



# MongoDB Essentials Training



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# MongoDB Essentials Training

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**MongoDB, Inc.**

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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:

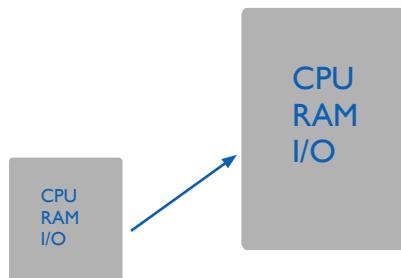
- Python dictionaries
- Ruby hashes
- PHP arrays
- JSON objects

## An Example MongoDB Document

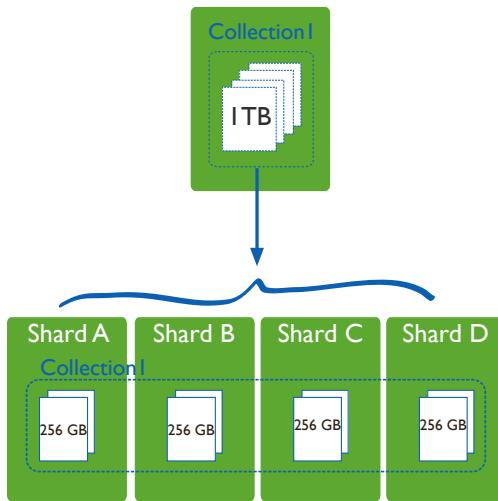
A MongoDB document expressed using JSON syntax.

```
{  
  "_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?" }  
  ]  
}
```

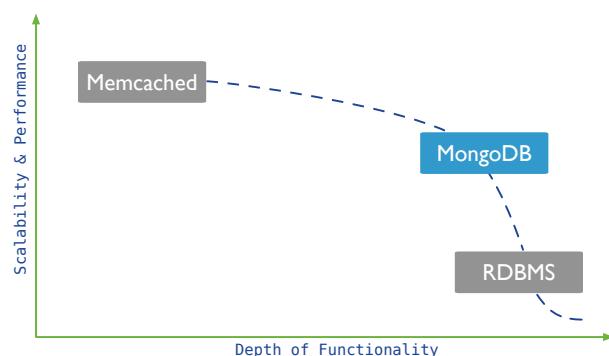
## Vertical Scaling



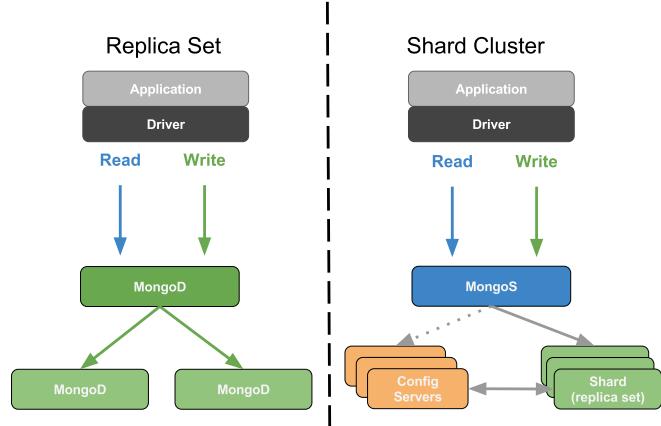
## Scaling with MongoDB



## 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.org](http://json.org/)<sup>1</sup>.

### 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" ]  
    ]  
}
```

---

<sup>1</sup> <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.org](http://bsonspec.org)<sup>2</sup>.

## 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
```

<sup>2</sup> <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.org](http://bsonspec.org)<sup>3</sup>

---

**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”

---

<sup>3</sup> <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](#)<sup>4</sup>.

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")
```

<sup>4</sup> <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](http://mongodb.org/downloads).
- To run the msi installation from the command line, run the following:

```
msiexec.exe /l*v mdbinstall.log /qb /i mongodb-win32-x86_64-2008plus-ssl-4.0.5-  
↳signed.msi INSTALLLOCATION="C:\MongoDB\Server\4.0\"
```

- 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.

## Install on Windows cont.

- To do this, from “System Properties” select “Advanced” then “Environment Variables”
- MongoDB Compass will be installed by default with the msi installation.
- To suppress the installation of MongoDB Compass, you must explicitly include the SHOULD\_INSTALL\_COMPASS="0" argument.

```
msiexec.exe /l*v mdbinstall.log /qb /i mongodb-win32-x86_64-2008plus-ssl-4.0.5-  
↳signed.msi SHOULD_INSTALL_COMPASS="0"
```

## 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 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 WiredTiger 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
  - Each collection and index stored in its own file.

## 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

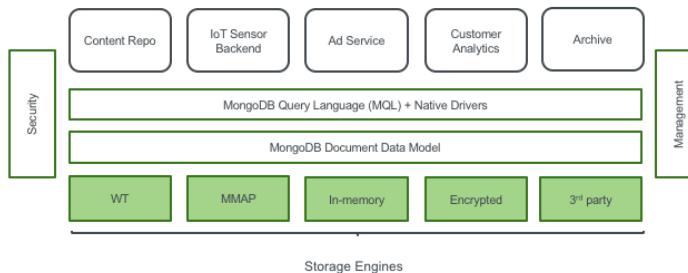
### 2.1 Introduction to Storage Engines

#### 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)
- 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 <YourStorageEngine>
```

## 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<sup>5</sup>.

## 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

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

## Compression in MongoDB

- Compression can significantly reduce the amount of disk space / memory required.
- The tradeoff is that compression requires more CPU.

## WiredTiger Storage Engine

- Notable features of the WiredTiger 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**

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

## **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 introduced pluggable storage engines.
- The default is WiredTiger
- WiredTiger introduced the following to MongoDB:
  - Compression
  - Document-level concurrency

# 3 CRUD

*Creating and Deleting Documents (page 22)* Inserting documents into collections, deleting documents, and dropping collections

*Reading Documents (page 27)* The find() command, query documents, dot notation, and cursors

*Query Operators (page 34)* MongoDB query operators including: comparison, logical, element, and array operators

*Lab: Finding Documents (page 39)* Exercises for querying documents in MongoDB

*Updating Documents (page 39)* Using update methods and associated operators to mutate existing documents

*Lab: Updating Documents (page 47)* 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.insertOne( { "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.testcoll.insertOne( { a : 1 } )
db.testcol2.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.
- `sort ()`: Sorts results by one or more keys.

### 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,
    "rotten_tomatoes": 7.1 },
  { "title" : "Godzilla",
    "category" : [ "action", "adventure", "sci-fi" ],
    "imdb_rating" : 6.6,
    "rotten_tomatoes": 8.0},
  { "title" : "Home Alone",
    "category" : [ "family", "comedy" ],
    "imdb_rating" : 7.4,
    "rotten_tomatoes": 6.3 } ] )
```

## 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 mediocre family movie
db.movies.find( { $or : [
  { "category" : "sci-fi", "imdb_rating" : { $gte : 8 } },
  { "category" : "family", "imdb_rating" : { $gte : 7 } }
] } )
```

### Example: Logical Operators

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

## Element Query Operators

- `$exists`: Select documents based on the existence of a particular field.
- `$type`: Select documents based on their type.
  - Accepts an array of possible types for field matching
- See [BSON types<sup>6</sup>](#) for reference on types.

Changed in version 3.6.

- `$type` allows to match element types within arrays

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

## Example: Element Operators

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

// type 1 or alias "double"
db.movies.find( { "budget" : { $type : 1 } } )
db.movies.find( { "budget": { $type: "double" }})

// type 3 or alias "object" (embedded document)
db.movies.find( { "budget" : { $type : 3 } } )
db.movies.find( { "budget": { $type: "object" }})

// type 'string' matching array elements
db.movies.find({ "category": { $type: "string" }})
```

## \$expr Operator

New in version 3.6.

\$expr allows the use of aggregation expression within the MongoDB query language.

- Enables the comparison of fields within the same document using aggregation path expresions<sup>7</sup>

```
{ $expr: { <expression> } }
```

## Example: \$expr Operator

```
// find all movies where roten_tomatoes is higher than imdb_rating
db.movies.find( {
  $expr: { $gt: [ "$rotten_tomatoes" , "$rating" ] }
} )
```

## 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

<sup>7</sup> <https://docs.mongodb.com/manual/meta/aggregation-quick-reference/#field-path-and-system-variables>

## 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 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: `$set` and `$unset` (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, 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

- `$push`: Appends an element to the end of the array.
- `$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" },  
  { $pop : { "category" : 1 } } )  
db.movies.updateOne(  
  { "title" : "Batman" },  
  { $pull : { "category" : "action" } } )  
db.movies.updateOne(  
  { "title" : "Batman" },  
  { $pullAll : { "category" : [ "villain", "comic-based" ] } } )  
db.movies.updateOne(  
  { "title" : "Batman" },  
  { $addToSet : { "category" : "action" } } )  
db.movies.updateOne(  
  { "title" : "Batman" },  
  { $addToSet : { "category" : "action" } } )
```

## The Positional `$` Operator

- `$`<sup>8</sup> is a positional operator that specifies an element in an array to update.
- It acts as a placeholder for the first element that matches the query document.
- `$` replaces the element in the specified position with the value given.
- Syntax:

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

<sup>8</sup> <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" } } )

db.movies.find()
```

## Array Filters

New in version 3.6.

- Using the `arrayFilters` option with an update allows the selection of specific array elements from a document.
- Using a syntax like `$[<identifier>]` allows to apply changes to all array elements that match the array filter predicate.
- `arrayFilter` uses query operators, like the ones for `find()`, to express the matching rules.

```
{ <update operator>: { "<array>.$[<identifier>]" : value } },
{ arrayFilters: [ { <identifier>: <condition> } ] }
```

## Example: Array Filters

Suppose we would like to give a bonus to certain scores:

```
db.grades.findOne()
db.grades.updateOne(
  { "scores.type": "homework" },
  { "$inc": { "scores.$[filter1].score": 10 } },
  { "arrayFilters": [ { "filter1.score" : { "$gte": 40, "$lt": 60 } } ] }
)
db.grades.findOne()
```

## 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 } )
```

## `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 fail, 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 49) An introduction to MongoDB indexes

*Lab: Basic Indexes* (page 55) A short exercise on the basic of index usage

*Compound Indexes* (page 56) Indexes on two or more fields

*Lab: Optimizing an Index* (page 61) Lab on optimizing a compound index

*Multikey Indexes* (page 62) Indexes on array fields

*Hashed Indexes* (page 66) Hashed indexes

*Geospatial Indexes* (page 67) 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 74) Using Compass to create a geospatial index

*TTL Indexes* (page 78) Time-To-Live indexes

*Text Indexes* (page 80) Free text indexes on string fields

*Partial Indexes* (page 83) Partial indexes in MongoDB

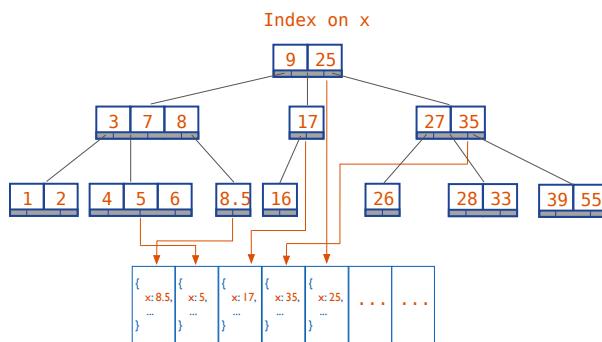
### 4.1 Index Fundamentals

#### 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 `.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 32 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”       | 3         |
| “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 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.

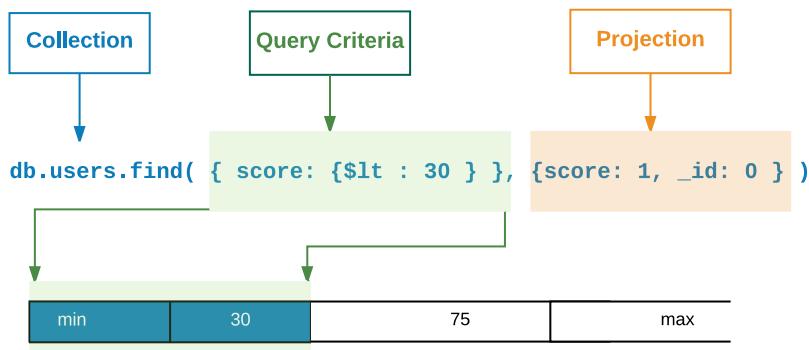
## No need for stage : SORT

| 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( { tstamp : -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( { tstamp : -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<sup>9</sup>](#) 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.

---

<sup>9</sup> <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.

## Find using \$near

New York City Hall is at  $40.7127^{\circ}$  N,  $74.0059^{\circ}$  W. If we would like to find all flights, that depart from within 15 kilometers of New York City Hall, we could express the following query:

```
db.flights.find(
{origin :
  {$near :
    {$nearSphere :
      {$geometry :
        {
          type : "Point",
          coordinates : [ -74.0059, 40.7127 ]
        },
        $maxDistance : 15000
      }
    }
  }
})
```

- \$nearSphere and \$near
  - supported in sharded collections starting MongoDB 4.0

## 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 `test.col` 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:
  - `long` (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

## 4.8 Exercise: Inserting GeoJSON Objects

### Step 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

## Step 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".

## Step 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.

## 4.9 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 ] } }
}
```

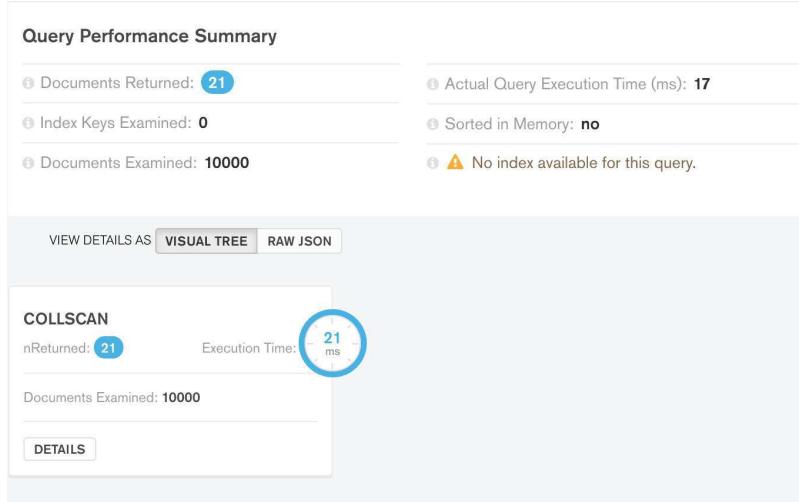
## GeoJSON Query Example

The screenshot shows the MongoDB Compass interface for the 'citibike.trips' collection. The left sidebar lists databases and collections, with 'citibike' selected. The main area displays a map of Manhattan with several blue dots representing bike stations. A search bar labeled 'start station location' contains 'coordinates'. Below the map is a histogram of start station names, with 'long' being the most frequent. The top right shows document statistics: 10.0K documents, total size 4.2MB, avg size 440B, and one index.

## GeoJSON Query Explain Plan

The screenshot shows the MongoDB Compass interface for the 'citibike.trips' collection, focusing on the 'EXPLAIN PLAN' tab. It displays a 'Query Performance Summary' with the following details: Documents Retuned: 21, Actual Query Execution Time (ms): 17, Index Keys Examined: 0, Started In Memory: no, and Documents Examined: 10000. A note indicates 'No index available for this query.' Below this, a 'COLLSCAN' section shows 21 documents examined and an execution time of 17 ms. The bottom of the screen has a toolbar with various icons.

## 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

MongoDB Compass - localhost:27017/citibike.trips

citibike.trips

DOCUMENTS 10.0K TOTAL SIZE 4.9MB AVE. SIZE 440B INDEXES 1 TOTAL SIZE 92.0KB AVE. SIZE 92.0KB

SCHEMA DOCUMENTS INDEXES EXPLAIN PLAN VALIDATION

CREATE INDEX

| Name and Definition | Type    | Size    | Usage                    | Properties | Drop |
|---------------------|---------|---------|--------------------------|------------|------|
| _id                 | REGULAR | 92.0 kB | 72 since Wed May 03 2017 | UNIQUE     |      |

## Creating an Index Example

### Create Index

Choose an index name

Configure the index definition

|                        |          |   |
|------------------------|----------|---|
| start station location | 2dsphere | - |
| end station location   | 2dsphere | - |

**ADD ANOTHER FIELD**

▼ Options

Build index in the background

Create unique index

Create TTL

seconds

Partial Filter Expression

{}

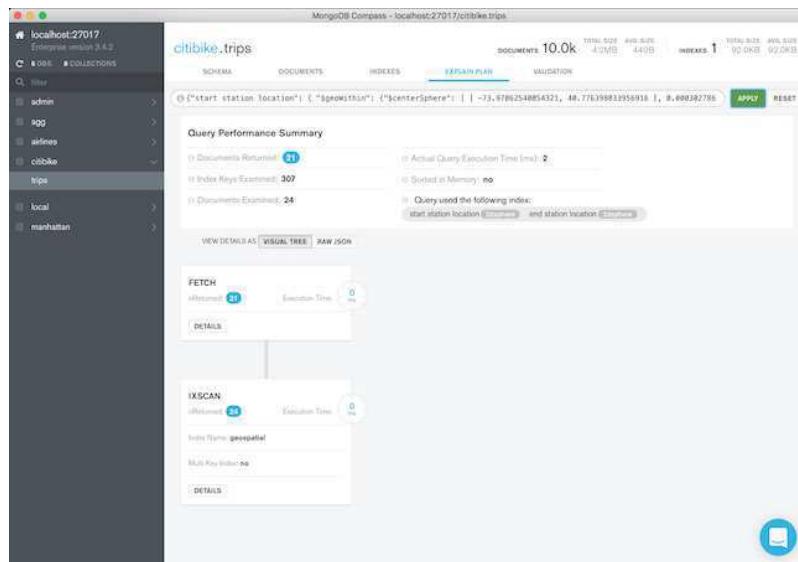
**CANCEL** **CREATE**

## 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



## 4.10 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);
}
```

## 4.11 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" } }
) )
```

## Text Index Restrictions

There are some restrictions on using indexes of type `text`:

- Only **one** text index per collection
- Cannot use hints on a text search
- Text index and Sort: sort operations cannot obtain sort order from a text index, even from compound text index.
- Compound index can include a `text` index key, however:
  - Only combined with ascending or descending sort order index keys
  - Cannot be compound with other special index types like geospatial or multi-key
  - All text index keys must be listed adjacently

```
db.<COLLECTION>.createIndex( { "a": "text", "b": "text", "c": 1 } )
```

- The index can only be dropped by name, not by spec.

## **Text Index Performance and Storage Requirements**

Text indexes are by definition very resource intensive.

- Every single token in a string can generate an index entry
- Text Search is based on relevance instead of matching
  - This means that, in general, more results are returned per query
  - The scoring and calculation of relevance will be driven by both the query selector and indexed field
  - Results will also be driven by the expected language defined in the query selector

Text indexes require more storage, RAM and CPU to handle text indexes, when compared to other index types.

## **4.12 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:

```
db.integers.insertOne(  
  { "_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" }
```

# 5 Aggregation

*Intro to Aggregation (page 87)* An introduction to the the aggregation framework, pipeline concept, and stages

*Aggregation - Utility (page 95)* Utility stages in the aggregation pipeline

*Aggregation - \$lookup and \$graphLookup (page 97)* \$lookup and \$graphLookup in the aggregation pipeline

*Lab: Using \$graphLookup (page 102)* \$graphLookup lab

*Aggregation - Unwind (page 102)* The \$unwind stage in depth

*Lab: Aggregation Framework (page 104)* Aggregation labs

*Aggregation - \$facet, \$bucket, and \$bucketAuto (page 105)* The \$facet, \$bucket, and \$bucketAuto stages

*Aggregation - Recap (page 109)* Recap of the aggregation framework

## 5.1 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>`"
  - There is a fair amount of documentation on variables in aggregation expressions<sup>10</sup>

## 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.

---

<sup>10</sup> <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 user.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<sup>11</sup>.

## 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

<sup>11</sup> <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
  - In SQL terms, performs joins
  - The second collection must be in the same database
  - The second collection cannot be sharded
- Documents based on a matching field in each collection

```
show collections
a
b
db.a.aggregate( [ {"$lookup": {
  from: "b", localField: "local", foreignField: "foreign", as: "results"  }
}])
```

## The Lookup Stage (continued)

New in version 3.6.

- `$lookup` allows the definition of sub-pipelines in the `from` collection, like projection of fields and extended filtering, or even further nested inner joins, making it ever more expressive.

