol.deleteOne( { a : { $lt : 10 } } ) // Remove one more

db.testcol.deleteMany() // Error: requires a query document.

db.testcol.deleteMany( { } ) // All documents removed
```

Dropping a Collection

- You can drop an entire collection with db.<COLLECTION>.drop()
- The collection and all documents will be deleted.
- It will also remove any metadata associated with that collection.
- Indexes are one type of metadata removed.
- **All collection and indexes files are removed and space allocated reclaimed.**
 - Wired Tiger only!
- More on meta data later.

Example: Dropping a Collection

```
db.colToBeDropped.insertOne( { a : 1 } )
show collections // Shows the colToBeDropped collection

db.colToBeDropped.drop()
show collections // collection is gone
```

Dropping a Database

- You can drop an entire database with `db.dropDatabase()`
- This drops the database on which the method is called.
- It also deletes the associated data files from disk, freeing disk space.
- Beware that in the mongo shell, this does not change database context.

Example: Dropping a Database

```
use tempDB
db.testcoll1.insertOne( { a : 1 } )
db.testcoll2.insertOne( { a : 1 } )

show dbs // Here they are
show collections // Shows the two collections

db.dropDatabase()
show collections // No collections
show dbs // The db is gone

use sample // take us back to the sample db
```

3.2 Reading Documents

Learning Objectives

Upon completing this module students should understand:

- The query-by-example paradigm of MongoDB
- How to query on array elements
- How to query embedded documents using dot notation
- How the mongo shell and drivers use cursors
- Projections
- Cursor methods: `.count()`, `.sort()`, `.skip()`, `.limit()`

The `find()` Method

- This is the fundamental method by which we read data from MongoDB.
- We have already used it in its basic form.
- `find()` returns a cursor that enables us to iterate through all documents matching a query.
- We will discuss cursors later.

Query by Example

- To query MongoDB, specify a document containing the key / value pairs you want to match
- You need only specify values for fields you care about.
- Other fields will not be used to exclude documents.
- The result set will include all documents in a collection that match.

Example: Querying by Example

Experiment with the following sequence of commands.

```
db.movies.drop()
db.movies.insertMany( [
  { "title" : "Jaws", "year" : 1975, "imdb_rating" : 8.1 },
  { "title" : "Batman", "year" : 1989, "imdb_rating" : 7.6 }
] )
db.movies.find()

db.movies.find( { "year" : 1975 } )

// Multiple Batman movies from different years, find the correct one
db.movies.find( { "year" : 1989, "title" : "Batman" } )
```

Querying Arrays

- In MongoDB you may query array fields.
- Specify a single value you expect to find in that array in desired documents.
- Alternatively, you may specify an entire array in the query document.
- As we will see later, there are also several operators that enhance our ability to query array fields.

Example: Querying Arrays

```
db.movies.drop()
db.movies.insertMany(
  [{ "title" : "Batman", "category" : [ "action", "adventure" ] },
    { "title" : "Godzilla", "category" : [ "action", "adventure", "sci-fi" ] },
    { "title" : "Home Alone", "category" : [ "family", "comedy" ] }
  ])

// Match documents where "category" contains the value specified
db.movies.find( { "category" : "action" } )

// Match documents where "category" equals the value specified
db.movies.find( { "category" : [ "action", "sci-fi" ] } ) // no documents

// only the second document
db.movies.find( { "category" : [ "action", "adventure", "sci-fi" ] } )
```

Querying with Dot Notation

- Dot notation is used to query on fields in embedded documents.
- The syntax is:

```
"field1.field2" : value
```

- Put quotes around the field name when using dot notation.

Example: Querying with Dot Notation

```
db.movies.insertMany(
  [ {
    "title" : "Avatar",
    "box_office" : { "gross" : 760,
                    "budget" : 237,
                    "opening_weekend" : 77
                  },
  },
    {
    "title" : "E.T.",
    "box_office" : { "gross" : 349,
                    "budget" : 10.5,
                    "opening_weekend" : 14
                  },
  }
  ] )

db.movies.find( { "box_office" : { "gross" : 760 } } ) // no values

// dot notation
db.movies.find( { "box_office.gross" : 760 } ) // expected value
```

Example: Arrays and Dot Notation

```
db.movies.insertMany( [
  { "title" : "E.T.",
    "filming_locations" :
      [ { "city" : "Culver City", "state" : "CA", "country" : "USA" },
        { "city" : "Los Angeles", "state" : "CA", "country" : "USA" },
        { "city" : "Cresecent City", "state" : "CA", "country" : "USA" }
      ] },
  { "title": "Star Wars",
    "filming_locations" :
      [ { "city" : "Ajim", "state" : "Jerba", "country" : "Tunisia" },
        { "city" : "Yuma", "state" : "AZ", "country" : "USA" }
      ] } ] )

db.movies.find( { "filming_locations.country" : "USA" } ) // two documents
```

Projections

- You may choose to have only certain fields appear in result documents.
- This is called projection.
- You specify a projection by passing a second parameter to `find()`.

Projection: Example (Setup)

```
db.movies.insertOne(
{
  "title" : "Forrest Gump",
  "category" : [ "drama", "romance" ],
  "imdb_rating" : 8.8,
  "filming_locations" : [
    { "city" : "Savannah", "state" : "GA", "country" : "USA" },
    { "city" : "Monument Valley", "state" : "UT", "country" : "USA" },
    { "city" : "Los Anegeles", "state" : "CA", "country" : "USA" }
  ],
  "box_office" : {
    "gross" : 557,
    "opening_weekend" : 24,
    "budget" : 55
  }
})
```

Projection: Example

```
db.movies.findOne( { "title" : "Forrest Gump" },
                  { "title" : 1, "imdb_rating" : 1 } )
{
  "_id" : ObjectId("5515942d31117f52a5122353"),
  "title" : "Forrest Gump",
  "imdb_rating" : 8.8
}
```

Projection Documents

- Include fields with `fieldName: 1`.
 - Any field not named will be excluded
 - except `_id`, which must be explicitly excluded.
- Exclude fields with `fieldName: 0`.
 - Any field not named will be included.

Example: Projections

```
for (i=1; i<=20; i++) {
  db.movies.insertOne(
    { "_id" : i, "title" : i,
      "imdb_rating" : i, "box_office" : i } )
}
db.movies.find()
// no "box_office"
db.movies.find( { "_id" : 3 }, { "title" : 1, "imdb_rating" : 1 } )
// no "imdb_rating"
db.movies.find( { "_id" : { $gte : 10 } }, { "imdb_rating" : 0 } )
// just "title"
db.movies.find( { "_id" : 4 }, { "_id" : 0, "title" : 1 } )
// just "imdb_rating", "box_office"
db.movies.find( { "_id" : 5 }, { _id : 0, "title" : 0 } )
// Can't mix inclusion/exclusion except _id
db.movies.find( { "_id" : 6 }, { "title" : 1, "imdb_rating" : 0 } )
```

Cursors

- When you use `find()`, MongoDB returns a cursor.
- A cursor is a pointer to the result set
- You can get iterate through documents in the result using `next()`.
- By default, the mongo shell will iterate through 20 documents at a time.

Example: Introducing Cursors

```
db.testcol.drop()
for (i=1; i<=10000; i++) {
    db.testcol.insertOne( { a : Math.floor( Math.random() * 100 + 1 ),
                          b : Math.floor( Math.random() * 100 + 1 ) } )
}
db.testcol.find()

it
it
```

Example: Cursor Objects in the Mongo Shell

```
// Assigns the cursor returned by find() to a variable x
var x = db.testcol.find()

// Displays the first document in the result set.
x.next()

// True because there are more documents in the result set.
x.hasNext()

// Assigns the next document in the result set to the variable y.
y = x.next()

// Return value is the value of the a field of this document.
y.a

// Displaying a cursor prints the next 20 documents in the result set.
x
```

Cursor Methods

- `count()`: Returns the number of documents in the result set.
- `limit()`: Limits the result set to the number of documents specified.
- `skip()`: Skips the number of documents specified.

Example: Using `count()`

```
db.testcol.drop()
for (i=1; i<=100; i++) { db.testcol.insertOne( { a : i } ) }

// all 100
db.testcol.count()

// just 41 docs
db.testcol.count( { a : { $lt : 42 } } )

// Another way of writing the same query
db.testcol.find( { a : { $lt : 42 } } ).count( )
```

Example: Using sort ()

```
db.testcol.drop()
for (i=1; i<=20; i++) {
    db.testcol.insertOne( { a : Math.floor( Math.random() * 10 + 1 ),
                           b : Math.floor( Math.random() * 10 + 1 ) } )
}

db.testcol.find()

// sort descending; use 1 for ascending
db.testcol.find().sort( { a : -1 } )

// sort by b, then a
db.testcol.find().sort( { b : 1, a : 1 } )

// $natural order is just the order on disk.
db.testcol.find().sort( { $natural : 1 } )
```

The skip () Method

- Skips the specified number of documents in the result set.
- The returned cursor will begin at the first document beyond the number specified.
- Regardless of the order in which you specify skip () and sort () on a cursor, sort () happens first.

The limit () Method

- Limits the number of documents in a result set to the first k.
- Specify k as the argument to limit ()
- Regardless of the order in which you specify limit (), skip (), and sort () on a cursor, sort () happens first.
- Helps reduce resources consumed by queries.

The distinct () Method

- Returns all values for a field found in a collection.
- Only works on one field at a time.
- Input is a string (not a document)

Example: Using distinct ()

```
db.movie_reviews.drop()
db.movie_reviews.insertMany( [
  { "title" : "Jaws", "rating" : 5 },
  { "title" : "Home Alone", "rating" : 1 },
  { "title" : "Jaws", "rating" : 7 },
  { "title" : "Jaws", "rating" : 4 },
  { "title" : "Jaws", "rating" : 8 } ] )
db.movie_reviews.distinct( "title" )
```

3.3 Query Operators

Learning Objectives

Upon completing this module students should understand the following types of MongoDB query operators:

- Comparison operators
- Logical operators
- Element query operators
- Operators on arrays

Comparison Query Operators

- \$lt: Exists and is less than
- \$lte: Exists and is less than or equal to
- \$gt: Exists and is greater than
- \$gte: Exists and is greater than or equal to
- \$ne: Does not exist or does but is not equal to
- \$in: Exists and is in a set
- \$nin: Does not exist or is not in a set

Example (Setup)

```
// insert sample data
db.movies.insertMany( [
  {
    "title" : "Batman",
    "category" : [ "action", "adventure" ],
    "imdb_rating" : 7.6,
    "budget" : 35
  },
  {
    "title" : "Godzilla",
    "category" : [ "action",
    "adventure", "sci-fi" ],
    "imdb_rating" : 6.6
  },
]
```

```

{
  "title" : "Home Alone",
  "category" : [ "family", "comedy" ],
  "imdb_rating" : 7.4
}
] )

```

Example: Comparison Operators

```

db.movies.find()

db.movies.find( { "imdb_rating" : { $gte : 7 } } )

db.movies.find( { "category" : { $ne : "family" } } )

db.movies.find( { "title" : { $in : [ "Batman", "Godzilla" ] } } )

db.movies.find( { "title" : { $nin : [ "Batman", "Godzilla" ] } } )

```

Logical Query Operators

- `$or`: Match either of two or more values
- `$not`: Used with other operators
- `$nor`: Match neither of two or more values
- `$and`: Match both of two or more values
 - This is the default behavior for queries specifying more than one condition.
 - Use `$and` if you need to include the same operator more than once in a query.

Example: Logical Operators

```

db.movies.find( { $or : [
  { "category" : "sci-fi" }, { "imdb_rating" : { $gte : 7 } }
] } )

// more complex $or, really good sci-fi movie or medicore family movie
db.movies.find( { $or : [
  { "category" : "sci-fi", "imdb_rating" : { $gte : 8 } },
  { "category" : "family", "imdb_rating" : { $gte : 7 } }
] } )

// find bad movies
db.movies.find( { "imdb_rating" : { $not : { $gt : 7 } } } )

```

Example: Logical Operators

```
// find movies within an imdb_rating range
db.movies.find( { "imdb_rating" : { $gt : 5 , $lte : 7 } } ) // and is implicit

// queries can be nested, why are there no results?
db.movies.find( { $and : [
  { $or : [
    { "category" : "sci-fi", "imdb_rating" : { $gte : 8 } },
    { "category" : "family", "imdb_rating" : { $gte : 7 } }
  ] } ,
  { $or : [
    { "category" : "action", "imdb_rating" : { $gte : 6 } }
  ] }
] } )
```

Element Query Operators

- `$exists`: Select documents based on the existence of a particular field.
- `$type`: Select documents based on their type.
- See [BSON types](#)⁶ for reference on types.

Example: Element Operators

```
db.movies.find( { "budget" : { $exists : true } } )

// type 1 is Double
db.movies.find( { "budget" : { $type : 1 } } )

// type 3 is Object (embedded document)
db.movies.find( { "budget" : { $type : 3 } } )
```

Array Query Operators

- `$all`: Array field must contain all values listed.
- `$size`: Array must have a particular size. E.g., `$size : 2` means 2 elements in the array
- `$elemMatch`: All conditions must be matched by at least one element in the array

⁶ <http://docs.mongodb.org/manual/reference/bson-types>

Example: Array Operators

```
db.movies.find( { "category" : { $all : [ "sci-fi", "action" ] } } )  
  
db.movies.find( { "category" : { $size : 3 } } )
```

Example: \$elemMatch

```
db.movies.insertOne( {  
  "title" : "Raiders of the Lost Ark",  
  "filming_locations" : [  
    { "city" : "Los Angeles", "state" : "CA", "country" : "USA" },  
    { "city" : "Rome", "state" : "Lazio", "country" : "Italy" },  
    { "city" : "Florence", "state" : "SC", "country" : "USA" }  
  ] } )  
  
// This query is incorrect, it won't return what we want  
db.movies.find( {  
  "filming_locations.city" : "Florence",  
  "filming_locations.country" : "Italy"  
} )  
  
// $elemMatch is needed, now there are no results, this is expected  
db.movies.find( {  
  "filming_locations" : {  
    $elemMatch : {  
      "city" : "Florence",  
      "country" : "Italy"  
    } } } )
```

3.4 Lab: Finding Documents

Exercise: student_id < 65

In the sample database, how many documents in the grades collection have a student_id less than 65?

Exercise: Inspection Result “Fail” & “Pass”

In the sample database, how many documents in the inspections collection have *result* “Pass” or “Fail”?

Exercise: View Count > 1000

In the stories collection, write a query to find all stories where the view count is greater than 1000.

Exercise: Most comments

Find the news article that has the most comments in the stories collection

Exercise: Television or Videos

Find all digg stories where the topic name is “Television” or the media type is “videos”. Skip the first 5 results and limit the result set to 10.

Exercise: News or Images

Query for all digg stories whose media type is either “news” or “images” and where the topic name is “Comedy”. (For extra practice, construct two queries using different sets of operators to do this.)

3.5 Updating Documents

Learning Objectives

Upon completing this module students should understand

- The `replaceOne()` method
- The `updateOne()` method
- The `updateMany()` method
- The required parameters for these methods
- Field update operators
- Array update operators
- The concept of an upsert and use cases.
- The `findOneAndReplace()` and `findOneAndUpdate()` methods

The `replaceOne()` Method

- Takes one document and replaces it with another
 - But leaves the `_id` unchanged
- Takes two parameters:
 - A matching document
 - A replacement document
- This is, in some sense, the simplest form of update

First Parameter to `replaceOne()`

- Required parameters for `replaceOne()`
 - The query parameter:
 - * Use the same syntax as with `find()`
 - * Only the first document found is replaced
- `replaceOne()` cannot delete a document

Second Parameter to `replaceOne()`

- The second parameter is the replacement parameter:
 - The document to replace the original document
- The `_id` must stay the same
- You must replace the entire document
 - You cannot modify just one field
 - Except for the `_id`

Example: `replaceOne()`

```
db.movies.insertOne( { title: "Batman" } )
db.movies.find()
db.movies.replaceOne( { title : "Batman" }, { imdb_rating : 7.7 } )
db.movies.find()
db.movies.replaceOne( { imdb_rating: 7.7 },
                      { title: "Batman", imdb_rating: 7.7 } )
db.movies.find()
db.movies.replaceOne( { }, { title: "Batman" } )
db.movies.find() // back in original state
db.movies.replaceOne( { }, { _id : ObjectId() } )
```

The updateOne () Method

- Mutate one document in MongoDB using updateOne ()
 - Affects only the _first_ document found
- Two parameters:
 - A query document
 - * same syntax as with find ()
 - Change document
 - * Operators specify the fields and changes

\$set and \$unset

- Use to specify fields to update for UpdateOne ()
- If the field already exists, using \$set will change its value
 - If not, \$set will create it, set to the new value
- Only specified fields will change
- Alternatively, remove a field using \$unset

Example (Setup)

```
db.movies.insertMany( [  
  {  
    "title" : "Batman",  
    "category" : [ "action", "adventure" ],  
    "imdb_rating" : 7.6,  
    "budget" : 35  
  },  
  {  
    "title" : "Godzilla",  
    "category" : [ "action",  
      "adventure", "sci-fi" ],  
    "imdb_rating" : 6.6  
  },  
  {  
    "title" : "Home Alone",  
    "category" : [ "family", "comedy" ],  
    "imdb_rating" : 7.4  
  }  
] )
```

Example: \$set and \$unset

```
db.movies.updateOne( { "title" : "Batman" },
                    { $set : { "imdb_rating" : 7.7 } } )
db.movies.updateOne( { "title" : "Godzilla" },
                    { $set : { "budget" : 1 } } )
db.movies.updateOne( { "title" : "Home Alone" },
                    { $set : { "budget" : 15,
                              "imdb_rating" : 5.5 } } )
db.movies.updateOne( { "title" : "Home Alone" },
                    { $unset : { "budget" : 1 } } )
db.movies.find()
```

Update Operators

- **\$inc**: Increment a field's value by the specified amount.
- **\$mul**: Multiply a field's value by the specified amount.
- **\$rename**: Rename a field.
- **\$set**: Update one or more fields (already discussed).
- **\$unset**: Delete a field (already discussed).
- **\$min**: Updates the field value to a specified value if the specified value is less than the current value of the field
- **\$max**: Updates the field value to a specified value if the specified value is greater than the current value of the field
- **\$currentDate**: Set the value of a field to the current date or timestamp.

Example: Update Operators

```
db.movies.updateOne( { title: "Batman" }, { $inc: { "imdb_rating" : 2 } } )
db.movies.updateOne( { title: "Home Alone" }, { $inc: { "budget" : 5 } } )
db.movies.updateOne( { title: "Batman" }, { $mul: { "imdb_rating" : 4 } } )
db.movies.updateOne( { title: "Batman" },
                    { $rename: { budget: "estimated_budget" } } )
db.movies.updateOne( { title: "Home Alone" }, { $min: { budget: 5 } } )
db.movies.updateOne( { title: "Home Alone" },
                    { $currentDate : { last_updated: { $type: "timestamp" } } } )
// increment movie rating by 1
db.movie_mentions.updateOne( { title: "Batman" },
                              { $inc: { "imdb_rating" : 1 } } )
```

The `updateMany()` Method

- Takes the same arguments as `updateOne`
- Updates all documents that match
 - `updateOne` stops after the first match
 - `updateMany` continues until it has matched all

Warning: Without an appropriate index, you may scan every document in the collection.

Example: `updateMany()`

```
// let's start tracking the number of sequels for each movie
db.movies.updateOne( { }, { $set : { "sequels" : 0 } } )
db.movies.find()
// we need updateMany to change all documents
db.movies.updateMany( { }, { $set : { "sequels" : 0 } } )
db.movies.find()
```

Array Element Updates by Index

- You can use dot notation to specify an array index
- You will update only that element
 - Other elements will not be affected

Example: Update Array Elements by Index

```
// add a sample document to track mentions per hour
db.movie_mentions.insertOne(
  { "title" : "E.T.",
    "day" : ISODate("2015-03-27T00:00:00.000Z"),
    "mentions_per_hour" : [ 0, 0, 0, 0, 0, 0, 0, 0,
                           0, 0, 0, 0, 0, 0, 0, 0, 0, 0,
                           0, 0 ]
  } )

// update all mentions for the fifth hour of the day
db.movie_mentions.updateOne(
  { "title" : "E.T." },
  { "$set" : { "mentions_per_hour.5" : 2300 } } )
```

Array Operators

- `$push`: Appends an element to the end of the array.
- `$pushAll`: Appends multiple elements to the end of the array.
- `$pop`: Removes one element from the end of the array.
- `$pull`: Removes all elements in the array that match a specified value.
- `$pullAll`: Removes all elements in the array that match any of the specified values.
- `$addToSet`: Appends an element to the array if not already present.

Example: Array Operators

```
db.movies.updateOne(
  { "title" : "Batman" },
  { $push : { "category" : "superhero" } } )
db.movies.updateOne(
  { "title" : "Batman" },
  { $pushAll : { "category" : [ "villain", "comic-based" ] } } )
db.movies.updateOne(
  { "title" : "Batman" },
  { $pop : { "category" : 1 } } )
db.movies.updateOne(
  { "title" : "Batman" },
  { $pull : { "category" : "action" } } )
db.movies.updateOne(
  { "title" : "Batman" },
  { $pullAll : { "category" : [ "villain", "comic-based" ] } } )
```

The Positional \$ Operator

- `$7` is a positional operator that specifies an element in an array to update.
- It acts as a placeholder for the first element that matches the query document.
- `$` replaces the element in the specified position with the value given.
- Example:

```
db.<COLLECTION>.updateOne(
  { <array> : value ... },
  { <update operator> : { "<array>.$" : value } }
)
```

⁷ <http://docs.mongodb.org/manual/reference/operator/update/postional>

Example: The Positional \$ Operator

```
// the "action" category needs to be changed to "action-adventure"
db.movies.updateMany( { "category": "action", },
                      { $set: { "category.$" : "action-adventure" } } )
```

Upserts

- If no document matches a write query:
 - By default, nothing happens
 - With `upsert: true`, inserts one new document
 - * `$setOnInsert` will add fields only in the insert scenario
- Works for `updateOne()`, `updateMany()`, `replaceOne()`
- Syntax:

```
db.<COLLECTION>.updateOne( <query document>,
                           <update document>,
                           { upsert: true } )
```

Upsert Mechanics

- Will update if documents matching the query exist
- Will insert if no documents match
 - Creates a new document using equality conditions in the query document
 - Adds an `_id` if the query did not specify one
 - Performs the write on the new document
- `updateMany()` will only create one document
 - If none match, of course

Example: Upserts

```
db.movies.updateOne( { "title" : "Jaws" },
                    { $inc: { "budget" : 5 } },
                    { upsert: true } )

db.movies.updateMany( { "title" : "Jaws II" },
                     { $inc: { "budget" : 5 } },
                     { upsert: true } )

db.movies.replaceOne( { "title" : "E.T.", "category" : [ "scifi" ] },
                     { "title" : "E.T.", "category" : [ "scifi" ], "budget" : 1 },
                     { upsert: true } )
```

save ()

- The `db.<COLLECTION>.save ()` method is syntactic sugar
 - Similar to `replaceOne ()`, querying the `_id` field
 - Upsert if `_id` is not in the collection
- Syntax:

```
db.<COLLECTION>.save( <document> )
```

Example: save ()

- If the document in the argument does not contain an `_id` field, then the `save ()` method acts like `insertOne ()` method
 - An `ObjectId` will be assigned to the `_id` field.
- If the document in the argument contains an `_id` field: then the `save ()` method is equivalent to a `replaceOne` with the query argument on `_id` and the `upsert` option set to `true`

```
// insert
db.movies.save( { "title" : "Beverly Hills Cops", "imdb_rating" : 7.3 } )

// update with { upsert: true }
db.movies.save( { "_id" : 1234, "title" : "Spider Man", "imdb_rating" : 7.3 } )
```

Be careful with save ()

Careful not to modify stale data when using `save ()`. Example:

```
db.movies.drop()
db.movies.insertOne( { "title" : "Jaws", "imdb_rating" : 7.3 } )

db.movies.find( { "title" : "Jaws" } )

// store the complete document in the application
doc = db.movies.findOne( { "title" : "Jaws" } )

db.movies.updateOne( { "title" : "Jaws" }, { $inc: { "imdb_rating" : 2 } } )
db.movies.find()

doc.imdb_rating = 7.4

db.movies.save(doc) // just lost our incrementing of "imdb_rating"
db.movies.find()
```

findOneAndUpdate() and findOneAndReplace()

- Update (or replace) one document and return it
 - By default, the document is returned pre-write
- Can return the state before or after the update
- Makes a read plus a write atomic
- Can be used with upsert to insert a document

findOneAndUpdate() and findOneAndReplace() Options

- The following are optional fields for the options document
- `projection`: `<document>` - select the fields to see
- `sort`: `<document>` - sort to select the first document
- `maxTimeoutMS`: `<number>` - how long to wait
 - Returns an error, kills operation if exceeded
- `upsert`: `<boolean>` if true, performs an upsert

Example: findOneAndUpdate()

```
db.worker_queue.findOneAndUpdate(  
  { state : "unprocessed" },  
  { $set: { "worker_id" : 123, "state" : "processing" } },  
  { upsert: true } )
```

findOneAndDelete()

- Not an update operation, but fits in with findOneAnd ...
- Returns the document and deletes it.
- Example:

```
db.foo.drop();  
db.foo.insertMany( [ { a : 1 }, { a : 2 }, { a : 3 } ] );  
db.foo.find(); // shows the documents.  
db.foo.findOneAndDelete( { a : { $lte : 3 } } );  
db.foo.find();
```

3.6 Lab: Updating Documents

Exercise: Pass Inspections

In the `sample.inspections` collection, let's imagine that we want to do a little data cleaning.

We've decided to eliminate the "Completed" inspection result and use only "No Violation Issued" for such inspection cases.

Please update all inspections accordingly.

Exercise: Set `fine` value

For all inspections that failed, set a `fine` value of 100.

Exercise: Increase `fine` in ROSEDALE

- Update all inspections done in the city of "ROSEDALE".
- For failed inspections, raise the "fine" value by 150.

Exercise: Give a pass to "MongoDB"

- Today MongoDB got a visit from the inspectors.
- We passed, of course.
- So go ahead and update "MongoDB" and set the `result` to "AWESOME" and give a corresponding certificate.
- The inspector may not have uploaded the basic details for "MongoDB", so ensure the update takes place even if "MongoDB" isn't in the collection
- MongoDB's information is

```
business name: MongoDB
id: 10407-2017-ENFO
address:
  city: New York, zip: 10036, street: 43, number: 229
```

Exercise: Updating Array Elements

Insert a document representing product metrics for a backpack:

```
db.product_metrics.insertOne(
  { name: "backpack",
    purchasesPast7Days: [ 0, 0, 0, 0, 0, 0, 0 ] })
```

Each 0 within the "purchasesPast7Days" field corresponds to a day of the week. The first element is Monday, the second element is Tuesday, etc.).

Write an update statement to increment the number of backpacks sold on Friday by 200.

4 Indexes

Index Fundamentals (page 50) An introduction to MongoDB indexes

Lab: Basic Indexes (page 56) A short exercise on the basic of index usage

Compound Indexes (page 57) Indexes on two or more fields

Lab: Optimizing an Index (page 62) Lab on optimizing a compound index

Multikey Indexes (page 63) Indexes on array fields

Hashed Indexes (page 67) Hashed indexes

Geospatial Indexes (page 68) Geospatial indexes: both those on legacy coordinate pairs and those supporting queries that calculate geometries on an earth-like sphere.

Using Compass with Indexes (page 75) Using Compass to create a geospatial index

TTL Indexes (page 79) Time-To-Live indexes

Text Indexes (page 81) Free text indexes on string fields

Partial Indexes (page 83) Partial indexes in MongoDB

Lab: Finding and Addressing Slow Operations (page 86) Lab on finding and addressing slow queries

Lab: Using explain() (page 87) Lab on using the explain operation to review execution stats

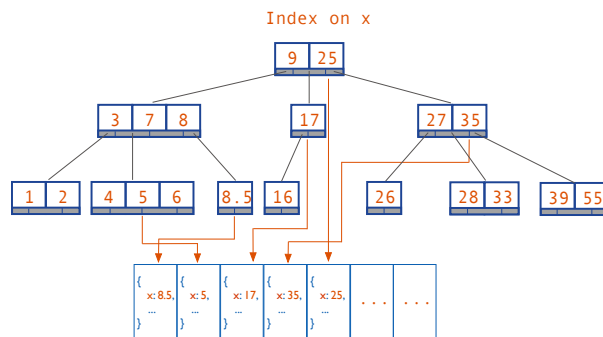
4.1 Index Fundamentals

Learning Objectives

Upon completing this module students should understand:

- The impact of indexing on read performance
- The impact of indexing on write performance
- How to choose effective indexes
- The utility of specific indexes for particular query patterns

Why Indexes?



Types of Indexes

- Single-field indexes
- Compound indexes
- Multikey indexes
- Geospatial indexes
- Text indexes

Exercise: Using `explain()`

Let's explore what MongoDB does for the following query by using `explain()`.

We are projecting only `user.name` so that the results are easy to read.