```
db.users.aggregate([{"$lookup": {  
    "from": "tickets",  
    "let": { "userid": "$userid" },  
    "pipeline": [  
        { "$match": { "$expr": {  
            "$and": [  
                { "$eq": ["$$userid": "$_id" ], "$eq": [ "$type", "VIP" ] }  
            ] } } },  
        { "$project": { "date": 1, "name": 1, "arena": "$location" } },  
        { "$sort": { "date": -1 } }  
    ],  
    "as": "vip_tickets" } }])
```

### Example: Using `$lookup`

- Import the companies dataset into a collection called **companies**
- Create a separate collection for `$lookup`

```
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",  
        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 was the business is about" } ] );
```

## Example: Using \$lookup (Continued)

```
db.companies.aggregate( [
  { $match: { number_of_employees: { $gte: 200000 } } },
  { $sort : { number_of_employees: -1 } },
  { $lookup: {
      from: "commentOnCategory",
      localField: "category_code",
      foreignField: "category_id",
      as: "example_comments"
    },
  { $project: { _id :0, name: 1, number_of_employees: 1, example_comments: 1 } }
] )
```

## 5.2 Aggregation - Utility

### The \$sort Stage

- Works like the `.sort()` cursor method
- 1 to sort ascending; -1 to sort descending

```
db.testcol.aggregate( [ { $sort : { b : 1, a : -1 } } ] )
```

### The \$skip Stage

- Works like the `.skip()` cursor method.
- Value is an integer specifying the number of documents to skip.
- 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.
- The following will only pass 3 documents to the stage that comes next in the pipeline:

```
db.testcol.aggregate( [ { $limit: 3 }, ... ] )
```

## The `$count` Stage

- Used to count the number of documents that this stage receives in input
- The following would count all documents in a **users** collection with a **firstName** field set to “Mary”

```
db.users.aggregate([
  { $match: { firstName: "Mary" } },
  { $count: "usersNamedMary" }
])
```

## The `$sample` Stage

- Randomized sample of documents
- Useful for calculating statistics
- `$sample` provides an efficient means of sampling a data set
- If the sample size requested is larger than 5% of the collection `$sample` will perform a collection scan
  - Also happens if collection has fewer than 100 documents
- Can use `$sample` only as a first stage of the pipeline

### Example: `$sample`

```
db.companies.aggregate( [
  { $sample : { size : 5 } },
  { $project : { _id : 0, number_of_employees: 1 } }
] )
```

## The `$indexStats` Stage

- Tells you how many times each index has been used since the server process began
- Must be the first stage of the pipeline
- Returns one document per index
- The `accesses.ops` field reports the number of times an index was used

### **Example: \$indexStats**

Issue each of the following commands in the mongo shell, one at a time.

```
db.companies.dropIndexes()
db.companies.createIndex( { number_of_employees : 1 } )
db.companies.aggregate( [ { $indexStats: {} } ] )
db.companies.find( { number_of_employees : { $gte : 100 } },
                   { number_of_employees: 1 } ).next()
db.companies.find( { number_of_employees : { $gte : 100 } },
                   { number_of_employees: 1 } ).next()
db.companies.aggregate( [ { $indexStats: {} } ] )
```

### **The \$out Stage**

- Creates a new collection from the output of the aggregation pipeline.
- Can only be the last stage in the pipeline.
- If a collection by the name already exists, it replaces that collection.
  - Will keep existing indexes in place

### **Example: \$out**

```
db.tweets.aggregate([
  { $group: {
    _id: null,
    users: { $push: {
      user: "$$CURRENT.user.screen_name",
      activity: "$$CURRENT.user.statuses_count"
    }}
  },
  { $unwind: "$users" },
  { $project: { _id: 0, user: "$users.user", activity: "$users.activity" } },
  { $sort: { activity: -1 } },
  { $out: "usersByActivity" }
])
```

## **5.3 Aggregation - \$lookup and \$graphLookup**

### **The Lookup Stage**

- Pulls documents from a second collection into the pipeline
  - In SQL terms, performs joins
  - The second collection must be in the same database
  - The second collection cannot be sharded
- Documents based on a matching field in each collection

```

show collections
a
b
db.a.aggregate( [ { "$lookup": {
    from: "b", localField: "local", foreignField: "foreign", as: "results"  }
}])

```

## The Lookup Stage (continued)

New in version 3.6.

- `$lookup` allows the definition of sub-pipelines in the **from** collection, like projection of fields and extended filtering, or even further nested inner joins, making it ever more expressive.

```

db.users.aggregate([{ "$lookup": {
    "from": "tickets",
    "let": { "userid": "$userid" },
    "pipeline": [
        { "$match": { "$expr": {
            "$and": [
                { "$eq": ["$$userid": "$_id" ], { "$eq": ["$type", "VIP" ] }
            ] }}},
        { "$project": { "date": 1, "name": 1, "arena": "$location" }},
        { "$sort": { "date": -1}}
    ],
    "as": "vip_tickets" }}])

```

## Example: Using `$lookup`

- Import the companies dataset into a collection called **companies**
- Create a separate collection for `$lookup`

```

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",
      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 was the business is about" } ] );

```

## Example: Using \$lookup (Continued)

```
db.companies.aggregate( [
  { $match: { number_of_employees: { $gte: 200000 } } },
  { $sort : { number_of_employees: -1 } },
  { $lookup: {
      from: "commentOnCategory",
      localField: "category_code",
      foreignField: "category_id",
      as: "example_comments"
    },
    { $project: { _id :0, name: 1, number_of_employees: 1, example_comments: 1 } }
] )
```

## The GraphLookup Stage

- Used to perform a recursive search on a collection, with options for restricting the search by recursion depth and query filter.
- Has the following prototype form:

```
$graphLookup: {
  from: <collection>,
  startWith: <expression>,
  connectFromField: <string>,
  connectToField: <string>,
  as: <string>,
  maxDepth: <number>,
  depthField: <string>,
  restrictSearchWithMatch: <document>
}
```

## \$graphLookup Fields

- **from:** The target collection for \$graphLookup to search
- **startWith:** Expression that specifies the value of the connectFromField with which to start the recursive search
- **connectFromField:** field name whose value \$graphLookup uses to recursively match against the connectToField of other documents in the collection
- **connectToField:** Field name in other documents against which to match the value of the field specified by the connectFromField parameter
- **as:** Name of the array field added to each output document

## \$graphLookup Optional Fields

- **maxDepth**: Optional. Non-negative integral number specifying the maximum recursion depth.
- **depthField**: Optional. Name of the field to add to each traversed document in the search path. The value of this field is the recursion depth for the document
- **restrictSearchWithMatch**: Optional. A document specifying additional conditions for the recursive search. The syntax is identical to query filter syntax.

Query Documentation<sup>12</sup>

## \$graphLookup Search Process

Input documents flow into the \$graphLookup stage of an aggregation

- \$graphLookup targets the search to the collection designated by the `from` parameter

For each input document, the search begins with the value designated by `startWith` - \$graphLookup matches the `startWith` value against the field designated by the `connectToField` in other documents in the `from` collection

## \$graphLookup Search Process (continued)

For each matching document, \$graphLookup takes the value of the `connectFromField` and checks every document in the `from` collection for a matching `connectToField` value

- For each match, \$graphLookup adds the matching document in the `from` collection to an array field named by the `as` parameter
- This step continues recursively until no more matching documents are found, or until it reaches the recursion depth specified by `maxDepth`

## \$graphLookup Considerations

- The collection specified in `from` cannot be sharded.
- Setting `maxDepth` to 0 is equivalent to `$lookup`
- The \$graphLookup stage must stay within the 100 megabyte memory limit.
- \$graphLookup will ignore `allowDiskUse: true`

<sup>12</sup> <https://docs.mongodb.com/manual/tutorial/query-documents/#read-operations-query-argument>

## \$graphLookup Example

Let's illustrate how \$graphLookup works with an example.

```
use company;
db.employees.insertMany([
  { "_id" : 1, "name" : "Dev" },
  { "_id" : 2, "name" : "Eliot", "reportsTo" : "Dev" },
  { "_id" : 3, "name" : "Ron", "reportsTo" : "Eliot" },
  { "_id" : 4, "name" : "Andrew", "reportsTo" : "Eliot" },
  { "_id" : 5, "name" : "Asya", "reportsTo" : "Ron" },
  { "_id" : 6, "name" : "Dan", "reportsTo" : "Andrew" }
])
```

## \$graphLookup Example (continued)

With the sample data inserted, perform the following aggregation:

```
db.employees.aggregate([
  {
    $match: { "name": "Dan" }
  },
  {
    $graphLookup: {
      from: "employees",
      startWith: "$reportsTo",
      connectFromField: "reportsTo",
      connectToField: "name",
      as: "reportingHierarchy"
    }
  }
]).pretty()
```

## \$graphLookup Example Results

The previous \$graphLookup operation will produce the following:

```
{
  "_id" : 6,
  "name" : "Dan",
  "reportsTo" : "Andrew",
  "reportingHierarchy" : [
    { "_id" : 1, "name" : "Dev" },
    { "_id" : 2, "name" : "Eliot", "reportsTo" : "Dev" },
    { "_id" : 4, "name" : "Andrew", "reportsTo" : "Eliot" }
  ]
}
```

## 5.4 Lab: Using \$graphLookup

### Exercise: Finding Airline Routes

For this exercise, you will incorporate the `$graphLookup` stage into an aggregation pipeline.

A client would like you to present them with a list of possible vacation destinations. Their requirements are as follows:

- They only want to fly *Lufthansa* airlines.
- They must leave from Berlin, airport code *TXL*.
- They must fly through Paris as the first destination, airport code *CDG*.
- They want no more than 2 follow on flights after departing *CDG*.

How many destinations meet the above criteria?

Import the necessary dataset with the following:

```
mongoimport -d air -c routes routes.json
mongo air
> db.routes.count()
66985
```

## 5.5 Aggregation - Unwind

### Learning Objectives

Upon completing this module students should understand:

- How to use the `$unwind` stage and its behavior

### The Unwind Stage

- In many situations we want to aggregate using values in an array field.
- In our tweets dataset we need to do this to answer the question:
  - “Who includes the most user mentions in their tweets?”
- User mentions are stored within an embedded document for entities.
- This embedded document also lists any urls and hashtags used in the tweet.

## Example: User Mentions in a Tweet

```
...
"entities" : {
    "user_mentions" : [
        {
            "indices" : [
                28,
                44
            ],
            "screen_name" : "LatinsUnitedGSX",
            "name" : "Henry Ramirez",
            "id" : 102220662
        }
    ],
    "urls" : [ ],
    "hashtags" : [ ]
},
...
}
```

## Using \$unwind

Who includes more mentions of other users in their tweets?

```
db.tweets.aggregate(
    { $unwind: "$entities.user_mentions" },
    { $group: { _id: "$user.screen_name",
                count: { $sum: 1 } } },
    { $sort: { count: -1 } },
    { $limit: 1 })
```

## \$unwind Behavior

- \$unwind no longer errors on non-array operands.
- If the operand is not:
  - An array,
  - Missing
  - null
  - An empty array
- \$unwind treats the operand as a single element array.

## 5.6 Lab: Aggregation Framework

### Exercise: Working with Array Fields

Use the aggregation framework to find the name of the individual who has made the most comments on a blog.

Start by importing the necessary data if you have not already.

```
# for version <= 2.6.x
mongoimport -d blog -c posts --drop posts.json
# for version > 3.0
mongoimport -d blog -c posts --drop --batchSize=100 posts.json
```

To help you verify your work, the author with the fewest comments is Mariela Sherer and she commented 387 times.

### Exercise: Repeated Aggregation Stages

Import the zips.json file from the data handouts provided:

```
mongoimport -d sample -c zips --drop zips.json
```

Consider together cities in the states of California (CA) and New York (NY) with populations over 25,000. Calculate the average population of this sample of cities.

Please note:

- Different states might have the same city name.
- A city might have multiple zip codes.

### Exercise: Projection

Calculate the total number of people who live in a zip code in the US where the city starts with a digit.

`$project` can extract the first digit from any field. E.g.,

```
db.zips.aggregate([
    {$project:
        {
            first_char: { $substr: ["$city", 0, 1] },
        }
    }
])
```

## Exercise: Descriptive Statistics

From the `grades` collection, find the class (display the `class_id`) with the highest average student performance on `exams`. To solve this problem you'll want an average of averages.

First calculate the average exam score of each student in each class. Then determine the average class exam score using these values. If you have not already done so, import the `grades` collection as follows.

```
mongoimport -d sample -c grades --drop grades.json
```

Before you attempt this exercise, explore the `grades` collection a little to ensure you understand how it is structured.

For additional exercises, consider other statistics you might want to see with this data and how to calculate them.

## 5.7 Aggregation - `$facet`, `$bucket`, and `$bucketAuto`

### Learning Objectives

Upon completing this module students should understand:

- How to use `$bucket`
- How to use `$bucketAuto`
- How to use `$facet`
- How to combine `$facet` with buckets for a multi-faceted view

### The `$bucket` stage

- Groups documents based on a specified expression and bucket boundaries.
- Each bucket is represented as a document in the output.
- Each `_id` field in the output specifies the inclusive lower bound
- The `count` field is included by default when the output is not specified.
- A list of accumulators that can be used with buckets can be found here. [Accumulators<sup>13</sup>](#)

### `$bucket` Form

```
{
  $bucket: {
    groupBy: <expression>,
    boundaries: [ <lowerbound1>, <lowerbound2>, ... ],
    default: <literal>,
    output: {
      <output1>: { <$accumulator expression> },
      ...
      <outputN>: { <$accumulator expression> }
    }
  }
}
```

<sup>13</sup> <https://docs.mongodb.com/manual/meta/aggregation-quick-reference/#agg-quick-reference-accumulators>

## \$bucket Exercise

- Using our twitter dataset, let's group users by their tweet/retweet activity
- The bounds should be 0, 100, 500, 2000, 5000, 10000, and 25000
- Produce the following results

```
{ "_id" : 0, "count" : 5036 }
{ "_id" : 100, "count" : 7711 }
{ "_id" : 500, "count" : 12205 }
{ "_id" : 2000, "count" : 9916 }
{ "_id" : 5000, "count" : 7229 }
{ "_id" : 10000, "count" : 6679 }
{ "_id" : 25000, "count" : 2652 }
```

## \$bucketAuto

- Groups documents into buckets much like \$bucket
- Bucket boundaries are determined by MongoDB in an attempt to evenly distribute the data
  - A number series can be specified as an argument to **granularity** for boundary edges.
  - More information about this can be found here. [Granularity and number series<sup>14</sup>](#)

## \$bucketAuto Form

```
{
  $bucketAuto: {
    groupBy: <expression>,
    buckets: <number>,
    output: {
      <output1>: { <$accumulator expression> },
      ...
    }
    granularity: <string>
  }
}
```

<sup>14</sup> <https://docs.mongodb.com/manual/reference/operator/aggregation/bucketAuto/#granularity>

## \$bucketAuto Exercise

- Using our twitter dataset, use \$bucketAuto to group documents into the following result

```
{ "_id" : { "min" : 1, "max" : 342 }, "count" : 10287 }
{ "_id" : { "min" : 342, "max" : 1300 }, "count" : 10293 }
{ "_id" : { "min" : 1300, "max" : 3492 }, "count" : 10287 }
{ "_id" : { "min" : 3492, "max" : 9075 }, "count" : 10286 }
{ "_id" : { "min" : 9075, "max" : 518702 }, "count" : 10275 }
```

## \$facet

- Processes multiple aggregation pipelines within a single stage
- Each sub-pipeline has its own field in the output document
- Input documents are passed to \$facet only once
- Can be used to avoid retrieving input documents multiple times
- Categorize and group incoming documents

## \$facet (cont)

- Has the following form

```
{ $facet:
  {
    <outputField1>: [ <stage1>, <stage2>, ...<stageN>],
    <outputField2>: [ <stage1>, <stage2>, ...<stageN>],
    ...
  }
}
```

## Behavior

- Combined with \$bucket, \$bucketAuto, and \$sortByCount performs a multi-faceted aggregation
- Can't be used with the following:
  - \$facet (Can't have a \$facet within a \$facet)
  - \$out
  - \$geoNear
  - \$indexStats
  - \$collStats

## Behavior (cont)

- Each sub-pipeline receives the exact same set of input documents
- Sub-pipelines are independent of each other
- Output from one sub-pipeline can not be used as input to a different sub-pipeline within the same \$facet

## \$facet Exercise

Using our twitter dataset, output a single document with the following fields:

- **mostActive**: <User with the most user.statuses\_count>
  - name: <user.screen\_name>
  - numTweetsAndRetweets: <user.statuses\_count>
- **leastActive**: <Of users who have at least 1 tweet/retweet, user with the least statuses\_count and lexicographically first screen\_name>
  - name: <user.screen\_name>
  - numTweetsAndRetweets: <user.statuses\_count>

## \$facet Exercise (cont)

- Your aggregation should produce the following results:

```
{  
    "mostActive" : {  
        "name": "currentutc",  
        "numTweetsAndRetweets": 518702  
    },  
    "leastActive" : {  
        "name": "ACunninghamMP",  
        "numTweetsAndRetweets": 1  
    }  
}
```

## Multi-faceted Aggregation Exercise (Optional)

- Using the twitter dataset, determine how many unique users are in both the top ~10% by tweets/retweets and the top ~10% by number of followers

## 5.8 Aggregation - Recap

### Learning Objectives

Upon completing this module students should understand:

- The stages of the aggregation pipeline
- How to use aggregation operators
- Using the same operator in multiple stages of an aggregation pipeline
- The fundamentals of using aggregation for data analysis
- Aggregation on sharded clusters

### Aggregation Stages

- `$match`: Similar to `find()`
- `$project`: Shape documents
- `$sort`: Like the cursor method of the same name
- `$skip`: Like the cursor method of the same name
- `$limit`: Like the cursor method of the same name
- `$unwind`: Used for working with arrays
- `$group`: Used to aggregate field values from multiple documents
- `$lookup`: Performs a left outer join to another collection
- ... (more on next slide)

### Aggregation Stages (continued)

- `$sample`: Randomly selects the specified number of documents from its input.
- `$graphLookup`: Performs a recursive search on a collection
- `$indexStats`: Returns statistics regarding the use of each index for the collection
- `$out`: Creates a new collection from the output of an aggregation pipeline
- `$facet`: Allows multiple independent aggregation stages to happen concurrently
- Even more stages available!

For more information please check the [aggregation framework stages<sup>15</sup>](#) documentation page.

<sup>15</sup> <https://docs.mongodb.com/manual/reference/operator/aggregation/#stage-operators>

## Data Processing Pipelines

- The aggregation framework creates a data processing pipeline.
- For each stage consider:
  - What input that stage will receive
  - What output it should produce.
- Many tasks include more than one stage using a given operator.

## Most Unique User Mentions

- We frequently need multiple \$group stages to achieve our goal.
- We've seen a pipeline to find the tweeter that mentioned the most users.
- Let's change this to examine a tweeter's active network.

## Same Operator, Multiple Stages

Which tweeter has mentioned the most unique users in their tweets?

```
db.tweets.aggregate([
  { $unwind: "$entities.user_mentions" },
  { $group: {
    _id: "$user.screen_name",
    mset: { $addToSet: "$entities.user_mentions.screen_name" } } },
  { $unwind: "$mset" },
  { $group: { _id: "$_id", count: { $sum: 1 } } },
  { $sort: { count: -1 } },
  { $limit: 1 }
])
```

## A Sample Dataset

- Insert the following documents into a collection called sales. We'll be using them for the next few sections.

```
db.sales.insertMany([{"month": "January", "sales": 4712348},
{ "month": "February", "sales": 4109822 },
{ "month": "March", "sales": 5423843 },
{ "month": "April", "sales": 6789314 },
{ "month": "May", "sales": 4824326 },
{ "month": "June", "sales": 3455466 },
{ "month": "July", "sales": 5579351 },
{ "month": "August", "sales": 4973550 },
{ "month": "September", "sales": 5032479 },
{ "month": "October", "sales": 8675309 },
{ "month": "November", "sales": 4265357 },
{ "month": "December", "sales": 5498463 }])
```

## Data Analytics with Aggregation

- Using a combination of operators, it is possible to query and transform our data into useful ways for study and interpretation.
- For example, given sales data for a year, identify the months that over and under performed with some statistical significance.

```
db.sales.aggregate([...])
{ "_id" : ObjectId("58f552fef704abcdc99b737b"), "month" : "April", "sales" : 6789314,
  ↵"outsideVariance" : true }
{ "_id" : ObjectId("58f552fef704abcdc99b737d"), "month" : "June", "sales" : 3455466,
  ↵"outsideVariance" : true }
{ "_id" : ObjectId("58f552fef704abcdc99b7381"), "month" : "October", "sales" : 8675309,
  ↵"outsideVariance" : true }
```

## Aggregation on Sharded Clusters

- Pipelines that begin with an exact \$match on a shard key will run on that shard only
- For operations that must run on multiple shards, grouping and merging will route to a random shard unless they require running on the primary shard. This avoids overloading the primary shard
- The \$out and \$lookup stages require running on the primary shard

# 6 Views

*Views Tutorial (page 112)* Creating and Deleting views

*Lab: Vertical Views (page 114)* Creating a vertical view lab

*Lab: Horizontal Views (page 115)* Creating a horizontal view lab

*Lab: Reshaped Views (page 116)* Creating a reshaped view lab

## 6.1 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

## 6.2 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" : ""  
})
```

## **6.3 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"  
}
```

## **6.4 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 115)

### **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  
        }  
    ]  
}
```

# 7 Introduction to Schema Design

*Schema Design Core Concepts (page 117)* An introduction to schema design in MongoDB

*Schema Evolution (page 124)* Considerations for evolving a MongoDB schema design over an application's lifetime

*Schema Visualization With MongoDB Compass (page 128)* Using Compass to visualize schema

*Document Validation (page 133)* An introduction to document validation in MongoDB

*Lab: Document Validation (page 139)* An exercise on document validation

*Common Schema Design Models (page 142)* Common design models for representing 1-1, 1-M, and M-M relationships and tree structures in MongoDB

## 7.1 Schema Design Core Concepts

### Learning Objectives

Upon completing this module, students should understand:

- Basic schema design principles for MongoDB
- Tradeoffs for embedded documents in a schema
- Tradeoffs for linked documents in a schema
- The use of array fields as part of a schema design

### What is a schema?

- Maps concepts and relationships to data
- Sets expectations for the data
- Minimizes overhead of iterative modifications
- Ensures compatibility

### Example: Normalized Data Model

| User:       | Book:       | Author:     |
|-------------|-------------|-------------|
| - userName  | - title     | - firstName |
| - firstName | - isbn      | - lastName  |
| - lastName  | - language  |             |
|             | - createdBy |             |
|             | - author    |             |

## Example: Denormalized Version

```
User:          Book:  
- userName      - title  
- firstName    - isbn  
- lastName     - language  
               - createdBy  
               - author  
               - firstName  
               - lastName
```

## Schema Design in MongoDB

- Schema is defined at the application-level
- Design is part of each phase in its lifetime
- There is no magic formula

## Four Considerations

- The data your application needs
- Your application's read usage of the data
- Your application's write usage of the data
- Data growth and possible outliers

## Case Study

- A Library Web Application
- Different schemas are possible.

## Author Schema

```
{  "_id": ObjectId,  
  "firstName": string,  
  "lastName": string  
}
```

## User Schema

```
{  "_id": ObjectId,
  "userName": string,
  "password": string
}
```

## Book Schema

```
{  "_id": ObjectId,
  "title": string,
  "slug": string,
  "author": int32,
  "available": boolean,
  "isbn": string,
  "pages": int32,
  "publisher": {
    "city": string,
    "date": date,
    "name": string
  },
  "subjects": [ string, string ],
  "language": string,
  "reviews": [ { "user": ObjectId, "text": string },
               { "user": ObjectId, "text": string } ]
}
```

## Example Documents: Author

```
{  _id: ObjectId(...),
  firstName: "F. Scott",
  lastName: "Fitzgerald"
}
```

## Example Documents: User

```
{ _id: ObjectId(...),
  userName: "emily@mongodb.com",
  password: "slsjfk4odk84k209dlkj90009283d"
}
```

## Example Documents: Book

```
{
  _id: ObjectId(...),
  title: "The Great Gatsby",
  slug: "9781857150193-the-great-gatsby",
  author: 1,
  available: true,
  isbn: "9781857150193",
  pages: 176,
  publisher: {
    name: "Everyman's Library",
    date: ISODate("1991-09-19T00:00:00Z"),
    city: "London"
  },
  subjects: ["Love stories", "1920s", "Jazz Age"],
  language: "English",
  reviews: [
    { user: ObjectId(11AB...), text: "One of the best..." },
    { user: ObjectId(12AB...), text: "It's hard to..." }
  ]
}
```

## Embedded Documents

- AKA sub-documents or embedded objects
- What advantages do they have?
- When should they be used?

## Example: Embedded Documents

```
{
  ...
  publisher: {
    name: "Everyman's Library",
    date: ISODate("1991-09-19T00:00:00Z"),
    city: "London"
  },
  subjects: ["Love stories", "1920s", "Jazz Age"],
  language: "English",
  reviews: [
    { user: ObjectId(11AB...), text: "One of the best..." },
    { user: ObjectId(12AB...), text: "It's hard to..." }
  ]
}
```

## Embedded Documents: Pros and Cons

- Great for read performance
- One seek to find the document
- At most, one sequential read to retrieve from disk
- Writes can be slow if constantly adding to objects

## Linked Documents

- What advantages does this approach have?
- When should they be used?

## Example: Linked Documents

Here all reviews for a given author are kept separately and linked to the author.

```
{  
    ...  
    author: 1,  
    reviews: [  
        { user: ObjectId("11AB..."), text: "One of the best..." },  
        { user: ObjectId("12AB..."), text: "It's hard to..." }  
    ]  
}
```

## Linked Documents: Pros and Cons

- More, smaller documents
- Can make queries by ID very simple
- Accessing linked documents requires extra seeks + reads.
- What effect does this have on the system?

## Arrays

- Array of scalars
- Array of documents

## Array of Scalars

```
{  
  ...  
  subjects: ["Love stories", "1920s", "Jazz Age"],  
}
```

## Array of Documents

```
{  
  ...  
  reviews: [  
    { user: ObjectId("11AB..."), text: "One of the best..." },  
    { user: ObjectId("12AB..."), text: "It's hard to..." }  
  ]  
}
```

## Exercise: Users and Book Reviews

Design a schema for users and their book reviews. UserNames are immutable.

- Users
  - userName (string)
  - email (string)
- Reviews
  - text (string)
  - rating (int32)
  - created\_at (date)

## Solution A: Users and Book Reviews

Reviews may be queried by user or book

```
// db.users (one document per user)  
{  
  _id: ObjectId("..."),  
  userName: "bob",  
  email: "bob@example.com"  
}  
  
// db.reviews (one document per review)  
{  
  _id: ObjectId("..."),  
  user: ObjectId("..."),  
  book: ObjectId("..."),  
  rating: 5,  
  text: "This book is excellent!",  
  created_at: ISODate("2012-10-10T21:14:07.096Z")  
}
```

## Solution B: Users and Book Reviews

Optimized to retrieve reviews by user

```
// db.users, one document per user with all reviews
{
  _id: ObjectId("..."),
  userName: "bob",
  email: "bob@example.com",
  reviews: [
    {
      book: ObjectId("..."),
      rating: 5,
      text: "This book is excellent!",
      created_at: ISODate("2012-10-10T21:14:07.096Z")
    }
  ]
}
```

## Solution C: Users and Book Reviews

Optimized to retrieve reviews by book

```
// db.users (one document per user)
{
  _id: ObjectId("..."),
  userName: "bob",
  email: "bob@example.com"
}

// db.books, one document per book with all reviews
{
  _id: ObjectId("..."),
  // Other book fields...
  reviews: [
    {
      user: ObjectId("..."),
      rating: 5,
      text: "This book is excellent!",
      created_at: ISODate("2014-11-10T21:14:07.096Z")
    }
  ]
}
```

## Store Binary Files in MongoDB with GridFS

- Application may have a requirement for binary file storage
- GridFS is a specification for storing files larger than 16MB in MongoDB
- Handled automatically by most drivers
- “mongofiles” is the command line tool for working with GridFS

## **How GridFS Works**

- Files are split into chunks
- Default chunk size is 255k
- fs.files collection stores meta data for the file (name, size, etc.)
- fs.chunks collection stores chunks for binary file

## **Schema Design Use Cases with GridsFS**

- Store large video files and stream chunks to a user
- Enterprise assets, replicated across data centers
- Medical record attachments (x-rays, reports, etc.)

## **7.2 Schema Evolution**

### **Learning Objectives**

Upon completing this module, students should understand the basic philosophy of evolving a MongoDB schema during an application's lifetime:

- Development Phase
- Production Phase
- Iterative Modifications

### **Development Phase**

Support basic CRUD functionality:

- Inserts for authors and books
- Find authors by name
- Find books by basics of title, subject, etc.

## Development Phase: Known Query Patterns

```
// Find authors by last name.  
db.authors.createIndex({ "lastName": 1 })  
  
// Find books by slug for detail view  
db.books.createIndex({ "slug": 1 })  
  
// Find books by subject (multi-key)  
db.books.createIndex({ "subjects": 1 })  
  
// Find books by publisher (index on embedded doc)  
db.books.createIndex({ "publisher.name": 1 })
```

## Production Phase

Evolve the schema to meet the application's read and write patterns.

### Production Phase: Read Patterns

List books by author last name

```
authors = db.authors.find({ lastName: /^f.*$/i }, { _id: 1 });  
  
authorIds = authors.map(function(x) { return x._id; });  
  
db.books.find({author: { $in: authorIds }});
```

### Addressing List Books by Last Name

“Cache” the author name in an embedded document.

```
{  
  _id: 1,  
  title: "The Great Gatsby",  
  author: {  
    firstName: "F. Scott",  
    lastName: "Fitzgerald"  
  }  
  // Other fields follow...  
}
```

Queries are now one step

```
db.books.find({ "author.firstName": /^f.*$/i })
```

## Production Phase: Write Patterns

Users can review a book.

```
review = {  
    user: 1,  
    text: "I thought this book was great!",  
    rating: 5  
};  
  
db.books.updateOne(  
    { _id: 3 },  
    { $push: { reviews: review } }  
) ;
```

Caveats:

- Document size limit (16MB)
- Storage fragmentation after many updates/deletes

### Exercise: Recent Reviews

- Display the 10 most recent reviews by a user.
- Make efficient use of memory and disk seeks.

### Solution: Recent Reviews, Schema

Store users' reviews in monthly buckets.

```
// db.reviews (one document per user per month)  
{  
    _id: "bob-201412",  
    reviews: [  
        { _id: ObjectId("..."),  
            rating: 5,  
            text: "This book is excellent!",  
            created_at: ISODate("2014-12-10T21:14:07.096Z")  
        },  
        { _id: ObjectId("..."),  
            rating: 2,  
            text: "I didn't really enjoy this book.",  
            created_at: ISODate("2014-12-11T20:12:50.594Z")  
        }  
    ]  
}
```

## Solution: Recent Reviews, Update

Adding a new review to the appropriate bucket

```
myReview = {  
    rating: 3,  
    text: "An average read.",  
    created_at: ISODate("2012-10-13T12:26:11.502Z")  
};  
  
db.reviews.updateOne(  
    { _id: "bob-201210" },  
    { $push: { reviews: myReview } },  
    { upsert: true }  
);
```

## Solution: Recent Reviews, Read

Display the 10 most recent reviews by a user

```
var cursor = db.reviews.find(  
    { _id: /^bob-/ },  
    { reviews: { $slice: -10 } }  
) .sort({ _id: -1 }) .batchSize(5);  
  
num = 0;  
  
while (cursor.hasNext() && num < 10) {  
    doc = cursor.next();  
  
    for (var i = 0; i < doc.reviews.length && num < 10; ++i, ++num) {  
        printjson(doc.reviews[i]);  
    }  
}
```

## Solution: Recent Reviews, Delete

Deleting a review

```
db.reviews.updateOne(  
    { _id: "bob-201210" },  
    { $pull: { reviews: { _id: ObjectId("...") } } }  
) ;
```

## 7.3 Schema Visualization With MongoDB Compass

### Learning Objectives

Upon completing this module, students should understand:

- How to use MongoDB Compass to explore and visualize schema
- Point and click queries
- GeoJSON queries
- How to use MongoDB Compass to update a document

### Using MongoDB Compass to Visualize Schema

- Schema tab shows an overview of document schema, to include types
- Based on a `$sample`<sup>16</sup> of the overall collection, up to 1000 documents
- Fields can be clicked for interactive query and further visualization

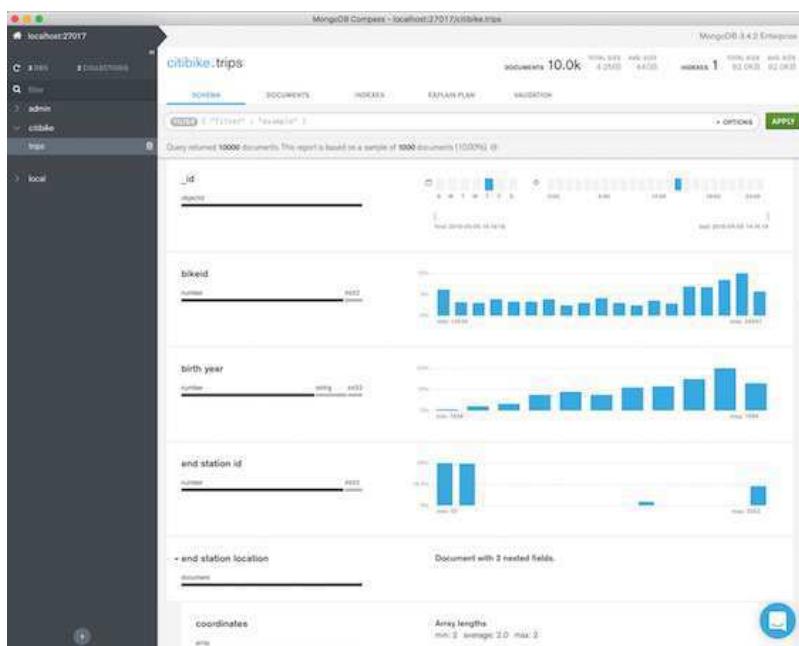
### Lesson Setup

- Import the `trips.json` collection to a running mongod

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

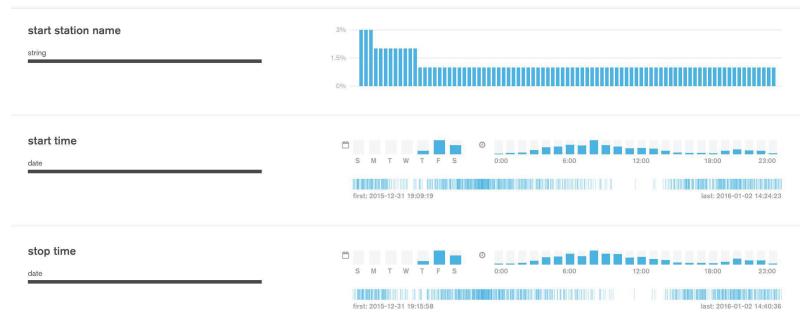
- Connect to your mongod with MongoDB Compass and select the trips collection