```
db.tweets.find( { "user.followers_count" : 1000 },
                { "_id" : 0, "user.name": 1 } )

db.tweets.find( { "user.followers_count" : 1000 } ).explain()
```

Results of `explain()`

With the default `explain()` verbosity, you will see results similar to the following:

```
{
  "queryPlanner" : {
    "plannerVersion" : 1,
    "namespace" : "twitter.tweets",
    "indexFilterSet" : false,
    "parsedQuery" : {
      "user.followers_count" : {
        "$eq" : 1000
      }
    }
  },
```

Results of `explain()` - Continued

```
    "winningPlan" : {
      "stage" : "COLLSCAN",
      "filter" : {
        "user.followers_count" : {
          "$eq" : 1000
        }
      },
      "direction" : "forward"
    },
    "rejectedPlans" : [ ]
  },
  ...
}
```

explain() Verbosity Can Be Adjusted

- **default:** determines the winning query plan but does not execute query
- **executionStats:** executes query and gathers statistics
- **allPlansExecution:** runs all candidate plans to completion and gathers statistics

explain("executionStats")

```
> db.tweets.find( { "user.followers_count" : 1000 } )  
  .explain("executionStats")
```

Now we have query statistics:

```
..  
"executionStats" : {  
  "executionSuccess" : true,  
  "nReturned" : 8,  
  "executionTimeMillis" : 107,  
  "totalKeysExamined" : 0,  
  "totalDocsExamined" : 51428,  
  "executionStages" : {  
    "stage" : "COLLSCAN",  
    "filter" : {  
      "user.followers_count" : {  
        "$eq" : 1000  
      }  
    }  
  },  
}
```

explain("executionStats") - Continued

```
  "nReturned" : 8,  
  "executionTimeMillisEstimate" : 100,  
  "works" : 51430,  
  "advanced" : 8,  
  "needTime" : 51421,  
  "needFetch" : 0,  
  "saveState" : 401,  
  "restoreState" : 401,  
  "isEOF" : 1,  
  "invalidates" : 0,  
  "direction" : "forward",  
  "docsExamined" : 51428  
}  
...  
}
```

explain("executionStats") Output

- `nReturned` : number of documents returned by the query
- `totalDocsExamined` : number of documents touched during the query
- `totalKeysExamined` : number of index keys scanned
- A `totalKeysExamined` or `totalDocsExamined` value much higher than `nReturned` indicates we need a better index
- Based on `.explain()` output, this query would benefit from a better index

Other Operations

In addition to `find()`, we often want to use `explain()` to understand how other operations will be handled.

- `aggregate()`
- `count()`
- `group()`
- `update()`
- `remove()`
- `findAndModify()`
- `insert()`

db.<COLLECTION>.explain()

`db.<COLLECTION>.explain()` returns an `ExplainableCollection`.

```
> var explainable = db.tweets.explain()
> explainable.find( { "user.followers_count" : 1000 } )
```

equivalent to

```
> db.tweets.explain().find( { "user.followers_count" : 1000 } )
```

also equivalent to

```
> db.tweets.find( { "user.followers_count" : 1000 } ).explain()
```

Using `explain()` for Write Operations

Simulate the number of writes that would have occurred and determine the index(es) used:

```
> db.tweets.explain("executionStats").remove( { "user.followers_count" : 1000 } )
```

```
> db.tweets.explain("executionStats").update( { "user.followers_count" : 1000 },  
  { $set : { "large_following" : true } }, { multi: true } )
```

Single-Field Indexes

- Single-field indexes are based on a single field of the documents in a collection.
- The field may be a top-level field.
- You may also create an index on fields in embedded documents.

Creating an Index

The following creates a single-field index on `user.followers_count`.

```
db.tweets.createIndex( { "user.followers_count" : 1 } )  
db.tweets.find( { "user.followers_count" : 1000 } ).explain()
```

`explain()` indicated there will be a substantial performance improvement in handling this type of query.

Listing Indexes

List indexes for a collection:

```
db.tweets.getIndexes()
```

List index keys:

```
db.tweets.getIndexKeys()
```

Indexes and Read/Write Performance

- Indexes improve read performance for queries that are supported by the index.
- Inserts will be slower when there are indexes that MongoDB must also update.
- The speed of updates may be improved because MongoDB will not need to do a collection scan to find target documents.
- An index is modified any time a document:
 - Is inserted (applies to *all* indexes)
 - Is deleted (applies to *all* indexes)
 - Is updated in such a way that its indexed field changes

Index Limitations

- You can have up to 64 indexes per collection.
- You should NEVER be anywhere close to that upper bound.
- Write performance will degrade to unusable at somewhere between 20-30.

Use Indexes with Care

- Every query should use an index.
- Every index should be used by a query.
- Any write that touches an indexed field will update every index that touches that field.
- Indexes require RAM.
- Be mindful about the choice of key.

Additional Index Options

- Sparse
- Unique
- Background

Sparse Indexes in MongoDB

- Sparse indexes only contain entries for documents that have the indexed field.

```
db.<COLLECTION>.createIndex(  
  { field_name : 1 },  
  { sparse : true } )
```

Defining Unique Indexes

- Enforce a unique constraint on the index
 - On a per-collection basis
- Can't insert documents with a duplicate value for the field
 - Or update to a duplicate value
- No duplicate values may exist prior to defining the index

```
db.<COLLECTION>.createIndex(  
  { field_name : 1 },  
  { unique : true } )
```

Building Indexes in the Background

- Building indexes in foreground is a blocking operation.
- Background index creation is non-blocking, however, takes longer to build.
- Initially larger, or less compact, than an index built in the foreground.

```
db.<COLLECTION>.createIndex(  
  { field_name : 1 },  
  { background : true } )
```

4.2 Lab: Basic Indexes

Exercise: Creating a Basic Index

- Begin by importing the routes collection from the usb drive into a running mongod process
- You should import 66985

```
# if no mongod running  
mkdir -p data/db  
mongod --port 30000 --dbpath data/db --logpath data/mongod.log --append --fork  
# end if no mongod running  
mongoimport --drop -d airlines -c routes routes.json
```

Executing a Query

- With the documents inserted, perform the following two queries, finding all routes for Delta

```
db.routes.find({"airline.id": 2009})  
db.routes.find({"airline.id": 2009}).explain("executionStats")
```

Creating an Index

- Create an index on the routes collection
- The index should be on the "airline.id" key, in descending order
- Rerun the query with explain
- Verify that the newly created index supports the query

4.3 Compound Indexes

Learning Objectives

Upon completing this module students should understand:

- What a compound index is.
- How compound indexes are created.
- The importance of considering field order when creating compound indexes.
- How to efficiently handle queries involving some combination of equality matches, ranges, and sorting.
- Some limitations on compound indexes.

Introduction to Compound Indexes

- It is common to create indexes based on more than one field.
- These are called `compound indexes`.
- You may use up to 31 fields in a compound index.
- You may not use hashed index fields.

The Order of Fields Matters

Specifically we want to consider how the index will be used for:

- Equality tests, e.g.,

```
db.movies.find( { "budget" : 7, "imdb_rating" : 8 } )
```

- Range queries, e.g.,

```
db.movies.find( { "budget" : 10, "imdb_rating" : { $lt : 9 } } )
```

- Sorting, e.g.,

```
db.movies.find( { "budget" : 10, "imdb_rating" : 6 }  
                ).sort( { "imdb_rating" : -1 } )
```

Designing Compound Indexes

- Let's look at some guiding principles for building compound indexes.
- These will generally produce a good if not optimal index.
- You can optimize after a little experimentation.
- We will explore this in the context of a running example.

Example: A Simple Message Board

Requirements:

- Find all messages in a specified timestamp range.
- Select for whether the messages are anonymous or not.
- Sort by rating from highest to lowest.

Load the Data

```
a = [ { "timestamp" : 1, "username" : "anonymous", "rating" : 3 },
      { "timestamp" : 2, "username" : "anonymous", "rating" : 5 },
      { "timestamp" : 3, "username" : "sam", "rating" : 1 },
      { "timestamp" : 4, "username" : "anonymous", "rating" : 2 },
      { "timestamp" : 5, "username" : "martha", "rating" : 5 } ]
db.messages.insertMany(a)
```

Start with a Simple Index

Start by building an index on { timestamp : 1 }

```
db.messages.createIndex( { timestamp : 1 }, { name : "myindex" } )
```

Now let's query for messages with timestamp in the range 2 through 4 inclusive.

```
db.messages.find( { timestamp : { $gte : 2, $lte : 4 } } ).explain("executionStats")
```

Analysis:

- Explain plan shows good performance, i.e. totalKeysExamined = n.
- However, this does not satisfy our query.
- Need to query again with { username : "anonymous" } as part of the query.

Query Adding username

Let's add the user field to our query.

```
db.messages.find( { timestamp : { $gte : 2, $lte : 4 },
                  username : "anonymous" } ).explain("executionStats")
```

totalKeysExamined > n.

Include username in Our Index

```
db.messages.dropIndex( "myindex" );
db.messages.createIndex( { timestamp : 1, username : 1 },
                        { name : "myindex" } )
db.messages.find( { timestamp : { $gte : 2, $lte : 4 },
                  username : "anonymous" } ).explain("executionStats")
```

totalKeysExamined is still > n. Why?

totalKeysExamined > n

timestamp	username
1	"anonymous"
2	"anonymous"
3	"sam"
4	"anonymous"
5	"martha"

A Different Compound Index

Drop the index and build a new one with user.

```
db.messages.dropIndex( "myindex" );
db.messages.createIndex( { username : 1, timestamp : 1 },
                        { name : "myindex" } )
db.messages.find( { timestamp : { $gte : 2, $lte : 4 },
                  username : "anonymous" } ).explain("executionStats")
```

totalKeysExamined is 2. n is 2.

totalKeysExamined == n

username	timestamp
"anonymous"	1
"anonymous"	2
"anonymous"	4
"sam"	2
"martha"	5

Let Selectivity Drive Field Order

- Order fields in a compound index from most selective to least selective.
- Usually, this means equality fields before range fields.
- When dealing with multiple equality values, start with the most selective.
- If a common range query is more selective instead (rare), specify the range component first.

Adding in the Sort

Finally, let's add the sort and run the query

```
db.messages.find( {  
    timestamp : { $gte : 2, $lte : 4 },  
    username : "anonymous"  
} ).sort( { rating : -1 } ).explain("executionStats");
```

- Note that the winningPlan includes a SORT stage
- This means that MongoDB had to perform a sort in memory
- In memory sorts on can degrade performance significantly
 - Especially if used frequently
 - In-memory sorts that use > 32 MB will abort

In-Memory Sorts

Let's modify the index again to allow the database to sort for us.

```
db.messages.dropIndex( "myindex" );  
db.messages.createIndex( { username : 1, timestamp : 1, rating : 1 },  
    { name : "myindex" } );  
db.messages.find( {  
    timestamp : { $gte : 2, $lte : 4 },  
    username : "anonymous"  
} ).sort( { rating : -1 } ).explain("executionStats");
```

- The explain plan remains unchanged, because the sort field comes after the range fields.
- The index does not store entries in order by rating.
- Note that this requires us to consider a tradeoff.

Avoiding an In-Memory Sort

Rebuild the index as follows.

```
db.messages.dropIndex( "myindex" );
db.messages.createIndex( { username : 1, rating : 1, timestamp : 1 },
                        { name : "myindex" } );
db.messages.find( {
    timestamp : { $gte : 2, $lte : 4 },
    username : "anonymous"
} ).sort( { rating : -1 } ).explain("executionStats");
```

- We no longer have an in-memory sort, but need to examine more keys.
- `totalKeysExamined` is 3 and `n` is 2.
- This is the best we can do in this situation and this is fine.
- However, if `totalKeysExamined` is much larger than `n`, this might not be the best index.

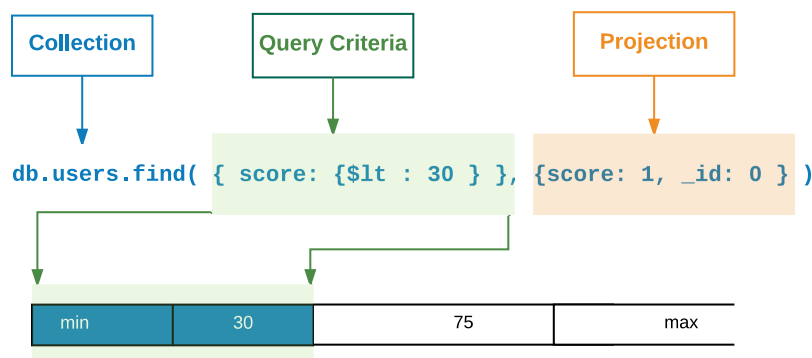
No need for stage : SORT

username	rating	timestamp
"anonymous"	2	4
"anonymous"	3	1
"anonymous"	5	2
"sam"	1	2
"martha"	5	5

General Rules of Thumb

- Equality before range
- Equality before sorting
- Sorting before range

Covered Queries



- When a query and projection include only the indexed fields, MongoDB will return results directly from the index.
- There is no need to scan any documents or bring documents into memory.

- These covered queries can be very efficient.

Exercise: Covered Queries

```
db.testcol.drop()
for (i=1; i<=20; i++) {
  db.testcol.insertOne({ "_id" : i, "title" : i, "name" : i,
    "rating" : i, "budget" : i })
};
db.testcol.createIndex( { "title" : 1, "name" : 1, "rating" : 1 } )

// Not covered because _id is present.
db.testcol.find( { "title" : 3 },
  { "title" : 1, "name" : 1, "rating" : 1 }
).explain("executionStats")

// Not covered because other fields may exist in matching docs.
db.testcol.find( { "title" : 3 },
  { "_id" : 0, "budget" : 0 } ).explain("executionStats")

// Covered query!
db.testcol.find( { "title" : 3 },
  { "_id" : 0, "title" : 1, "name" : 1, "rating" : 1 }
).explain("executionStats")
```

4.4 Lab: Optimizing an Index

Exercise: What Index Do We Need?

Run the the following Javascript file from the handouts.

```
mongo --shell localhost/performance performance.js
```

In the shell that launches execute the following method

```
performance.init()
```

The method above will build a sample data set in the “sensor_readings” collection. What index is needed for this query?

```
db.sensor_readings.find( { tstamp: { $gte: ISODate("2012-08-01"),
    $lte: ISODate("2012-09-01") },
  active: true } ).limit(3)
```

Exercise: Avoiding an In-Memory Sort

What index is needed for the following query to avoid an in-memory sort?

```
db.sensor_readings.find( { active: true } ).sort( { timestamp : -1 } )
```

Exercise: Avoiding an In-Memory Sort, 2

What index is needed for the following query to avoid an in-memory sort?

```
db.sensor_readings.find(
  { x : { $in : [100, 200, 300, 400] } }
).sort( { timestamp : -1 } )
```

4.5 Multikey Indexes

Learning Objectives

Upon completing this module, students should understand:

- What a multikey index is
- When MongoDB will use a multikey index to satisfy a query
- How multikey indexes work
- How multikey indexes handle sorting
- Some limitations on multikey indexes

Introduction to Multikey Indexes

- A multikey index is an index on an array.
- An index entry is created on each value found in the array.
- Multikey indexes can support primitives, documents, or sub-arrays.
- There is nothing special that you need to do to create a multikey index.
- You create them using `createIndex()` just as you would with an ordinary single-field index.
- If there is an array as a value for an indexed field, the index will be multikey on that field.

Example: Array of Numbers

```
db.race_results.drop()
db.race_results.createIndex( { "lap_times" : 1 } )
a = [ { "lap_times" : [ 3, 5, 2, 8 ] },
      { "lap_times" : [ 1, 6, 4, 2 ] },
      { "lap_times" : [ 6, 3, 3, 8 ] } ]
db.race_results.insertMany( a )

// Used the index
db.race_results.find( { lap_times : 1 } ).explain()

// One document found.
// Index not used, because it is naive to position.
db.race_results.find( { "lap_times.2" : 3 } ).explain()
```

Exercise: Array of Documents, Part 1

Create a collection and add an index on the `comments.rating` field:

```
db.blog.drop()
b = [ { "comments" : [
      { "name" : "Bob", "rating" : 1 },
      { "name" : "Frank", "rating" : 5.3 },
      { "name" : "Susan", "rating" : 3 } ] },
      { "comments" : [
      { name : "Megan", "rating" : 1 } ] },
      { "comments" : [
      { "name" : "Luke", "rating" : 1.4 },
      { "name" : "Matt", "rating" : 5 },
      { "name" : "Sue", "rating" : 7 } ] } ]
db.blog.insertMany(b)

db.blog.createIndex( { "comments" : 1 } )
// vs
db.blog.createIndex( { "comments.rating" : 1 } )

// for this query
db.blog.find( { "comments.rating" : 5 })
```

Exercise: Array of Documents, Part 2

For each of the three queries below:

- How many documents will be returned?
- Will it use our multi-key index? Why or why not?
- If a query will not use the index, which index will it use?

```
db.blog.find( { "comments" : { "name" : "Bob", "rating" : 1 } } )
db.blog.find( { "comments" : { "rating" : 1 } } )
db.blog.find( { "comments.rating" : 1 } )
```

Exercise: Array of Arrays, Part 1

Add some documents and create an index simulating a player in a game moving on an X,Y grid.

```
db.player.drop()
db.player.createIndex( { "last_moves" : 1 } )
c = [ { "last_moves" : [ [ 1, 2 ], [ 2, 3 ], [ 3, 4 ] ] },
      { "last_moves" : [ [ 3, 4 ], [ 4, 5 ] ] },
      { "last_moves" : [ [ 4, 5 ], [ 5, 6 ] ] },
      { "last_moves" : [ [ 3, 4 ] ] },
      { "last_moves" : [ [ 4, 5 ] ] } ]
db.player.insertMany(c)
db.player.find()
```

Exercise: Array of Arrays, Part 2

For each of the queries below:

- How many documents will be returned?
- Does the query use the multi-key index? Why or why not?
- If the query does not use the index, what is an index it could use?

```
db.player.find( { "last_moves" : [ 3, 4 ] } )
db.player.find( { "last_moves" : 3 } )
db.player.find( { "last_moves.1" : [ 4, 5 ] } )
db.player.find( { "last_moves.2" : [ 2, 3 ] } )
```

How Multikey Indexes Work

- Each array element is given one entry in the index.
- So an array with 17 elements will have 17 entries – one for each element.
- Multikey indexes can take up much more space than standard indexes.

Multikey Indexes and Sorting

- If you sort using a multikey index:
 - A document will appear at the first position where a value would place the document.
 - It will not appear multiple times.
- This applies to array values generally.
- It is not a specific property of multikey indexes.

Exercise: Multikey Indexes and Sorting

```
db.testcol.drop()
a = [ { x : [ 1, 11 ] }, { x : [ 2, 10 ] }, { x : [ 3 ] },
      { x : [ 4 ] }, { x : [ 5 ] } ]
db.testcol.insert(a)

db.testcol.createIndex( { x : 1 } )

// x : [ 1, 11 ] array comes first. It contains the lowest value.
db.testcol.find().sort( { x : 1 } )

// x : [ 1, 11 ] array still comes first. Contains the highest value.
db.testcol.find().sort( { x : -1 } )
```

Limitations on Multikey Indexes

- You cannot create a compound index using more than one array-valued field.
- This is because of the combinatorics.
- For a compound index on two array-valued fields you would end up with $N * M$ entries for one document.
- You cannot have a hashed multikey index.
- You cannot have a shard key use a multikey index.
- We discuss shard keys in another module.
- The index on the `_id` field cannot become a multikey index.

Example: Multikey Indexes on Multiple Fields

```
db.testcol.drop()
db.testcol.createIndex( { x : 1, y : 1 } )

// no problems yet
db.testcol.insertOne( { _id : 1, x : 1, y : 1 } )

// still OK
db.testcol.insertOne( { _id : 2, x : [ 1, 2 ], y : 1 } )

// still OK
db.testcol.insertOne( { _id : 3, x : 1, y : [ 1, 2 ] } )

// Won't work
db.testcol.insertOne( { _id : 4, x : [ 1, 2 ], y : [ 1, 2 ] } )
```

4.6 Hashed Indexes

Learning Objectives

Upon completing this module, students should understand:

- What a hashed index is
- When to use a hashed index

What is a Hashed Index?

- Hashed indexes are based on field values like any other index.
- The difference is that the values are hashed and it is the hashed value that is indexed.
- The hashing function collapses sub-documents and computes the hash for the entire value.
- MongoDB can use the hashed index to support equality queries.
- Hashed indexes do not support multi-key indexes, i.e. indexes on array fields.
- Hashed indexes do not support range queries.

Why Hashed Indexes?

- In MongoDB, the primary use for hashed indexes is to support sharding a collection using a hashed shard key.
- In some cases, the field we would like to use to shard data would make it difficult to scale using sharding.
- Using a hashed shard key to shard a collection ensures an even distribution of data and overcomes this problem.
- See [Shard a Collection Using a Hashed Shard Key](#)⁸ for more details.
- We discuss sharding in detail in another module.

Limitations

- You may not create compound indexes that have hashed index fields.
- You may not specify a unique constraint on a hashed index.
- You can create both a hashed index and a non-hashed index on the same field.

⁸ <http://docs.mongodb.org/manual/tutorial/shard-collection-with-a-hashed-shard-key/>

Floating Point Numbers

- MongoDB hashed indexes truncate floating point numbers to 64-bit integers before hashing.
- Do not use a hashed index for floating point numbers that cannot be reliably converted to 64-bit integers.
- MongoDB hashed indexes do not support floating point values larger than 2^{53} .

Creating a Hashed Index

Create a hashed index using an operation that resembles the following. This operation creates a hashed index for the active collection on the a field.

```
db.active.createIndex( { a: "hashed" } )
```

4.7 Geospatial Indexes

Learning Objectives

Upon completing this module, students should understand:

- Use cases of geospatial indexes
- The two types of geospatial indexes
- How to create 2d geospatial indexes
- How to query for documents in a region
- How to create 2dsphere indexes
- Types of GeoJSON objects
- How to query using 2dsphere indexes

Introduction to Geospatial Indexes

We can use geospatial indexes to quickly determine geometric relationships:

- All points within a certain radius of another point
- Whether or not points fall within a polygon
- Whether or not two polygons intersect

Easiest to Start with 2 Dimensions

- Initially, it is easiest to think about geospatial indexes in two dimensions.
- One type of geospatial index in MongoDB is a flat 2d index.
- With a geospatial index we can, for example, search for nearby items.
- This is the type of service that many phone apps provide when, say, searching for a nearby cafe.
- We might have a query location identified by an X in a 2d coordinate system.

Location Field

- A geospatial index is based on a location field within documents in a collection.
- The structure of location values depends on the type of geospatial index.
- We will go into more detail on this in a few minutes.
- We can identify other documents in this collection with Xs in our 2d coordinate system.

Find Nearby Documents

- A geospatial index enables us to efficiently query a collection based on geometric relationships between documents and the query.
- For example, we can quickly locate all documents within a certain radius of our query location.
- In this example, we've illustrated a `$near` query in a 2d geospatial index.

Flat vs. Spherical Indexes

There are two types of geospatial indexes:

- Flat, made with a 2d index
- Two-dimensional spherical, made with the `2dsphere` index
 - Takes into account the curvature of the earth
 - Joins any two points using a geodesic or “great circle arc”
 - Deviates from flat geometry as you get further from the equator, and as your points get further apart

Flat Geospatial Index

- This is a Cartesian treatment of coordinate pairs.
- E.g., the index would not reflect the fact that the shortest path from Canada to Siberia is over the North Pole (if units are degrees).
- 2d indexes can be used to describe any flat surface.
- Recommended if:
 - You have legacy coordinate pairs (MongoDB 2.2 or earlier).
 - You do not plan to use GeoJSON objects such as LineStrings or Polygons.
 - You are not going to use points far enough North or South to worry about the Earth's curvature.

Spherical Geospatial Index

- Spherical indexes model the curvature of the Earth
- If you want to plot the shortest path from the Klondike to Siberia, this will know to go over the North Pole.
- Spherical indexes use GeoJSON objects (Points, LineString, and Polygons)
- Coordinate pairs are converted into GeoJSON Points.

Creating a 2d Index

Creating a 2d index:

```
db.<COLLECTION>.createIndex(  
  { field_name : "2d", <optional additional field> : <value> },  
  { <optional options document> } )
```

Possible options key-value pairs:

- min : <lower bound>
- max : <upper bound>
- bits : <bits of precision for geohash>

Exercise: Creating a 2d Index

Create a 2d index on the collection `testcol` with:

- A min value of -20
- A max value of 20
- 10 bits of precision
- The field indexed should be `xy`.

Inserting Documents with a 2d Index

There are two accepted formats:

- Legacy coordinate pairs
- Document with the following fields specified:
 - lng (longitude)
 - lat (latitude)

Exercise: Inserting Documents with 2d Fields

- Insert 2 documents into the 'twoD' collection.
- Assign 2d coordinate values to the xy field of each document.
- Longitude values should be -3 and 3 respectively.
- Latitude values should be 0 and 0.4 respectively.

Querying Documents Using a 2d Index

- Use \$near to retrieve documents close to a given point.
- Use \$geoWithin to find documents with a shape contained entirely within the query shape.
- Use the following operators to specify a query shape:
 - \$box
 - \$polygon
 - \$center (circle)

Example: Find Based on 2d Coords

Write a query to find all documents in the testcol collection that have an xy field value that falls entirely within the circle with center at [-2.5, -0.5] and a radius of 3.

```
db.testcol.find( { xy : { $geoWithin : { $center : [ [ -2.5, -0.5 ], 3 ] } } }
```

Creating a 2dsphere Index

You can index one or more 2dsphere fields in an index.

```
db.<COLLECTION>.createIndex( { <location field> : "2dsphere" } )
```

The GeoJSON Specification

- The GeoJSON format encodes location data on the earth.
- The spec is at <http://geojson.org/geojson-spec.html>
- This spec is incorporated in MongoDB 2dsphere indexes.
- It includes Point, LineString, Polygon, and combinations of these.

GeoJSON Considerations

- The coordinates of points are given in degrees (longitude then latitude).
- The LineString that joins two points will always be a geodesic.
- Short lines (around a few hundred kilometers or less) will go about where you would expect them to.
- Polygons are made of a closed set of LineStrings.

Simple Types of 2dsphere Objects

Point: A single point on the globe

```
{ <field_name> : { type : "Point",  
                  coordinates : [ <longitude>, <latitude> ] } }
```

LineString: A geodesic line that is defined by its two end Points

```
{ <field_name> : { type : "LineString",  
                  coordinates : [ [ <longitude 1>, <latitude 1> ],  
                                  [ <longitude 2>, <latitude 2> ],  
                                  ...,  
                                  [ <longitude n>, <latitude n> ] ] } }
```

Polygons

Simple Polygon:

```
{ <field_name> : { type : "Polygon",
                  coordinates : [ [ [ <Point1 coordinate pair> ],
                                    [ <Point2 coordinate pair> ],
                                    ...
                                    [ <Point1 coordinate pair again> ] ] ]
                  } }
```

Polygon with One Hole:

```
{ <field_name> : { type : "Polygon",
                  coordinates : [ [ <Points that define outer polygon> ],
                                    [ <Points that define inner polygon> ] ]
                  } }
```

Other Types of 2dsphere Objects

- **MultiPoint:** One or more Points in one document
- **MultiLine:** One or more LineStrings in one document
- **MultiPolygon:** One or more Polygons in one document
- **GeometryCollection:** One or more GeoJSON objects in one document

Exercise: Inserting GeoJSON Objects (1)

Create a coordinate pair for each the following airports. Create one variable per airport.

- LaGuardia (New York): 40.7772° N, 73.8726° W
- JFK (New York): 40.6397° N, 73.7789° W
- Newark (New York): 40.6925° N, 74.1686° W
- Heathrow (London): 52.4775° N, 0.4614° W
- Gatwick (London): 51.1481° N, 0.1903° W
- Stansted (London): 51.8850° N, 0.2350° E
- Luton (London): 51.9000° N, 0.4333° W

Exercise: Inserting GeoJSON Objects (2)

- Now let's make arrays of these.
- Put all the New York area airports into an array called `nyPorts`.
- Put all the London area airports into an array called `londonPorts`.
- Create a third array for flight numbers: "AA4453", "VA3333", "UA2440".

Exercise: Inserting GeoJSON Objects (3)

- Create documents for every possible New York to London flight.
- Include a `flightNumber` field for each flight.

Exercise: Creating a 2dsphere Index

- Create two indexes on the collection `flights`.
- Make the first a compound index on the fields:
 - `origin`
 - `destination`
 - `flightNumber`
- Specify 2dsphere indexes on both `origin` and `destination`.
- Specify a simple index on `name`.
- Make the second index just a 2dsphere index on `destination`.

Querying 2dsphere Objects

`$geoNear`: Finds all points, orders them by distance from a position.