### Schema Visualization

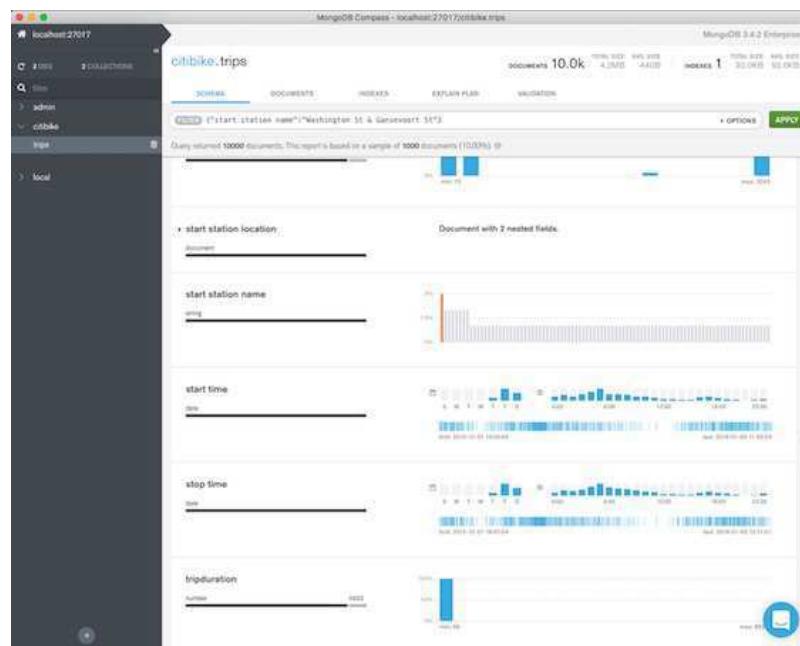


<sup>16</sup> <https://docs.mongodb.com/manual/reference/operator/aggregation/sample/>

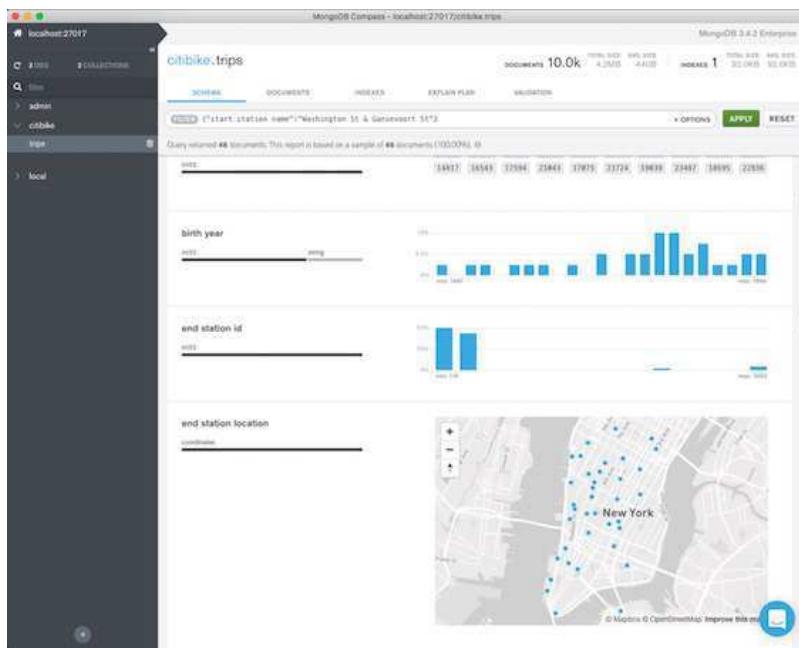
## Schema Visualization Detail



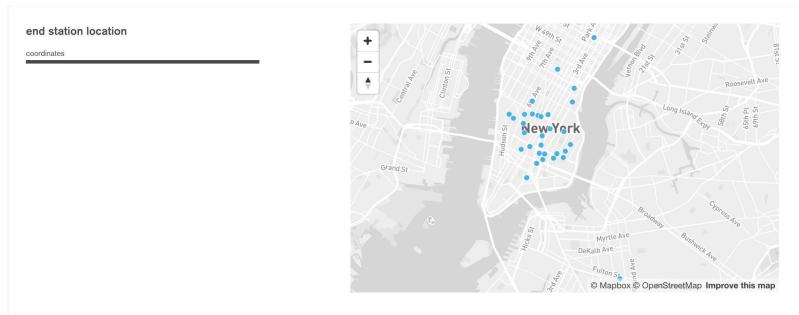
## MongoDB Compass Interactive Queries



## Visualizing GeoJSON



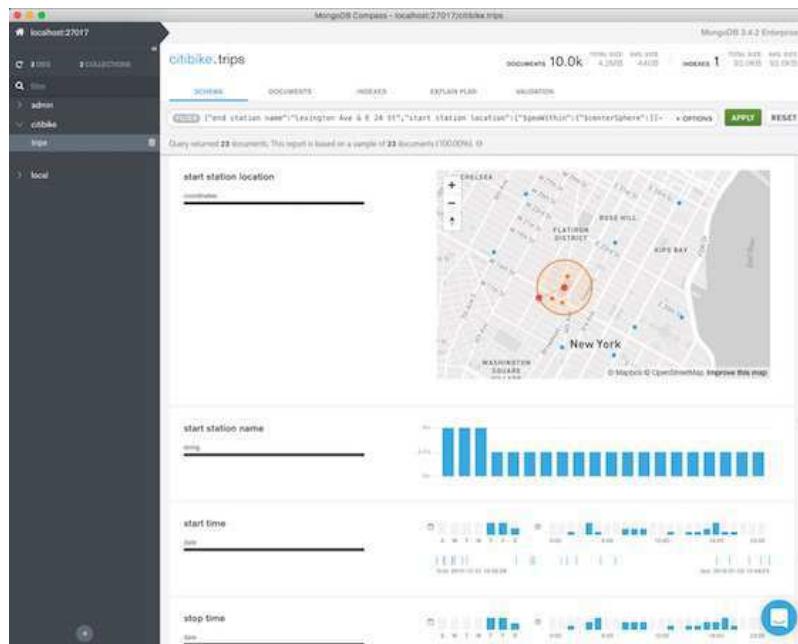
## Visualizing GeoJSON Detail



## Interactively Build a GeoJSON query

- Select the “start station location” visualizer
- Pan the map around and find a location that interests you
- If you are unfamiliar with New York and Manhattan, pan down to Battery Park on the furthest most southwest tip of Manhattan
- Center your mouse in your area of interest, hold shift, click and drag outwards
- You will see an orange circle appear, and the filter/query bar being updated to include a \$geoWithin query
- When you are satisfied, click apply to see the results

## GeoJSON Query Results



## Documents Explorer

- After executing your query, navigate to the `documents` tab
- Mouse over one of the documents
- In the upper right corner of the results window you'll see a toolbar
- This allows us to expand, edit, delete, or clone the document with a single click
- Click the pencil icon

## Documents Explorer Example

The screenshot shows the MongoDB Compass interface with the database 'citibike' selected. The 'trips' collection is open. The 'DOCUMENTS' tab is active, displaying four documents. Each document is a trip record with fields like 'start station name', 'end station name', and 'start station location'. The interface includes a search bar at the top, a toolbar with 'APPLY' and 'RESET' buttons, and a 'REFRESH' button.

```
_id: ObjectId("572f94222222222222222222")
tripduration: 242
start station id: 120
start station name: "Brooklyn Ave & 34 St"
end station id: 121
end station name: "Lexington Ave & E 24 St"
bikeid: 10016
usertype: "Customer"
birth year: 1989
gender: 1
start station location: Object
end station location: Object
start time: 2013-01-21 13:31:09.000
stop time: 2013-01-21 13:33:11.000

_id: ObjectId("572f94222222222222222223")
tripduration: 242
start station id: 122
start station name: "University Pl & E 14 St"
end station id: 123
end station name: "Lexington Ave & E 24 St"
bikeid: 20016
usertype: "Customer"
birth year: 1989
gender: 1
start station location: Object
end station location: Object
start time: 2013-01-21 04:31:07.000
stop time: 2013-01-21 04:33:07.000

_id: ObjectId("572f94222222222222222224")
tripduration: 242
start station id: 123
start station name: "E 27 St & Brooklyn"
end station id: 124
end station name: "Lexington Ave & E 24 St"
bikeid: 30016
usertype: "Customer"
birth year: 1989
gender: 1
start station location: Object
end station location: Object
start time: 2013-01-21 04:31:07.000
stop time: 2013-01-21 04:33:07.000

_id: ObjectId("572f94222222222222222225")
tripduration: 242
start station id: 124
start station name: "Lexington Ave & E 24 St"
end station id: 125
end station name: "University Pl & E 14 St"
bikeid: 40016
usertype: "Customer"
birth year: 1989
gender: 1
start station location: Object
end station location: Object
start time: 2013-01-21 13:31:09.000
stop time: 2013-01-21 13:33:11.000
```

## Updating a Document

This screenshot shows the same MongoDB Compass interface as the previous one, but with an update operation in progress. A modal dialog is open over the document list, showing the current state of the document and the update operation details. The 'UPDATE' button is visible at the bottom of the dialog.

```
_id: ObjectId("572f94222222222222222222")
tripduration: 242
start station id: 120
start station name: "Brooklyn Ave & 34 St"
end station id: 121
end station name: "Lexington Ave & E 24 St"
bikeid: 10016
usertype: "Customer"
birth year: 1989
gender: 1
start station location: Object
end station location: Object
start time: 2013-01-21 13:31:09.000
stop time: 2013-01-21 13:33:11.000

_id: ObjectId("572f94222222222222222223")
tripduration: 242
start station id: 122
start station name: "University Pl & E 14 St"
end station id: 123
end station name: "Lexington Ave & E 24 St"
bikeid: 20016
usertype: "Customer"
birth year: 1989
gender: 1
start station location: Object
end station location: Object
start time: 2013-01-21 04:31:07.000
stop time: 2013-01-21 04:33:07.000

_id: ObjectId("572f94222222222222222224")
tripduration: 242
start station id: 123
start station name: "E 27 St & Brooklyn"
end station id: 124
end station name: "Lexington Ave & E 24 St"
bikeid: 30016
usertype: "Customer"
birth year: 1989
gender: 1
start station location: Object
end station location: Object
start time: 2013-01-21 04:31:07.000
stop time: 2013-01-21 04:33:07.000

_id: ObjectId("572f94222222222222222225")
tripduration: 242
start station id: 124
start station name: "Lexington Ave & E 24 St"
end station id: 125
end station name: "University Pl & E 14 St"
bikeid: 40016
usertype: "Customer"
birth year: 1989
gender: 1
start station location: Object
end station location: Object
start time: 2013-01-21 13:31:09.000
stop time: 2013-01-21 13:33:11.000
```

## Updating Detail

- Document update allows many things, including:
  - Adding or deleting fields
  - Changing the value of fields
  - Changing the type of fields, for example from *Int32* to *Int64* or *Decimal128*

## 7.4 Document Validation

### Learning Objectives

Upon completing this module, students should be able to:

- Define the different types of document validation
- Distinguish use cases for document validation
- Create, discover, and bypass document validation in a collection
- List the restrictions on document validation

New in version 3.6.

- JSON Schema document validation support
- Strict Document validation with JSON Schema

### Introduction

- Prevents or warns when the following occurs:
  - Inserts/updates that result in documents that don't match a schema
- Prevents or warns when inserts/updates do not match schema constraints
- Can be implemented for a new or existing collection
- Can be bypassed, if necessary

### Example

```
db.createCollection( "products",
{
    validator: {
        price : { $exists : true }
    },
    validationAction: "error"
})
```

## Why Document Validation?

Consider the following use case:

- Several applications write to your data store
- Individual applications may validate their data
- You need to ensure validation across all clients

## Why Document Validation? (Continued)

Another use case:

- You have changed your schema in order to improve performance
- You want to ensure that any write will also map the old schema to the new schema
- Document validation is a simple way of enforcing the new schema after migrating
  - You will still want to enforce this with the application
  - Document validation gives you another layer of protection

## Anti-Patterns

- Using document validation at the database level without writing it into your application
  - This would result in unexpected behavior in your application
- Allowing uncaught exceptions from the DB to leak into the end user's view
  - Catch it and give them a message they can parse

### **validationAction and validationLevel**

- Two settings control how document validation functions
- validationLevel – determines how strictly MongoDB applies validation rules
- validationAction – determines whether MongoDB should error or warn on invalid documents

## Details

|                  |       | validationLevel |                                                                                                                    |                                                                                      |
|------------------|-------|-----------------|--------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
|                  |       | off             | moderate                                                                                                           | strict                                                                               |
| validationAction | warn  | No checks       | Warn on validation failure for inserts & updates to existing valid documents. Updates to existing invalid docs OK. | Warn on any validation failure for any insert or update.                             |
|                  | error | No checks       | Reject invalid inserts & updates to existing valid documents. Updates to existing invalid docs OK.                 | Reject any violation of validation rules for any insert or update.<br><b>DEFAULT</b> |

### **validationLevel: “strict”**

- Useful when:
  - Creating a new collection
  - Validating writes to an existing collection already in compliance
  - Insert only workloads
  - Changing schema and updates should map documents to the new schema
- This will impose validation on update even to invalid documents

### **validationLevel: “moderate”**

- Useful when:
  - Changing a schema and you have not migrated fully
  - Changing schema but the application can't map the old schema to the new in just one update
  - Changing a schema for new documents but leaving old documents with the old schema

### **validationAction: “error”**

- Useful when:
  - Your application will no longer support invalid documents
  - Not all applications can be trusted to write valid documents
  - Invalid documents create regulatory compliance problems

### **validationAction: "warn"**

- Useful when:
  - You need to receive all writes
  - Your application can handle multiple versions of the schema
  - Tracking schema-related issues is important
    - \* For example, if you think your application is probably inserting compliant documents, but you want to be sure

## **Creating a Collection with Document Validation**

```
db.createCollection( "products",
{
    validator: {
        price: { $exists: true }
    },
    validationAction: "error"
}
)
```

## **Seeing the Results of Validation**

To see what the validation rules are for all collections in a database:

```
db.getCollectionInfos()
```

And you can see the results when you try to insert:

```
db.products.insertOne( { price: 25, currency: "USD" } )
```

## **Adding Validation to an Existing Collection**

```
db.products.drop()
db.products.insertOne( { name: "watch", price: 10000, currency: "USD" } )
db.products.insertOne( { name: "happiness" } )
db.runCommand( {
    collMod: "products",
    validator: {
        price: { $exists: true }
    },
    validationAction: "error",
    validationLevel: "moderate"
} )
db.products.updateOne( { name : "happiness" }, { $set : { note: "Priceless." } } )
db.products.updateOne( { name : "watch" }, { $unset : { price : 1 } } )
db.products.insertOne( { name : "inner peace" } )
```

## Bypassing Document Validation

- You can bypass document validation using the `bypassDocumentValidation` option
  - On a per-operation basis
  - Might be useful when:
    - \* Restoring a backup
    - \* Re-inserting an accidentally deleted document
- For deployments with access control enabled, this is subject to user roles restrictions
- See the MongoDB server documentation for details

## Limits of Document Validation

- Document validation is not permitted for the following databases:
  - admin
  - local
  - config
- You cannot specify a validator for `system.*` collections

## Document Validation and Performance

- Validation adds an expression-matching evaluation to every insert and update
- Performance load depends on the complexity of the validation document
  - Many workloads will see negligible differences

## JSON Schema Document Validation

Using the `$jsonSchema` query operator enables the usage of JSON Schema<sup>17</sup> expressions to match documents in MongoDB.

This enables the definition of document validation rules using such format.

```
db.createCollection( "products", {  
    validator: {  
        $jsonSchema : {  
            bsonType: "object"  
            properties: {  
                price: {  
                    bsonType: "decimal",  
                    description: "must be a double value"  
                } } } }  
})
```

<sup>17</sup> <http://json-schema.org/>

## JSON Schema Support

MongoDB supports the [draft 4<sup>18</sup>](#) of JSON Schema, including core and validation specifications.

However, there are a few omissions and extensions that MongoDB implements for compatibility with the MongoDB query language and native operators.

## JSON Schema Omissions

JSON Schema operators not supported by MongoDB:

- Hypertext definitions
- Keywords
  - \$ref
  - \$schema
  - default
  - definitions
  - information
  - id
- Hypermedia and linking properties of JSON Schema
  - JSON References & JSON Pointers

## JSON Schema Extensions and Types

JSON `integer` is not supported and should be set to BSON type `int` or `long`.

BSON has more and richer integer types than JSON.

Extensions to JSON Schema:

- `bsonType`: accepts the same string aliases used with the `$type` MongoDB query operator.

## JSON Schema Strict Validation

The support of JSON Schema allows strict document validation:

```
Full definition of all possible fields a document can contain
```

This can be achieved by specifying the `required` keyword in the JSON Schema validation object:

```
db.createCollection( "products", {  
    validator: {  
        $jsonSchema : {  
            bsonType: "object",  
            required: [ "price", "sku", "name" ]  
        }  
    }  
})
```

<sup>18</sup> <https://tools.ietf.org/html/draft-zyp-json-schema-04>

## Quiz

What are the validation levels available and what are the differences?

## Quiz

What command do you use to determine what the validation rule is for the *things* collection?

## Quiz

On which three databases is document validation not permitted?

## 7.5 Lab: Document Validation

### Exercise: Add validator to existing collection

- Import the `posts` collection (from `posts.json`) and look at a few documents to understand the schema.
- Insert the following document into the `posts` collection

```
{"Hi": "I'm not really a post, am I?"}
```

- Discuss: what are some restrictions on documents that a validator could and should enforce?
- Add a validator to the `posts` collection that enforces those restrictions
- Remove the previously inserted document and try inserting it again and see what happens

### Exercise: Create collection with validator

Create a collection `employees` with a validator that enforces the following restrictions on documents:

- The `name` field must exist and be a string
- The `salary` field must exist and be between 0 and 10,000 inclusive.
- The `email` field is optional but must be an email address in a valid format if present.
- The `phone` field is optional but must be a phone number in a valid format if present.
- At least one of the `email` and `phone` fields must be present.

### Exercise: Create collection with validator (expected results)

```
// Valid documents
{"name": "Jane Smith", "salary": 45, "email": "js@example.com"}
{"name": "Tim R. Jones", "salary": 30,
 "phone": "234-555-6789", "email": "trj@example.com"}
 {"name": "Cedric E. Oxford", "salary": 600, "phone": "918-555-1234"}

// Invalid documents
 {"name": "Connor MacLeod", "salary": 9001, "phone": "999-555-9999",
 "email": "thrcnbnly1"}
 {"name": "Herman Hermit", "salary": 9}
 {"name": "Betsy Bedford", "salary": 50, "phone": "", "email": "bb@example.com"}
```

### Exercise: Change validator rules

Modify the validator for the employees collection to support the following additional restrictions:

- The `status` field must exist and must only be one of the following strings: “active”, “on\_vacation”, “terminated”
- The `locked` field must exist and be a boolean

### Exercise: Change validator rules (expected results)

```
// Valid documents
 {"name": "Jason Serivas", "salary": 65, "email": "js@example.com",
 "status": "terminated", "locked": true}
 {"name": "Logan Drizt", "salary": 39,
 "phone": "234-555-6789", "email": "ld@example.com", "status": "active",
 "locked": false}
 {"name": "Mann Edger", "salary": 100, "phone": "918-555-1234",
 "status": "on_vacation", "locked": false}

// Invalid documents
 {"name": "Steven Cha", "salary": 15, "email": "sc@example.com", "status": "alive"
 ↵,
 "locked": false}
 {"name": "Julian Barriman", "salary": 15, "email": "jb@example.com",
 "status": "on_vacation", "locked": "no"}
```

### **Exercise: Change validation level**

Now that the `employees` validator has been updated, some of the already-inserted documents are not valid. This can be a problem when, for example, just updating an employee's salary.

- Try to update the salary of "Cedric E. Oxford". You should get a validation error.
- Now, change the validation level of the `employees` collection to allow updates of existing invalid documents, but still enforce validation of inserted documents and existing valid documents.

### **Exercise: Use Compass to Create and Change validation rules**

Now that we've explored document validation in the Mongo shell, let's explore how easy it is to do with MongoDB Compass.

- Click below for an overview of MongoDB Compass.

/modules/compass

- Connect to your local database with Compass
- Open the `employees` collection, and view the validation rules.

### **Exercise: Compass Validation (continued)**

- From a Mongo shell, create a new collection called `employees_v2`
- Implement the initial validation rules for the `employees` collection on `employees_v2` using Compass
  - Ensure you select "strict" as the validation level, and "error" as the validation action
  - Try inserting some documents either through Compass or the shell to confirm your validation is working.

### **Exercise: Bypass validation**

In some circumstances, it may be desirable to bypass validation to insert or update documents.

- Use the `bypassDocumentValidation` option to insert the document `{"hi": "there"}` into the `employees` collection
- Use the `bypassDocumentValidation` option to give all employees a salary of 999999.

### **Exercise: Change validation action**

In some cases, it may be desirable to simply log invalid actions, rather than prevent them.

- Change the validation action of the `employees` collection to reflect this behavior

## **7.6 Common Schema Design Models**

### **Learning Objectives**

Upon completing this module students should understand common design for modeling:

- One-to-One Relationships
- One-to-Many Relationships
- Many-to-Many Relationships
- Tree Structures

### **One-to-One Relationship**

Let's pretend that authors only write one book.

#### **One-to-One: Linking**

Either side, or both, can track the relationship.

```
db.books.findOne()
{
  _id: 1,
  title: "The Great Gatsby",
  slug: "9781857150193-the-great-gatsby",
  author: 1,
  // Other fields follow...
}

db.authors.findOne({ _id: 1 })
{
  _id: 1,
  firstName: "F. Scott",
  lastName: "Fitzgerald"
  book: 1,
}
```

## One-to-One: Embedding

```
db.books.findOne()
{
  _id: 1,
  title: "The Great Gatsby",
  slug: "9781857150193-the-great-gatsby",
  author: {
    firstName: "F. Scott",
    lastName: "Fitzgerald"
  }
  // Other fields follow...
}
```

## One-to-Many Relationship

In reality, authors may write multiple books.

### One-to-Many: Array of IDs

The “one” side tracks the relationship.

- Flexible and space-efficient
- Additional query needed for non-ID lookups

```
db.authors.findOne()
{
  _id: 1,
  firstName: "F. Scott",
  lastName: "Fitzgerald",
  books: [1, 3, 20]
}
```

### One-to-Many: Single Field with ID

The “many” side tracks the relationship.

```
db.books.find({ author: 1 })
{
  _id: 1,
  title: "The Great Gatsby",
  slug: "9781857150193-the-great-gatsby",
  author: 1,
  // Other fields follow...
}

{
  _id: 3,
  title: "This Side of Paradise",
  slug: "9780679447238-this-side-of-paradise",
  author: 1,
  // Other fields follow...
}
```

## One-to-Many: Array of Documents

```
db.authors.findOne()
{
  _id: 1,
  firstName: "F. Scott",
  lastName: "Fitzgerald",
  books: [
    { _id: 1, title: "The Great Gatsby" },
    { _id: 3, title: "This Side of Paradise" }
  ]
  // Other fields follow...
}
```

## Many-to-Many Relationship

Some books may also have co-authors.

## Many-to-Many: Array of IDs on Both Sides

```
db.books.findOne()
{
  _id: 1,
  title: "The Great Gatsby",
  authors: [1, 5]
  // Other fields follow...
}

db.authors.findOne()
{
  _id: 1,
  firstName: "F. Scott",
  lastName: "Fitzgerald",
  books: [1, 3, 20]
}
```

## Many-to-Many: Array of IDs on Both Sides

Query for all books by a given author.

```
db.books.find({ authors: 1 });
```

Query for all authors of a given book.

```
db.authors.find({ books: 1 });
```

## Many-to-Many: Array of IDs on One Side

```
db.books.findOne()
{
  _id: 1,
  title: "The Great Gatsby",
  authors: [1, 5]
  // Other fields follow...
}

db.authors.find({ _id: { $in: [1, 5] } })
{
  _id: 1,
  firstName: "F. Scott",
  lastName: "Fitzgerald"
}
{
  _id: 5,
  firstName: "Unknown",
  lastName: "Co-author"
}
```

## Many-to-Many: Array of IDs on One Side

Query for all books by a given author.

```
db.books.find({ authors: 1 });
```

Query for all authors of a given book.

```
book = db.books.findOne(
  { title: "The Great Gatsby" },
  { authors: 1 }
);

db.authors.find({ _id: { $in: book.authors } });
```

## Tree Structures

E.g., modeling a subject hierarchy.

### Allow users to browse by subject

```
db.subjects.findOne()
{
  _id: 1,
  name: "American Literature",
  sub_category: {
    name: "1920s",
    sub_category: { name: "Jazz Age" }
  }
}
```

- How can you search this collection?
- Be aware of document size limitations
- Benefit from hierarchy being in same document

### Alternative: Parents and Ancestors

```
db.subjects.find()
{ _id: "American Literature" }

{ _id : "1920s",
  ancestors: ["American Literature"],
  parent: "American Literature"
}

{ _id: "Jazz Age",
  ancestors: ["American Literature", "1920s"],
  parent: "1920s"
}

{ _id: "Jazz Age in New York",
  ancestors: ["American Literature", "1920s", "Jazz Age"],
  parent: "Jazz Age"
}
```

## Find Sub-Categories

```
db.subjects.find({ ancestors: "1920s" })
{
  _id: "Jazz Age",
  ancestors: ["American Literature", "1920s"],
  parent: "1920s"
}

{
  _id: "Jazz Age in New York",
  ancestors: ["American Literature", "1920s", "Jazz Age"],
  parent: "Jazz Age"
}
```

## Summary

- Schema design is different in MongoDB.
- Basic data design principles apply.
- It's about your application.
- It's about your data and how it's used.
- It's about the entire lifetime of your application.

# 8 Replica Sets

*Introduction to Replica Sets (page 148)* An introduction to replication and replica sets

*Elections in Replica Sets (page 151)* The process of electing a new primary (automated failover) in replica sets

*Replica Set Roles and Configuration (page 156)* Configuring replica set members for common use cases

*The Oplog: Statement Based Replication (page 157)* The process of replicating data from one node of a replica set to another

*Lab: Working with the Oplog (page 159)* A brief lab that illustrates how the oplog works

*Write Concern (page 161)* Balancing performance and durability of writes

*Read Concern (page 166)* Settings to minimize/prevent stale and dirty reads

*Read Preference (page 174)* Configuring clients to read from specific members of a replica set

*Lab: Setting up a Replica Set (page 175)* Launching members, configuring, and initiating a replica set

## 8.1 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**

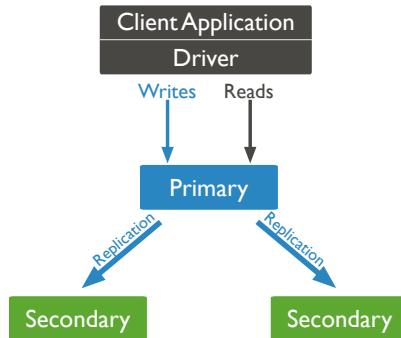
Functional segregation can be further exploited by using large replica sets.

- 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



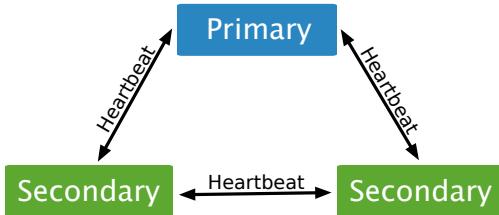
## Primary Server

- 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  $\geq 3.4$ , all indexes are built while data is copied
- As of MongoDB  $\geq 3.4$ , initial sync is more resilient to intermittent network failure/degradation

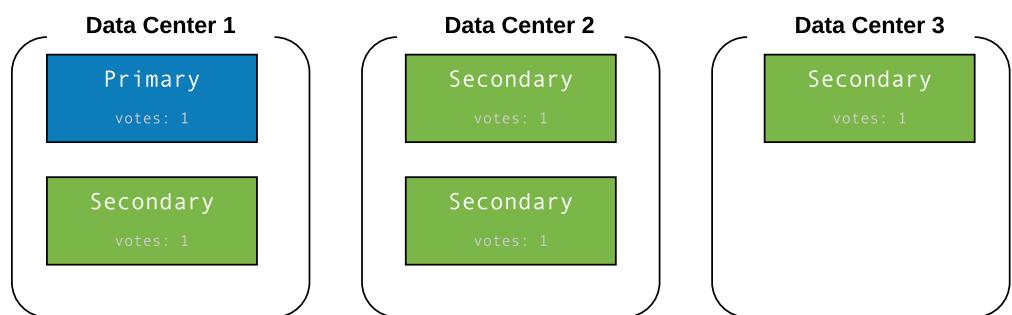
## 8.2 Elections in Replica Sets

### Learning Objectives

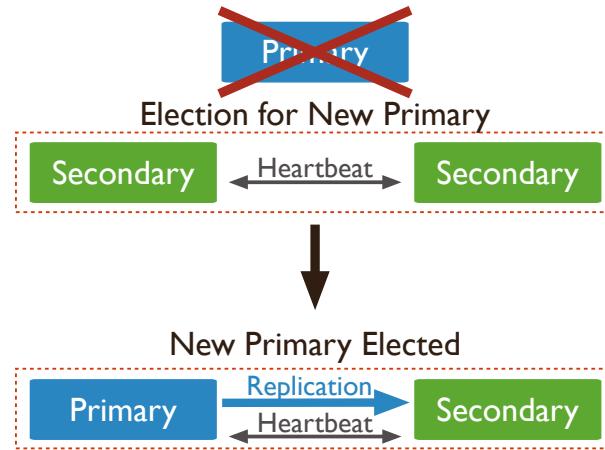
Upon completing this module students should understand:

- 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 three factors
  - Optime
  - Connections
  - Priority

## Priority

- The default priority is 1.
- With PV1 elections will favour an up to date node to become primary over a node with a higher priority.
- Priority is not given as much precedence since the introduction of Protocol Version 1 (PV1)
- **If a lower priority node is up to date, it can win an election, however, if a higher priority node is up to date, it will call for an election after the first election completes.**
- 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 optimizes 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**

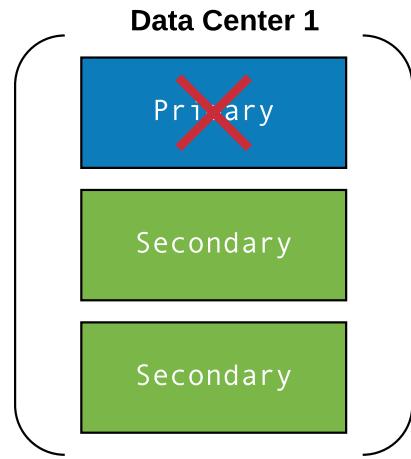
- Primary will attempt to terminate long running operations before stepping down.
- Primary will wait for electable secondary to catch up before stepping down.
- “`secondaryCatchUpPeriodSecs`” can be specified to limit the amount of time the primary will wait for a secondary to catch up before the primary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

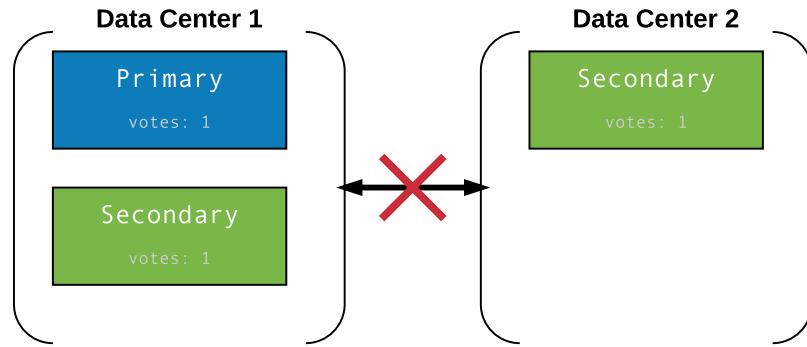
### **Scenario A: 3 Data Nodes in 1 DC**

Which secondary will become the new primary?



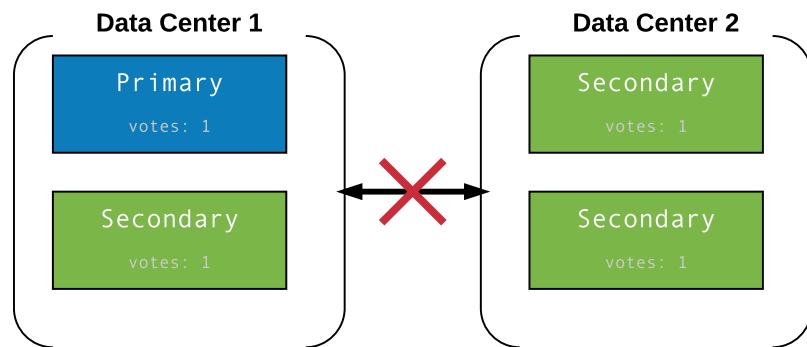
### Scenario B: 3 Data Nodes in 2 DCs

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



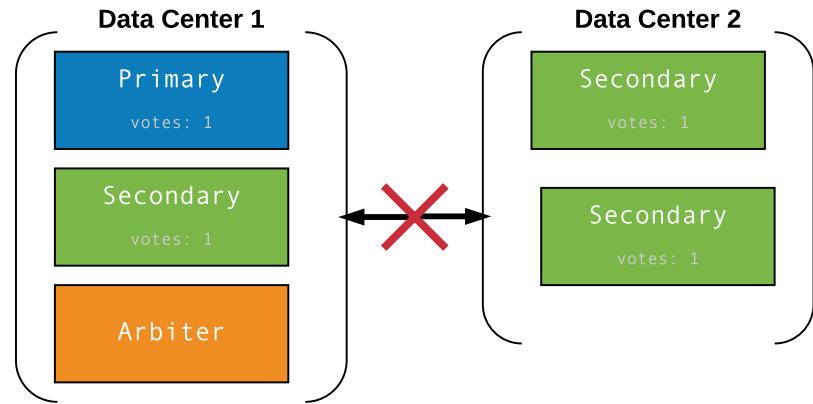
### Scenario C: 4 Data Nodes in 2 DCs

What happens following this network partition?



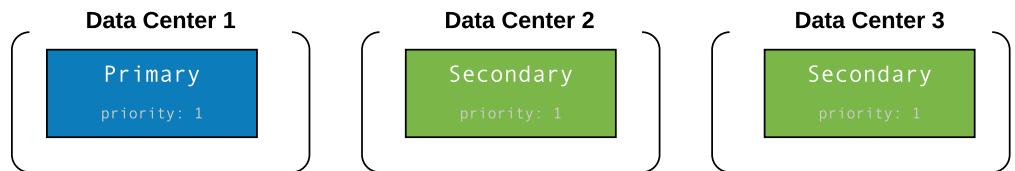
### Scenario D: 5 Nodes in 2 DCs

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



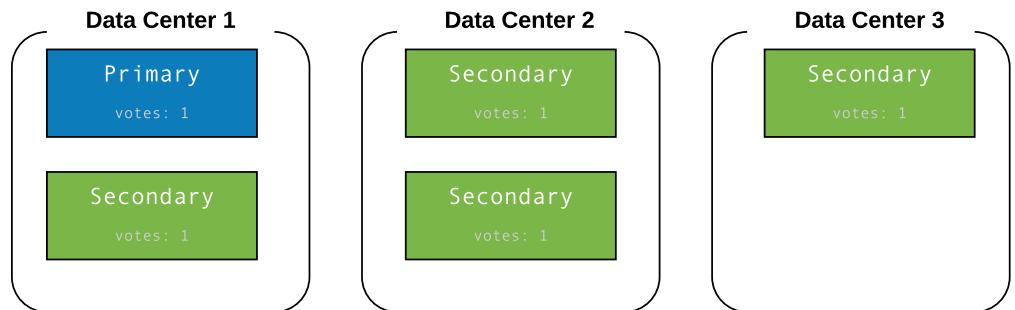
### Scenario E: 3 Data Nodes in 3 DCs

- 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?



## 8.3 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,
      priority : 0 },
    { _id : 4, host : "dc2-2.example.net:27017", hidden : true,
      priority : 0, 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, priority : 0 },  
{ _id : 4, host : "dc2-2.example.net:27017", hidden : true, priority : 0,  
  slaveDelay: 7200 }
```

### What about dc2-2?

```
{ _id : 4, host : "dc2-2.example.net:27017", hidden : true,  
  priority : 0, slaveDelay : 7200 }
```

## 8.4 The Oolog: 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 Oolog are Idempotent

- Each operation in the oolog 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 Oolog Window

- Ologs 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 Oolog

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

## 8.5 Lab: Working with the Oolog

### 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 } } }
```

## 8.6 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`.

## **rollbackTimeLimitSecs**

New in version 4.0.