```
{ <field name> : { $near : { $geometry : {  
    type : "Point",  
    coordinates : [ lng, lat ] },  
    $maxDistance : <meters> } } } }
```

`$near`: Just like `$geoNear`, except in very edge cases; check the docs.

`$geoWithin`: Only returns documents with a location completely contained within the query.

`$geoIntersects`: Returns documents with their indexed field intersecting any part of the shape in the query.

4.8 Using Compass with Indexes

Learning Objectives

Upon completing this module, students should understand:

- How to view index usage with Compass
- How to create indexes with Compass

Introduction

- Compass provides a user friendly interface for interacting with MongoDB
- If you are unfamiliar with Compass, click below for a high level overview

</modules/compass>

Execute a GeoJSON query with Compass

- Import the `trips.json` dataset into a database called `citibike` and a collection called `trips`
- Execute a `geoSpatial` query finding all trips that
 - Begin within a 1.2 mile radius (1.93 kilometers) of the middle of Central Park:
* `[ -73.97062540054321, 40.776398033956916 ]`
 - End within a 0.25 mile radius (.40 kilometers) of Madison Square Park:
* `[ -73.9879247077942, 40.742201076382784 ]`

Execute Query (cont)

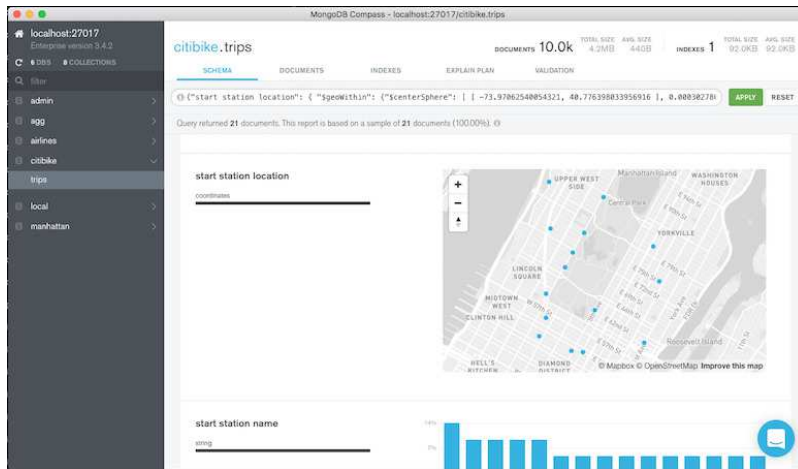
- Importing the data

```
mongoimport --drop -d citibike -c trips trips.json
```

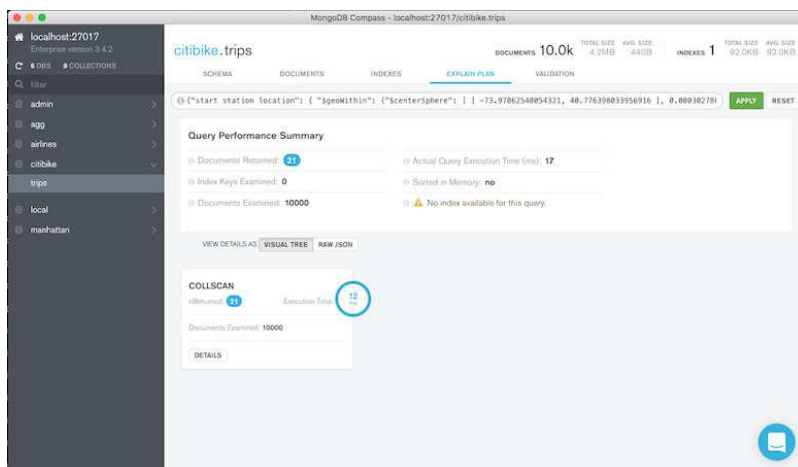
- In Compass, executing the query

```
{
  "start station location": { "$geoWithin": { "$centerSphere": [
    [ -73.97062540054321, 40.776398033956916 ], 0.000302786 ] } },
  "end station location": { "$geoWithin": { "$centerSphere": [
    [ -73.9879247077942, 40.742201076382784 ], 0.00006308 ] } }
}
```

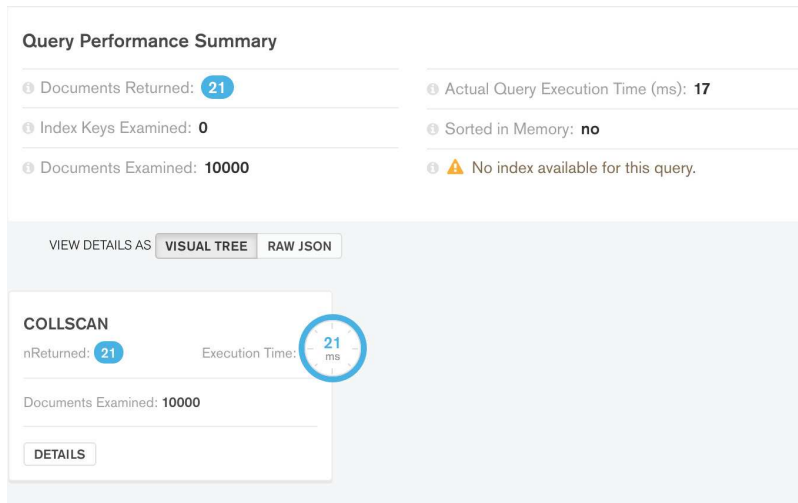
GeoJSON Query Example



GeoJSON Query Explain Plan



GeoJSON Query Explain Detail



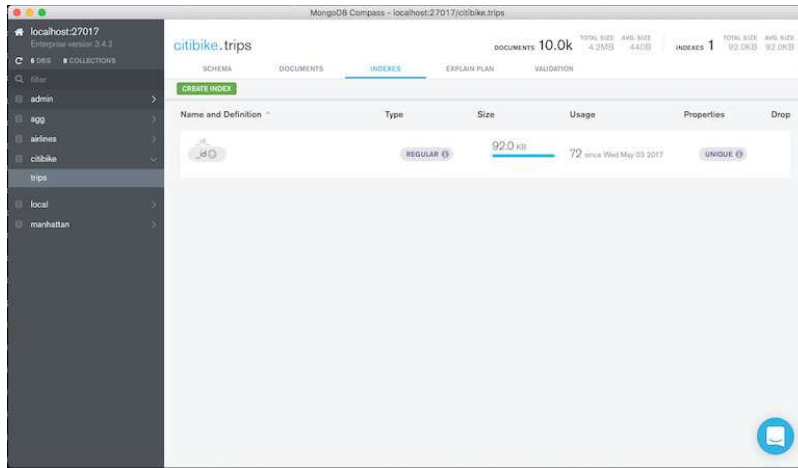
Query Explain (cont)

- Our explain visualizer is telling us key details
 - Documents returned, index keys examined, documents examined
 - Query execution time, sorting information, and **if an index was available**
 - A visualization of the query plan

Creating an Index Using Compass

- Navigate to the Indexes tab
- Create a new index named `geospatial_start_end`
- Select the “start station location” field and choose `2dsphere`
- Add another field
- Select the “end station location field and choose `2dsphere`
- Click “Create”

The Index Tab



Creating an Index Example

Create Index

Choose an index name

Configure the index definition

ADD ANOTHER FIELD

Options

☒ Build index in the background

☐ Create unique index

☐ Create TTL

seconds

☐ Partial Filter Expression

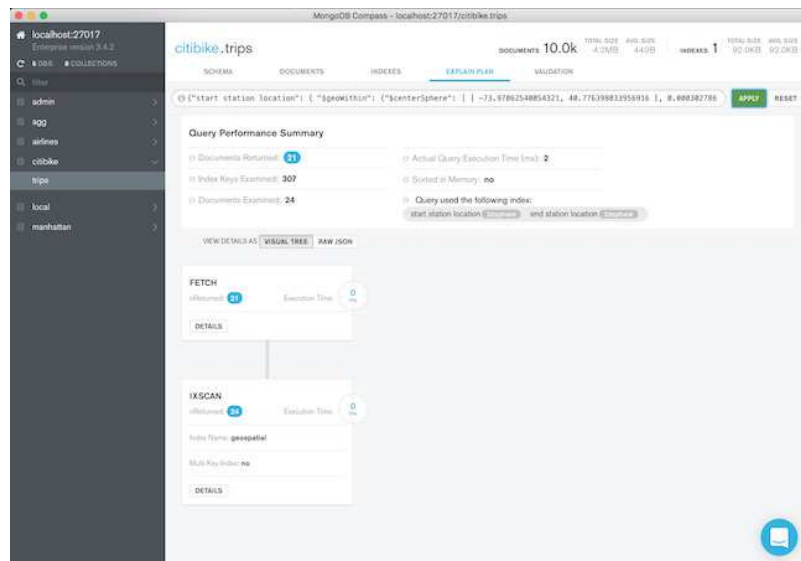
CANCEL **CREATE**

Verifying the Index

- Navigate to the *Schema* tab
- Reset the query bar, and then re-run our geo query
- Navigate to the *Explain* tab

```
{
  "start station location": { "$geoWithin": { "$centerSphere": [
    [ -73.97062540054321, 40.776398033956916 ], 0.000302786 ] } },
  "end station location": { "$geoWithin": { "$centerSphere": [
    [ -73.9879247077942, 40.742201076382784 ], 0.00006308 ] } }
}
```

Index Performance



4.9 TTL Indexes

Learning Objectives

Upon completing this module students should understand:

- How to create a TTL index
- When a TTL indexed document will get deleted
- Limitations of TTL indexes

TTL Index Basics

- TTL is short for “Time To Live”.
- TTL indexes must be based on a field of type Date (including ISODate) or Timestamp.
- Any document with a Date value older than `expireAfterSeconds` in the targeted field of the index, will get deleted at some point.

Creating a TTL Index

Create with:

```
db.<COLLECTION>.createIndex( { field_name : 1 },
                              { expireAfterSeconds : some_number } )
```

Exercise: Creating a TTL Index

Let’s create a TTL index on the `ttl` collection that will delete documents older than 30 seconds. Write a script that will insert documents at a rate of one per second.

```
db.sessions.drop()
db.sessions.createIndex( { "last_user_action" : 1 },
                        { "expireAfterSeconds" : 30 } )

i = 0
while (true) {
  i += 1;
  db.sessions.insertOne( { "last_user_action" : ISODate(), "b" : i } );
  sleep(1000); // Sleep for 1 second
}
```

Exercise: Check the Collection

Then, leaving that window open, open up a new terminal and connect to the database with the mongo shell. This will allow us to verify the TTL behavior.

```
// look at the output and wait. After a ramp-up of up to a minute or so,
// count() will be reset to 30 once/minute.
while (true) {
  print(db.sessions.count());
  sleep(100);
}
```

4.10 Text Indexes

Learning Objectives

Upon completing this module, students should understand:

- The purpose of a text index
- How to create text indexes
- How to search using text indexes
- How to rank search results by relevance score

What is a Text Index?

- A text index is based on the tokens (words, etc.) used in string fields.
- MongoDB supports text search for a number of languages.
- Text indexes drop language-specific stop words (e.g. in English “the”, “an”, “a”, “and”, etc.).
- Text indexes use simple, language-specific suffix stemming (e.g., “running” to “run”).

Creating a Text Index

You create a text index a little bit differently than you create a standard index.

```
db.<COLLECTION>.createIndex( { <field name> : "text" } )
```

Exercise: Creating a Text Index

Create a text index on the “dialog” field of the montyPython collection.

```
db.montyPython.createIndex( { dialog : "text" } )
```

Creating a Text Index with Weighted Fields

- The default weight is 1 for each indexed field.
- The weight is relative to other weights in a text index.

```
db.<COLLECTION>.createIndex(  
  { "title" : "text", "keywords": "text", "author" : "text" },  
  { "weights" : {  
    "title" : 10,  
    "keywords" : 5  
  }} )
```

- Term match in “title” field has 10 times (i.e. 10:1) the impact as a term match in the “author” field.

Text Indexes are Similar to Multikey Indexes

- Continuing our example, you can treat the `dialog` field as a multikey index.
- A multikey index with each of the words in `dialog` as values.
- You can query the field using the `$text` operator.

Exercise: Inserting Texts

Let's add some documents to our `montyPython` collection.

```
db.montyPython.insertMany( [
  { _id : 1,
    dialog : "What is the air-speed velocity of an unladen swallow?" },
  { _id : 2,
    dialog : "What do you mean? An African or a European swallow?" },
  { _id : 3,
    dialog : "Huh? I... I don't know that." },
  { _id : 45,
    dialog : "You're using coconuts!" },
  { _id : 55,
    dialog : "What? A swallow carrying a coconut?" } ] )
```

Querying a Text Index

Next, let's query the collection. The syntax is:

```
db.<COLLECTION>.find( { $text : { $search : "query terms go here" } } )
```

Exercise: Querying a Text Index

Using the text index, find all documents in the `montyPython` collection with the word “swallow” in it.

```
// Returns 3 documents.
db.montyPython.find( { $text : { $search : "swallow" } } )
```

Exercise: Querying Using Two Words

- Find all documents in the `montyPython` collection with either the word ‘coconut’ or ‘swallow’.
- By default MongoDB ORs query terms together.
- E.g., if you query on two words, results include documents using either word.

```
// Finds 4 documents, 3 of which contain only one of the two words.
db.montyPython.find( { $text : { $search : "coconut swallow" } } )
```

Search for a Phrase

- To match an exact phrase, include search terms in quotes (escaped).
- The following query selects documents containing the phrase “European swallow”:

```
db.montyPython.find( { $text: { $search: "\"European swallow\"" } } )
```

Text Search Score

- The search algorithm assigns a relevance score to each search result.
- The score is generated by a vector ranking algorithm.
- The documents can be sorted by that score.

```
db.<COLLECTION>.find(  
  { $text : { $search : "swallow coconut" } },  
  { textScore: { $meta : "textScore" } }  
) .sort(  
  { textScore: { $meta: "textScore" } }  
) )
```

4.11 Partial Indexes

Learning Objectives

Upon completing this module, students should be able to:

- Outline how partial indexes work
- Distinguish partial indexes from sparse indexes
- List and describe the use cases for partial indexes
- Create and use partial indexes

What are Partial Indexes?

- Indexes with keys only for the documents in a collection that match a filter expression.
- Relative to standard indexes, benefits include:
 - Lower storage requirements
 - * On disk
 - * In memory
 - Reduced performance costs for index maintenance as writes occur

Creating Partial Indexes

- Create a partial index by:
 - Calling `db.collection.createIndex()`
 - Passing the `partialFilterExpression` option
- You can specify a `partialFilterExpression` on any MongoDB index type.
- Filter does not need to be on indexed fields, but it can be.

Example: Creating Partial Indexes

- Consider the following schema:

```
{ "_id" : 7, "integer" : 7, "importance" : "high" }
```

- Create a partial index on the “integer” field
- Create it only where “importance” is “high”

Example: Creating Partial Indexes (Continued)

```
db.integers.createIndex(  
  { integer : 1 },  
  { partialFilterExpression : { importance : "high" },  
    name : "high_importance_integers" } )
```

Filter Conditions

- As the value for `partialFilterExpression`, specify a document that defines the filter.
- The following types of expressions are supported.
- Use these in combinations that are appropriate for your use case.
- Your filter may stipulate conditions on multiple fields.
 - equality expressions
 - `$exists: true` expression
 - `$gt, $gte, $lt, $lte` expressions
 - `$type` expressions
 - `$and` operator at the top-level only

Partial Indexes vs. Sparse Indexes

- Both sparse indexes and partial indexes include only a subset of documents in a collection.
- Sparse indexes reference only documents for which at least one of the indexed fields exist.
- Partial indexes provide a richer way of specifying what documents to index than does sparse indexes.

```
db.integers.createIndex(  
  { importance : 1 },  
  { partialFilterExpression : { importance : { $exists : true } } }  
) // similar to a sparse index
```

Quiz

Which documents in a collection will be referenced by a partial index on that collection?

Identifying Partial Indexes

```
> db.integers.getIndexes()  
[  
  ...,  
  {  
    "v" : 1,  
    "key" : {  
      "integer" : 1  
    },  
    "name" : "high_importance_integers",  
    "ns" : "test.integers",  
    "partialFilterExpression" : {  
      "importance" : "high"  
    }  
  },  
  ...  
]
```

Partial Indexes Considerations

- Not used when:
 - The indexed field is not in the query
 - A query goes outside of the filter range, even if no documents are out of range
- You can `.explain()` queries to check index usage

Quiz

Consider the following partial index. Note the `partialFilterExpression` in particular:

```
{
  "v" : 1,
  "key" : {
    "score" : 1,
    "student_id" : 1
  },
  "name" : "score_1_student_id_1",
  "ns" : "test.scores",
  "partialFilterExpression" : {
    "score" : {
      "$gte" : 0.65
    },
    "subject_name" : "history"
  }
}
```

Quiz (Continued)

Which of the following documents are indexed?

```
{ "_id" : 1, "student_id" : 2, "score" : 0.84, "subject_name" : "history" }
{ "_id" : 2, "student_id" : 3, "score" : 0.57, "subject_name" : "history" }
{ "_id" : 3, "student_id" : 4, "score" : 0.56, "subject_name" : "physics" }
{ "_id" : 4, "student_id" : 4, "score" : 0.75, "subject_name" : "physics" }
{ "_id" : 5, "student_id" : 3, "score" : 0.89, "subject_name" : "history" }
```

4.12 Lab: Finding and Addressing Slow Operations

Set Up

- In this exercise let's bring up a mongo shell with the following instructions

```
mongo --shell localhost/performance performance.js
```

In the shell that launches execute the following method

```
performance.init()
```

Exercise: Determine Indexes Needed

- In a mongo shell run `performance.b()`. This will run in an infinite loop printing some output as it runs various statements against the server.
- Now imagine we have detected a performance problem and suspect there is a slow operation running.
- Find the slow operation and terminate it. Every slow operation is assumed to run for 100ms or more.
- In order to do this, open a second window (or tab) and run a second instance of the mongo shell.
- What indexes can we introduce to make the slow queries more efficient? Disregard the index created in the previous exercises.

4.13 Lab: Using `explain()`

Exercise: `explain("executionStats")`

Drop all indexes from previous exercises:

```
mongo performance
> db.sensor_readings.dropIndexes()
```

Create an index for the “active” field:

```
db.sensor_readings.createIndex({ "active" : 1 } )
```

How many index entries and documents are examined for the following query? How many results are returned?

```
db.sensor_readings.find(
  { "active": false, "_id": { $gte: 99, $lte: 1000 } }
).explain("executionStats")
```

5 Replica Sets

Introduction to Replica Sets (page 88) An introduction to replication and replica sets

Elections in Replica Sets (page 91) The process of electing a new primary (automated failover) in replica sets

Replica Set Roles and Configuration (page 96) Configuring replica set members for common use cases

The Oplog: Statement Based Replication (page 97) The process of replicating data from one node of a replica set to another

Lab: Working with the Oplog (page 99) A brief lab that illustrates how the oplog works

Write Concern (page 101) Balancing performance and durability of writes

Read Concern (page 106) Settings to minimize/prevent stale and dirty reads

Read Preference (page 113) Configuring clients to read from specific members of a replica set

Lab: Setting up a Replica Set (page 114) Launching members, configuring, and initiating a replica set

5.1 Introduction to Replica Sets

Learning Objectives

Upon completing this module, students should understand:

- Striking the right balance between cost and redundancy
- The many scenarios replication addresses and why
- How to avoid downtime and data loss using replication

Use Cases for Replication

- High Availability
- Disaster Recovery
- Functional Segregation

High Availability (HA)

- Data still available following:
 - Equipment failure (e.g. server, network switch)
 - Datacenter failure
- This is achieved through automatic failover.

Disaster Recovery (DR)

- We can duplicate data across:
 - Multiple database servers
 - Storage backends
 - Datacenters
- Can restore data from another node following:
 - Hardware failure
 - Service interruption

Functional Segregation

There are opportunities to exploit the topology of a replica set:

- Based on physical location (e.g. rack or datacenter location)
- For analytics, reporting, data discovery, system tasks, etc.
- For backups

Large Replica Sets

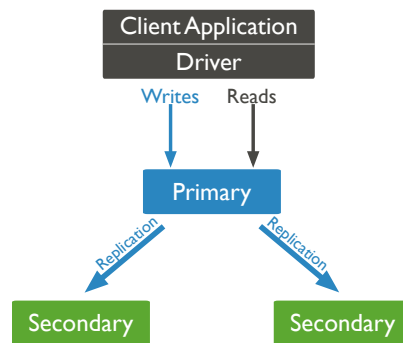
Functional segregation can be further exploited by using large replica sets.

- 50 node replica set limit with a maximum of 7 voting members
- Useful for deployments with a large number of data centers or offices
- Read only workloads can position secondaries in data centers around the world (closer to application servers)

Replication is Not Designed for Scaling

- Can be used for scaling reads, but generally not recommended.
- Drawbacks include:
 - Eventual consistency
 - Not scaling writes
 - Potential system overload when secondaries are unavailable
- Consider sharding for scaling reads and writes.

Replica Sets



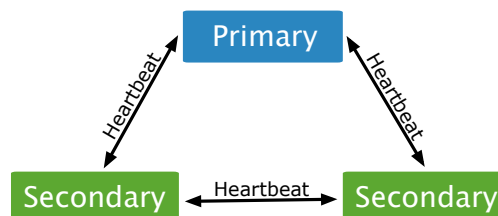
Primary Server

- Clients send writes to the primary only.
- MongoDB, Inc. maintains client drivers in many programming languages like Java, C#, Javascript, Python, Ruby, and PHP.
- MongoDB drivers are replica set aware.

Secondaries

- A secondary replicates operations from another node in the replica set.
- Secondaries usually replicate from the primary.
- Secondaries may also replicate from other secondaries. This is called replication chaining.
- A secondary may become primary as a result of a failover scenario.

Heartbeats



The Oplog

- The operations log, or oplog, is a special capped collection that is the basis for replication.
- The oplog maintains one entry for each document affected by every write operation.
- Secondaries copy operations from the oplog of their sync source.

Initial Sync

- Occurs when a new server is added to a replica set, or we erase the underlying data of an existing server (`--dbpath`)
- All existing collections except the *local* collection are copied
- As of MongoDB ≥ 3.4 , all indexes are built while data is copied
- As of MongoDB ≥ 3.4 , initial sync is more resilient to intermittent network failure/degradation

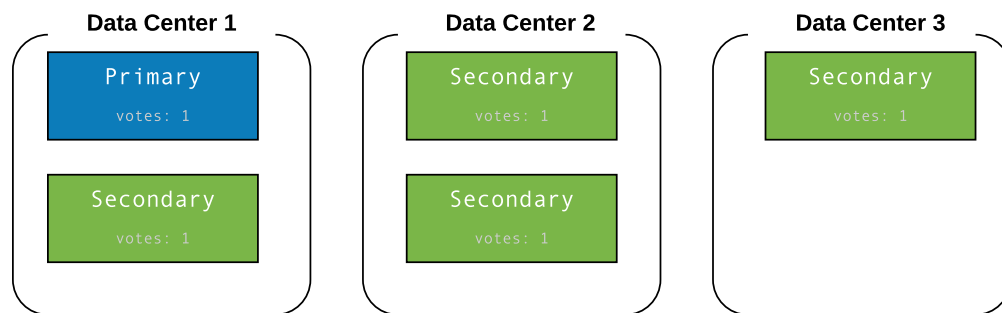
5.2 Elections in Replica Sets

Learning Objectives

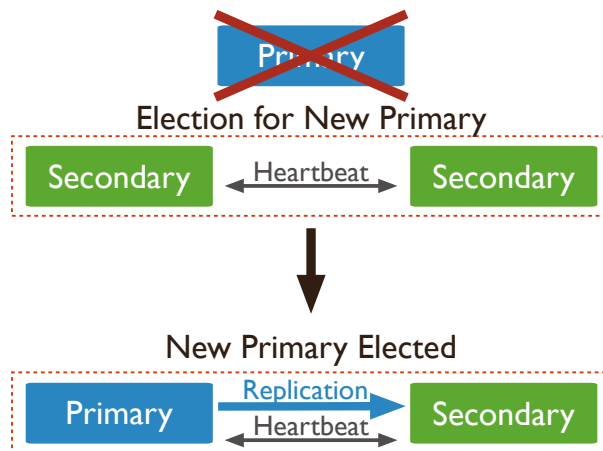
Upon completing this module students should understand:

- That elections enable automated failover in replica sets
- How votes are distributed to members
- What prompts an election
- How a new primary is selected

Members and Votes



Calling Elections



Selecting a New Primary

- Depends on which replication protocol version is in use
- PV0
 - Priority
 - Optime
 - Connections
- PV1
 - Optime
 - Connections

Priority

- PV0 factors priority into voting.
- The higher its priority, the more likely a member is to become primary.
- The default is 1.
- Servers with a priority of 0 will never become primary.
- Priority values are floating point numbers 0 - 1000 inclusive.

Optime

- Optime: Operation time, which is the timestamp of the last operation the member applied from the oplog.
- To be elected primary, a member must have the most recent optime.
- Only optimes of visible members are compared.

Connections

- Must be able to connect to a majority of the members in the replica set.
- Majority refers to the total number of votes.
- Not the total number of members.

When will a primary step down?

- After receiving the `replSetStepDown` or `rs.stepDown()` command.
- If a secondary is eligible for election and has a higher priority.
- If it cannot contact a majority of the members of the replica set.

replSetStepDown Behavior

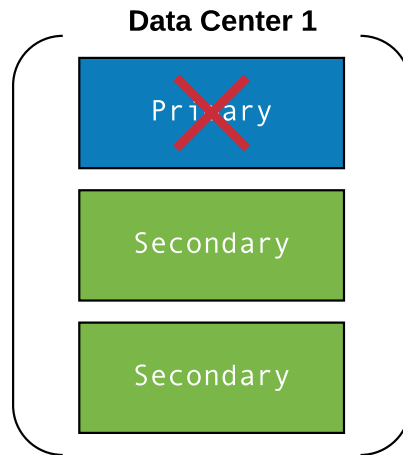
- Primary will attempt to terminate long running operations before stepping down.
- Primary will wait for electable secondary to catch up before stepping down.
- “secondaryCatchUpPeriodSecs” can be specified to limit the amount of time the primary will wait for a secondary to catch up before the primary steps down.

Exercise: Elections in Failover Scenarios

- We have learned about electing a primary in replica sets.
- Let’s look at some scenarios in which failover might be necessary.

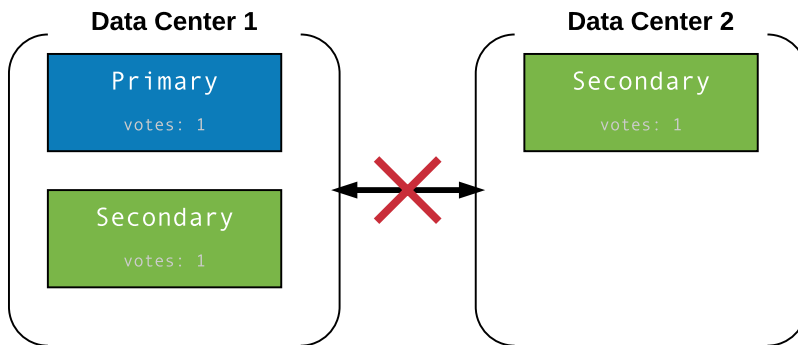
Scenario A: 3 Data Nodes in 1 DC

Which secondary will become the new primary?



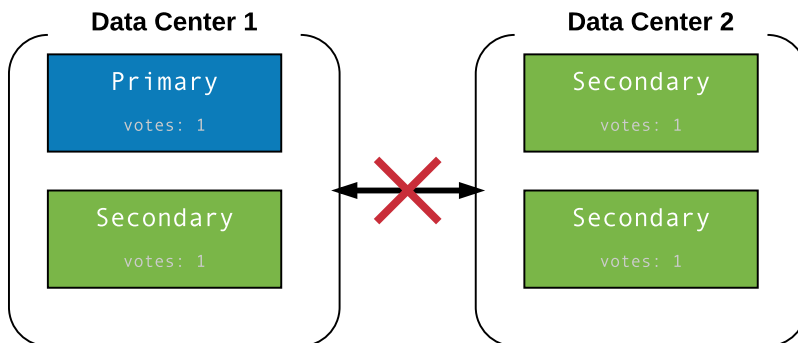
Scenario B: 3 Data Nodes in 2 DCs

Which member will become primary following this type of network partition?



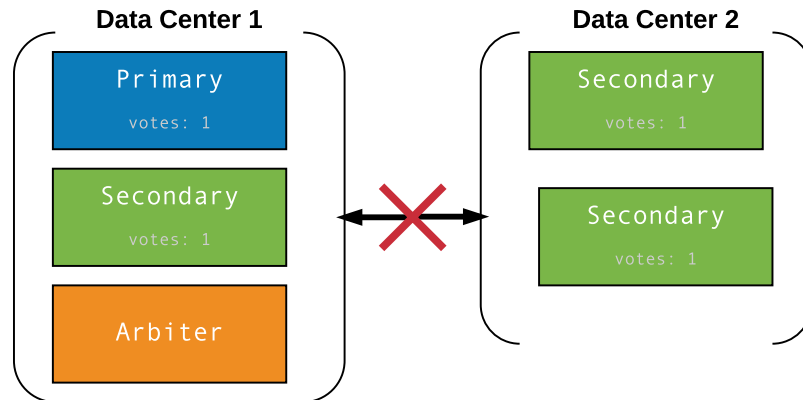
Scenario C: 4 Data Nodes in 2 DCs

What happens following this network partition?



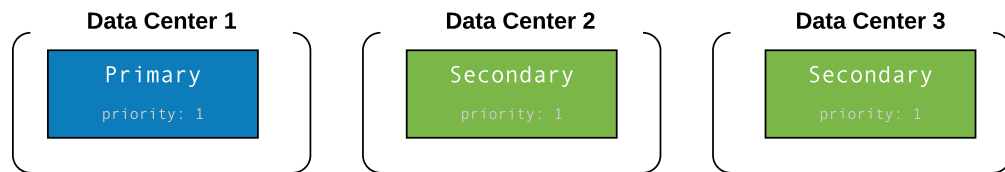
Scenario D: 5 Nodes in 2 DCs

The following is similar to Scenario C, but with the addition of an arbiter in Data Center 1. What happens here?



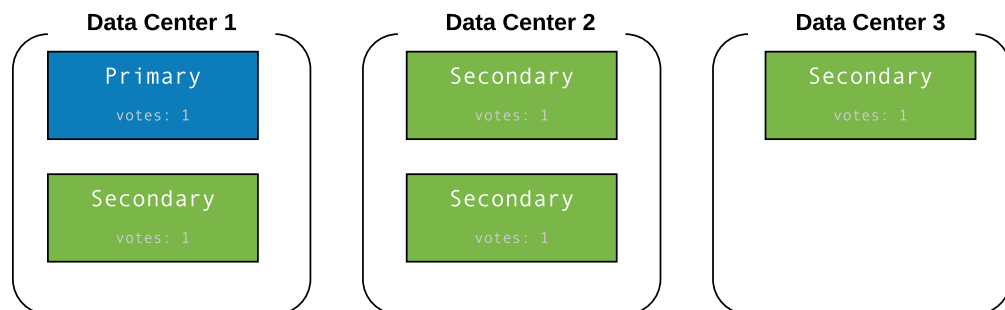
Scenario E: 3 Data Nodes in 3 DCs

- What happens here if any one of the nodes/DCs fail?
- What about recovery time?



Scenario F: 5 Data Nodes in 3 DCs

What happens here if any one of the nodes/DCs fail? What about recovery time?



5.3 Replica Set Roles and Configuration

Learning Objectives

Upon completing this module students should understand:

- The use of priority to preference certain members or datacenters as primaries.
- Hidden members.
- The use of hidden secondaries for data analytics and other purposes (when secondary reads are used).
- The use of slaveDelay to protect against operator error.

Example: A Five-Member Replica Set Configuration

- For this example application, there are two datacenters.
- We name the hosts accordingly: dc1-1, dc1-2, dc2-1, etc.
 - This is just a clarifying convention for this example.
 - MongoDB does not care about host names except to establish connections.
- The nodes in this replica set have a variety of roles in this application.

Configuration

```
conf = {                                // 5 data-bearing nodes
  _id: "mySet",
  members: [
    { _id : 0, host : "dc1-1.example.net:27017", priority : 5 },
    { _id : 1, host : "dc1-2.example.net:27017", priority : 5 },
    { _id : 2, host : "dc2-1.example.net:27017" },
    { _id : 3, host : "dc1-3.example.net:27017", hidden : true },
    { _id : 4, host : "dc2-2.example.net:27017", hidden : true,
      slaveDelay: 7200 }
  ]
}
```

Principal Data Center

```
{ _id : 0, host : "dc1-1.example.net", priority : 5 },
{ _id : 1, host : "dc1-2.example.net", priority : 5 },
```

Data Center 2

```
{ _id : 2, host : "dc2-1.example.net:27017" },
```

What about dc1-3 and dc2-2?