- This `mongod` parameter is configured in seconds, which refers to the gap, in optime, since the last common point between the node and the primary.
- All `mongod` in a replica set should share the same configuration for this parameter.
- The default is 86400 (1 day).

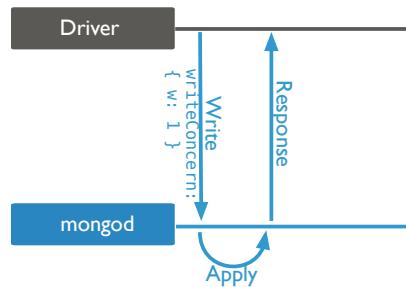
## **Balancing Durability with Performance**

- 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.

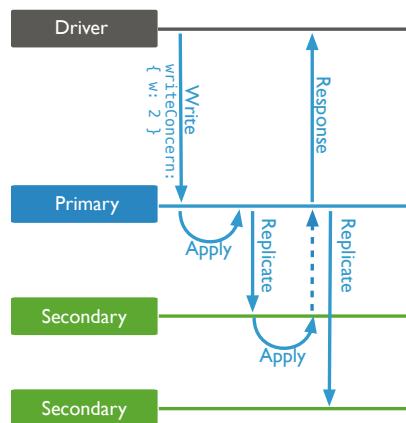
### Write Concern: { w : 1 }



### 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 writeConcern-MajorityJournalDefault<sup>19</sup>
- 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 of acknowledged writes to the application.

### 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 time 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" }

<sup>19</sup> <http://docs.mongodb.org/manual/reference/replica-configuration/#rsconf.writeConcernMajorityJournalDefault>

## Further Reading

See [Write Concern Reference<sup>20</sup>](#) for more details on write concern configurations, including setting timeouts and identifying specific replica set members that must acknowledge writes (i.e. [tag sets<sup>21</sup>](#)).

---

<sup>20</sup> <http://docs.mongodb.org/manual/reference/write-concern>

<sup>21</sup> <http://docs.mongodb.org/manual/tutorial/configure-replica-set-tag-sets/#replica-set-configuration-tag-sets>

## 8.7 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*
- **Available:** Added in MongoDB 3.6
- **Majority:** Added in MongoDB 3.2, requires WiredTiger and 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.

#### Available

New in version 3.6.

- Provides the lowest latency data available in the node
- No guarantees in data has been replicated to a majority of nodes in the set
- For sharded collections, `available` can return incorrect results!
  - Potentially including orphan documents
  - In unsharded collections, `available` and `local` have the same behavior

## 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
  - you can disable majority read concern by setting `--enableMajorityReadConcern` to false.
- Under certain circumstances (high volume, flaky network), can result in stale reads.

## Linearizable

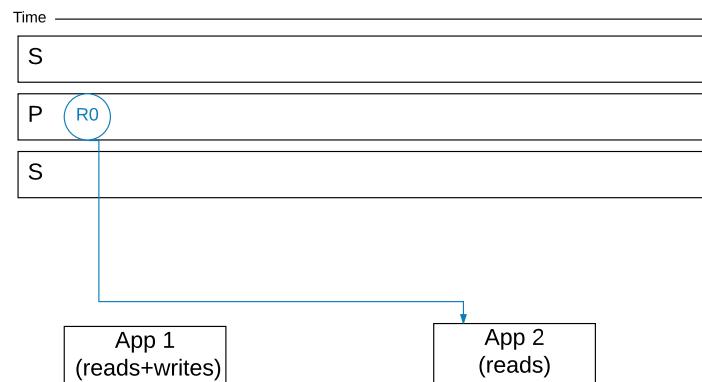
New in version 3.4.

- Will read latest data acknowledged with `w : majority`, or block until replica set acknowledges a write in progress with `w : 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

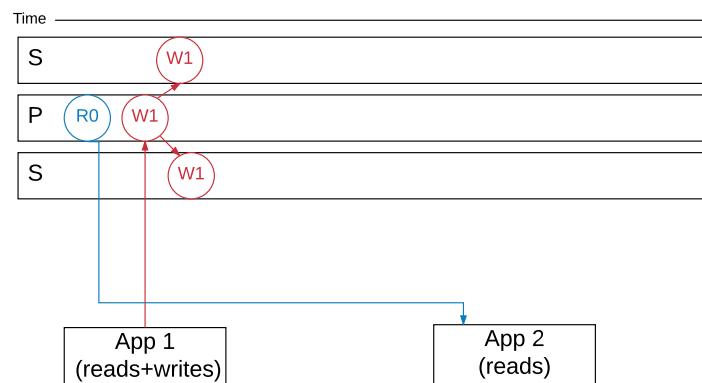
## Example: Read Concern Level Majority

*App1* is doing writes to a document with `w : "majority"`

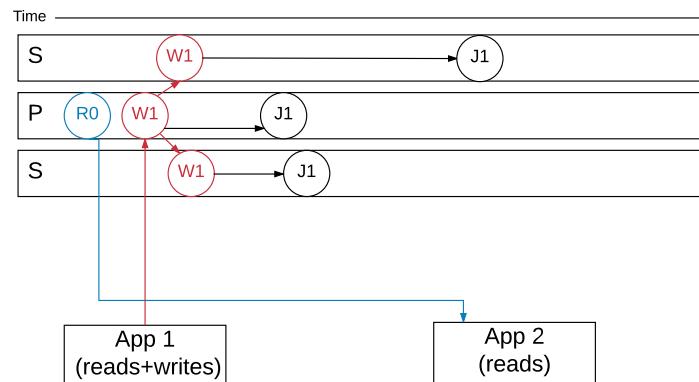
*App2* is reading the same document with **read concern level: "majority"**



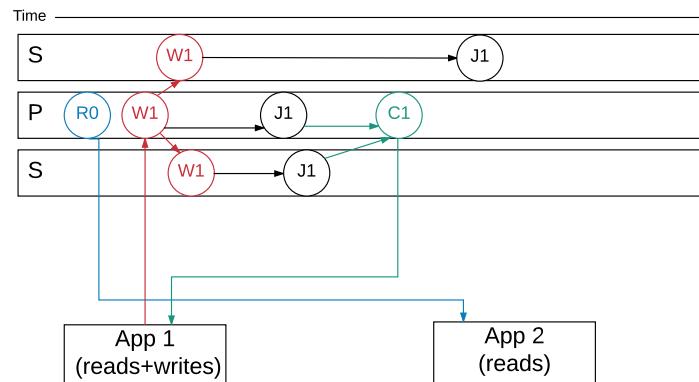
A new version of the document (W1) is written by *App1*, and the write is propagated to the secondaries



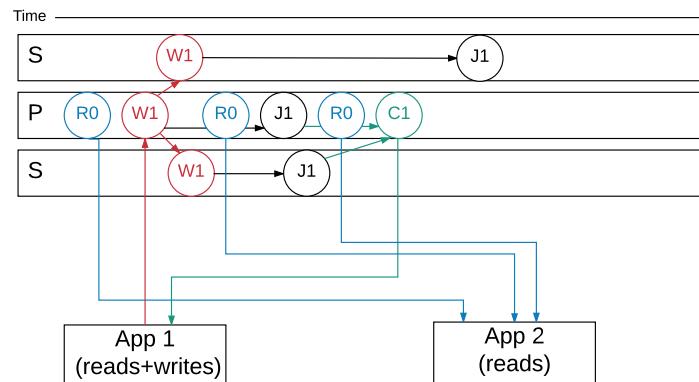
The *write*, also needs to be *journalized* (J1) on each secondary



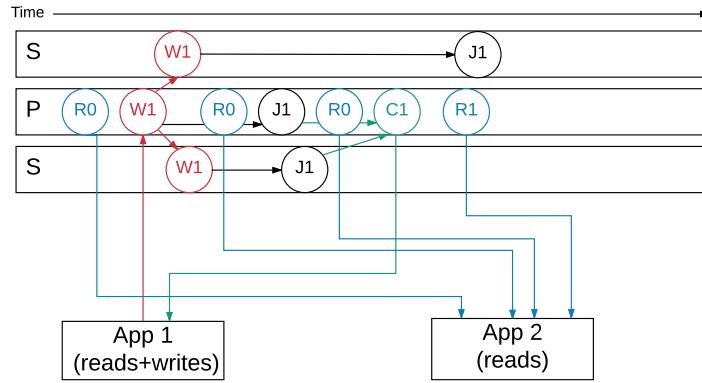
Once the write is journalized on a majority of nodes, *App1* will get a confirmation of the commit on a majority (C1) of nodes.



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
- 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?

## Read Concern Snapshot

New in version 4.0.

- Read Concern Snapshot is only available for transactions.
- The Read Concern for a transaction is set at transaction level, any read concern set at the collection and database level is ignored inside the transaction.
- Read Concern Snapshot enables you to ensure that all reads in a transaction are from the same point in time, isolating your reads from other writes.
- It also you perform repeatable reads which are guaranteed to be consistent with that point in time.

## **Non-Blocking Reads**

New in version 4.0.

- With replication, oplog is applied in batches on secondaries.
- Prior to 4.0, we used to block readers to allow oplog to be applied.
- This ensures that readers would not ever return data that is not in the same causal order as data on the primary.

## **Non-Blocking Reads cont.**

- With WiredTiger timestamps and transactions, we can now read from a consistent snapshot of a point in time of the database without having to block readers on secondaries to allow oplog to be applied.
- This feature is on by default and does not need to be activated on the mongod.

## **Replication Protocol Version 1**

New in version 3.2.

- PV1 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](#)<sup>22</sup> for more details on read concerns.

---

<sup>22</sup> <http://docs.mongodb.org/manual/reference/read-concern>

## 8.8 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<sup>23</sup> 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.

---

<sup>23</sup> <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)
```

## 8.9 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<sup>24</sup>](#)
- [Replica States<sup>25</sup>](#)

<sup>24</sup> <http://docs.mongodb.org/manual/reference/replica-configuration/>

<sup>25</sup> <http://docs.mongodb.org/manual/reference/replica-states/>

# 9 Sharding

*Introduction to Sharding (page 179)* An introduction to sharding

*Balancing Shards (page 186)* Chunks, the balancer, and their role in a sharded cluster

*Shard Zones (page 189)* How zone-based sharding works

*Lab: Setting Up a Sharded Cluster (page 190)* Deploying a sharded cluster

## 9.1 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.

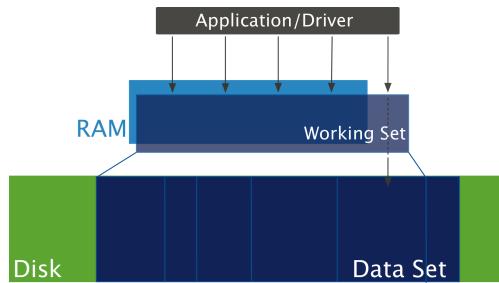
### Sharding is Concerned with Scale

- 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.

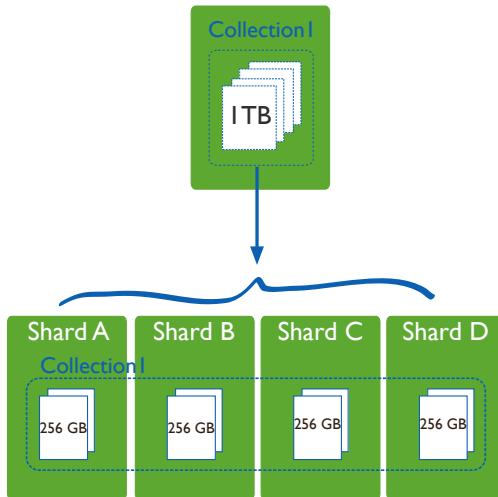
## Sharding Overview

- 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 understand how sharding works in MongoDB, we need to understand:

- Shard Keys
- Chunks

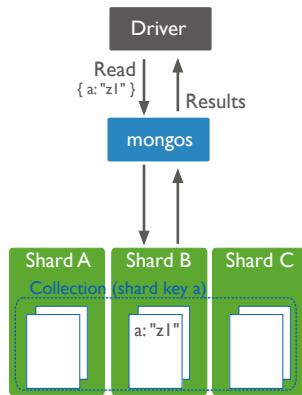
### Shard Key

- 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

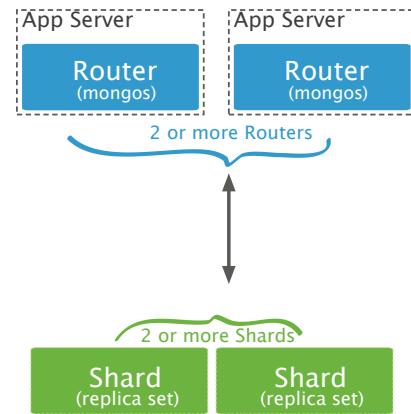
## Targeted Query Using Shard Key



## 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.

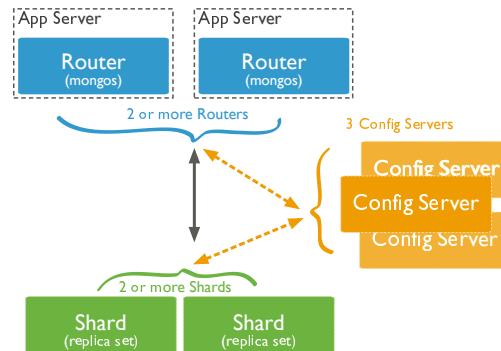
## Sharded Cluster Architecture



## 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.

## Logging Slow Queries

- `--slowms <integer>`
  - defines the *slow* operation time threshold (default 100 ms)
  - operations that run for longer than the given threshold are considered *slow*
  - For `mongod` instances, `--slowms` affects the diagnostic log and, if enabled, the profiler.
- You can now activate the profiler using `db.setProfilingLevel()`, from the *mongos*.
- In sharded clusters, you can now also analyze slow queries from the *mongos* logs directly, as opposed to having to check the logs of each shard individually.

## 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.

## 9.2 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.

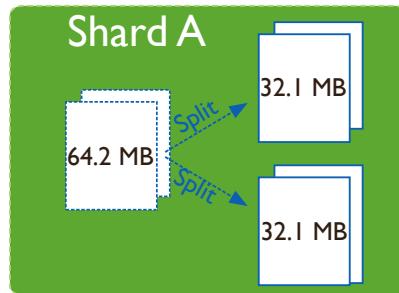
## Chunks in a Newly Sharded Collection

- 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.

## **9.3 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.
- As documents age and pass into a new zone range, the balancer will migrate them automatically.

### **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.

### **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](#)<sup>26</sup>

### **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.

## **9.4 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

---

<sup>26</sup> <http://docs.mongodb.org/manual/tutorial/manage-shard-zone/>

## 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
- Three config servers
- Two mongos servers

| Replica Set | port  | port  | port  |
|-------------|-------|-------|-------|
| shard0      | 27107 | 27108 | 27109 |
| shard1      | 27117 | 27118 | 27119 |
| shard2      | 27127 | 27128 | 27129 |

| Config Server | port  | port  | port  |
|---------------|-------|-------|-------|
| csrs          | 27227 | 27228 | 27229 |

| Mongos | port  | port  |
|--------|-------|-------|
|        | 27017 | 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,m2}
mkdir -p ~/data/cluster/shard1/{m0,m1,m2}
mkdir -p ~/data/cluster/shard2/{m0,m1,m2}
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\m2
md c:\data\cluster\shard1\m0 c:\data\cluster\shard1\m1 c:\data\cluster\shard1\m2
md c:\data\cluster\shard2\m0 c:\data\cluster\shard2\m1 c:\data\cluster\shard2\m2
```

## 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 --bind_ip_all

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

mongod --replSet shard0 --dbpath ~/data/cluster/shard0/m2 \
    --logpath ~/data/cluster/shard0/m2/mongod.log \
    --fork --port 27109 --shardsvr --bind_ip_all

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

## Initiate a Replica Set (Windows)

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

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

mongod --replSet shard0 --dbpath c:\data\cluster\shard0\m2 \
    --port 27109 --oplogSize 10 --shardsvr --bind_ip_all

mongo --port 27107 --eval "
    rs.initiate(); sleep(3000);
    rs.add('%HOSTNAME%:27108');
    rs.add('%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 --bind_ip_all

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

mongod --replSet shard1 --dbpath ~/data/cluster/shard1/m2 \
    --logpath ~/data/cluster/shard1/m2/mongod.log \
    --fork --port 27119 --shardsvr --bind_ip_all

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

## Spin Up a Second Replica Set (Windows)

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

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

mongod --replSet shard1 --dbpath c:\data\cluster\shard1\m2 \
--port 27119 --oplogSize 10 --shardsvr --bind_ip_all

mongo --port 27117 --eval "
rs.initiate(); sleep(3000);\
rs.add('%HOSTNAME%:27118');\
rs.add('%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 --bind_ip_all

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

mongod --replSet shard2 --dbpath ~/data/cluster/shard2/m2 \
--logpath ~/data/cluster/shard2/m2/mongod.log \
--fork --port 27129 --shardsvr --bind_ip_all

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

## A Third Replica Set (Windows)

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

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

mongod --replSet shard2 --dbpath c:\data\cluster\shard2\m2 \
--port 27129 --oplogSize 10 --shardsvr --bind_ip_all

mongo --port 27127 --eval "
rs.initiate(); sleep(3000);
rs.add('%HOSTNAME%:27128');
rs.add('%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 --bind_ip_all

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

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

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 \
    --port 27217 --configsvr --bind_ip_all

mongod --dbpath c:\data\cluster\config\c1 \
    --replSet csrs \
    --port 27218 --configsvr --bind_ip_all

mongod --dbpath c:\data\cluster\config\c2 \
    --replSet csrs \
    --port 27219 --configsvr --bind_ip_all
```

(continues on next page)

```
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. 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" \
--bind_ip_all

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

## Launch the Mongos Processes (Windows)

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

```
mongos --port 27017 --bind_ip_all \
--configdb csrs/%HOSTNAME%:27217,%HOSTNAME%:27218,%HOSTNAME%:27219

mongos --port 27018 --bind_ip_all \
--configdb csrs/localhost:27217,localhost:27218,localhost:27219
```

## Add All Shards (Linux/MacOS)

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

## Add All Shards (Windows)

```
mongo --eval "sh.addShard( 'shard0/%HOSTNAME%:27107' );
    sh.addShard( 'shard1/%HOSTNAME%:27117' );
    sh.addShard( 'shard2/%HOSTNAME%:27127' );
    sh.status()"
```

---

**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 } )
sh.stopBalancer()
for (i=0; i<1000; i++) {
  docArr = [];
  for (j=0; j<1000; j++) {
    docArr.push(
    {
      a : i, b : j,
      c : "Filler String: ".pad(256, 1, ""+j)
    })
  }
  db.testcol.insert(docArr);
}
sh.startBalancer();
```

## Observe What Happens

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

```
sh.status()
```

# 10 Change Streams

*Introduction to Change Streams (page 197)* Introduction to Change Streams

## 10.1 Introduction to Change Streams

### Learning Objectives

Upon completing this module, students will be able to:

- Define Change Streams and supporting stream aggregation pipeline operators
- Use Change Streams to identify realtime changes in documents and collections
- Use `updateLookup` to retrieve full document structure in update events
- Implement a simple Change Stream to track changes in collections

### Change Streams

New in version 3.6.

Change Streams allow your application to access real-time data changes, through a dedicated API, without relying on complex oplog tailing commands.

Things like:

- Internal `noop` oplog entries
- Dealing with initial syncs
- Resuming streams
- Schema changes to the Oplog entries
- and others ...

are complex operations, surfaced by tailing the oplog, that may change and offer little value to your application notification requirements.

### Change Stream Requirements

Opening a Change Stream requires the following:

- Replica Set or Sharded Cluster
  - We cannot open a Change Stream against a standalone mongod
- The cluster needs to be configured using [Protocol Version<sup>27</sup>](#) 1 (pv1 is the default)
- Change Streams in Sharded Clusters need to be open against the mongos
- Once opened, the Change Stream can be bound to a collection, database or an entire replica set and the cursor is kept open until explicitly closed
  - As long as the connection remains open and the collection exists

---

<sup>27</sup> <https://docs.mongodb.com/manual/reference/replica-set-protocol-versions/index.html>

## Change Stream Requirements (cont.)

- The following items will not be watched when change streams is open:
  - system collection
  - admin, local, and config databases
- Change Streams have been designed to support up to 100 concurrent streams

## Exercise: First Change Stream

Let's go ahead and open our first Change Stream. We need the following:

- Replica Set cluster
- A client process that continuously writes data into a collection
- watch that collection for modifications/write operations

## Task: Setup Replica Set (Unix)

Bring up the Replica Set nodes:

```
mkdir -p ~/change_streams/{0,1,2}
mongod --replSet CS --port 32000 --bind_ip_all --dbpath ~/change_streams/0 \
--logpath ~/change_streams/0/mongod.log --fork --oplogSize 10 --wiredTigerCacheSizeGB \
↪ 0.25
mongod --replSet CS --port 32001 --bind_ip_all --dbpath ~/change_streams/1 \
--logpath ~/change_streams/1/mongod.log --fork --oplogSize 10 --wiredTigerCacheSizeGB \
↪ 0.25
mongod --replSet CS --port 32002 --bind_ip_all --dbpath ~/change_streams/2 \
--logpath ~/change_streams/2/mongod.log --fork --oplogSize 10 --wiredTigerCacheSizeGB \
↪ 0.25
```

## Task: Setup Replica Set (Win)

Bring up the Replica Set nodes:

```
md c:\data\change_streams\0 c:\data\change_streams\1 c:\data\change_streams\2
mongod --replSet CS --port 32000 --bind_ip_all --dbpath c:\data\change_streams\0 \
--logpath c:\data\change_streams\0\mongod.log --oplogSize 10 --wiredTigerCacheSizeGB \
↪ 0.25

mongod --replSet CS --port 32001 --bind_ip_all --dbpath c:\data\change_streams\1 \
--logpath c:\data\change_streams\0\mongod.log --oplogSize 10 --wiredTigerCacheSizeGB \
↪ 0.25

mongod --replSet CS --port 32002 --bind_ip_all --dbpath c:\data\change_streams\2 \
--logpath c:\data\change_streams\2\mongod.log --oplogSize 10 --wiredTigerCacheSizeGB \
↪ 0.25
```

## Task: Configure Replica Set

Configure the Replica Set cluster:

```
mongo --port 32000 --eval '
var conf = {_id: "CS", members: [
    {_id:0, host:"localhost:32000"}, 
    {_id:1, host:"localhost:32001"}, 
    {_id:2, host:"localhost:32002"}]
}
rs.initiate(conf)
'
```

## Task: Setup Continuous Write Load

In a separate mongo shell let's run an infinite loop that inserts documents in the collection worldcup.scores

```
mongo worldcup --host CS/localhost:32000,localhost:32001,localhost:32002 \
--eval '
while(1){
    var ts = ["Portugal", "Argentina"];
    if((Math.random() *10) > 8){
        ts = ["Real Madrid", "Barcelona"];
    }
    if((Math.random() *10) > 5){
        db.scores.insert({"player": "Ronaldo", "time": ISODate(), "team": ts[0]});
    } else {
        db.scores.insert({"player": "Messi", "time": ISODate(), "team": ts[1]});
    }
    sleep(100);
}
'
```

## Task: Open Change Stream

Now that we have a continuous flow of write operations, let's go ahead and open a Change Stream against the worldcup.scores collection:

- In a separate mongo shell we connect to the Replica Set

```
mongo worldcup --host CS/localhost:32000,localhost:32001,localhost:32002
```

- Then we use the `watch()` command to open the Change Stream.

```
db.scores.watch()
```

## Change Event

Once we open a Change Stream the application starts to receive Change Events<sup>28</sup>.

Change Events are documents that represent a write operation that matches the filter defined in the Change Stream.

```
{ "_id" : { "_data" :BinData(0,"gl...==") },
  "operationType" : "insert",
  "fullDocument" : {
    "_id" : ObjectId("5ae0f2f2168d063c28d296e9"),
    "player" : "Ronaldo",
    "time" : ISODate("2018-04-25T21:28:18.052Z"),
    "team" : "Portugal" ,
    "ns" : { "db" :"worldcup", "coll" : "scores" },
    "documentKey" : { "_id" :ObjectId("5ae0f2f2168d063c28d296e9") }
}
```

## Change Event Anatomy

- `_id`: Identifier of the Change Stream. To resume a change stream we will be passing this field as `resumeToken`
- `operationType`: The type of operation currently being streamed
- `fullDocument`: Only available when the operation is either an `insert` or `replace` operation. In update operations this field will be populated in case we use the `updateLookup` when opening the Change Stream.
- `ns`: Bounded namespace of our Change Stream
- `documentKey`: Streamed document identifier

## Change Event Output

Change Streams allows us to use aggregation pipeline stages to *shape* the output of the Change Event messages.

The allowed aggregation stages are the following:

- `$match`: Enables our application to listen only to certain events
- `$project`: Shape our Change Event message to show only some fields, or even computed fields using the `$project` expressions
- `$addFields`: Following the same logic as in the `$project` stage, we can shape the Change Event message by computing and shaping fields to the application needs
- `$replaceRoot`: Used to re-arrange Change Stream event message documents
- `$redact`: Allows us to perform field level redaction

<sup>28</sup> <https://docs.mongodb.com/manual/reference/change-events/#change-stream-output>

## Filter Change Stream

Using `$match` stage we could filter our Change Stream to listen to only a subset of the write operations using as query predicate any field available in the Change Event document:

```
var pipeline = [{ "$match": { "fullDocument.player": "Ronaldo" } }]
db.scores.watch( pipeline )
```

## Updates on Change Streams

The Change Event message will have a slight different composition depending on the `operationType`.

In case of **update** commands, we will retrieve something the command that originated in the change

- mongo shell 1

```
var pipeline = [{ "$match": { "operationType": "update" } }]
var cursor = db.scores.watch( pipeline );
cursor.forEach( function(x){printjson(x);})
```

- mongo shell 2

```
db.scores.updateOne({team: "Real Madrid", competition: {"$exists": false}},
{ "$set": { "competition": "UC" }})
```

## Updates Change Event

```
{
  "_id" : {"_data" : BinData(0,"...A==") },
  "operationType" : "update",
  "ns" : { "db" : "worldcup", "coll" : "scores" },
  "documentKey" : { "_id" : ObjectId("5ae0f2a8168d063c28d29425") },
  "updateDescription" : {
    "updatedFields" : {
      "competition" : "UC"
    },
    "removedFields" : [ ]
  }
}
```

From this example of a Change Event originated by the previous **update** operation, we can see that only the resulting changes are notified.

## updateLookup

To retrieve the full document *at its current state*, when opening a Change Stream, set the **fullDocument** option with updateLookup value:

```
var pipeline = [{ "$match": { "operationType": "update" } }]
db.scores.watch( pipeline, { fullDocument:"updateLookup" } );
```

- Resulting Change Event

```
{ "_id" : { "_data" : BinData(0,"....==") }, "operationType" : "update",
  "fullDocument" : {
    "_id" : ObjectId("5ae0f2a8168d063c28d2942c"),
    "player" : "Ronaldo",
    "time" : ISODate("2018-04-25T21:27:04.857Z"),
    "team" : "Real Madrid",
    "competition" : "UC"
  },
  "updateDescription" : { "updatedFields" : { "competition" : "UC"}, ... }
... }
```

## startAtOperation

- You can specify a startAtOperationTime to open the cursor at a particular point in time.
- If the specified starting point is in the past, it must be in the time range of the oplog.
  - startAtOperationTime is mutually exclusive with resumeAfter.

```
var pipeline = [{ "$match": { "operationType": "update" } }];
Mongo.watch(pipeline, { "startAtOperationTime": Timestamp(1412180887, 1) });
```

- Mongo.watch() only notifies on data changes that have persisted to a majority of data-bearing members.

## Recap

- Change Streams allows applications to be notified of write events
- Change Streams provides a clean and concise API that removes the need to tail the Replication *oplog*
- Change Streams are resumable
- Different operationType may result in a different Change Event messages
- Change Event documents can be *reshaped* and filtered using aggregation pipeline stages
- We can use updateLookup to retrieve the actual state of documents in update operations
- We can use startAtOperationTime to open a change streams at a specified point in time

You can learn more details about Change Streams in this [blog post<sup>29</sup>](https://www.mongodb.com/blog/post/an-introduction-to-change-streams).

<sup>29</sup> <https://www.mongodb.com/blog/post/an-introduction-to-change-streams>

# 11 Drivers

*Introduction to MongoDB Drivers (page 203)* An introduction to the MongoDB drivers

*Lab: Driver Tutorial (Optional) (page 206)* A quick tour through the Python driver

## 11.1 Introduction to MongoDB Drivers

### Learning Objectives

Upon completing this module, students should understand:

- What MongoDB drivers are available
- Where to find MongoDB driver specifications
- Key driver settings

### MongoDB Supported Drivers

- C<sup>30</sup>
- C++<sup>31</sup>
- C#<sup>32</sup>
- Java<sup>33</sup>
- Node.js<sup>34</sup>
- Perl<sup>35</sup>
- PHP<sup>36</sup>
- Python<sup>37</sup>
- Ruby<sup>38</sup>
- Scala<sup>39</sup>

---

<sup>30</sup> <http://docs.mongodb.org/ecosystem/drivers/c>

<sup>31</sup> <http://docs.mongodb.org/ecosystem/drivers/cpp>

<sup>32</sup> <http://docs.mongodb.org/ecosystem/drivers/csharp>

<sup>33</sup> <http://docs.mongodb.org/ecosystem/drivers/java>

<sup>34</sup> <http://docs.mongodb.org/ecosystem/drivers/node-js>

<sup>35</sup> <http://docs.mongodb.org/ecosystem/drivers/perl>

<sup>36</sup> <http://docs.mongodb.org/ecosystem/drivers/php>

<sup>37</sup> <http://docs.mongodb.org/ecosystem/drivers/python>

<sup>38</sup> <http://docs.mongodb.org/ecosystem/drivers/ruby>

<sup>39</sup> <http://docs.mongodb.org/ecosystem/drivers/scala>

## MongoDB Community Supported Drivers

35+ different drivers for MongoDB:

Go, Erlang, Clojure, D, Delphi, F#, Groovy, Lisp, Objective C, Prolog, Smalltalk, and more

## Driver Specs

To ensure drivers have a consistent functionality, series of publicly available specification documents<sup>40</sup> for:

- Authentication<sup>41</sup>
- CRUD operations<sup>42</sup>
- Index management<sup>43</sup>
- SDAM<sup>44</sup>
- Server Selection<sup>45</sup>
- Etc.

## Driver Settings (Per Operation)

- Read preference
- Write concern
- Maximum operation time (maxTimeMS)
- Batch Size (batchSize)
- Exhaust cursor (exhaust)
- Etc.

## Driver Settings (Per Connection)

- Connection timeout
- Connections per host
- Time that a thread will block waiting for a connection (maxWaitTime)
- Socket keep alive
- Sets the multiplier for number of threads allowed to block waiting for a connection
- Etc.

<sup>40</sup> <https://github.com/mongodb/specifications>

<sup>41</sup> <https://github.com/mongodb/specifications/tree/master/source/auth>

<sup>42</sup> <https://github.com/mongodb/specifications/tree/master/source/crud>

<sup>43</sup> <https://github.com/mongodb/specifications/blob/master/source/index-management.rst>

<sup>44</sup> <https://github.com/mongodb/specifications/tree/master/source/server-discovery-and-monitoring>

<sup>45</sup> <https://github.com/mongodb/specifications/tree/master/source/server-selection>

## **Insert a Document with the Java Driver**

Connect to a MongoDB instance on localhost:

```
MongoClient mongoClient = new MongoClient();
```

Access the test database:

```
MongoDatabase db = mongoClient.getDatabase("test");
```

Insert a myDocument Document into the test.blog collection:

```
db.getCollection("blog").insertOne(myDocument);
```

## **Insert a Document with the Python Driver**

Connect to a MongoDB instance on localhost:

```
client = MongoClient()
```

Access the test database:

```
db = client['test']
```

Insert a myDocument Document into the test.blog collection:

```
db.blog.insert_one(myDocument);
```

## **Insert a Document with the C++ Driver**

Connect to the “test” database on localhost:

```
mongocxx::instance inst{};  
mongocxx::client conn{};  
  
auto db = conn["test"];
```

Insert a myDocument Document into the test.blog collection:

```
auto res = db["blog"].insert_one(myDocument);
```

## 11.2 Lab: Driver Tutorial (Optional)

### Tutorial

Complete the Python driver tutorial<sup>46</sup> for a concise introduction to:

- Creating MongoDB documents in Python
- Connecting to a database
- Writing and reading documents
- Creating indexes

---

<sup>46</sup> <http://api.mongodb.org/python/current/tutorial.html>

# 12 Security

*Security Introduction* ([page 207](#)) A high level overview of security in MongoDB

*Authorization* ([page 210](#)) Authorization in MongoDB

*Lab: Administration Users* ([page 216](#)) Lab on creating admin users

*Lab: Create User-Defined Role (Optional)* ([page 217](#)) Lab on creating custom user roles

*Authentication* ([page 219](#)) Authentication in MongoDB

*Lab: Secure mongod* ([page 220](#)) Lab on standing up a mongod with authorization enabled

*Auditing* ([page 221](#)) Auditing in MongoDB

*Encryption* ([page 223](#)) Encryption at rest in MongoDB

*Log Redaction* ([page 225](#)) Enabling log redaction in MongoDB

*Lab: Secured Replica Set - KeyFile (Optional)* ([page 226](#)) Using keyfiles to secure a replica set

*Lab: Security Workshop* ([page 229](#)) Securing a full deployment

## 12.1 Security Introduction

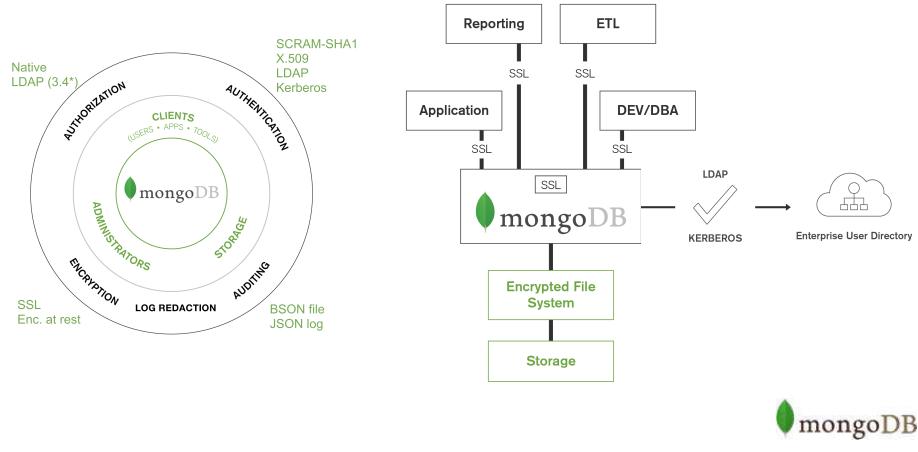
### Learning Objectives

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

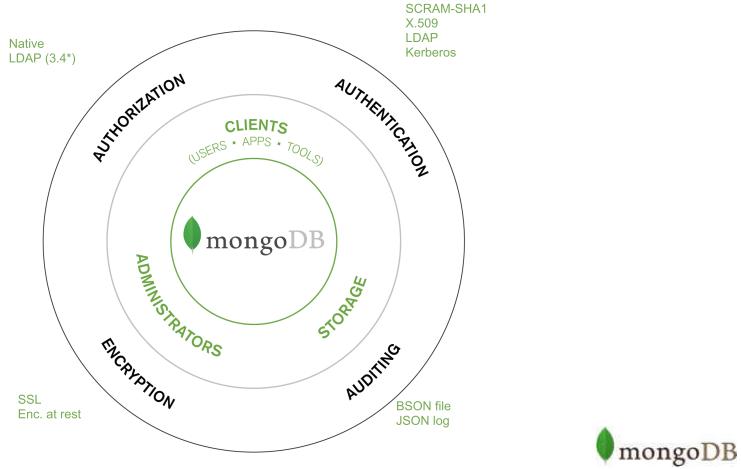
## A High Level Overview

### Security Architecture



### Security Mechanisms

### Security Mechanisms



## **Authentication Options**

- Community
  - Challenge/response authentication using SCRAM-SHA-256 (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**

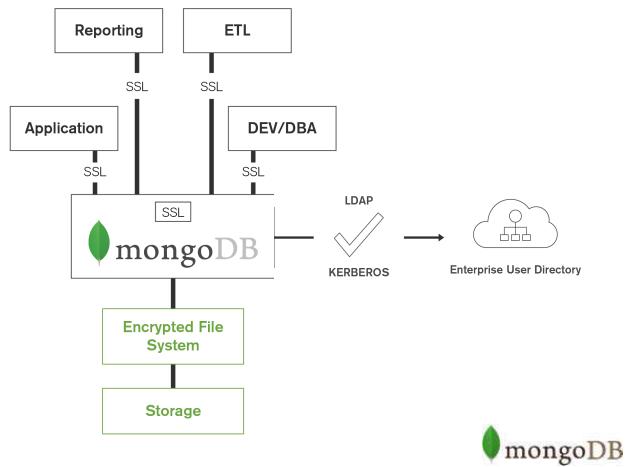
- TLS/SSL
  - May use certificates signed by a certificate authority or self-signed.
- FIPS (MongoDB Enterprise)

## **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

### Security Flow



## 12.2 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

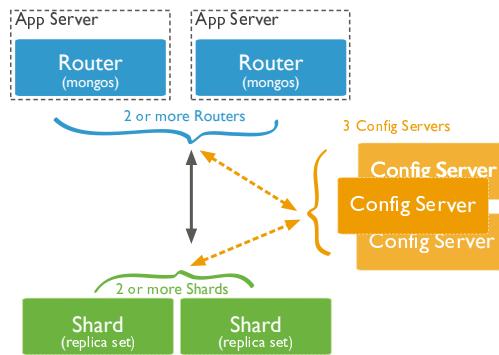
### **What is a resource?**

- 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<sup>47</sup>](#) 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          |

<sup>47</sup> <https://docs.mongodb.com/manual/reference/privilege-actions/>

|           |          |
|-----------|----------|
| Superuser | Internal |
| root      | system   |

## 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 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 tranformed 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 entitiy'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
```

## 12.3 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 has 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](#)<sup>48</sup>.