```
// Both are hidden.  
// Clients will not distribute reads to hidden members.  
// We use hidden members for dedicated tasks.  
{ _id : 3, host : "dc1-3.example.net:27017", hidden : true },  
{ _id : 4, host : "dc2-2.example.net:27017", hidden : true,  
  slaveDelay: 7200 }
```

What about dc2-2?

```
{ _id : 4, host : "dc2-2.example.net:27017", hidden : true,  
  slaveDelay : 7200 }
```

5.4 The Oplog: Statement Based Replication

Learning Objectives

Upon completing this module students should understand:

- Binary vs. statement-based replication.
- How the oplog is used to support replication.
- How operations in MongoDB are translated into operations written to the oplog.
- Why oplog operations are idempotent.
- That the oplog is a capped collection and the implications this holds for syncing members.

Binary Replication

- MongoDB replication is statement based.
- Contrast that with binary replication.
- With binary replication we would keep track of:
 - The data files
 - The offsets
 - How many bytes were written for each change
- In short, we would keep track of actual bytes and very specific locations.
- We would simply replicate these changes across secondaries.

Tradeoffs

- The good thing is that figuring out where to write, etc. is very efficient.
- But we must have a byte-for-byte match of our data files on the primary and secondaries.
- The problem is that this couples our replica set members in ways that are inflexible.
- Binary replication may also replicate disk corruption.

Statement-Based Replication

- Statement-based replication facilitates greater independence among members of a replica set.
- MongoDB stores a statement for every operation in a capped collection called the `oplog`.
- Secondaries do not simply apply exactly the operation that was issued on the primary.

Example

Suppose the following command is issued and it deletes 100 documents:

```
db.foo.deleteMany({ age : 30 })
```

This will be represented in the `oplog` with records such as the following:

```
{ "ts" : Timestamp(1407159845, 5), "h" : NumberLong("-704612487691926908"),  
  "v" : 2, "op" : "d", "ns" : "bar.foo", "b" : true, "o" : { "_id" : 65 } }  
{ "ts" : Timestamp(1407159845, 1), "h" : NumberLong("6014126345225019794"),  
  "v" : 2, "op" : "d", "ns" : "bar.foo", "b" : true, "o" : { "_id" : 333 } }  
{ "ts" : Timestamp(1407159845, 4), "h" : NumberLong("8178791764238465439"),  
  "v" : 2, "op" : "d", "ns" : "bar.foo", "b" : true, "o" : { "_id" : 447 } }  
{ "ts" : Timestamp(1407159845, 3), "h" : NumberLong("-1707391001705528381"),  
  "v" : 2, "op" : "d", "ns" : "bar.foo", "b" : true, "o" : { "_id" : 1033 } }  
{ "ts" : Timestamp(1407159845, 2), "h" : NumberLong("-6814297392442406598"),  
  "v" : 2, "op" : "d", "ns" : "bar.foo", "b" : true, "o" : { "_id" : 9971 } }
```

Replication Based on the Oplog

- One statement per document affected by each write: insert, update, or delete.
- Provides a level of abstraction that enables independence among the members of a replica set:
 - With regard to MongoDB version.
 - In terms of how data is stored on disk.
 - Freedom to do maintenance without the need to bring the entire set down.

Operations in the Oplog are Idempotent

- Each operation in the oplog is idempotent.
- Whether applied once or multiple times it produces the same result.
- Necessary if you want to be able to copy data while simultaneously accepting writes.

The Oplog Window

- Oplogs are capped collections.
- Capped collections are fixed-size.
- They guarantee preservation of insertion order.
- They support high-throughput operations.
- Like circular buffers, once a collection fills its allocated space:
 - It makes room for new documents.
 - By overwriting the oldest documents in the collection.

Sizing the Oplog

- The oplog should be sized to account for latency among members.
- The default size oplog is usually sufficient.
- But you want to make sure that your oplog is large enough:
 - So that the oplog window is large enough to support replication
 - To give you a large enough history for any diagnostics you might wish to run.

5.5 Lab: Working with the Oplog

Create a Replica Set

Let's take a look at a concrete example. Launch mongo shell as follows.

```
mkdir -p /data/db  
mongo --nodb
```

Create a replica set by running the following command in the mongo shell.

```
replicaSet = new ReplSetTest( { nodes : 3 } )
```

ReplSetTest

- ReplSetTest is useful for experimenting with replica sets as a means of hands-on learning.
- It should never be used in production. Never.
- The command above will create a replica set with three members.
- It does not start the mongods, however.
- You will need to issue additional commands to do that.

Start the Replica Set

Start the mongod processes for this replica set.

```
replicaSet.startSet()
```

Issue the following command to configure replication for these mongods. You will need to issue this while output is flying by in the shell.

```
replicaSet.initiate()
```

Status Check

- You should now have three mongods running on ports 20000, 20001, and 20002.
- You will see log statements from all three printing in the current shell.
- To complete the rest of the exercise, open a new shell.

Connect to the Primary

Open a new shell, connecting to the primary.

```
mongo --port 20000
```

Create some Inventory Data

Use the `store` database:

```
use store
```

Add the following inventory:

```
inventory = [ { _id: 1, inStock: 10 }, { _id: 2, inStock: 20 },  
              { _id: 3, inStock: 30 }, { _id: 4, inStock: 40 },  
              { _id: 5, inStock: 50 }, { _id: 6, inStock: 60 } ]  
db.products.insert(inventory)
```

Perform an Update

Issue the following update. We might issue this update after a purchase of three items.

```
db.products.update({ _id: { $in: [ 2, 5 ] } },
                   { $inc: { inStock : -1 } },
                   { multi: true })
```

View the Oplog

The oplog is a capped collection in the `local` database of each replica set member:

```
use local
db.oplog.rs.find()
{ "ts" : Timestamp(1406944987, 1), "h" : NumberLong(0), "v" : 2, "op" : "n",
  "ns" : "", "o" : { "msg" : "initiating set" } }
...
{ "ts" : Timestamp(1406945076, 1), "h" : NumberLong("-9144645443320713428"),
  "v" : 2, "op" : "u", "ns" : "store.products", "o2" : { "_id" : 2 },
  "o" : { "$set" : { "inStock" : 19 } } }
{ "ts" : Timestamp(1406945076, 2), "h" : NumberLong("-7873096834441143322"),
  "v" : 2, "op" : "u", "ns" : "store.products", "o2" : { "_id" : 5 },
  "o" : { "$set" : { "inStock" : 49 } } }
```

5.6 Write Concern

Learning Objectives

Upon completing this module students should understand:

- How and when rollback occurs in MongoDB.
- The tradeoffs between durability and performance.
- Write concern as a means of ensuring durability in MongoDB.
- The different levels of write concern.
- Relation between voting member and write concern

What happens to the write?

- A write is sent to a primary.
- The primary acknowledges the write to the client.
- The primary then becomes unavailable before a secondary can replicate the write

Answer to ‘What happens to the write?’

- Another member might be elected primary.
- It will not have the last write that occurred before the previous primary became unavailable.
- When the previous primary becomes available again:
 - It will note it has writes that were not replicated.
 - It will put these writes into a `rollback` file.
 - A human will need to determine what to do with this data.
- This is default behavior in MongoDB and can be controlled using `write concern`.

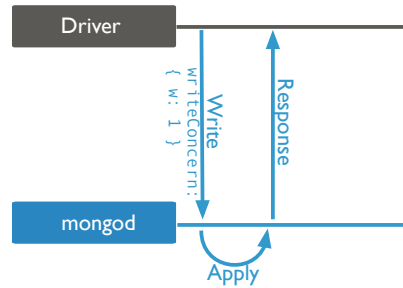
Balancing Durability with Performance

- The previous scenario is a specific instance of a common distributed systems problem.
- For some applications it might be acceptable for writes to be rolled back.
- Other applications may have varying requirements with regard to durability.
- Tunable write concern:
 - Make critical operations persist to an entire MongoDB deployment.
 - Specify replication to fewer nodes for less important operations.

Defining Write Concern

- MongoDB acknowledges its writes
- Write concern determines when that acknowledgment occurs
 - How many servers
 - Whether on disk or not
- Clients may define the write concern per write operation, if necessary.
- Standardize on specific levels of write concerns for different classes of writes.
- In the discussion that follows we will look at increasingly strict levels of write concern.
- Only voting members participate in write concern count.

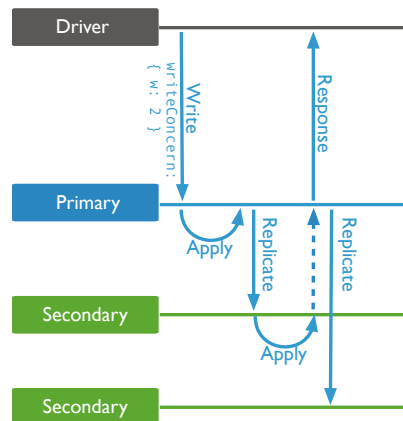
Write Concern: { w : 1 }



Example: { w : 1 }

```
db.edges.insertOne( { from : "tom185", to : "mary_p" },  
                    { writeConcern : { w : 1 } } )
```

Write Concern: { w : 2 }



Example: { w : 2 }

```
db.customer.updateOne( { user : "mary_p" },  
                      { $push : { shoppingCart:  
                                { _id : 335443, name : "Brew-a-cup",  
                                  price : 45.79 } } },  
                      { writeConcern : { w : 2 } } )
```

Other Remarks regarding Write Concerns

- `w` can use any integer for write concern.
- Acknowledgment guarantees the write has propagated to the specified number of voting members.
 - E.g., `{ w : 3 }`, `{ w : 4 }`, etc.
- `j : true` ensures the writes are in the journal (which is written to disk) before being acknowledged
 - PV0: on the *primary* need to write to the journal
 - PV1: all nodes contributing to the majority write the journal to disk before acknowledge `writeConcernMajorityJournalDefault`⁹
- `w : majority` implies `j : true` in PV1

Write Concern: `{ w : "majority" }`

- Ensures the primary completed the write (in RAM).
 - By default, also on disk
- Ensures write operations have propagated to a majority of the **voting** members.
- Avoids hard coding assumptions about the size of your replica set into your application.
- Using majority trades off performance for durability.
- It is suitable for critical writes and to avoid rollbacks.

Example: `{ w : "majority" }`

```
db.products.updateOne({ _id : 335443 },
                      { $inc : { inStock : -1 } },
                      { writeConcern : { w : "majority" } })
```

Quiz: Which write concern?

Suppose you have a replica set with 7 data nodes, all voting members in the replica set. Your application has critical inserts for which you do not want rollbacks to happen. Secondaries may be taken down from to time for maintenance, leaving you with a potential 4 server replica set. Which write concern is best suited for these critical inserts?

- `{ w : 1 }`
- `{ w : 2 }`
- `{ w : 3 }`
- `{ w : 4 }`
- `{ w : "majority" }`

⁹ <http://docs.mongodb.org/manual/reference/replica-configuration/#rsconf.writeConcernMajorityJournalDefault>

Further Reading

See [Write Concern Reference](#)¹⁰ for more details on write concern configurations, including setting timeouts and identifying specific replica set members that must acknowledge writes (i.e. [tag sets](#)¹¹).

¹⁰ <http://docs.mongodb.org/manual/reference/write-concern>

¹¹ <http://docs.mongodb.org/manual/tutorial/configure-replica-set-tag-sets/#replica-set-configuration-tag-sets>

5.7 Read Concern

Learning Objectives

Upon completing this module, students will be able to:

- Define read concern
- Distinguish stale from dirty reads
- Describe how read concern prevents dirty reads
- Understand how to use read concern in MongoDB
- Understand the differences between replication protocol version 0 and 1

Read Concerns

- **Local:** *Default*
- **Majority:** Added in MongoDB 3.2, requires WiredTiger and election Protocol Version 1 (PV1)
- **Linearizable:** Added in MongoDB 3.4, works with MMAP or WiredTiger

Local

- Default read concern
- Will return data from the primary.
- Does not wait for the write to be replicated to other members of the replica set.

Majority

- Available only with WiredTiger and PV1.
- Reads majority acknowledged writes from a snapshot.
 - server will need additional memory to keep additional snapshot in memory
 - need to start *mongod* with *-enableMajorityReadConcern*
- Under certain circumstances (high volume, flaky network), can result in stale reads.

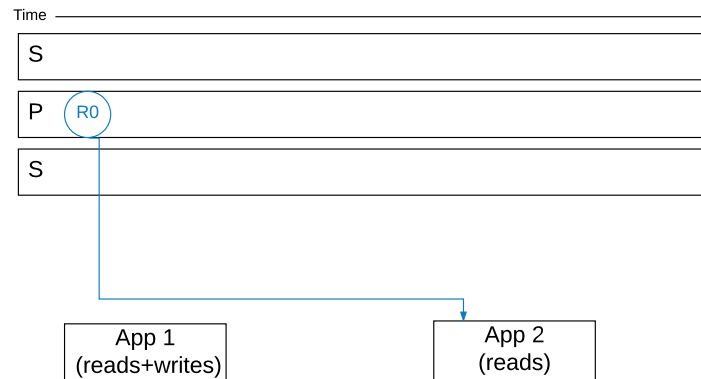
Linearizable

- Available with MongoDB versions ≥ 3.4
- Will read latest data acknowledged with $w: \text{majority}$, or block until replica set acknowledges a write in progress with $w: \text{majority}$
- Can result in **very slow** queries.
 - Always use **maxTimeMS** with **linearizable**
- Only guaranteed to be a linearizable read when the query fetches a single document

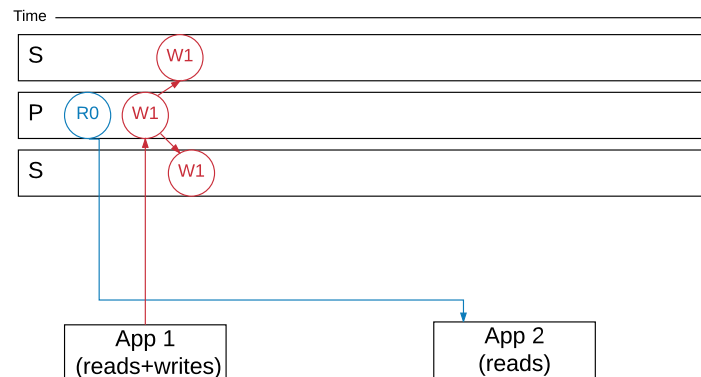
Example: Read Concern Level Majority

App1 is doing writes to a document with $w: \text{"majority"}$

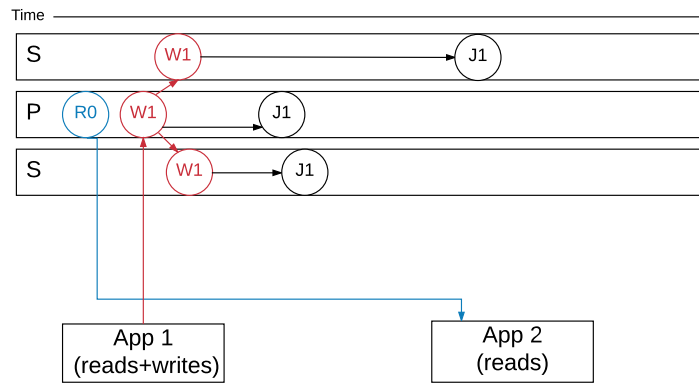
App2 is reading the same document with **read concern level: "majority"**



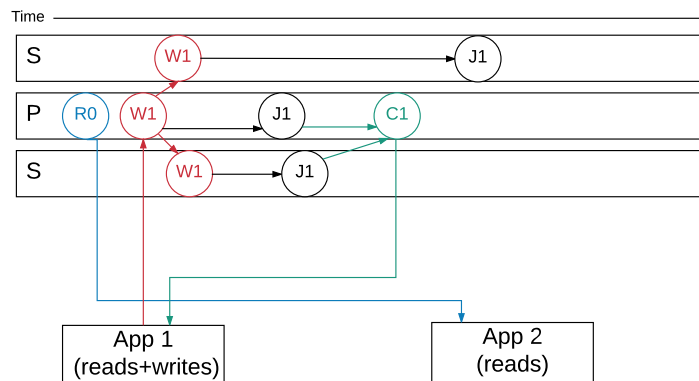
A new version of the document (W1) is written by *App1*, and the write is propagated to the secondaries



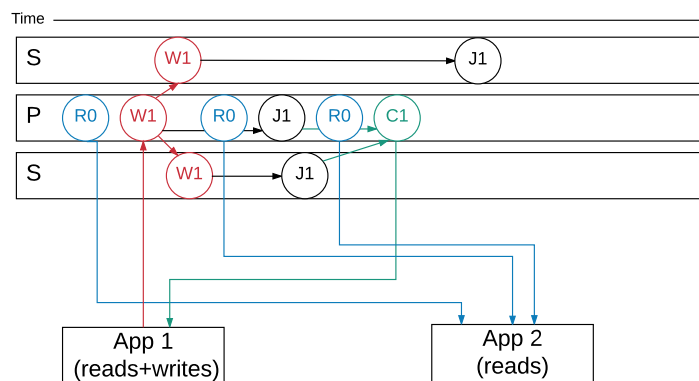
The *write*, also needs to be *journalled* (J1) on each secondary



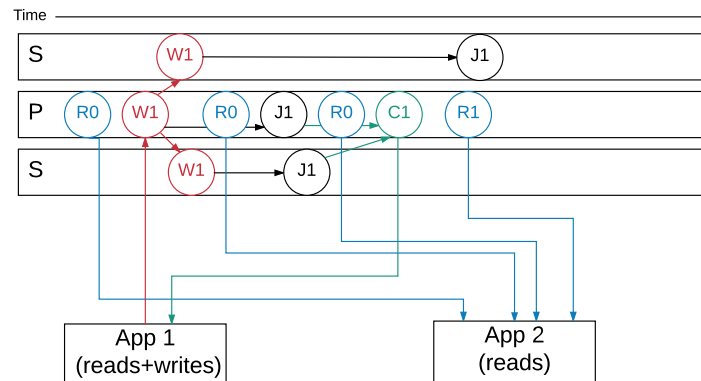
Once the write is journaled on a majority of nodes, *App1* will get a confirmation of the commit on a majority (C1) of nodes.



If *App2* reads the document with a *read concern level majority* at any time before *C1*, it will get the value *R0*



However after the committed state (C1), it will get the new value for the document (R1)



Background: Stale Reads

- Reads that do not reflect the most recent writes are stale
- These can occur when reading from secondaries
- Systems with stale reads are “eventually consistent”
- Reading from the primary minimizes odds of stale reads
 - They can still occur in rare cases

Stale Reads on a Primary

- In unusual circumstances, two members may simultaneously believe that they are the primary
 - One can acknowledge { w : "majority" } writes
 - * This is the true primary
 - The other was a primary
 - * But a new one has been elected
- In this state, the other primary will serve stale reads

Background: Dirty Reads

- Dirty reads are not stale reads
- Dirty reads occur when you see a view of the data
 - ... but that view *may* not persist
 - ... even in the history (i.e., oplog)
- Occur when data is read that has not been committed to a majority of the replica set
 - Because that data *could* get rolled back

Dirty Reads and Write Concern

- Write concern alone can not prevent dirty reads
 - Data on the primary may be vulnerable to rollback
 - The exception being **linearizable** reads on a primary with `writeConcernMajorityJournalDefault` set to true.
- Read concern was implemented to allow developers the option of preventing dirty reads

Quiz

What is the difference between a dirty read and a stale read?

Read Concern and Read Preference

- Read preference determines the server you read from
 - Primary, secondary, etc.
- Read concern determines the view of the data you see, and does not update its data the moment writes are received

Read Concern and Read Preference: Secondary

- The primary has the most current view of the data
 - Secondaries learn which writes are committed from the primary
- Data on secondaries might be behind the primary
 - But never ahead of the primary

Using Read Concern

- To use level: `majority` read concern, you must:
 - Use WiredTiger on all members
 - Launch all mongods in the set with
 - * `--enableMajorityReadConcern`
 - Specify the read concern level to the driver
- You should:
 - Use write concern { w : "majority" }
 - Otherwise, an application may not see its own writes

Example: Using Read Concern

- First, launch a replica set
 - Use `--enableMajorityReadConcern`
- A script is in the *shell_scripts* directory of the USB drive.

```
./launch_replset_for_majority_read_concern.sh
```

Example: Using Read Concern (Continued)

```
#!/usr/bin/env bash
echo 'db.testCollection.drop();' | mongo --port 27017 readConcernTest; wait
echo 'db.testCollection.insertOne({message: "probably on a secondary." });' |
mongo --port 27017 readConcernTest; wait
echo 'db.fsyncLock()' | mongo --port 27018; wait
echo 'db.fsyncLock()' | mongo --port 27019; wait
echo 'db.testCollection.insertOne( { message : "Only on primary." } );' |
mongo --port 27017 readConcernTest; wait
echo 'db.testCollection.find().readConcern("majority");' |
mongo --port 27017 readConcernTest; wait
echo 'db.testCollection.find(); // read concern "local"' |
mongo --port 27017 readConcernTest; wait
echo 'db.fsyncUnlock()' | mongo --port 27018; wait
echo 'db.fsyncUnlock()' | mongo --port 27019; wait
echo 'db.testCollection.drop();' | mongo --port 27017 readConcernTest
```

Quiz

What must you do in order to make the database return documents that have been replicated to a majority of the replica set members?

Replication Protocol Version 0

- Better data consistency when using arbiters and `w: 1` writes
- Does not support `majority` read concern
- 30 second buffer between elections
- Supports vetoes based on **priority**
 - Should have fewer elections, and fewer `w: 1` rollbacks.

Replication Protocol Version 1

- Version 1 is the default in MongoDB ≥ 3.2 .
- With version 1, secondaries now write to disk before acknowledging writes.
- `{ w : "majority" }` now implies `{ j : true }`
 - Can be disabled by setting `writeConcernMajorityJournalDefault` to `false` for versions ≥ 3.4
- Set the replication protocol version using the `protocolVersion` parameter in your replica set configuration.

Replication Protocol Version 1 (continued)

- Also adds `electionTimeoutMillis` as an option
 - For secondaries: How long to wait before calling for an election
 - For primaries: How long to wait before stepping down
 - * After losing contact with the majority
 - * This applies to the primary only
- Required for read concern level “majority”

Quiz

What are the advantages of replication protocol 1?

Further Reading

See [Read Concern Reference](http://docs.mongodb.org/manual/reference/read-concern)¹² for more details on read concerns.

¹² <http://docs.mongodb.org/manual/reference/read-concern>

5.8 Read Preference

What is Read Preference?

- Read preference allows you to specify the nodes in a replica set to read from.
- Clients only read from the primary by default.
- There are some situations in which a client may want to read from:
 - Any secondary
 - A specific secondary
 - A specific type of secondary
- Only read from a secondary if you can tolerate possibly stale data, as not all writes might have replicated.

Use Cases

- Running systems operations without affecting the front-end application.
- Providing local reads for geographically distributed applications.
- Maintaining availability during a failover.

Not for Scaling

- In general, do *not* read from secondaries to provide extra capacity for reads.
- [Sharding](http://docs.mongodb.org/manual/sharding)¹³ increases read and write capacity by distributing operations across a group of machines.
- Sharding is a better strategy for adding capacity.

Read Preference Modes

MongoDB drivers support the following read preferences. Note that hidden nodes will never be read from when connected via the replica set.

- **primary**: Default. All operations read from the primary.
- **primaryPreferred**: Read from the primary but if it is unavailable, read from secondary members.
- **secondary**: All operations read from the secondary members of the replica set.
- **secondaryPreferred**: Read from secondary members but if no secondaries are available, read from the primary.
- **nearest**: Read from member of the replica set with the least network latency, regardless of the member's type.

¹³ <http://docs.mongodb.org/manual/sharding>

Tag Sets

- There is also the option to use tag sets.
- You may tag nodes such that queries that contain the tag will be routed to one of the servers with that tag.
- This can be useful for running reports, say for a particular data center or nodes with different hardware (e.g. hard disks vs SSDs).

For example, in the mongo shell:

```
conf = rs.conf()
conf.members[0].tags = { dc : "east", use : "production" }
conf.members[1].tags = { dc : "east", use : "reporting" }
conf.members[2].tags = { use : "production" }
rs.reconfig(conf)
```

5.9 Lab: Setting up a Replica Set

Overview

- In this exercise we will setup a 3 data node replica set on a single machine.
- In production, each node should be run on a dedicated host:
 - To avoid any potential resource contention
 - To provide isolation against server failure

Create Data Directories

Since we will be running all nodes on a single machine, make sure each has its own data directory.

On Linux or Mac OS, run the following in the terminal to create the 3 directories ~/data/rs1, ~/data/rs2, and ~/data/rs3:

```
mkdir -p ~/data/rs{1,2,3}
```

On Windows, run the following command instead in Command Prompt or PowerShell:

```
md c:\data\rs1 c:\data\rs2 c:\data\rs3
```

Launch Each Member

Now start 3 instances of `mongod` in the foreground so that it is easier to observe and shutdown.

On Linux or Mac OS, run *each* of the following commands in its *own terminal window*:

```
mongod --replSet myReplSet --dbpath ~/data/rs1 --port 27017 --oplogSize 200
mongod --replSet myReplSet --dbpath ~/data/rs2 --port 27018 --oplogSize 200
mongod --replSet myReplSet --dbpath ~/data/rs3 --port 27019 --oplogSize 200
```

On Windows, run *each* of the following commands in its *own Command Prompt or PowerShell window*:

```
mongod --replSet myReplSet --dbpath c:\data\rs1 --port 27017 --oplogSize 200
mongod --replSet myReplSet --dbpath c:\data\rs2 --port 27018 --oplogSize 200
mongod --replSet myReplSet --dbpath c:\data\rs3 --port 27019 --oplogSize 200
```

Status

- At this point, we have 3 `mongod` instances running.
- They were all launched with the same `replSet` parameter of “myReplSet”.
- Despite this, the members are not aware of each other yet.
- This is fine for now.

Connect to a MongoDB Instance

- Connect to the one of the MongoDB instances with the mongo shell.
- To do so run the following command in the terminal, Command Prompt, or PowerShell:

```
mongo // connect to the default port 27017
```

Configure the Replica Set

```
rs.initiate()
// wait a few seconds
rs.add ('<HOSTNAME>:27018')
rs.addArb ('<HOSTNAME>:27019')

// Keep running rs.status() until there's a primary and 2 secondaries
rs.status()
```

Problems That May Occur When Initializing the Replica Set

- bindIp parameter is incorrectly set
- Replica set configuration may need to be explicitly specified to use a different hostname:

```
> conf = {
  _id: "<REPLICA-SET-NAME>",
  members: [
    { _id : 0, host : "<HOSTNAME>:27017"},
    { _id : 1, host : "<HOSTNAME>:27018"},
    { _id : 2, host : "<HOSTNAME>:27019",
      "arbiterOnly" : true},
  ]
}
> rs.initiate(conf)
```

Write to the Primary

While still connected to the primary (port 27017) with mongo shell, insert a simple test document:

```
db.testcol.insert({ a: 1 })
db.testcol.count()

exit    // Or Ctrl-d
```

Read from a Secondary

Connect to one of the secondaries. E.g.:

```
mongo --port 27018
```

Read from the secondary

```
rs.slaveOk()
db.testcol.find()
```

Review the Oplog

```
use local
db.oplog.rs.find()
```

Changing Replica Set Configuration

To change the replica set configuration, first connect to the primary via mongo shell:

```
mongo --port <PRIMARY_PORT> # e.g. 27017
```

Let's raise the priority of one of the secondaries. Assuming it is the 2nd node (e.g. on port 27018):

```
cfg = rs.conf()
cfg["members"][1]["priority"] = 10
rs.reconfig(cfg)
```

Verifying Configuration Change

You will see errors like the following, which are expected:

```
2014-10-07T17:01:34.610+0100 DBClientCursor::init call() failed
2014-10-07T17:01:34.613+0100 trying reconnect to 127.0.0.1:27017 (127.0.0.1) failed
2014-10-07T17:01:34.617+0100 reconnect 127.0.0.1:27017 (127.0.0.1) ok
reconnected to server after rs command (which is normal)
```

Verify that the replica set configuration is now as expected:

```
rs.conf()
```

The secondary will now become a primary. Check by running:

```
rs.status()
```

Further Reading

- [Replica Configuration](#)¹⁴
- [Replica States](#)¹⁵

¹⁴ <http://docs.mongodb.org/manual/reference/replica-configuration/>

¹⁵ <http://docs.mongodb.org/manual/reference/replica-states/>

6 Sharding

Introduction to Sharding (page 118) An introduction to sharding

Balancing Shards (page 125) Chunks, the balancer, and their role in a sharded cluster

Shard Zones (page 127) How zone-based sharding works

Lab: Setting Up a Sharded Cluster (page 129) Deploying a sharded cluster

6.1 Introduction to Sharding

Learning Objectives

Upon completing this module, students should understand:

- What problems sharding solves
- When sharding is appropriate
- The importance of the shard key and how to choose a good one
- Why sharding increases the need for redundancy

Contrast with Replication

- In an earlier module, we discussed Replication.
- This should never be confused with sharding.
- Replication is about high availability and durability.
 - Taking your data and constantly copying it
 - Being ready to have another machine step in to field requests.

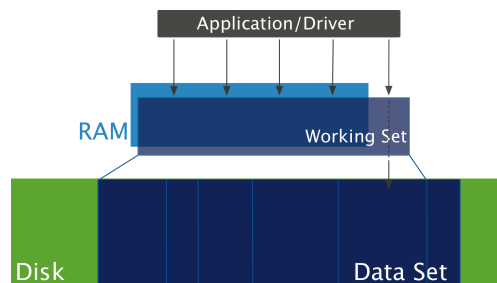
Sharding is Concerned with Scale

- What happens when a system is unable to handle the application load?
- It is time to consider scaling.
- There are 2 types of scaling we want to consider:
 - Vertical scaling
 - Horizontal scaling

Vertical Scaling

- Adding more RAM, faster disks, etc.
- When is this the solution?
- First, consider a concept called the *working set*.

The Working Set



Limitations of Vertical Scaling

- There is a limit to how much RAM one machine can support.
- There are other bottlenecks such as I/O, disk access and network.
- Cost may limit our ability to scale up.
- There may be requirements to have a large working set that no single machine could possibly support.
- This is when it is time to scale horizontally.

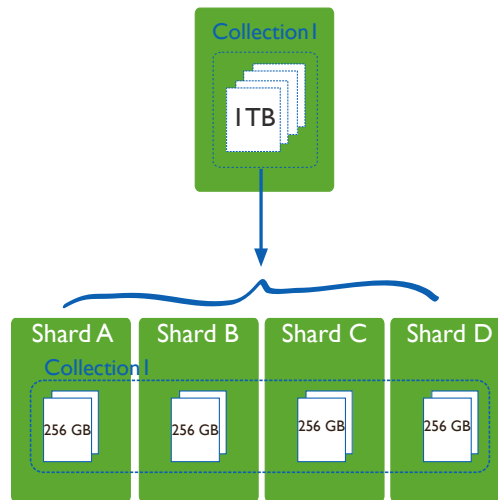
Sharding Overview

- MongoDB enables you to scale horizontally through sharding.
- Sharding is about adding more capacity to your system.
- MongoDB's sharding solution is designed to perform well on commodity hardware.
- The details of sharding are abstracted away from applications.
- Queries are performed the same way as if sending operations to a single server.
- Connections work the same by default.

When to Shard

- If you have more data than one machine can hold on its drives
- If your application is write heavy and you are experiencing too much latency.
- If your working set outgrows the memory you can allocate to a single machine.

Dividing Up Your Dataset



Sharding Concepts

To understanding how sharding works in MongoDB, we need to understand:

- Shard Keys
- Chunks

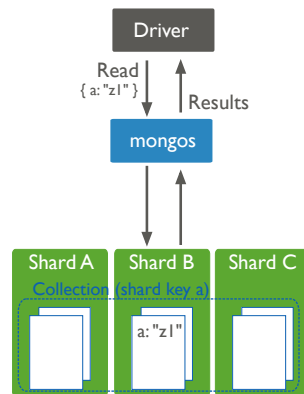
Shard Key

- You must define a shard key for a sharded collection.
- Based on one or more fields (like an index)
- Shard key defines a space of values
- Think of the key space like points on a line
- A key range is a segment of that line

Shard Key Ranges

- A collection is partitioned based on shard key ranges.
- The shard key determines where documents are located in the cluster.
- It is used to route operations to the appropriate shard.
- For reads and writes.
- Once a collection is sharded, you cannot change a shard key.
- You can not *update* the value of the shard key for a document

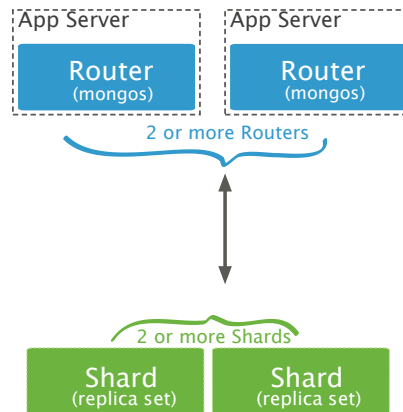
Targeted Query Using Shard Key



Chunks

- MongoDB partitions data into `chunks` based on shard key ranges.
- This is bookkeeping metadata.
- MongoDB attempts to keep the amount of data balanced across shards.
- This is achieved by migrating chunks from one shard to another as needed.
- There is nothing in a document that indicates its chunk.
- The document does not need to be updated if its assigned chunk changes.

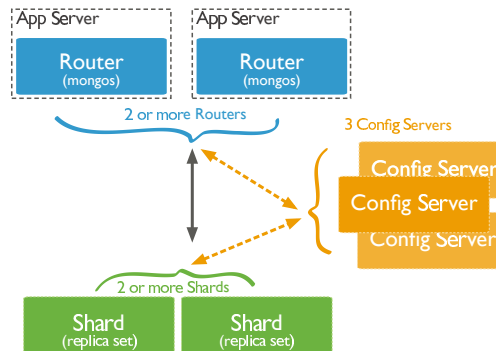
Sharded Cluster Architecture



Mongos

- A mongos is responsible for accepting requests and returning results to an application driver.
- In a sharded cluster, nearly all operations go through a mongos.
- A sharded cluster can have as many mongos routers as required.
- It is typical for each application server to have one mongos.
- Always use more than one mongos to avoid a single point of failure.

Config Servers



Config Server Hardware Requirements

- Quality network interfaces
- A small amount of disk space (typically a few GB)
- A small amount of RAM (typically a few GB)
- The larger the sharded cluster, the greater the config server hardware requirements.

Possible Imbalance?

- Depending on how you configure sharding, data can become unbalanced on your sharded cluster.
 - Some shards might receive more inserts than others.
 - Some shards might have documents that grow more than those in other shards.
- This may result in too much load on a single shard.
 - Reads and writes
 - Disk activity
- This would defeat the purpose of sharding.

Balancing Shards

- If a chunk grows too large MongoDB will split it into two chunks.
- The MongoDB balancer keeps chunks distributed across shards in equal numbers.
- However, a balanced sharded cluster depends on a good shard key.

With a Good Shard Key

You might easily see that:

- Reads hit only 1 or 2 shards per query.
- Writes are distributed across all servers.
- Your disk usage is evenly distributed across shards.
- Things stay this way as you scale.

With a Bad Shard Key

You might see that:

- Your reads hit every shard.
- Your writes are concentrated on one shard.
- Most of your data is on just a few shards.
- Adding more shards to the cluster will not help.

Choosing a Shard Key

Generally, you want a shard key:

- That has high cardinality
- That is used in the majority of read queries
- For which the values read and write operations use are randomly distributed
- For which the majority of reads are routed to a particular server

More Specifically

- Your shard key should be consistent with your query patterns.
- If reads usually find only one document, you only need good cardinality.
- If reads retrieve many documents:
 - Your shard key supports locality
 - Matching documents will reside on the same shard

Cardinality

- A good shard key will have high cardinality.
- A relatively small number of documents should have the same shard key.
- Otherwise operations become isolated to the same server.
- Because documents with the same shard key reside on the same shard.
- Adding more servers will not help.
- Hashing will not help.

Non-Monotonic

- A good shard key will generate new values non-monotonically.
- Datetimes, counters, and ObjectIds make bad shard keys.
- Monotonic shard keys cause all inserts to happen on the same shard.
- Hashing will solve this problem.
- However, doing range queries with a hashed shard key will perform a scatter-gather query across the cluster.

Shards Should be Replica Sets

- As the number of shards increases, the number of servers in your deployment increases.
- This increases the probability that one server will fail on any given day.
- With redundancy built into each shard you can mitigate this risk.

6.2 Balancing Shards

Learning Objectives

Upon completing this module students should understand:

- Chunks and the balancer
- The status of chunks in a newly sharded collection
- How chunk splits automatically occur
- Advantages of pre-splitting chunks
- How the balancer works

Chunks and the Balancer

- Chunks are groups of documents.
- The shard key determines which chunk a document will be contained in.
- Chunks can be split when they grow too large.
- The balancer decides where chunks go.
- It handles migrations of chunks from one server to another.

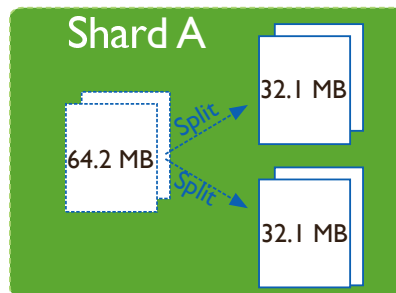
Chunks in a Newly Sharded Collection

- The range of a chunk is defined by the shard key values of the documents the chunk contains.
- When a collection is sharded it starts with just one chunk.
- The first chunk for a collection will have the range:

```
{ $minKey : 1 } to { $maxKey : 1 }
```

- All shard key values from the smallest possible to the largest fall in this chunk's range.

Chunk Splits



Pre-Splitting Chunks

- You may pre-split data before loading data into a sharded cluster.
- Pre-splitting is useful if:
 - You plan to do a large data import early on
 - You expect a heavy initial server load and want to ensure writes are distributed

Start of a Balancing Round

- A balancing round is initiated by the balancer process on the primary config server.
- This happens when the difference in the number of chunks between two shards becomes too large.
- Specifically, the difference between the shard with the most chunks and the shard with the fewest.
- A balancing round starts when the imbalance reaches:
 - 2 when the cluster has < 20 chunks
 - 4 when the cluster has 20-79 chunks
 - 8 when the cluster has 80+ chunks

Balancing is Resource Intensive

- Chunk migration requires copying all the data in the chunk from one shard to another.
- Each individual shard can be involved in one migration at a time. Parallel migrations can occur for each shard migration pair (source + destination).
- The amount of possible parallel chunk migrations for n shards is $n/2$ rounded down.
- MongoDB creates splits only after an insert operation.
- For these reasons, it is possible to define a balancing window to ensure the balancer will only run during scheduled times.

Chunk Migration Steps

1. The balancer process sends the `moveChunk` command to the source shard.
2. The source shard continues to process reads/writes for that chunk during the migration.
3. The destination shard requests documents in the chunk and begins receiving copies.
4. After receiving all documents, the destination shard receives any changes to the chunk.
5. Then the destination shard tells the config db that it has the chunk.
6. The destination shard will now handle all reads/writes.
7. The source shard deletes its copy of the chunk.

Concluding a Balancing Round

- Each chunk will move:
 - From the shard with the most chunks
 - To the shard with the fewest
- A balancing round ends when all shards differ by at most one chunk.

6.3 Shard Zones

Learning Objectives

Upon completing this module students should understand:

- The purpose for shard zones
- Advantages of using shard zones
- Potential drawbacks of shard zones

Zones - Overview

- Shard zones allow you to “tie” data to one or more shards.
- A shard zone describes a range of shard key values.
- If a chunk is in the shard tag range, it will live on a shard with that tag.
- Shard tag ranges cannot overlap. In the case we try to define overlapping ranges an error will occur during creation.

Example: DateTime

- Documents older than one year need to be kept, but are rarely used.
- You set a part of the shard key as the ISODate of document creation.
- Add shards to the LTS zone.
- These shards can be on cheaper, slower machines.
- Invest in high-performance servers for more frequently accessed data.

Example: Location

- You are required to keep certain data in its home country.
- You include the country in the shard tag.
- Maintain data centers within each country that house the appropriate shards.
- Meets the country requirement but allows all servers to be part of the same system.
- As documents age and pass into a new zone range, the balancer will migrate them automatically.

Example: Premium Tier

- You have customers who want to pay for a “premium” tier.
- The shard key permits you to distinguish one customer’s documents from all others.
- Tag the document ranges for each customer so that their documents will be located on shards of the appropriate tier (zone).
- Shards tagged as premium tier run on high performance servers.
- Other shards run on commodity hardware.
- See [Manage Shard Zone](#)¹⁶

¹⁶ <http://docs.mongodb.org/manual/tutorial/manage-shard-zone/>

Zones - Caveats

- Because tagged chunks will only be on certain servers, if you tag more than those servers can handle, you'll have a problem.
 - You're not only worrying about your overall server load, you're worrying about server load for each of your tags.
- Your chunks will evenly distribute themselves across the available zones. You cannot control things more fine grained than your tags.

6.4 Lab: Setting Up a Sharded Cluster

Learning Objectives

Upon completing this module students should understand:

- How to set up a sharded cluster including:
 - Replica sets as shards
 - Config Servers
 - Mongos processes
- How to enable sharding for a database
- How to shard a collection
- How to determine where data will go

Our Sharded Cluster

- In this exercise, we will set up a cluster with 3 shards.
- Each shard will be a replica set with 3 members (including one arbiter).
- We will insert some data and see where it goes.

Sharded Cluster Configuration

- Three shards:
 1. A replica set on ports 27107, 27108, 27109
 2. A replica set on ports 27117, 27118, 27119
 3. A replica set on ports 27127, 27128, 27129
- Three config servers on ports 27217, 27218, 27219
- Two mongos servers at ports 27017 and 27018

Build Our Data Directories

On Linux or MacOS, run the following in the terminal to create the data directories we'll need.

```
mkdir -p ~/data/cluster/config/{c0,c1,c2}
mkdir -p ~/data/cluster/shard0/{m0,m1,arb}
mkdir -p ~/data/cluster/shard1/{m0,m1,arb}
mkdir -p ~/data/cluster/shard2/{m0,m1,arb}
mkdir -p ~/data/cluster/{s0,s1}
```

On Windows, run the following commands instead:

```
md c:\data\cluster\config\c0 c:\data\cluster\config\c1 c:\data\cluster\config\c2
md c:\data\cluster\shard0\m0 c:\data\cluster\shard0\m1 c:\data\cluster\shard0\arb
md c:\data\cluster\shard1\m0 c:\data\cluster\shard1\m1 c:\data\cluster\shard1\arb
md c:\data\cluster\shard2\m0 c:\data\cluster\shard2\m1 c:\data\cluster\shard2\arb
md c:\data\cluster\s0 c:\data\cluster\s1
```

Initiate a Replica Set (Linux/MacOS)

```
mongod --replSet shard0 --dbpath ~/data/cluster/shard0/m0 \
--logpath ~/data/cluster/shard0/m0/mongod.log \
--fork --port 27107 --shardsvr

mongod --replSet shard0 --dbpath ~/data/cluster/shard0/m1 \
--logpath ~/data/cluster/shard0/m1/mongod.log \
--fork --port 27108 --shardsvr

mongod --replSet shard0 --dbpath ~/data/cluster/shard0/arb \
--logpath ~/data/cluster/shard0/arb/mongod.log \
--fork --port 27109 --shardsvr

mongo --port 27107 --eval "\
rs.initiate(); sleep(3000);\
rs.add('$HOSTNAME:27108');\
rs.addArb('$HOSTNAME:27109')"
```

Initiate a Replica Set (Windows)

```
mongod --replSet shard0 --dbpath c:\data\cluster\shard0\m0 \
--logpath c:\data\cluster\shard0\m0\mongod.log \
--port 27107 --oplogSize 10 --shardsvr

mongod --replSet shard0 --dbpath c:\data\cluster\shard0\m1 \
--logpath c:\data\cluster\shard0\m1\mongod.log \
--port 27108 --oplogSize 10 --shardsvr

mongod --replSet shard0 --dbpath c:\data\cluster\shard0\arb \
--logpath c:\data\cluster\shard0\arb\mongod.log \
--port 27109 --oplogSize 10 --shardsvr

mongo --port 27107 --eval "\
rs.initiate(); sleep(3000);\
rs.add('<HOSTNAME>:27108');\
rs.addArb('<HOSTNAME>:27109')"
```

Spin Up a Second Replica Set (Linux/MacOS)

```
mongod --replSet shard1 --dbpath ~/data/cluster/shard1/m0 \
--logpath ~/data/cluster/shard1/m0/mongod.log \
--fork --port 27117 --shardsvr

mongod --replSet shard1 --dbpath ~/data/cluster/shard1/m1 \
--logpath ~/data/cluster/shard1/m1/mongod.log \
--fork --port 27118 --shardsvr

mongod --replSet shard1 --dbpath ~/data/cluster/shard1/arb \
--logpath ~/data/cluster/shard1/arb/mongod.log \
--fork --port 27119 --shardsvr

mongo --port 27117 --eval "\
rs.initiate(); sleep(3000);\
rs.add ('$HOSTNAME:27118');\
rs.addArb('$HOSTNAME:27119')"
```

Spin Up a Second Replica Set (Windows)

```
mongod --replSet shard1 --dbpath c:\data\cluster\shard1\m0 \
--logpath c:\data\cluster\shard1\m0\mongod.log \
--port 27117 --oplogSize 10 --shardsvr

mongod --replSet shard1 --dbpath c:\data\cluster\shard1\m1 \
--logpath c:\data\cluster\shard1\m1\mongod.log \
--port 27118 --oplogSize 10 --shardsvr

mongod --replSet shard1 --dbpath c:\data\cluster\shard1\arb \
--logpath c:\data\cluster\shard1\arb\mongod.log \
--port 27119 --oplogSize 10 --shardsvr

mongo --port 27117 --eval "\
rs.initiate(); sleep(3000);\
rs.add ('<HOSTNAME>:27118');\
rs.addArb('<HOSTNAME>:27119')"
```

A Third Replica Set (Linux/MacOS)

```
mongod --replSet shard2 --dbpath ~/data/cluster/shard2/m0 \
--logpath ~/data/cluster/shard2/m0/mongod.log \
--fork --port 27127 --shardsvr

mongod --replSet shard2 --dbpath ~/data/cluster/shard2/m1 \
--logpath ~/data/cluster/shard2/m1/mongod.log \
--fork --port 27128 --shardsvr

mongod --replSet shard2 --dbpath ~/data/cluster/shard2/arb \
--logpath ~/data/cluster/shard2/arb/mongod.log \
--fork --port 27129 --shardsvr

mongo --port 27127 --eval "\
rs.initiate(); sleep(3000);\
```

```
rs.add ('$HOSTNAME:27128');\
rs.addArb('$HOSTNAME:27129')"
```

A Third Replica Set (Windows)

```
mongod --replSet shard2 --dbpath c:\data\cluster\shard2\m0 \
--logpath c:\data\cluster\shard2\m0\mongod.log \
--port 27127 --oplogSize 10 --shardsvr

mongod --replSet shard2 --dbpath c:\data\cluster\shard2\m1 \
--logpath c:\data\cluster\shard2\m1\mongod.log \
--port 27128 --oplogSize 10 --shardsvr

mongod --replSet shard2 --dbpath c:\data\cluster\shard2\arb \
--logpath c:\data\cluster\shard2\arb\mongod.log \
--port 27129 --oplogSize 10 --shardsvr

mongo --port 27127 --eval "\
rs.initiate(); sleep(3000);\
rs.add ('<HOSTNAME>:27128');\
rs.addArb('<HOSTNAME>:27129')"
```

Status Check

- Now we have three replica sets running.
- We have one for each shard.
- They do not know about each other yet.
- To make them a sharded cluster we will:
 - Build our config databases
 - Launch our mongos processes
 - Add each shard to the cluster
- To benefit from this configuration we also need to:
 - Enable sharding for a database
 - Shard at least one collection within that database

Launch Config Servers (Linux/macOS)

```
mongod
  --dbpath ~/data/cluster/config/c0 \
  --replSet csrs \
  --logpath ~/data/cluster/config/c0/mongod.log \
  --fork --port 27217 --configsvr

mongod
  --dbpath ~/data/cluster/config/c1 \
  --replSet csrs \
  --logpath ~/data/cluster/config/c1/mongod.log \
  --fork --port 27218 --configsvr

mongod
  --dbpath ~/data/cluster/config/c2 \
  --replSet csrs \
  --logpath ~/data/cluster/config/c2/mongod.log \
  --fork --port 27219 --configsvr

mongo --port 27217 --eval "\
  rs.initiate(); sleep(3000);\
  rs.add ('<HOSTNAME>:27218');\
  rs.add ('<HOSTNAME>:27219')"
```

Launch Config Servers (Windows)

```
mongod --dbpath c:\data\cluster\config\c0 \
  --replSet csrs \
  --logpath c:\data\cluster\config\c0\mongod.log \
  --port 27217 --configsvr

mongod --dbpath c:\data\cluster\config\c1 \
  --replSet csrs \
  --logpath c:\data\cluster\config\c1\mongod.log \
  --port 27218 --configsvr

mongod --dbpath c:\data\cluster\config\c2 \
  --replSet csrs \
  --logpath c:\data\cluster\config\c2\mongod.log \
  --port 27219 --configsvr

mongo --port 27217 --eval "\
  rs.initiate(); sleep(3000);\
  rs.add ('<HOSTNAME>:27218');\
  rs.add ('<HOSTNAME>:27219')"
```

Launch the Mongos Processes (Linux/macOS)

Now our mongos's. We need to tell them about our config servers.

```
mongos --logpath ~/data/cluster/s0/mongos.log --fork --port 27017 \
--configdb "csrs/$HOSTNAME:27217,$HOSTNAME:27218,$HOSTNAME:27219"

mongos --logpath ~/data/cluster/s1/mongos.log --fork --port 27018 \
--configdb "csrs/$HOSTNAME:27217,$HOSTNAME:27218,$HOSTNAME:27219"
```

Launch the Mongos Processes (Windows)

Now our mongos's. We need to tell them about our config servers.

```
configseedlist="csrs/$HOSTNAME:27217,$HOSTNAME:27218,$HOSTNAME:27219"
mongos --logpath c:\data\cluster\s0\mongos.log --port 27017 \
       --configdb $configseedlist

mongos --logpath c:\data\cluster\s1\mongos.log --port 27018 \
       --configdb csrs/localhost:27217,localhost:27218,localhost:27219
```

Add All Shards

```
echo "sh.addShard( 'shard0/$HOSTNAME:27107' ); \  
sh.addShard( 'shard1/$HOSTNAME:27117' ); \  
sh.addShard( 'shard2/$HOSTNAME:27127' ); sh.status()" | mongo
```

Note: Instead of doing this through a bash (or other) shell command, you may prefer to launch a mongo shell and issue each command individually.

Enable Sharding and Shard a Collection

Enable sharding for the test database, shard a collection, and insert some documents.

```
mongo --port 27017
```

```
sh.enableSharding("test")  
sh.shardCollection("test.testcol", { a : 1, b : 1 } )  
  
for (i=0; i<1000; i++) {  
    docArr = [];  
    for (j=0; j<1000; j++) {  
        docArr.push(  
            {  
                a : i, b : j,  
                c : "Filler String 0000000000000000000000000000000000000000"  
            } )  
    };  
    db.testcol.insert(docArr)  
};
```

Observe What Happens

Connect to either mongos using a mongo shell and frequently issue:

```
sh.status()
```

7 Reporting Tools and Diagnostics

Performance Troubleshooting (page 136) An introduction to reporting and diagnostic tools for MongoDB

7.1 Performance Troubleshooting

Learning Objectives

Upon completing this module students should understand basic performance troubleshooting techniques and tools including:

- `mongostat`
- `mongotop`
- `db.setProfilingLevel()`
- `db.currentOp()`
- `db.<COLLECTION>.stats()`
- `db.serverStatus()`

mongostat and mongotop

- `mongostat` samples a server every second.
 - See current ops, pagefaults, network traffic, etc.
 - Does not give a view into historic performance; use Ops Manager for that.
- `mongotop` looks at the time spent on reads/writes in each collection.

Exercise: mongostat (setup)

In one window, perform the following commands.

```
db.testcol.drop()
for (i=1; i<=10000; i++) {
  arr = [];
  for (j=1; j<=1000; j++) {
    doc = { _id: (1000 * (i-1) + j), a: i, b: j, c: (1000 * (i-1) + j) };
    arr.push(doc)
  };
  db.testcol.insertMany(arr);
  var x = db.testcol.find( { b : 255 } );
  x.next();
  var x = db.testcol.find( { _id : 1000 * (i-1) + 255 } );
  x.next();
  var x = "asdf";
  db.testcol.updateOne( { a : i, b : 255 }, { $set : { d : x.pad(1000) } });
  print(i)
}
```

Exercise: mongostat (run)

- In another window/tab, run mongostat.
- You will see:
 - Inserts
 - Queries
 - Updates

Exercise: mongostat (create index)

- In a third window, create an index when you see things slowing down:

```
db.testcol.createIndex( { a : 1, b : 1 } )
```

- Look at mongostat.
- Notice that things are going significantly faster.
- Then, let's drop that and build another index.

```
db.testcol.dropIndexes()  
db.testcol.createIndex( { b : 1, a : 1 } )
```

Exercise: mongotop

Perform the following then, in another window, run mongotop.

```
db.testcol.drop()  
for (i=1; i<=10000; i++) {  
  arr = [];  
  for (j=1; j<=1000; j++) {  
    doc = { _id: (1000*(i-1)+j), a: i, b: j, c: (1000*(i-1)+j) };  
    arr.push(doc)  
  };  
  db.testcol.insertMany(arr);  
  var x = db.testcol.find( {b: 255} ); x.next();  
  var x = db.testcol.find( { _id: 1000*(i-1)+255 } ); x.next();  
  var x = "asdf";  
  db.testcol.updateOne( {a: i, b: 255}, { $set: {d: x.pad(1000)}} );  
  print(i)  
}
```

db.currentOp()

- currentOp is a tool that asks what the db is doing at the moment.
- currentOp is useful for finding long-running processes.
- Fields of interest:
 - microsecs_running
 - op
 - query
 - lock
 - waitingForLock

Exercise: db.currentOp()

Do the following then, connect with a separate shell, and repeatedly run `db.currentOp()`.

```
db.testcol.drop()
for (i=1; i<=10000; i++) {
  arr = [];
  for (j=1; j<=1000; j++) {
    doc = {_id: (1000*(i-1)+j), a: i, b: j, c: (1000*(i-1)+j)};
    arr.push(doc)
  };
  db.testcol.insertMany(arr);
  var x = db.testcol.find( {b: 255} ); x.next();
  var x = db.testcol.find( {_id: 1000*(i-1)+255 } ); x.next();
  var x = "asdf";
  db.testcol.updateOne( {a: i, b: 255}, {$set: {d: x.pad(1000)}});
  print(i)
}
```

db.<COLLECTION>.stats()

- Used to view the current stats for a collection.
- Everything is in bytes; use the multiplier parameter to view in KB, MB, etc
- You can also use `db.stats()` to do this at scope of the entire database

Exercise: Using Collection Stats

Look at the output of the following:

```
db.testcol.drop()
db.testcol.insertOne( { a : 1 } )
db.testcol.stats()
var x = "asdf"
db.testcol2.insertOne( { a : x.pad(10000000) } )
db.testcol2.stats()
db.stats()
```

The Profiler

- Off by default.
- To reset, `db.setProfilingLevel(0)`
- At setting 1, it captures “slow” queries.
- You may define what “slow” is.
- Default is 100ms: `db.setProfilingLevel(1)`
- E.g., to capture 20 ms: `db.setProfilingLevel(1, 20)`

The Profiler (continued)

- If the profiler level is 2, it captures all queries.
 - This will severely impact performance.
 - Turns all reads into writes.
- Always turn the profiler off when done (set level to 0)
- Creates `db.system.profile` collection

Exercise: Exploring the Profiler

Perform the following, then look in your `db.system.profile`.

```
db.setProfilingLevel(0)
db.testcol.drop()
db.system.profile.drop()
db.setProfilingLevel(2)
db.testcol.insertOne( { a : 1 } )
db.testcol.find()
var x = "asdf"
db.testcol.insertOne( { a : x.pad(10000000) } ) // ~10 MB
db.setProfilingLevel(0)
db.system.profile.find().pretty()
```

db.serverStatus()

- Takes a snapshot of server status.
- By taking diffs, you can see system trends.
- Most of the data that Ops Manager, Cloud Manager and Atlas get is from this command.

Exercise: Using db.serverStatus()

- Open up two windows. In the first, type:

```
db.testcol.drop()  
var x = "asdf"  
for (i=0; i<=10000000; i++) {  
    db.testcol.insertOne( { a : x.pad(100000) } )  
}
```

- In the second window, type periodically:

```
var x = db.serverStatus(); x.metrics.document
```

Analyzing Profiler Data

- Enable the profiler at default settings.
- Run for 5 seconds.
- Slow operations are captured.
- The issue is there is not a proper index on the message field.
- You will see how fast documents are getting inserted.
- It will be slow b/c the documents are big.

Performance Improvement Techniques

- Appropriate write concerns
- Bulk operations
- Good schema design
- Good Shard Key choice
- Good indexes

Performance Tips: Write Concern

- Increasing the write concern increases data safety.
- This will have an impact on performance, however.
- This is especially true when there are network issues.
- You will want to balance business needs against speed.

Bulk Operations

- Using bulk operations (including `insertMany` and `updateMany`) can improve performance, especially when using write concern greater than 1.
- These enable the server to amortize acknowledgement.
- Can be done with both `insertMany` and `updateMany` .

Exercise: Comparing `insertMany` with `mongostat`

Let's spin up a 3-member replica set:

```
mkdir -p /data/replset/{1,2,3}
mongod --logpath /data/replset/1/mongod.log \
      --dbpath /data/replset/1 --replSet mySet --port 27017 --fork
mongod --logpath /data/replset/2/mongod.log \
      --dbpath /data/replset/2 --replSet mySet --port 27018 --fork
mongod --logpath /data/replset/3/mongod.log \
      --dbpath /data/replset/3 --replSet mySet --port 27019 --fork

echo "conf = {_id: 'mySet', members: [{_id: 0, host: 'localhost:27017'}, \
    {_id: 1, host: 'localhost:27018'}, {_id: 2, host: 'localhost:27019'}]}; \
rs.initiate(conf)" | mongo
```

`mongostat`, `insertOne` with `{w: 1}`

Perform the following, with `writeConcern : 1` and `insertOne()`:

```
db.testcol.drop()
for (i=1; i<=10000; i++) {
  for (j=1; j<=1000; j++) {
    db.testcol.insertOne( { _id : (1000 * (i-1) + j),
                          a : i, b : j, c : (1000 * (i-1) + j) },
                        { writeConcern : { w : 1 } } );
  };
  print(i);
}
```

Run `mongostat` and see how fast that happens.

Multiple insertOne s with {w: 3}

Increase the write concern to 3 (safer but slower):

```
db.testcol.drop()
for (i=1; i<=10000; i++) {
  for (j=1; j<=1000; j++) {
    db.testcol.insertOne(
      { _id: (1000 * (i-1) + j), a: i, b: j, c: (1000 * (i-1)+ j)},
      { writeConcern: { w: 3 } }
    );
  };
  print(i);
}
```

Again, run mongostat.

mongostat, insertMany with {w: 3}

- Finally, let's use insertMany to our advantage:
- Note that writeConcern is still { w: 3 }

```
db.testcol.drop()
for (i=1; i<=10000; i++) {
  arr = []
  for (j=1; j<=1000; j++) {
    arr.push(
      { _id: (1000 * (i-1) + j), a: i, b: j, c: (1000 * (i-1)+ j) }
    );
  };
  db.testcol.insertMany( arr, { writeConcern : { w : 3 } } );
  print(i);
}
```

Schema Design

- The structure of documents affects performance.
- Optimize for your application's read/write patterns.
- We want as few requests to the database as possible to perform a given application task.

See the data modeling section for more information.

Shard Key Considerations

- Choose a shard key that distributes load across your cluster.
- Create a shard key such that only a small number of documents will have the same value.
- Create a shard key that has a high degree of randomness.
- Your shard key should enable a mongos to target a single shard for a given query.

Indexes and Performance

- Reads and writes that don't use an index will cripple performance.
- In compound indexes, order matters:
 - Sort on a field that comes before any range used in the index.
 - You can't skip fields; they must be used in order.
 - Revisit the indexing section for more detail.

8 Backup and Recovery

Backup and Recovery (page 144) An overview of backup options for MongoDB

8.1 Backup and Recovery

Disasters Do Happen



Human Disasters



Terminology: RPO vs. RTO

- **Recovery Point Objective (RPO):** How much data can you afford to lose?
- **Recovery Time Objective (RTO):** How long can you afford to be off-line?

Terminology: DR vs. HA

- **Disaster Recovery (DR)**
- **High Availability (HA)**
- Distinct business requirements
- Technical solutions may converge

Quiz

- Q: What's the hardest thing about backups?
- A: Restoring them!
- **Regularly test that restoration works!**

Backup Options

- Document Level
 - Logical
 - mongodump, mongorestore
- File system level
 - Physical
 - Copy files
 - Volume/disk snapshots

Document Level: mongodump

- Dumps collection to BSON files
- Mirrors your structure
- Can be run live or in offline mode
- Does not include indexes (rebuilt during restore)
- --dbpath for direct file access
- --oplog to record oplog while backing up
- --query/filter selective dump

mongodump

```
$ mongodump --help
Export MongoDB data to BSON files.

options:
  --help                produce help message
  -v [ --verbose ]      be more verbose (include multiple times for
                        more verbosity e.g. -vvvvv)
  --version             print the program's version and exit
  -h [ --host ] arg     mongo host to connect to ( /s1,s2 for
  --port arg            server port. Can also use --host hostname
  -u [ --username ] arg username
  -p [ --password ] arg password
  --dbpath arg          directly access mongod database files in path
  -d [ --db ] arg       database to use
  -c [ --collection ] arg collection to use (some commands)
  -o [ --out ] arg      (=dump) output directory or "-" for stdout
  -q [ --query ] arg    json query
  --oplog               Use oplog for point-in-time snapshotting
```

File System Level

- **Must use journaling!**
- Copy `/data/db` files
- Or snapshot volume (e.g., LVM, SAN, EBS)
- *Seriously, always use journaling!*

Ensure Consistency

Flush RAM to disk and stop accepting writes:

- `db.fsyncLock()`
- Copy/Snapshot
- `db.fsyncUnlock()`

File System Backups: Pros and Cons

- Entire database
- Backup files will be large
- Fastest way to create a backup
- Fastest way to restore a backup

Document Level: mongorestore

- `mongorestore`
- `--oplogReplay` replay oplog to point-in-time

File System Restores

- All database files
- Selected databases or collections
- Replay Oplog

Backup Sharded Cluster

1. Stop Balancer (and wait) or no balancing window
2. Stop one config server (data R/O)
3. Backup Data (shards, config)
4. Restart config server
5. Resume Balancer

Restore Sharded Cluster

1. Dissimilar # shards to restore to
2. Different shard keys?
3. Selective restores
4. Consolidate shards
5. Changing addresses of config/shards

Tips and Tricks

- mongodump/mongorestore
 - --oplog[Replay]
 - --objcheck/--repair
 - --dbpath
 - --query/--filter
- bsondump
 - inspect data at console
- LVM snapshot time/space tradeoff
 - Multi-EBS (RAID) backup
 - clean up snapshots

9 Aggregation

Intro to Aggregation (page 149) An introduction to the the aggregation framework, pipeline concept, and select stages

9.1 Intro to Aggregation

Learning Objectives

Upon completing this module students should understand:

- The concept of the aggregation pipeline
- Key stages of the aggregation pipeline
- What aggregation expressions and variables are
- The fundamentals of using aggregation for data analysis

Aggregation Basics

- Use the aggregation framework to transform and analyze data in MongoDB collections.
- For those who are used to SQL, aggregation comprehends the functionality of several SQL clauses like GROUP_BY, JOIN, AS, and several other operations that allow us to compute datasets.
- The aggregation framework is based on the concept of a pipeline.

The Aggregation Pipeline

- An aggregation pipeline is analogous to a UNIX pipeline.
- Each stage of the pipeline:
 - Receives a set of documents as input.
 - Performs an operation on those documents.
 - Produces a set of documents for use by the following stage.
- A pipeline has the following syntax:

```
pipeline = [$stage1, $stage2, ...$stageN]
db.<COLLECTION>.aggregate( pipeline, { options } )
```

Aggregation Stages

- There are many aggregation stages.
- In this introductory lesson, we'll cover:
 - `$match`: Similar to `find()`
 - `$project`: Shape documents
 - `$sort`: Like the cursor method of the same name
 - `$group`: Used to aggregate field values from multiple documents
 - `$limit`: Used to limit the amount of documents returned
 - `$lookup`: Replicates an SQL left outer-join

Aggregation Expressions and Variables

- Used to refer to data within an aggregation stage
- Expressions
 - Use field path to access fields in input documents, *e.g.* `"$field"`
- Variables
 - Can be both user-defined and system variables
 - Can hold any type of BSON data
 - Accessed like expressions, but with two \$, *e.g.* `"$$<variable>"`
 - For more information about variables in aggregation expressions, click [here](https://docs.mongodb.com/manual/reference/aggregation-variables/)¹⁷

The Match Stage

- The `$match` operator works like the query phase of `find()`
- Documents in the pipeline that match the query document will be passed to subsequent stages.
- `$match` is often the first operator used in an aggregation stage.
- Like other aggregation operators, `$match` can occur multiple times in a single pipeline.

¹⁷ <https://docs.mongodb.com/manual/reference/aggregation-variables/>

The Project Stage

- \$project allows you to shape the documents into what you need for the next stage.
 - The simplest form of shaping is using \$project to select only the fields you are interested in.
 - \$project can also create new fields from other fields in the input document.
 - * *E.g.*, you can pull a value out of an embedded document and put it at the top level.
 - * *E.g.*, you can create a ratio from the values of two fields as pass along as a single field.
- \$project produces 1 output document for every input document it sees.

A Twitter Dataset

- Let's look at some examples that illustrate the MongoDB aggregation framework.
- These examples operate on a collection of tweets.
 - As with any dataset of this type, it's a snapshot in time.
 - It may not reflect the structure of Twitter feeds as they look today.

Tweets Data Model

```
{
  "text" : "Something interesting ...",
  "entities" : {
    "user_mentions" : [
      {
        "screen_name" : "somebody_else",
        ...
      }
    ],
    "urls" : [ ],
    "hashtags" : [ ]
  },
  "user" : {
    "friends_count" : 544,
    "screen_name" : "somebody",
    "followers_count" : 100,
    ...
  }
}
```

Analyzing Tweets

- Imagine the types of analyses one might want to do on tweets.
- It's common to analyze the behavior of users and the networks involved.
- Our examples will focus on this type of analysis

Friends and Followers

- Let's look again at two stages we touched on earlier:
 - `$match`
 - `$project`
- In our dataset:
 - `friends` are those a user follows.
 - `followers` are others that follow a user.
- Using these operators we will write an aggregation pipeline that will:
 - Ignore anyone with no friends and no followers.
 - Calculate who has the highest followers to friends ratio.

Exercise: Friends and Followers

```
db.tweets.aggregate( [
  { $match: { "user.friends_count": { $gt: 0 },
             "user.followers_count": { $gt: 0 } } },
  { $project: { ratio: { $divide: ["$user.followers_count",
                                   "$user.friends_count"] },
              screen_name : "$user.screen_name" } },
  { $sort: { ratio: -1 } },
  { $limit: 1 } ] )
```

Exercise: \$match and \$project

- There is one document per Twitter user
- Of the users in the “Brasilia” timezone who have tweeted 100 times or more, who has the largest number of followers?
- Time zone is found in the “time_zone” field of the user object in each tweet.
- The number of tweets for each user is found in the “statuses_count” field.
- A result document should look something like the following:

```
{ _id      : ObjectId('52fd2490bac3fa1975477702'),
  followers : 2597,
  screen_name: 'marbles',
  tweets    : 12334
}
```

The Group Stage

- For those coming from the relational world, `$group` is similar to the SQL `GROUP BY` statement.
- `$group` operations require that we specify which field to group on.
- Documents with the same identifier will be aggregated together.
- With `$group`, we aggregate values using `accumulators`¹⁸.

Tweet Source

- The tweets in our twitter collection have a field called `source`.
- This field describes the application that was used to create the tweet.
- Let's write an aggregation pipeline that identifies the applications most frequently used to publish tweets.

Exercise: Tweet Source

```
db.tweets.aggregate( [
  { "$group" : { "_id" : "$source",
                  "count" : { "$sum" : 1 } } },
  { "$sort" : { "count" : -1 } }
] )
```

Group Aggregation Accumulators

Accumulators available in the group stage:

- `$sum`
- `$avg`
- `$first`
- `$last`
- `$max`
- `$min`
- `$push`
- `$addToSet`

¹⁸ <http://docs.mongodb.org/manual/meta/aggregation-quick-reference/#accumulators>

Rank Users by Number of Tweets

- One common task is to rank users based on some metric.
- Let's look at who tweets the most.
- Earlier we did the same thing for tweet source.
 - Group together all tweets by a user for every user in our collection
 - Count the tweets for each user
 - Sort in decreasing order
- Let's add the list of tweets to the output documents.
- Need to use an accumulator that works with arrays.
- Can use either `$addToSet` or `$push`.

Exercise: Adding List of Tweets

For each user, aggregate all their tweets into a single array.

```
db.tweets.aggregate( [
  { "$group" : { "_id" : "$user.screen_name",
                 "tweet_texts" : { "$push" : "$text" },
                 "count" : { "$sum" : 1 } } },
  { "$sort" : { "count" : -1 } },
  { "$limit" : 3 }
] )
```

The Sort Stage

- Uses the `$sort` operator
- Works like the `sort()` cursor method
- 1 to sort ascending; -1 to sort descending
- E.g, `db.testcol.aggregate( [ { $sort : { b : 1, a : -1 } } ] )`

The Skip Stage

- Uses the `$skip` operator
- Works like the `skip()` cursor method.
- Value is an integer specifying the number of documents to skip.
- E.g, the following will pass all but the first 3 documents to the next stage in the pipeline.
 - `db.testcol.aggregate( [ { $skip : 3 }, ... ] )`

The Limit Stage

- Used to limit the number of documents passed to the next aggregation stage.
- Works like the `limit()` cursor method.
- Value is an integer.
- E.g., the following will only pass 3 documents to the stage that comes next in the pipeline.
 - `db.testcol.aggregate( [ { $limit: 3 }, ... ] )`

The Lookup Stage

- Pulls documents from a second collection into the pipeline
 - The second collection must be in the same database
 - The second collection cannot be sharded
- Documents based on a matching field in each collection
- Previously, you could get this behavior with two separate queries

The Lookup Stage (continued)

- Documents based on a matching field in each collection
- Previously, you could get this behavior with two separate queries
 - One to the collection that contains reference values
 - The other to the collection containing the documents referenced

Example: Using \$lookup

- Import the companies dataset into a collection called **companies**
- Create a separate collection for \$lookup

```
// BEGIN EXAMPLES LOOKUP INSERT
db.commentOnCategory.insertMany( [
  { category_id: "consulting",
    comment: "Consulting - giving advices" },
  { category_id: "consulting",
    comment: "Consulting - providing human resources" },
  { category_id: "enterprise",
    comment: "Enterprise - constructing starships" },
  { category_id: "finance",
    comment: "Finance - making money" },
  { category_id: "hardware",
```

Example: Using \$lookup (Continued)

```
        comment: "Hardware - from a hammer to a laptop" },
    { category_id: "software",
      comment: "Software - everything else that is missing in order to have a solution
↔" },
    { category_id: null,
      comment: "Null - have not decided yet what the business is about" },
    { category_id: null,
      comment: "Null - can't really disclose what we do" },
    { category_id: null,
      comment: "Null - is not in business anymore" }
  ] )
// END EXAMPLES LOOKUP INSERT

// BEGIN EXAMPLES LOOKUP AGGREGATION
db.companies.aggregate( [
  { $match: { number_of_employees: { $gte: 200000 } } },
  { $sort : { number_of_employees: -1 } },
```

10 Views

Views Tutorial (page 157) Creating and Deleting views

Lab: Vertical Views (page 159) Creating a vertical view lab

Lab: Horizontal Views (page 160) Creating a horizontal view lab

Lab: Reshaped Views (page 161) Creating a reshaped view lab

10.1 Views Tutorial

Learning Objectives

Upon completing this module students should understand:

- What a view is
- What views are useful for
- How to create and drop a view
- Internal mechanisms of a view

What a View is

- A non-materialized collection created from one or more other collections.
- For those who are used to SQL, MongoDB views are equivalent.
- Can be thought of as a predefined aggregation that can be queried.

What Views are useful for

- Views provide an excellent mechanism for data abstraction.
- Views provide an excellent means to protect data
 - Sensitive data from a collection can be projected out of the view
 - Views are read only
 - Combined with role based authorization allows to select information by roles

How to create and drop a view

- Creating a view is a straightforward process.
 - We must give our view a <name>, which will be the name we can access it by
 - We must specify a <source> collection
 - We must define an aggregation <pipeline> to fill our new view with data
 - Optionally, we may also specify a <collation>

Example - Creating a view

```
# db.createView(<name>, <source>, <pipeline>, <collation>)
db.createView("contact_info", "patients", [
  { $project: {
    _id: 0,
    first_name: 1,
    last_name: 1,
    gender: 1,
    email: 1,
    phone: 1
  }
}] )
# views are shown along with other collections
show collections
# views metadata is stored in the system.views collection
db.system.views.find()
```

Dropping Views

- Views can be dropped like any other collection

```
db.contact_info.drop()
```

Internal mechanisms of a view

Views can be thought of as a predefined aggregation. As such:

- Views do not contain any data nor take disk space by themselves
- Views will benefit greatly from indexes on the source collection in their `$match` stage
- Views are considered sharded if their underlying collection is sharded.
- Views are immutable, and cannot be renamed
- A view will not be removed if the underlying collection is removed

10.2 Lab: Vertical Views

Exercise: Vertical View Creation

It is useful to create vertical views to give us a lens into a subset of our overall data.

- Start by importing the necessary data if you have not already.

```
tar xvzf views_dataset.tar.gz
```

```
# for version >= 3.4
mongoimport -d companies -c complaints --drop views_dataset.json
```

To help you verify your work, there are 404816 entries in this dataset.

Exercise : Vertical View Creation Instructions

Once you've verified the data import was successful:

- Create a view that only shows complaints in New York
- Ensure the view shows the most recently submitted complaints by default

Exercise : Vertical View Creation Instructions Result

The resulting data should look like:

```
db.companyComplaintsInNY.findOne()
{
  "complaint_id" : 1416985,
  "product" : "Debt collection",
  "sub-product" : "",
  "issue" : "Cont'd attempts collect debt not owed",
  "sub-issue" : "Debt is not mine",
  "state" : "NY",
  "zip_code" : 11360,
  "submitted_via" : "Web",
  "date_received" : ISODate("2015-06-11T04:00:00Z"),
  "date_sent_to_company" : ISODate("2015-06-11T04:00:00Z"),
  "company" : "Transworld Systems Inc.",
  "company_response" : "In progress",
  "timely_response" : "Yes",
  "consumer_disputed" : ""
}
```

Exercise: Vertical View Creation Validation Instructions

Verify the view is functioning correctly.

- Insert the document on the following slide
- Query your newly created view
- The newly inserted document should be the first in the result set

Exercise: Vertical View Creation Validation Instructions Cont'd

```
db.complaints.insert({
  "complaint_id" : 987654,
  "product" : "Food and Beverage",
  "sub-product" : "Coffee",
  "issue" : "Coffee is too hot",
  "sub-issue" : "",
  "state" : "NY",
  "zip_code" : 11360,
  "submitted_via" : "Web",
  "date_received" : new Date(),
  "date_sent_to_company" : "pending",
  "company" : "CoffeeMerks",
  "company_response" : "",
  "timely_response" : "",
  "consumer_disputed" : ""
})
```

10.3 Lab: Horizontal Views

Exercise: Horizontal View Creation

Horizontal views allow us to provide a selective set of fields of the underlying collection of documents for efficiency and role-based filtering of data.

- Let's go ahead and create a horizontal view of our dataset.
- Start by importing the necessary data if you have not already.

```
mongoimport -d companies -c complaints --drop views_dataset.json
```

To help you verify your work, there are 404816 entries in this dataset.

Exercise : Horizontal View Creation Instructions

Once you've verified the data import was successful, create a view that only shows the the following fields:

- product
- company
- state

Exercise : Horizontal View Creation Instructions Result

The resulting data should look like:

```
db.productComplaints.findOne()  
{  
  "product" : "Debt collection",  
  "state" : "FL",  
  "company" : "Enhanced Recovery Company, LLC"  
}
```

10.4 Lab: Reshaped Views

Exercise: Reshaped View

We can create a reshaped view of a collection to enable more intuitive data queries and make it easier for applications to perform analytics.

It is also possible to create a view from a view.

- Use the aggregation framework to create a reshaped view of our dataset.
- It is necessary to have completed *Lab: Horizontal Views* (page 160)

Exercise : Reshaped View Specification

Create a view that can be queried by company name that shows the amount of complaints by state. The resulting data should look like:

```
db.companyComplaintsByState.find({"company": "ROCKY MOUNTAIN MORTGAGE COMPANY"})  
  
{  
  "company" : "ROCKY MOUNTAIN MORTGAGE COMPANY",  
  "states" : [  
    {  
      "state" : "TX",  
      "count" : 4  
    }  
  ]  
}
```

11 Security

Security Introduction (**page 162**) A high level overview of security in MongoDB

Authorization (**page 165**) Authorization in MongoDB

Lab: Administration Users (**page 171**) Lab on creating admin users

Lab: Create User-Defined Role (Optional) (**page 172**) Lab on creating custom user roles

Authentication (**page 174**) Authentication in MongoDB

Lab: Secure mongod (**page 175**) Lab on standing up a mongod with authorization enabled

Auditing (**page 176**) Auditing in MongoDB

Encryption (**page 178**) Encryption at rest in MongoDB

Log Redaction (**page 180**) Enabling log redaction in MongoDB

Lab: Secured Replica Set - KeyFile (Optional) (**page 181**) Using keyfiles to secure a replica set

Lab: LDAP Authentication & Authorization (Optional) (**page 184**) Authentication & authorization with LDAP

Lab: Security Workshop (**page 186**) Securing a full deployment

11.1 Security Introduction

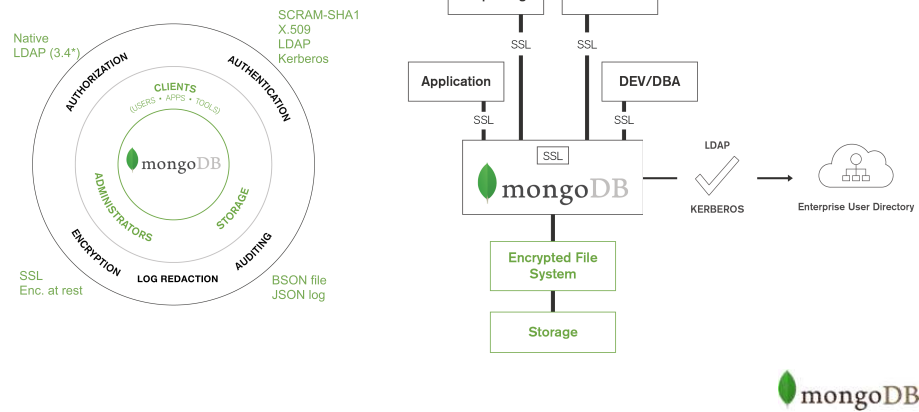
Learning Objectives

Upon completing this module students should understand:

- The high-level overview of security in MongoDB
- Security options for MongoDB
 - Authentication
 - Authorization
 - Transport Encryption
 - Enterprise only features

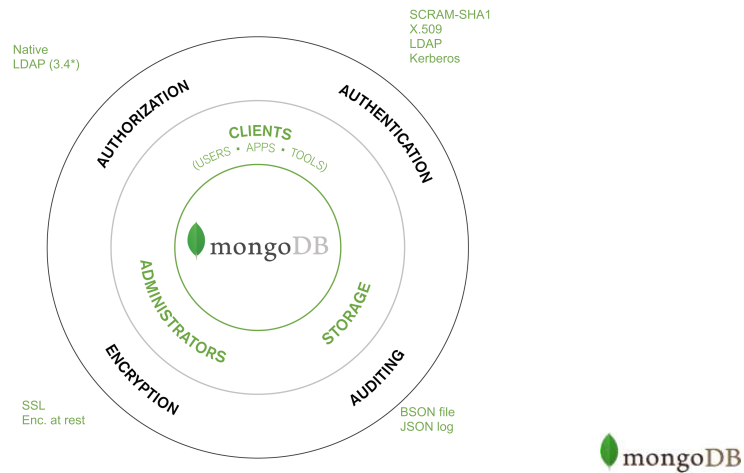
A High Level Overview

Security Architecture



Security Mechanisms

Security Mechanisms



Authentication Options

- Community
 - Challenge/response authentication using SCRAM-SHA-1 (username & password)
 - X.509 Authentication (using X.509 Certificates)
- Enterprise
 - Kerberos
 - LDAP

Authorization via MongoDB

- Predefined roles
- Custom roles
- LDAP authorization (MongoDB Enterprise)
 - Query LDAP server for groups to which a user belongs.
 - Distinguished names (DN) are mapped to roles on the `admin` database.
 - Requires external authentication (x.509, LDAP, or Kerberos).

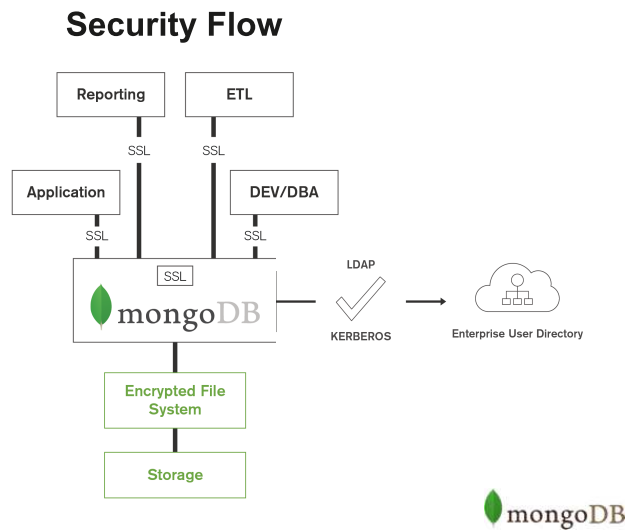
Transport Encryption

- TLS/SSL
 - May use certificates signed by a certificate authority or self-signed.
- FIPS (MongoDB Enterprise)

Network Exposure Options

- `bindIp` limits the ip addresses the server listens on.
- Using a non-standard port can provide a layer of obscurity.
- MongoDB should still be run only in a trusted environment.

Security Flow



11.2 Authorization

Learning Objectives

Upon completing this module, students should be able to:

- Outline MongoDB's authorization model
- List authorization resources
- Describe actions users can take in relation to resources
- Create roles
- Create privileges
- Outline MongoDB built-in roles
- Grant roles to users
- Explain LDAP authorization

Authorization vs Authentication

Authorization and Authentication are generally confused and misinterpreted concepts:

- Authorization defines the rules by which users can interact with a given system:
 - Which operations can they perform
 - Over which resources
- Authentication is the mechanism by which users identify and are granted access to a system:
 - Validation of credentials and identities
 - Controls access to the system and operational interfaces

Authorization Basics

- MongoDB enforces a role-based authorization model.
- A user is granted roles that determine the user's access to database resources and operations.

The model determines:

- Which roles are granted to users
- Which privileges are associated with roles
- Which actions can be performed over different resources

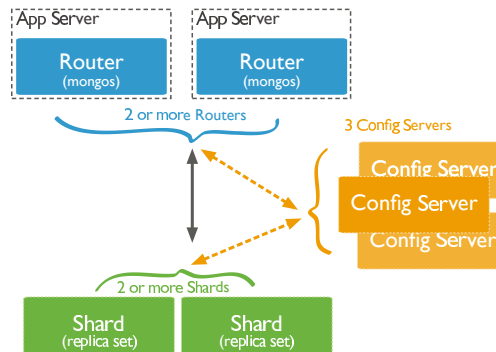
What is a resource?

- Databases?
- Collections?
- Documents?
- Users?
- Nodes?
- Shard?
- Replica Set?

Authorization Resources

- Databases
- Collections
- Cluster

Cluster Resources



Types of Actions

Given a resource, we can consider the available actions:

- Query and write actions
- Database management actions
- Deployment management actions
- Replication actions
- Sharding actions
- Server administration actions
- Diagnostic actions
- Internal actions

Specific Actions of Each Type

Query / Write	Database Mgmt	Deployment Mgmt
find	enableProfiler	planCacheRead
insert	createIndex	storageDetails
remove	createCollection	authSchemaUpgrade
update	changeOwnPassword	killop
	...	...

See the [complete list of actions](#)¹⁹ in the MongoDB documentation.

Authorization Privileges

A privilege defines a pairing between a resource as a set of permitted actions.

Resource:

```
{ "db": "yourdb", "collection": "mycollection" }
```

Action: find

Privilege:

```
{
  resource: { "db": "yourdb", "collection": "mycollection" },
  actions: [ "find" ]
}
```

Authorization Roles

MongoDB grants access to data through a role-based authorization system:

- Built-in roles: pre-canned roles that cover the most common sets of privileges users may require
- User-defined roles: if there is a specific set of privileges not covered by the existing built-in roles you are able to create your own roles

Built-in Roles

Database Admin	Cluster Admin	All Databases
dbAdmin	clusterAdmin	readAnyDatabase
dbOwner	clusterManager	readWriteAnyDatabase
userAdmin	clusterMonitor	userAdminAnyDatabase
	hostManager	dbAdminAnyDatabase

Database User	Backup & Restore
read	backup
readWrite	restore

Superuser	Internal
root	__system

¹⁹ <https://docs.mongodb.com/manual/reference/privilege-actions/>

Built-in Roles

To grant roles while creating an user:

```
use admin
db.createUser(
  {
    user: "myUser",
    pwd: "$up3r$3cr7",
    roles: [
      {role: "readAnyDatabase", db: "admin"},
      {role: "dbOwner", db: "superdb"},
      {role: "readWrite", db: "yourdb"}
    ]
  }
)
```

Built-in Roles

To grant roles to existing user:

```
use admin
db.grantRolesToUser(
  "reportsUser",
  [
    { role: "read", db: "accounts" }
  ]
)
```

User-defined Roles

- If no suitable built-in role exists, we can create a role.
- Define:
 - Role name
 - Set of privileges
 - List of inherit roles (optional)

```
use admin
db.createRole({
  role: "insertAndFindOnlyMyDB",
  privileges: [
    {resource: { db: "myDB", collection: "" }, actions: ["insert", "find"]}
  ],
  roles: []})
```

Role Privileges

To check the privileges of any particular role we can get that information using the `getRole` method:

```
db.getRole("insertAndFindOnlyMyDB", {showPrivileges: true})
```

LDAP Authorization

As of MongoDB 3.4, MongoDB supports *authorization* with LDAP.

How it works:

1. User authenticates via an external mechanism

```
$ mongo --username alice \  
--password secret \  
--authenticationMechanism PLAIN \  
--authenticationDatabase '$external'
```

LDAP Authorization (cont'd)

2. Username is transformed into LDAP query

```
[  
  {  
    match: "(.+@ENGINEERING",  
    substitution: "cn={0},ou=engineering,dc=example,dc=com"  
  }, {  
    match: "(.+@DBA",  
    substitution: "cn={0},ou=dba,dc=example,dc=com"  
  }  
]
```

LDAP Authorization (cont'd)

3. MongoDB queries the LDAP server
 - A single entity's attributes are treated as the user's roles
 - Multiple entity's distinguished names are treated as the user's roles

Mongoldap

mongoldap can be used to test configurations between MongoDB and an LDAP server

```
$ mongoldap -f mongod.conf \  
    --user "uid=alice,ou=Users,dc=example,dc=com" \  
    --password secret
```

11.3 Lab: Administration Users

Premise

Security roles often span different levels:

- Superuser roles
- DBA roles
- System administration roles
- User administration roles
- Application roles

In this lab we will look at several types of administration roles.

User Administration user

- Generally, in complex systems, we need someone to administer users.
- This role should be different from a `root` level user for a few reasons.
- `root` level users should be used as last resort user
- Administration of users is generally related with security officers

Create User Admin user

Create a user that will administer other users:

```
db.createUser(  
  {  
    user: "securityofficer",  
    pwd: "doughnuts",  
    customData: { notes: ["admin", "the person that adds other persons"] },  
    roles: [  
      { role: "userAdminAnyDatabase", db: "admin" }  
    ]  
  })
```

Create DBA user

DBAs are generally concerned with maintenance operations in the database.

```
db.createUser(
{
  user: "dba",
  pwd: "i+love+indexes",
  customData: { notes: ["admin", "the person that admins databases"] },
  roles: [
    { role: "dbAdmin", db: "X" }
  ]
})
```

If we want to make sure this DBA can administer all databases of the system, which role(s) should he have? See the [MongoDB documentation](#)²⁰.

Create a Cluster Admin user

Cluster administration is generally an operational role that differs from DBA in the sense that is more focussed on the deployment and cluster node management.

For a team managing a cluster, what roles enable individuals to do the following?

- Add and remove replica nodes
- Manage shards
- Do backups
- Cannot read data from any application database

11.4 Lab: Create User-Defined Role (Optional)

Premise

- MongoDB provides a set of built-in roles.
- Please consider those before generating another role on your system.
- Sometimes it is necessary to create roles match specific the needs of a system.
- For that we can rely on user-defined roles that system administrators can create.
- This function should be carried by `userAdmin` level administration users.

²⁰ <https://docs.mongodb.com/manual/reference/built-in-roles/>

Define Privileges

- Roles are sets of privileges that a user is granted.
- Create a role with the following privileges:
 - User can read user details from database `brands`
 - Can list all collections of database `brands`
 - Can update all collections on database `brands`
 - Can write to the collection `automotive` in database `brands`

Create the JSON array that describes the requested set of privileges.

Create Role

- Given the privileges we just defined, we now need to create this role specific to database `brands`.
- The name of this role should be `carlover`
- What command do we need to issue?

Grant Role: Part 1

We now want to grant this role to the user named `ilikecars` on the database `brands`.

```
use brands;
db.createUser(
{
  user: "ilikecars",
  pwd: "ferrari",
  customData: {notes: ["application user"]},
  roles: [
    {role: "carlover", db: "brands"}
  ]
})
```

Grant Role: Part 2

- We now want to grant greater responsibility to our recently created `ilikecars`!
- Let's grant the `dbOwner` role to the `ilikecars` user.

Revoke Role

- Let's assume that the role `carlover` is no longer valid for user `ilikecars`.
- How do we revoke this role?

11.5 Authentication

Learning Objectives

Upon completing this module, you should understand:

- Authentication mechanisms
- External authentication
- Native authentication
- Internal node authentication
- Configuration of authentication mechanisms

Authentication

- Authentication is concerned with:
 - Validating identities
 - Managing certificates / credentials
 - Allowing accounts to connect and perform authorized operations
- MongoDB provides native authentication and supports X509 certificates, LDAP, and Kerberos as well.

Authentication Mechanisms

MongoDB supports a number of authentication mechanisms:

- SCRAM-SHA-1 (default ≥ 3.0)
- MONGODB-CR (legacy)
- X509 Certificates
- LDAP (MongoDB Enterprise)
- Kerberos (MongoDB Enterprise)

Internal Authentication

For internal authentication purposes (mechanism used by replica sets and sharded clusters) MongoDB relies on:

- Keyfiles
 - Shared password file used by replica set members
 - Hexadecimal value of 6 to 1024 chars length
- X509 Certificates

Simple Authentication Configuration

To get started we just need to make sure we are launching our mongod instances with the `--auth` parameter.

```
mongod --dbpath /data/db --auth
```

For any connections to be established to this mongod instance, the system will require a username and password.

```
mongo --authenticationDatabase admin -u user -p
↵
↵
↵ MongoDB shell version: 3.2.5
Enter password:
```

11.6 Lab: Secure mongod

Premise

It is time for us to get started setting up our first MongoDB instance with authentication enabled!

Launch mongod

Let's start by launching a mongod instance:

```
mkdir /data/secure_instance_dbpath
mongod --dbpath /data/secure_instance_dbpath --port 28000
```

At this point there is nothing special about this setup. It is just an ordinary mongod instance ready to receive connections.

Root level user

Create a root level user:

```
mongo --port 28000 admin // Puts you in the _admin_ database
```

```
use admin
db.createUser( {
  user: "maestro",
  pwd: "maestro+rules",
  customData: { information_field: "information value" },
  roles: [ {role: "root", db: "admin" } ]
} )
```

Enable Authentication

Launch mongod with auth enabled

```
mongo admin --port 28000 --eval 'db.shutdownServer()'
mongod --port 28000 --dbpath /data/secure_instance_dbpath --auth
```

Connect using the recently created maestro user.

```
mongo --port 28000 admin -u maestro -p
```

11.7 Auditing

Learning Objectives

Upon completing this module, you should be able to:

- Outline the auditing capabilities of MongoDB
- Enable auditing
- Summarize auditing configuration options

Auditing

- MongoDB Enterprise includes an auditing capability for mongod and mongos instances.
- The auditing facility allows administrators and users to track system activity
- Important for deployments with multiple users and applications.

Audit Events

Once enabled, the auditing system can record the following operations:

- Schema
- Replica set and sharded cluster
- Authentication and authorization
- CRUD operations (DML, off by default)

Auditing Configuration

The following are command-line parameters to `mongod/mongos` used to configure auditing.

Enable auditing with `--auditDestination`.

- `--auditDestination`: where to write the audit log
 - `syslog`
 - `console`
 - `file`
- `--auditPath`: audit log path in case we define “file” as the destination

Auditing Configuration (cont'd)

- `--auditFormat`: the output format of the emitted event messages
 - `BSON`
 - `JSON`
- `--auditFilter`: an expression that will filter the types of events the system records

By default we only audit DDL operations but we can also enable DML (requires `auditAuthorizationSuccess` set to `true`)

Auditing Message

The audit facility will launch a message every time an auditable event occurs:

```
{
  atype: <String>,
  ts : { "$date": <timestamp> },
  local: { ip: <String>, port: <int> },
  remote: { ip: <String>, port: <int> },
  users : [ { user: <String>, db: <String> }, ... ],
  roles: [ { role: <String>, db: <String> }, ... ],
  param: <document>,
  result: <int>
}
```

Auditing Configuration

If we want to configure our audit system to generate a *JSON* file we would need express the following command:

```
mongod --auditDestination file --auditPath /some/dir/audit.log --auditFormat JSON
```

If we want to capture events from a particular user *myUser*:

```
mongod --auditDestination syslog --auditFilter '{"users.user": "myUser"}'
```

To enable DML we need to set a specific parameter:

```
mongod --auditDestination console --setParameter auditAuthorizationSuccess=true
```

11.8 Encryption

Learning Objectives

Upon completing this module, students should understand:

- The encryption capabilities of MongoDB
- Network encryption
- Native encryption
- Third party integrations

Encryption

MongoDB offers two levels of encryption

- Transport layer
- Encryption at rest (MongoDB Enterprise >=3.2)

Network Encryption

- MongoDB enables TLS/SSL for transport layer encryption of traffic between nodes in a cluster.
- Three different network architecture options are available:
 - Encryption of application traffic connections
 - Full encryption of all connections
 - Mixed encryption between nodes

Native Encryption

MongoDB Enterprise comes with a encrypted storage engine.

- Native encryption supported by WiredTiger
- Encrypts data at rest
 - AES256-CBC: 256-bit Advanced Encryption Standard in Cipher Block Chaining mode (default)
 - * symmetric key (same key to encrypt and decrypt)
 - AES256-GCM: 256-bit Advanced Encryption Standard in Galois/Counter Mode
 - FIPS is also available
- Enables integration with key management tools

Encryption and Replication

- Encryption is not part of replication:
 - Data is not natively encrypted on the wire
 - * Requires transport encryption to ensure secured transmission
 - Encryption keys are not replicated
 - * Each node should have their own individual keys

Third Party Integration

- Key Management Interoperability Protocol (KMIP)
 - Integrates with Vormetric Data Security Manager (DSM) and SafeNet KeySecure
- Storage Encryption
 - Linux Unified Key Setup (LUKS)
 - IBM Guardium Data Encryption
 - Vormetric Data Security Platform
 - * Also enables Application Level Encryption on per-field or per-document
 - Bitlocker Drive Encryption

11.9 Log Redaction

Learning Objectives

Upon completing this module students should understand:

- What log redaction is
- How to enable and disable log redaction

What is log redaction?

- Log redaction, when enabled, prevents the following
 - Details about specific queries from showing in the log when `verbose` mode is enabled
 - Details about specific queries that trigger a profiling event (a slow query, for example)

Enabling Log Redaction

- There are several ways to enable log redaction
 - In the configuration file via `redactClientLogData: true` under `security`
 - Passing the command line argument `--redactClientLogData` when starting a `mongod` or `mongos`
 - Connecting to a `mongod` or `mongos` and running

```
db.adminCommand({
  setParameter: 1, redactClientLogData: true
})
```

Exercise: Enable Log Redaction Setup

For this exercise we're going to start a `mongod` process with verbose logging enabled and then enable log redaction

- Start a `mongod` with verbose logging enabled

```
mkdir -p data/db
mongod -v --dbpath data/db --logpath data/mongod.log --logappend --port 31000 --fork
```

- In another terminal, tail the `mongod.log` to view realtime logging events

```
tail -f data/mongod.log
```

Exercise: Enable Log Redaction (cont)

- Connect to your `mongod` process from the shell.
- Use a database called `rd` and insert a document, observing the output in `mongod.log` with `tail`.

```
mongo --port 31000
use rd
db.foo.insertOne({name: "bob", medicalCondition: "SENSITIVE, should not be logged"})
```

- In the log output, you should see something similar to the following:

```
2017-04-28T09:39:41.629-0700 I COMMAND [conn1] command rd.foo appName: "MongoDB Shell"
↳ " command: insert {
insert: "foo", documents: [ { _id: ObjectId('5903704d2482ced24904c8a6'),
name: "bob", medicalCondition: "SENSITIVE, should not be logged"
} ],
...

```

Exercise: Enable Log Redaction (cont)

- From the `mongo` shell, enable log redaction
- Insert another document

```
mongo --port 31000
use rd
db.foo.insertOne({name: "mary", medicalCondition: "SENSITIVE, should not be logged"})
```

- Verify that the document is being redacted in the log

```
2017-04-28T12:23:07.111-0700 I COMMAND [conn1] command rd.foo appName: "MongoDB Shell"
↳ " command: insert {
insert: "###", documents: [ { _id: "###", name: "###", medicalCondition: "###" } ],
...

```

11.10 Lab: Secured Replica Set - KeyFile (Optional)

Premise

Security and Replication are two aspects that are often neglected during the Development phase to favor usability and faster development.

These are also important aspects to take in consideration for your Production environments, since you probably don't want to have your production environment **Unsecured** and without **High Availability**!

This lab is to get fully acquainted with all necessary steps to create a secured replica set using the `keyfile` for cluster authentication mode

Setup Secured Replica Set

A few steps are required to fully setup a secured Replica Set:

1. Instantiate one `mongod` node with no auth enabled
2. Create a `root` level user
3. Create a `clusterAdmin` user
4. Generate a keyfile for internal node authentication
5. Re-instantiate a `mongod` with auth enabled, keyfile defined and `replSet` name
6. Add Replica Set nodes

We will also be basing our setup using [MongoDB configuration files](#)²¹

Instantiate `mongod`

This is a rather simple operation that requires just a simple instruction:

```
$ pwd
/data
$ mkdir -p /data/secure_replset/{1,2,3}; cd secure_replset/1
```

Then go to [this yaml file](#)²² and copy it into your clipboard

```
$ pbpaste > mongod.conf; cat mongod.conf
```

Instantiate `mongod` (cont'd)

```
systemLog:
  destination: file
  path: "/data/secure_replset/1/mongod.log"
  logAppend: true
storage:
  dbPath: "/data/secure_replset/1"
  wiredTiger:
    engineConfig:
      cacheSizeGB: 1
net:
  port: 28001
processManagement:
  fork: true
# setParameter:
#   enableLocalhostAuthBypass: false
# security:
#   keyFile: /data/secure_replset/1/mongodb-keyfile
```

²¹ <https://docs.mongodb.org/manual/reference/configuration-options/>

²² https://github.com/thatnerd/work-public/blob/master/mongodb_trainings/secure_replset_config.yaml

Instantiate mongod (cont'd)

After defining the basic configuration we just need to call `mongod` passing the configuration file.

```
mongod -f mongod.conf
```

Create root user

We start by creating our typical `root` user:

```
$ mongo admin --port 28001
```

```
> use admin
> db.createUser(
{
  user: "maestro",
  pwd: "maestro+rules",
  roles: [
    { role: "root", db: "admin" }
  ]
})
```

Create clusterAdmin user

We then need to create a `clusterAdmin` user to enable management of our replica set.

```
$ mongo admin --port 28001
```

```
> db.createUser(
{
  user: "pivot",
  pwd: "i+like+nodes",
  roles: [
    { role: "clusterAdmin", db: "admin" }
  ]
})
```

Generate a keyfile

For internal Replica Set authentication we need to use a keyfile.

```
openssl rand -base64 741 > /data/secure_replset/1/mongodb-keyfile
chmod 600 /data/secure_replset/1/mongodb-keyfile
```

Add keyfile to the configuration file

Now that we have the *keyfile* generated it's time to add that information to our configuration file. Just un-comment the last few lines.

```
systemLog:
  destination: file
  path: "/data/secure_replset/1/mongod.log"
  logAppend: true
storage:
  dbPath: "/data/secure_replset/1"
net:
  port: 28001
processManagement:
  fork: true
setParameter:
  enableLocalhostAuthBypass: false
security:
  keyFile: /data/secure_replset/1/mongodb-keyfile
```

Configuring Replica Set

- Now it's time to configure our Replica Set
- The desired setup for this Replica Set should be named "VAULT"
- It should consist of 3 data bearing nodes

11.11 Lab: LDAP Authentication & Authorization (Optional)

Premise

- Authentication and authorization with an external service (like LDAP) is an important functionality for large organizations that rely on centralized user management tools.
- This lab is designed to get you familiar with the procedure to run a `mongod` with authentication and authorization enabled with an external LDAP service.

Test Connection to LDAP

- An LDAP server is up and running for you to connect to.
- **Server Info:**
 - **Server Address:** 192.168.19.100:8389
 - **User:** uid=alice,ou=Users,dc=mongodb,dc=com
 - **Password:** secret

Test Connection to LDAP (cont'd)

- Your goal is to fill in the following configuration file and get mongoldap to successfully talk to the LDAP server with the following command:

```
$ mongoldap --config mongod.conf --user alice --password secret
```

```
...
security:
  authorization: "enabled"
  ldap:
    servers: "XXXXXXXXXXXXX:8389"
    authz:
      queryTemplate: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX"
    userToDNMapping: ' [{match: "XXXX", substitution:
→ "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX"} ] '
    transportSecurity: "none"
    bind:
      method: "simple"
  setParameter:
    authenticationMechanisms: PLAIN
```

Authentication with LDAP

- Once you've successfully connected to LDAP with mongoldap you should be able to use the same config file with mongod.

```
$ mongod --config mongod.conf
```

- From here you should be able to authenticate with alice and secret.

```
$ mongo --username alice \
--password secret \
--authenticationMechanism PLAIN \
--authenticationDatabase '$external'
```

Authorization with LDAP

- After successfully *authenticating* with LDAP, you'll need to take advantage of the **localhost exception** to enable *authorization* with LDAP.
- Create a role that allows anyone who is apart of the **cn=admins,ou=Users,dc=mongodb,dc=com** LDAP group to be able to manage users (e.g., inheriting userAdminAnyDatabase).
- To confirm that you've successfully setup authorization the following command should execute without error if you're authenticated as *alice* since she's apart of the group.

```
> use admin
> db.getRoles()
```

11.12 Lab: Security Workshop

Learning Objectives

Upon completing this workshop, attendees will be able to:

- Secure application communication with MongoDB
- Understand all security authentication and authorization options of MongoDB
- Encrypt MongoDB data at rest using encrypted storage engine
- Enable auditing and understand the performance implications
- Feel comfortable deploying and securely configuring MongoDB

Introduction

In this workshop, attendees will install and configure a secure replica set on servers running in AWS.

- We are going to secure the backend communications using TLS/SSL
- Enable authorization on the backend side
- Encrypt the storage layer
- Make sure that there are no “*leaks*” of information

List of exercises

- 1: Accessing your AWS instances
- 2: Starting MongoDB and configuring the replica set
- 3: Launch the Client Application
- 4: Set up local accounts
- 5: Enable SSL between the nodes
- 6: Enable SSL Connection from the mongo shell and from the Application
- 7: Encrypt Storage Layer
- 8: Avoid any log leaks
- 9: Enable Auditing

Exercise: Accessing your instances from Windows

- Download and install Putty from <http://www.putty.org/>
- Start Putty with: **All Programs > PuTTY > PuTTY**
- In **Session**:
 - In the **Host Name** box, enter **centos@<publicIP>**
 - Under **Connection type**, select **SSH**
- In **Connection/SSH/Auth**,
 - Browse to the **AdvancedAdministrator.ppk** file
- Click **Open**
- Detailed info at: [Connect to AWS with Putty](#)²³

Exercise: Accessing your instances from Linux or Mac

- Get your .pem file and close the permissions on it

```
chmod 600 AdvancedAdministrator.pem
```

- Enable the keychain and ssh into node1, propagating your credentials

```
ssh-add -K AdvancedAdministrator.pem  
ssh -i AdvancedAdministrator.pem -A centos@54.235.1.1
```

- SSH into node2 from node1

```
ssh -A node2
```

Solution: Accessing your instances

In our machines we will have access to all nodes in the deployment:

```
cat /etc/hosts
```

A /share/downloads folder with all necessary software downloaded

```
ls /share/downloads  
ls /etc/ssl/mongodb
```

²³ <http://docs.aws.amazon.com/AWSEC2/latest/UserGuide/putty.html>

Important Notes

- only use `sudo` when needed, otherwise you can run in permission issues
 - use ‘`sudo service ...`’ to start `mongod`
- replica set should be named **SECURED**
- must use **Config Files** to start the `mongod` processes, not command line options
 - use `/etc/mongod.conf`
 - careful with the spacing in the YAML file

Exercise 2: Starting MongoDB and configuring the replica set

- `/share/downloads/mongodb_packages` contains MongoDB 3.2 and 3.4
- Installation instructions are at:
 - <https://docs.mongodb.com/manual/tutorial/install-mongodb-enterprise-on-red-hat/>
- Configure the 3 nodes as a replica set named **SECURED**
- Use `node1`, `node2` and `node3` for your host names
- You *MUST* use a [config file](#)²⁴

Solution 2: Installing MongoDB

- Installation

```
cd /data/downloads/mongodb_packages
sudo yum install -y mongodb-enterprise-3.4.9-1.el7.x86_64.rpm
sudo vi /etc/mongod.conf
sudo service mongod start
sudo service mongod status
# if errors OR mongod not running ...
cat /var/log/mongodb/mongod.log
```

Solution 2: Config File (cont)

- Configure the 3 nodes as a replica set named **SECURED**, change **bindIp** to the **10.0.0.X** address, plus **127.0.0.1**
- Use `/mongod-data/appdb` for your dbpath
- All other defaults are fine for now

```
storage:
  dbPath: /mongod-data/appdb/
  ...
replication:
  replSetName: SECURED
net:
  bindIp: 10.0.0.101,127.0.0.1
```

²⁴ <https://docs.mongodb.com/manual/reference/configuration-options/>

Solution 2: Replica Set Config (cont)

```
cfg = {
  _id: "SECURED",
  version: 1,
  members: [
    { _id: 0, host: "node1:27017" },
    { _id: 1, host: "node2:27017" },
    { _id: 2, host: "node3:27017" }
  ]
}
rs.initiate(cfg)
rs.status()
```

Solution 2: Verification (cont)

Let's try to connect to our running MongoDB cluster:

```
mongo --host node1
```

If you want to be sure to connect to the Primary, instead, use:

```
mongo --host SECURED/node1,node2,node3
```

Finally, verify that the replica set is healthy

```
rs.status()
```

Exercise 3: Launch the Client Application

It's time to connect our client application. Install the application on **node4**

```
cd ~
tar xzvf /share/downloads/apps/security_lab.tgz
cd mongo-messenger
npm install
npm start

... webpack: bundle is now VALID.
```

- If you get an **error** running `npm install`, there is workaround on the next page
- Connect to the public ip of your node4 instance, port 8080

```
http://NODE4-public-IP:8080
```

Fixing node/npm issue with SSL (Sept 2017 bug)

```
npm: relocation error: npm: symbol SSL_set_cert_cb, version libssl.so.10 not defined
↳ in file libssl.so.10 with link time reference
```

Update the OpenSSL lib

```
sudo yum update -y openssl
```

OR install a newer NPM version:

```
curl https://raw.githubusercontent.com/creationix/nvm/v0.13.1/install.sh | bash
source ~/.bash_profile
nvm install v8.6.0
```

OR use Yarn

```
sudo wget https://dl.yarnpkg.com/rpm/yarn.repo -O /etc/yum.repos.d/yarn.repo
sudo yum install yarn
```

How is the client application connecting to the database?

- The connection string used by the application is in `message.js` and looks like this:

```
const url = "mongodb://node1:27017,node2:27017,node3:27017/
security-lab?replicaSet=SECURED"
```

- confirm that the tool is writing to the database by running the following in a mongo shell:

```
use security-lab
db.messages.find({from:"your_username"}).pretty()
```

- This will work, for now...

WARNING: Spying your deployment!

Throughout the lab, the instructor will be spying on your deployment!

This checking is done by running a few scripts on your machines that will verify whether or not you have completely secured your deployment.

We will come back to this later on.

Authorization and Authentication

Discussion on the following questions:

- difference between authorization and authentication?
- which authentication mechanism to use?
- which authorization support will you use?

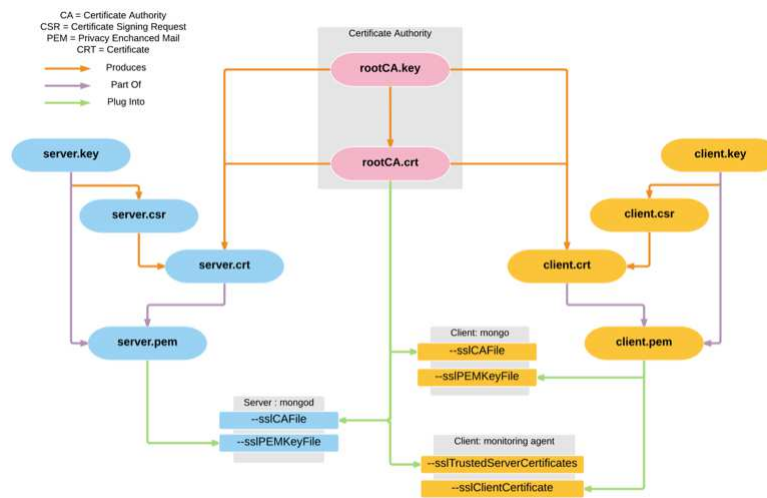
Exercise 4: Set up local accounts

It is time to start securing the system.

To do this, you will have to decide:

- Set of users required to operate this system
- Some references:
 - [MongoDB authentication](#)²⁵
 - [role-based access control](#)²⁶

SSL certificates



²⁵ <https://docs.mongodb.com/manual/core/authentication/>

²⁶ <https://docs.mongodb.com/manual/core/authorization/>

Exercise 5: Enable SSL between the nodes

- We restricted “bindIp” to a local network interface, however if this was an outside address, it would not be good enough
- Let’s ensure we limit the connections to a list of nodes we control
 - Let’s use SSL certificates
 - As a reminder, they are in `/etc/ssl/mongodb/`

Exercise 6: Enable SSL connection from the mongo shell and from the Application

- You will need to combine the `mongomessenger.key` and `mongomessenger.pem` files together to quickly test connection in the mongo shell.
- After you have tested SSL from the mongo shell, update the client’s connection info to [connect over SSL](#)²⁷.
- Use `mongomessenger.key`, `mongomessenger.pem`, and `messenger-CA.pem` for your client connection.

```
# Concatenate the PEM and KEY files. 'cut' will add the missing end of line chars
cut -b 1- /etc/ssl/mongodb/mongomessenger.* > ~/client.pem
mongo --ssl --sslCAFile /etc/ssl/mongodb/messenger-CA.pem \
  --sslPEMKeyFile ~/client.pem --host SECURED/node1,node2,node3
```

A note about X509 certificates with `clusterAuthMode: x509`

- Certificates **must** differ from the root CA certificate in the subject area by at least one of the following:
- “O”: Organization
- “OU”: Organizational Unit
- “DC”: Domain Component
- If the client presents a certificate that matches the CA certificate in these 3 fields, the client **will be given root access**, circumventing any role-based access control.

Gaining root access

```
openssl x509 -noout -subject -in /etc/ssl/mongodb/ca.pem
openssl x509 -noout -subject -in /etc/ssl/mongodb/node1.pem
# "O", "OU" (and no "DC") in the subject lines are the same!
# now, gain root even if a user is created
mongo --ssl --sslCAFile /etc/ssl/mongodb/messenger-CA.pem --sslPEMKeyFile \
  /etc/ssl/mongodb/node1.pem --authenticationMechanism MONGODB-X509 \
  --authenticationDatabase='$external' --host SECURED/node1,node2,node3
# using correctly created certs
openssl x509 -noout -subject -in ~/client.pem
# will fail
mongo --ssl --sslCAFile /etc/ssl/mongodb/messenger-CA.pem --sslPEMKeyFile \
  ~/client.pem --authenticationMechanism MONGODB-X509 \
  --authenticationDatabase='$external' --host SECURED/node1,node2,node3
# will connect
```

²⁷ <http://mongodb.github.io/node-mongodb-native/2.2/tutorials/connect/ssl/>

```
mongo --ssl --sslCAFile /etc/ssl/mongodb/messenger-CA.pem \  
  --sslPEMKeyFile ~/client.pem --host SECURED/node1,node2,node3  
# will not be authorized until auth'd with user  
show dbs
```

Exercise 7: Encrypt Storage Layer

To fully secure our MongoDB deployment we need to consider the actual MongoDB instance files.

Your instructor has some scripts that will enable him to have a peek into the your collection and indexes data files.

Don't let them do so!!!

Exercise 8: Avoid any log leaks

Logs are an important asset of your system.

Allow us to understand any potential issue with our cluster or deployment. But they can also **leak** some confidential information!

Make sure that you do not have any data leaks into your logs.

This should be done without downtime

Auditing

At this point we have a secured MongoDB deployment hardened against outside attacks, and used Role-Based Access Control to limit the access of users.

- The final step is to enable auditing, giving us a clear record of **who** performed an auditable action.

Exercise 9: Enable Auditing

- Enable auditing for all operations, to include CRUD operations, for the `security-lab` database
- Output the log file in JSON format
- Output the log file to `/mongod-data/audit/SECURED`
- There are many [filter options](#)²⁸

²⁸ <https://docs.mongodb.com/manual/tutorial/configure-audit-filters/>

Putting it together

```
storage:
  dbPath: /mongod-data/appdb/
  ...
net:
  ssl:
    mode: requireSSL
    PEMKeyFile: /etc/ssl/mongodb/node1.pem
    CAFile: /etc/ssl/mongodb/ca.pem

security:
  clusterAuthMode: x509
  enableEncryption : true
  encryptionKeyFile : /etc/ssl/mongodb/mongodb-keyfile
  redactClientLogData: true
```

Putting it together (cont)

```
auditLog:
  destination: file
  format: JSON
  path: /mongod-data/audit/SECURED/audit.json
  filter: '{ roles: { role: "readWrite", db: "security-lab" } }'

setParameter: { auditAuthorizationSuccess: true }
```

Summary

What we did:

- Enabled basic authorization
- Used SSL certificates for the cluster
- Used X509 certificate to authenticate the client
- Encrypted the database at rest
- Redacted the *mongod* logs
- Configured auditing for a specific user

12 MongoDB Atlas, Cloud & Ops Manager Fundamentals

MongoDB Cloud & Ops Manager (page 195) Learn about what Cloud & Ops Manager offers

Automation (page 197) Cloud & Ops Manager Automation

Lab: Cluster Automation (page 200) Set up a cluster with Cloud Manager Automation

Monitoring (page 201) Monitor a cluster with Cloud Manager

Lab: Create an Alert (page 203) Create an alert on Cloud Manager

Backups (page 203) Use Cloud Manager to create and administer backups

12.1 MongoDB Cloud & Ops Manager

Learning Objectives

Upon completing this module students should understand:

- Features of Cloud & Ops Manager
- Available deployment options
- The components of Cloud & Ops Manager

Cloud and Ops Manager

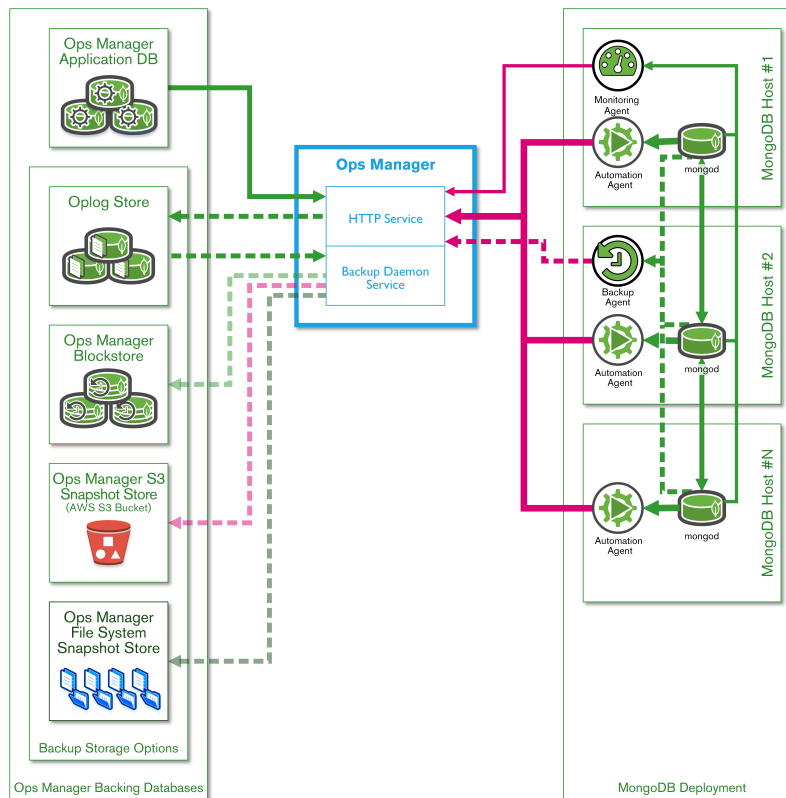
All services for managing a MongoDB cluster or group of clusters:

- Monitoring
- Automation
- Backups

Deployment Options

- Cloud Manager: Hosted, <https://www.mongodb.com/cloud>
- Ops Manager: On-premises

Architecture



Cloud Manager

- Manage MongoDB instances anywhere with a connection to Cloud Manager
- Option to provision servers via AWS integration

Ops Manager

On-premises, with additional features for:

- Alerting (SNMP)
- Deployment configuration (e.g. backup redundancy across internal data centers)
- Global control of multiple MongoDB clusters

Cloud & Ops Manager Use Cases

- Manage a 1000 node cluster (monitoring, backups, automation)
- Manage a personal project (3 node replica set on AWS, using Cloud Manager)
- Manage 40 deployments (with each deployment having different requirements)

Creating a Cloud Manager Account

Free account at <https://www.mongodb.com/cloud>

12.2 Automation

Learning Objectives

Upon completing this module students should understand:

- Use cases for Cloud / Ops Manager Automation
- The Cloud / Ops Manager Automation internal workflow

What is Automation?

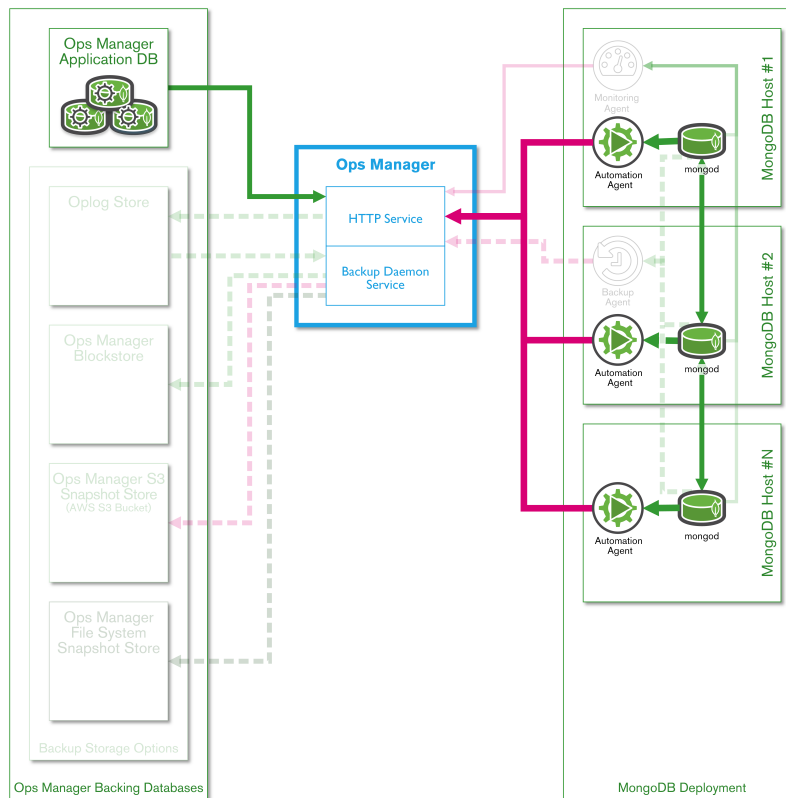
Fully managed MongoDB deployment on your own servers:

- Automated provisioning
- Dynamically add capacity (e.g. add more shards or replica set nodes)
- Upgrades
- Admin tasks (e.g. change the size of the oplog)

How Does Automation Work?

- Automation agent is installed on each server in cluster
- Administrator creates a goal environment/topology for system (through Cloud / Ops Manager interface)
- Automation agents periodically check with Cloud / Ops Manager to get new environment/topology instructions
- Agents create and follow a plan for implementing the instructions
- Minutes later, cluster design is complete, cluster is in goal state

Automation Agents



Sample Use Case

Administrator wants to create a 100-shard sharded cluster, with each shard comprised of a 3 node replica set:

- Administrator installs automation agent on 300 servers
- Cluster environment/topology is created in Cloud / Ops Manager, then deployed to agents
- Agents execute instructions until 100-shard cluster is complete (usually several minutes)

Upgrades Using Automation

- Upgrades without automation can be a manually intensive process (e.g. 300 servers)
- A lot of edge cases when scripting (e.g. 1 shard has problems, or one replica set is a mixed version)
- One click upgrade with Cloud / Ops Manager Automation for the entire cluster

Automation: Behind the Scenes

- Agents ping Cloud / Ops Manager for new instructions
- Agents compare their local configuration file with the latest version from Cloud / Ops Manager
- Configuration file in JSON
- All communications over SSL

```
{
  "groupId": "55120365d3e4b0cac8d8a52a737",
  "state": "PUBLISHED",
  "version": 4,
  "cluster": { ...
```

Configuration File

When version number of configuration file on Cloud / Ops Manager is greater than local version, agent begins making a plan to implement changes:

```
"replicaSets": [
{
  "_id": "shard_0",
  "members": [
    {
      "_id": 0,
      "host": "DemoCluster_shard_0_0",
      "priority": 1,
      "votes": 1,
      "slaveDelay": 0,
      "hidden": false,
      "arbiterOnly": false
    },
    ...
  ],
  ...
}
```

Automation Goal State

Automation agent is considered to be in goal state after all cluster changes (related to the individual agent) have been implemented.

Demo

- The instructor will demonstrate using Automation to set up a small cluster locally.
- Reference documentation:
- [The Automation Agent](#)²⁹
- [The Automation API](#)³⁰
- [Configuring the Automation Agent](#)³¹

12.3 Lab: Cluster Automation

Learning Objectives

Upon completing this exercise students should understand:

- How to deploy, dynamically resize, and upgrade a cluster with Automation

Exercise #1

Create a cluster using Cloud Manager automation with the following topology:

- 3 shards
- Each shard is a 3 node replica set (2 data bearing nodes, 1 arbiter)
- Version 2.6.8 of MongoDB
- **To conserve space, set “smallfiles” = true and “oplogSize” = 10**

²⁹ <https://docs.cloud.mongodb.com/tutorial/nav/automation-agent/>

³⁰ <https://docs.cloud.mongodb.com/api/>

³¹ <https://docs.cloud.mongodb.com/reference/automation-agent/>

Exercise #2

Modify the cluster topology from Exercise #1 to the following:

- 4 shards (add one shard)
- Version 3.0.1 of MongoDB (upgrade from 2.6.8 -> 3.0.1)

12.4 Monitoring

Learning Objectives

Upon completing this module students should understand:

- Cloud / Ops Manager monitoring fundamentals
- How to set up alerts in Cloud / Ops Manager

Monitoring in Cloud / Ops Manager

- Identify cluster performance issues
- Identify individual nodes in cluster with performance issues
- Visualize performance through graphs and overlays
- Configure and set alerts

Monitoring Use Cases

- Alert on performance issues, to catch them before they turn into an outage
- Diagnose performance problems
- Historical performance analysis
- Monitor cluster health
- Capacity planning and scaling requirements

Monitoring Agent

- Requests metrics from each host in the cluster
- Sends those metrics to Cloud / Ops Manager server
- Must be able to contact every host in the cluster (agent can live in a private network)
- Must have access to contact Cloud / Ops Manager website with metrics from hosts

Agent Configuration

- Can use HTTP proxy
- Can gather hardware statistics via munin-node
- Agent can optionally gather database statistics, and record slow queries (sampled)

Agent Security

- SSL certificate for SSL clusters
- LDAP/Kerberos supported
- Agent must have “clusterMonitor” role on each host

Monitoring Demo

Visit <https://www.mongodb.com/cloud>

Navigating Cloud Manager Charts

- Add charts to view by clicking the name of the chart at the bottom of the host’s page
- “i” icon next to each chart title can be clicked to learn what the chart means
- Holding down the left mouse button and dragging on top of the chart will let you zoom in

Metrics

- Minute-level metrics for 48 hours
- Hourly metrics for about 3 months
- Daily metrics for the life of the cluster

Alerts

- Every chart can be alerted on
- Changes to the state of the cluster can trigger alerts (e.g. a failover)
- Alerts can be sent to email, SMS, HipChat, or PagerDuty

12.5 Lab: Create an Alert

Learning Objectives

Upon completing this exercise students should understand:

- How to create an alert in Cloud Manager

Exercise #1

Create an alert through Cloud Manager for any node within your cluster that is down.

After the alert has been created, stop a node within your cluster to verify the alert.

12.6 Backups

Learning Objectives

Upon completing this module students should understand:

- How Cloud / Ops Manager Backups work
- Advantages to Cloud / Ops Manager Backups

Methods for Backing Up MongoDB

- mongodump
- File system backups
- Cloud / Ops Manager Backups

Comparing MongoDB Backup Methods

Considerations	Mongodump	File System	Cloud Backup	Ops Manager
Initial Complexity	Medium	High	Low	High
Replica Set PIT	Yes**	Yes**	Yes	Yes
Sharded Snapshot	No	Yes**	Yes	Yes
Restore Time	Slow	Fast	Medium	Medium

****Requires advanced scripting**

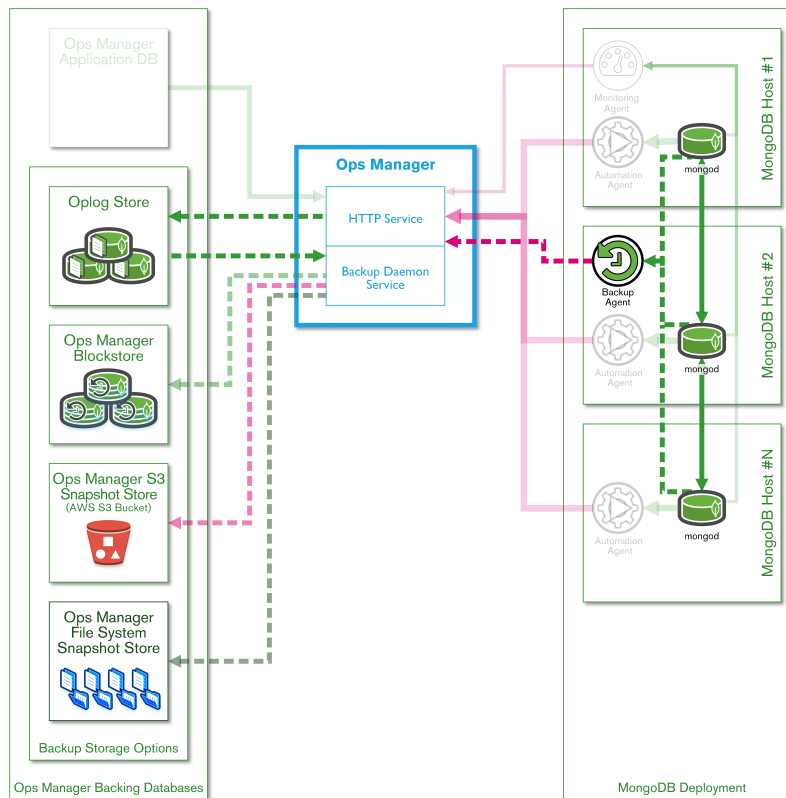
Cloud / Ops Manager Backups

- Based off oplogs (even for the config servers)
- Point-in-time recovery for replica sets, snapshots for sharded clusters
- Olog on config server for sharded cluster backup
- Ability to exclude collections, databases (such as logs)
- Retention rules can be defined

Restoring from Cloud / Ops Manager

- Specify which backup to restore
- SCP push or HTTPS pull (one time use link) for data files

Architecture



Snapshotting

- Local copy of every replica set stored by Cloud / Ops Manager
- *Oplog* entries applied on top of local copy
- Local copy is used for snapshotting
- Very little impact to the cluster (equivalent to adding another secondary)

Backup Agent

- Backup agent (can be managed by Automation agent)
- Backup agent sends oplog entries to Cloud / Ops Manager service to be apply on local copy

13 MongoDB Cloud & Ops Manager Under the Hood

API (page 206) Using the Cloud & Ops Manager API

Lab: Cloud Manager API (page 207) Cloud & Ops Manager API exercise

Architecture (Ops Manager) (page 208) Ops Manager

Security (Ops Manager) (page 210) Ops Manager Security

Lab: Install Ops Manager (page 211) Install Ops Manager

13.1 API

Learning Objectives

Upon completing this module students should understand:

- Overview of the Cloud / Ops Manager API
- Sample use cases for the Cloud / Ops Manager API

What is the Cloud / Ops Manager API?

Allows users to programmatically:

- Access monitoring data
- Backup functionality (request backups, change snapshot schedules, etc.)
- Automation cluster configuration (modify, view)

API Documentation

<https://docs.mms.mongodb.com/core/api/> <<https://docs.mms.mongodb.com/core/api/>>

Sample API Uses Cases

- Ingest Cloud / Ops Manager monitoring data
- Programmatically restore environments
- Configuration management

Ingest Monitoring Data

The monitoring API can be used to ingest monitoring data into another system, such as Nagios, HP OpenView, or your own internal dashboard.

Programmatically Restore Environments

Use the backup API to programmatically restore an integration or testing environment based on the last production snapshot.

Configuration Management

Use the automation API to integrate with existing configuration management tools (such as Chef or Puppet) to automate creating and maintaining environments.

13.2 Lab: Cloud Manager API

Learning Objectives

Upon completing this exercise students should understand:

- Have a basic understanding of working with the Cloud Manager API (or Ops Manager if the student chooses)

Using the Cloud Manager API

If Ops Manager is installed, it may be used in place of Cloud Manager for this exercise.

Exercise #1

Navigate the Cloud Manager interface to perform the following:

- Generate an API key
- Add your personal machine to the API whitelist

Exercise #2

Modify and run the following curl command to return alerts for your Cloud Manager group:

```
curl -u "username:apiKey" --digest -i  
"https://mms.mongodb.com/api/public/v1.0/groups/<GROUP-ID>/alerts"
```

Exercise #3

How would you find metrics for a given host within your Cloud Manager account? Create an outline for the API calls needed.

13.3 Architecture (Ops Manager)

Learning Objectives

Upon completing this module students should understand:

- Ops Manager overview
- Ops Manager components
- Considerations for sizing an Ops Manager environment

MongoDB Ops Manager

- On-premises version of Cloud Manager
- Everything stays within private network

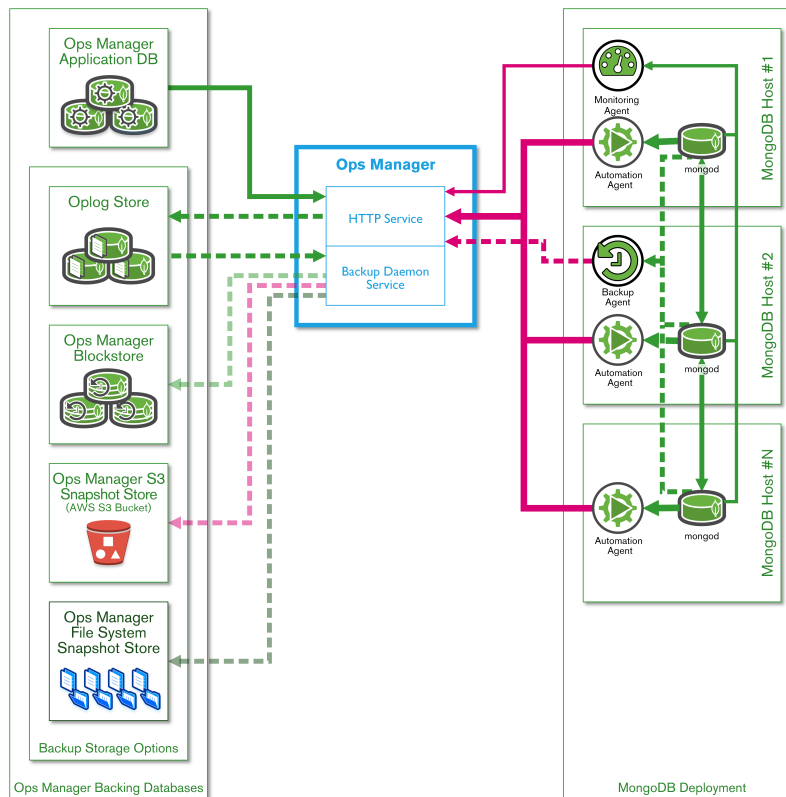
Components

- Application server(s): web interface
- Ops Manager application database: monitoring metrics, automation configuration, etc.
- Backup infrastructure: cluster backups and restores

Architecture

Application Server

- 15GB RAM, 50GB of disk space are required
- Equivalent to a m3.xlarge AWS instance



Application Database

- All monitoring metrics, automation configurations, etc. stored here
- Replica set, however, a standalone MongoDB node can also be used

Backup Infrastructure

- Backup database (blockstore, oplog, sync)
- Backup daemon process (manages applying oplog entries, creating snapshots, etc.)

Backup Database

- 3 sections: - blockstore for blocks - oplog - sync for initial sync slices
- Replica set, a standalone MongoDB node can also be used
- Must be sized carefully
- All snapshots are stored here
- Block level de-duping, the same block isn't stored twice (significantly reduces database size for deployment with low/moderate writes)

Backup Daemon Process

- The “workhorse” of the backup infrastructure
- Creates a local copy of the database it is backing up (references “HEAD” database)
- Requires 2-3X data space (of the database it is backing up)
- Can run multiple daemons, pointing to multiple backup databases (for large clusters)

13.4 Security (Ops Manager)

Learning Objectives

Upon completing this module students should understand:

- Ops Manager security overview
- Security and authentication options for Ops Manager

Ops Manager User Authentication

- Two-Factor authentication can be enabled (uses Google Authenticator)
- LDAP authentication option

Authentication for the Backing Ops Manager Databases

Ops Manager application database and backup database:

- MongoDB-CR (SCRAM-SHA1)
- LDAP
- Kerberos

Authenticating Between an Ops Manager Agent and Cluster

- LDAP
- MongoDB-CR
- Kerberos (Linux only)

Encrypting Communications

- All communications can be encrypted over SSL.

Ops Manager Groups

- Users can belong to many different groups
- Users have different levels of access per group

User Roles By Group

- Read Only
- User Admin
- Monitoring Admin
- Backup Admin
- Automation Admin
- Owner

Global User Roles

- Global Read Only
- Global User Admin
- Global Monitoring Admin
- Global Backup Admin
- Global Automation Admin
- Global Owner

13.5 Lab: Install Ops Manager

Learning Objectives

Upon completing this exercise students should understand:

- The components needed for Ops Manager
- How to successfully install Ops Manager

Install Ops Manager

A Linux machine with at least 15GB of RAM is required

Install Ops Manager

We will follow an outline of the installation instructions here:

<https://docs.opsmanager.mongodb.com/current/tutorial/install-basic-deployment/>

Exercise #1

Prepare your environment for running all Ops Manager components: Monitoring, Automation, and Backups

- Set up a 3 node replica set for the Ops Manager application database (2 data bearing nodes, 1 arbiter)
- Set up a 3 node replica set for Ops Manager backups (2 data bearing nodes, 1 arbiter)
- Verify both replica sets have been installed and configured correctly

Exercise #2

Install the Ops Manager application

- Ops Manager application requires a license for commercial use
- Download the Ops manager application (after completing form): <http://www.mongodb.com/download>
- Installation instructions (from above): docs.opsmanager.mongodb.com
- Verify Ops Manager is running successfully

Exercise #3

Install the Ops Manager Backup Daemon

- The Ops Manager backup daemon is required for using Ops Manager for backups
- Download and install the backup daemon (using the link from the past exercise)
- Verify the installation was successful by looking at the logs in: `<install_dir>/logs`

Exercise #4

Verify the Ops Manager installation was successful:

<https://docs.opsmanager.mongodb.com/current/tutorial/test-new-deployment/>

Exercise #5

Use Ops Manager to backup a test cluster:

- Create a 1 node replica set via Ops Manager automation
- Add sample data to the replica set:

```
> for (var i=0; i<10000; i++) { db.blog.insert( { "name" : i } ) }
WriteResult({ "nInserted" : 1 })
> db.blog.count()
10000
```

- Use Ops Manager to backup the test cluster
- Perform a restore via Ops Manager of the test cluster

14 Introduction to MongoDB BI Connector

MongoDB Connector for BI (page 214) An introduction to MongoDB Connector for BI

14.1 MongoDB Connector for BI

Learning Objectives

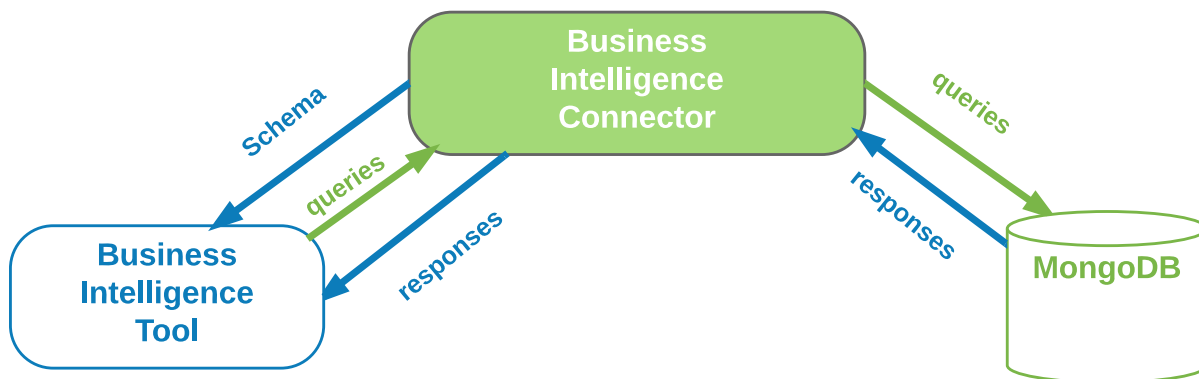
Upon completing this module students should understand:

- The different tools included in the MongoDB BI Connector package
- The different configuration files required by the BI Connector
- The supported SQL statements version
- How to launch `mongosqld`
- Run SQL statements in a MongoDB server instance

MongoDB BI Connector: Introduction

MongoDB Connector for BI enables the execution of SQL statements in a MongoDB server.

It's a native connector implementation that enables Business Intelligence tools to read data from a MongoDB server.



How it works

The MongoDB Connector for BI executes in the following mode:

- Generates a Document-Relational Definition Language (DRDL) file that defines a map between a given collection shape to a relational schema
- Once the `drdl` file is generate, BI tools are able to request the correspondant relational sql and express queries
- After receiving and processing a SQL statement, provides back results in tabular format, native to BI Tools.
- The BI connector also functions as a pass-through authentication proxy.

BI Connector Package

BI Connector is a composite of the connector *daemon* and a schema definition utility.

- `mongosqld`: Runs as a server *daemon* and responds to incoming SQL queries
- `mongodrdl`: Utility that generates `drdl` files from the databases and collections in MongoDB

The `mongodrdl`

`mongodrdl` generates a Document-Relation Definition Language file.

- The `drdl` file is a mapping between a given collection(s) shape and its corresponding relational schema

```
schema:
- db: <database name>
tables:
- table: <SQL table name>
  collection: <MongoDB collection name>
  pipeline:
  - <optional pipeline elements>
  columns:
  - Name: <MongoDB field name>
    MongoType: <MongoDB field type>
    SqlName: <mapped SQL column name>
    SqlType: <mapped SQL column type>
```

`mongodrdl` Example

To generate a `drdl` file we need to connect `mongodrdl` to a MongoDB instance:

```
mongodrdl -d training -c zips --host localhost:27017
cat zips.drdl
schema:
- db: training
  tables:
  - table: zips
    collection: zips
    pipeline: []
    columns:
    - Name: _id
      MongoType: bson.ObjectId
      SqlName: _id
      SqlType: varchar
    ...
```

Custom Filtering

mongodrdl allows you to define a `--customFilter` field in case we need to express MongoDB native queries from within our SQL query expression.

```
mongodrdl -c zips -d training -o zips.drdl --customFilterField "mongoqueryfield"
```

For example, executing a geospatial query:

```
SELECT * FROM zips
WHERE mongoqueryfield = "{{'loc': {'$geoNear': [30, 48, 100]}}}"
```

mongosqld Daemon

mongosqld runs as a server *daemon* and responds to incoming SQL queries.

```
mongosqld --mongo-uri mongodb://localhost:27017 --schema zips.drdl
```

- By default mongosqld will be listening for incoming requests on 127.0.0.1:3307

mongosqld Authentication & Authorization

The BI Connector offers integration for three different authentication mechanisms:

- SCRAM-SHA-1
- MONGODB-CR
- PLAIN (*LDAP Authentication*)

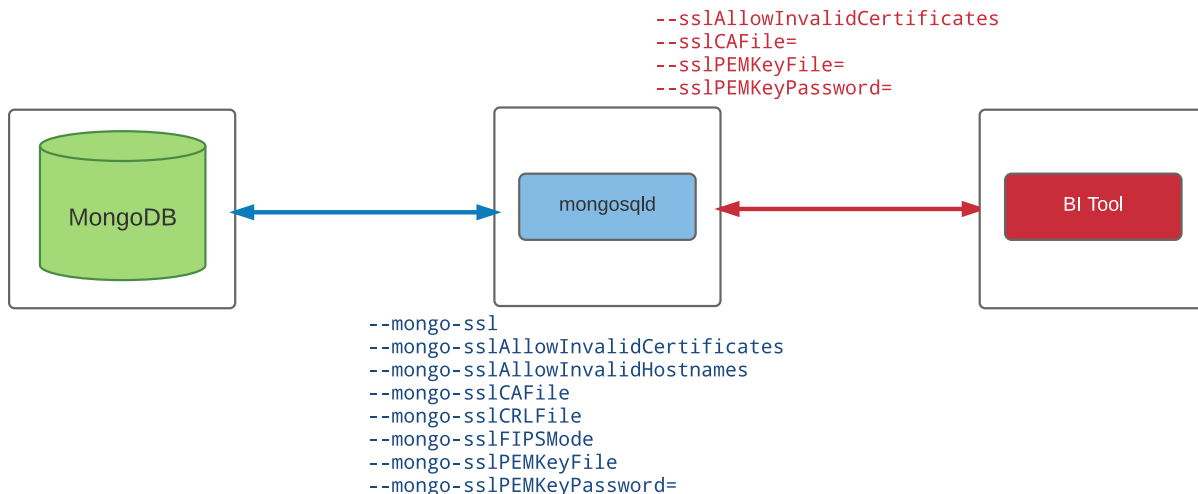
And external LDAP Authorization:

- requires defining the **source** attribute in the user name string

```
grace?mechanism=PLAIN&source=$external
```

mongosqld Encryption

BI Connector supports network encryption on all segments of the connection.



SQL Compatibility

- BI Connector version 2.0 is compatible with **SQL-99 SELECT**³² statements
- Uses MySQL wire protocol

```
mysql --protocol tcp --port 3307
```

- This means we can use a SQL client like `mysql` to query data on MongoDB

```
use training;  
SELECT * FROM zips;
```

³² <https://docs.mongodb.com/bi-connector/master/supported-operations/>



Find out more
mongodb.com | mongodb.org
university.mongodb.com

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