## 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

## 12.4 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.

<sup>48</sup> <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?

## **12.5 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-256 (default >= 4.0)
- 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:
```

## 12.6 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
```

## 12.7 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
```

## 12.8 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.
- MongoDB binaries (mongod, mongos, and mongo) disables support for TLS 1.0 encryption on systems where TLS 1.1+ is available.
- Three different network architecture options are available:
  - Encryption of application traffic connections
  - Full encryption of all connections
  - Mixed encryption between nodes

## **Network Encryption Continued**

- The `--sslAllowInvalidCertificates` option bypasses certificate validation.
- This option can leave you open to man in the middle style attacks. Should not be used in production.
- Starting in MongoDB 4.0, if you specify `--sslAllowInvalidCertificates` or `ssl.allowInvalidCertificates: true` when using x.509 authentication, an invalid certificate is only sufficient to establish a TLS/SSL connection but not for authentication.

## **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

## 12.9 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: "###" } ],
...
}
```

## 12.10 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<sup>49</sup>

### 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](#)<sup>50</sup> 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
```

<sup>49</sup> <https://docs.mongodb.org/manual/reference/configuration-options/>

<sup>50</sup> [https://github.com/thatnerd/work-public/blob/master/mongodb\\_trainings/secure\\_replset\\_config.yaml](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

## 12.11 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

## What you will do today!

Full screen<sup>51</sup>

## 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
- 10: Revoke Certificates (optional)
- 11: Use X.509 authentication for users (optional)
- 12: External Access (optional)

The solutions to the first 3 exercises are provided in case you need help.

---

<sup>51</sup> [https://docs.google.com/presentation/d/1-KwEGXdlXGVFcmbjh9JW7vrLbwJyQ9v6se2zaaj5js/edit#slide=id.g39a01a9844\\_0\\_0](https://docs.google.com/presentation/d/1-KwEGXdlXGVFcmbjh9JW7vrLbwJyQ9v6se2zaaj5js/edit#slide=id.g39a01a9844_0_0)

## Important Notes for the Exercises

1. Running commands in the Linux shell
  - only use sudo when we tell you so
  - use ‘sudo service mongod’ to start mongod
2. Creating your replica set and config files
  - use **node1**, **node2** and **node3** for the replica set (node4 is for the application)
  - must use **Config Files** /etc/mongod.conf for the mongod processes, not command line options
  - replica set should be named: **SECURED**
  - be careful with the spacing in the YAML file

## Topics for some exercises

Those are knowledge “checkpoints” you may want to consult before proceeding with some exercises

- 2. Which incoming traffic to accept?
- 4. Authorization and Authentication
- 5. SSL certificates
- 6a. Different Certificate File Formats
- 6b. X.509 certificates with clusterAuthMode: x.509

## List of Virtual Machines for your lab

You are given a JSON file with a list of hosts.

```
{  
  "SecurityGroup": "sg-0b968f7901f03c864",  
  "Hosts": [  
    {  
      "PublicName": "ec2-18-224-44-207.us-east-2.compute.amazonaws.com",  
      "PrivateName": "ip-10-0-0-101.us-east-2.compute.internal",  
      "PrivateIP": "10.0.0.101",  
      "PublicIP": "18.224.44.207",  
      "Role": "node1",  
      "Id": "i-0742ed5c9d1384e69"  
    },  
    {  
      "PublicName": "ec2-18-218-233-223.us-east-2.compute.amazonaws.com",  
      "PrivateName": "ip-10-0-0-102.us-east-2.compute.internal",  
      "PrivateIP": "10.0.0.102",  
      "PublicIP": "18.218.233.223",  
      "Role": "node2",  
      "Id": "i-0a4b0d4ba14fd5a46"  
    },  
    ...  
  ],  
  "VPC": "vpc-0bdd5ee2a2a1b1567",  
  "SubnetMask": "10.0.0.0/24",  
  "Id": "1",  
}
```

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```
    "LoadBalancer": "No Load Balancer/No Ops Manager instances"
}
```

### 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](#)<sup>52</sup>

### 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 and connect with the user centos to the external IP of the instance

```
ssh-add -K AdvancedAdministrator.pem
ssh -i AdvancedAdministrator.pem -A centos@54.235.1.1
```

- SSH into node2 from node1

```
ssh -A node2
```

<sup>52</sup> <http://docs.aws.amazon.com/AWSEC2/latest/UserGuide/putty.html>

## 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
```

## Topic 2: Which incoming traffic to accept?

### Exercise 2: Starting MongoDB and configuring the replica set

- /share/downloads/mongodb\_packages contains MongoDB 3.2, 3.4, 3.6 and 4.0
  - we will use 4.0!
- 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<sup>53</sup>
- bind to the 10.0.0.X address and to 127.0.0.1

## Solution 2: Installing MongoDB

- Installation

```
cd /data/downloads/mongodb_packages  
sudo yum install -y mongodb-enterprise-4.0.0-0.1.latest.el7.x86_64.rpm  
sudo vi /etc/mongod.conf  
sudo service mongod start  
sudo service mongod status  
# if errors OR mongod not running ...  
sudo cat /var/log/mongodb/mongod.log
```

<sup>53</sup> <https://docs.mongodb.com/manual/reference/configuration-options/>

## 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/  
  ...  
net:  
  bindIp: 10.0.0.101,127.0.0.1  
  ...  
replication:  
  replSetName: SECURED
```

## Solution 2: Replica Set Config (cont)

```
> mongo  
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 from node4:

```
mongo --host node1
```

If you want to be sure to connect to the Primary, instead, use:

```
mongo --host SECURED/node1,node2,node3  
mongo --host SECURED/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.
```

- Connect to the public ip of your node4 instance, port 8080

```
http://NODE4-public-IP:8080
```

- Referesh the browser page to see what other people are saying on the chat

### **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...

## Topic 4: Authorization and Authentication

Discussion on the following questions:

- difference between authorization and authentication?
- which authentication mechanism to use?
- which authorization support will you use?

### Users, authentication database and authorized databases

Using the `createUser` command below, let's see what happens for different values of **DB1**, **DB2** and **DB3**

```
use DB1
db.createUser({ user:"scott", password:"tiger", \
  db: "DB2", \
  roles: [ { db:"DB3", role: "readWrite" } ] })
```

| DB1   | DB2    | DB3  | authenticationDatabase | readWrite on | physical def of user |
|-------|--------|------|------------------------|--------------|----------------------|
| admin | <none> | data | admin                  | data         | admin                |
| admin | users  | data | users                  | data         | admin                |
| users | <none> | data | users                  | data         | admin                |
| users | data   | data | data                   | data         | admin                |
| data  | <none> | data | data                   | data         | admin                |
| data  | users  | data | users                  | data         | admin                |

### Exercise 4: Set up local accounts

It is time to start securing the system. You will have to decide the set of users required to operate this system

- Should we restrict from which machines some users can connect?

Discuss the list of users with your teammates, then proceed to the following page where we will give you the list to create for this lab.

- Some references:

- MongoDB authentication<sup>54</sup>
- role-based access control<sup>55</sup>
- Authentication Restrictions<sup>56</sup>

<sup>54</sup> <https://docs.mongodb.com/manual/core/authentication/>

<sup>55</sup> <https://docs.mongodb.com/manual/core/authorization/>

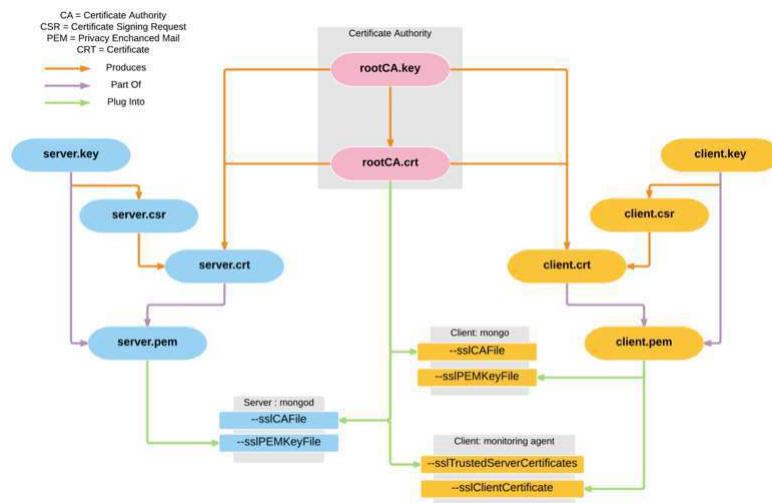
<sup>56</sup> <https://docs.mongodb.com/manual/reference/method/db.createUser/#authentication-restrictions>

## Exercise 4: Set up local accounts (con't)

- create 3 users, however **do not turn authentication on yet.**
  - a user called “foo” with “root” privileges
  - a user called “bar” that can create other users and manage the cluster
  - a user called “mongo-messenger” that we will use to authenticate our application

Note that you would normally use the second account to do administration. You should avoid running with “root” privileges, but for this workshop it will help you in case you have issues.

## Topic 5: SSL certificates



## 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/`
    - \* And turn cluster authentication to `X.509`, which also turns on user authentication for the clients
- Connect with the shell, with the user `foo` to the replica set once SSL is enabled
- Advanced
  - Up the level of difficulty by doing it without downtime

## Topic 6a: Different Certificate File Formats

For the next exercise, you will be using the following files:

- mongomessenger.pem : *PEM* file, without the private key
- mongomessenger.key : key for the PEM file above
- messenger-CA.pem : ca.pem, without the private key

The connection from the application uses a library that needs to receive different files, one with the key, and the *PEM* file for the rest

This is different from the mongod process which gets a *PEM* file with the private key in it.

For more details see the discussion on different file formats

## Topic 6b: X.509 certificates with clusterAuthMode: x509

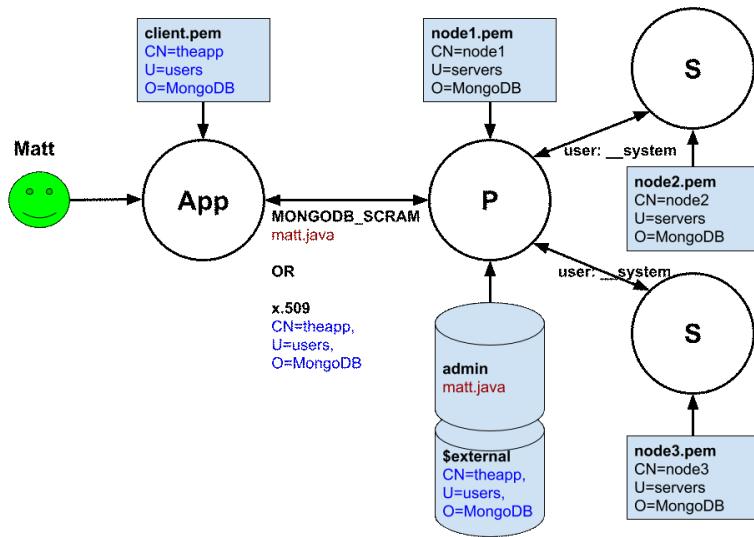
- Uses the certificates for the authentication between cluster nodes.
- Nodes with the same “DC”, “OU” and “O” are seen as the same cluster
  - “O”: Organization
  - “OU”: Organizational Unit
  - “DC”: Domain Component
- Turns on the authentication of clients/users with X.509, however the default MONGODB-SCRAM is still available
  - Alternative to *SCRAM*, where you don’t need a password
  - Client and user certificates **must** differ from the replica certificates in the subject area by at least one of O/OU/DC
  - Client presenting a certificate that matches the CA or a replica certificate with these 3 fields **will be given root access**

### X.509 Authentication

#### 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
mongo --ssl --sslCAFile /etc/ssl/mongodb/messenger-CA.pem \
    --sslPEMKeyFile ~/client.pem --host SECURED/node1,node2,node3
```

(continues on next page)



(continued from previous page)

```
# will not be authorized until auth'd with user
show dbs
```

### Exercise 6: Enable SSL connection from the mongo shell and from the Application

Using the following files to establish a successful connection between client applications and the replica section

1. You will need to combine the mongomessenger.key and mongomessenger.pem files together to test the connection with the mongo shell
2. Update the MongoMessenger connection info to connect over SSL<sup>57</sup>

```
# 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
```

### 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!!!

<sup>57</sup> <http://mongodb.github.io/node-mongodb-native/2.2/tutorials/connect/ssl/>

## **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

## **Exercise 9: Enable 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.

- Enable auditing to detect any writes to the collection containing the user definitions and privileges
- Output the log file in JSON format
- Output the log file to /mongod-data/audit/SECURED
- There are many [filter options](#)<sup>58</sup>

## **Exercise 10 (optional): Revoked Certificates**

The certificate used by our chatting application has been compromised. We will need to:

1. issue a new one
2. more important, revoke the current `mongomessenger.pem` file

We already prepared a CRL, Certificate Revocation List, called `crl.pem`, in which we revoked the compromised certificate.

Modify your replica set, without downtime, to ensure the chat application can't connect with the bad certificate.

## **Exercise 11 (optional): Use X.509 authentication for users**

Instead of using users/passwords for the client connections, we will use the SSL certificates themselves.

In this kind of deployment, you would issue a certificate to each user and/or application.

- Use the `mongo-messenger.pem` file for your client application
- Create the appropriate X.509 user
- Setup anything else that may need it

---

<sup>58</sup> <https://docs.mongodb.com/manual/tutorial/configure-audit-filters/>

### **Exercise 12 (optional): External Access**

- Application runs from outside the VPC in which your replica set is
- Application still authenticate with the “mongo-messenger” account
- What are the considerations to take into account?
- What has to be changed?
- What if the client may not have a certificate available?

### **Putting it together**

```
storage:
  dbPath: /mongod-data/appdb/
  ...
net:
  ssl:
    mode: requireSSL
    PEMKeyFile: /etc/ssl/mongodb/node1.pem
    CAFile: /etc/ssl/mongodb/ca.pem
    CRLFile: /etc/ssl/mongodb/crl.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: "write", db: "admin" } }'

setParameter: { auditAuthorizationSuccess: true }
```

### **Summary**

| Authentication | Authorization             | TLS/SSL                                 | Enterprise Only           |
|----------------|---------------------------|-----------------------------------------|---------------------------|
| Authentication | Role-Based Access Control | Transport Encryption                    | Kerberos Authentication   |
| SCRAM          | Enable Auth               | Configure mongod and mongos for TLS/SSL | LDAP Proxy Authentication |
| x.509          | Manage Users and Roles    | TLS/SSL Configuration for Clients       | Encryption at Rest        |
|                |                           |                                         | Auditing                  |

## References To Know More

- M103<sup>59</sup>
- Enforce Keyfile Access Control<sup>60</sup>
- AuthAAuthz LDAP<sup>61</sup>
- Security Additional Resources<sup>62</sup>

## 12.12 Solutions

### Solution 4: Set up local accounts (1/3)

- Create the first user, which must be able to create other users to avoid a lock in
- root is a dangerous privilege
- This user should only be allowed to connect from a shell within the private network.

```
use admin
db.createUser({
  "user": "foo",
  "pwd": "bar",
  "roles": [{ "role": "root", "db": "admin" }],
  "authenticationRestrictions": [ {
    "clientSource": ["10.0.0.0/24", "127.0.0.1"]
  }]
})
```

### Solution 4: Set up local accounts (2/3)

- This one also has kind of high privileges, let's restrict it to the internal network.
- Larger organization would probably separate administering the cluster from the databases themselves.

```
db.createUser({
  "user": "bar",
  "pwd": "baz",
  "roles": [
    { "role": "userAdminAnyDatabase", "db": "admin" },
    { "role": "clusterAdmin", "db": "admin" }
  ],
  "authenticationRestrictions": [
    { "clientSource": ["10.0.0.0/24", "127.0.0.1"] }
  ]
})
```

<sup>59</sup> <https://university.mongodb.com/courses/M310/about>

<sup>60</sup> <https://docs.mongodb.com/tutorials/enforce-keyfile-access-control-in-existing-sharded-cluster/>

<sup>61</sup> <https://docs.mongodb.com/tutorials/configure-ldap-sasl-active-directory/>

<sup>62</sup> <https://docs.mongodb.com/manual/security/#additional-resources>

#### Solution 4: Set up local accounts (3/3)

- And the user for the application
- Let's restrict this user to connecting from within the VPC

```
db.createUser({  
  "user": "mongo-messenger",  
  "pwd": "nodejs",  
  "roles": [  
    { "role": "readWrite", "db": "security-lab" }  
  ],  
  "authenticationRestrictions": [  
    { "serverAddress": ["10.0.0.0/24"] }  
  ]  
})
```

- Need to change *Mongo Messenger* (the application) to auth with this user, once authentication is enabled

#### Solution 5: Enable SSL between the nodes

- Stop each node with: `sudo service mongod stop`
- Change the mongod config files to have those sections:

```
net:  
  ...  
  ssl:  
    mode: requireSSL  
    PEMKeyFile: /etc/ssl/mongodb/node1.pem  
    CAFile: /etc/ssl/mongodb/ca.pem  
  security:  
    clusterAuthMode: x509
```

- Restart all mongod processes, and connect with the client

```
mongo --ssl --sslCAFile /etc/ssl/mongodb/ca.pem --sslPEMKeyFile /etc/ssl/mongodb/  
  ↵node1.pem --host node1  
mongo security-lab --authenticationDatabase admin --username mongo-messenger --  
  ↵password nodejs --ssl --sslCAFile /etc/ssl/mongodb/ca.pem --sslPEMKeyFile node1.  
  ↵pem --host node1
```

- Why no authorization: enabled in the config file?
  - Enabling `clusterAuthMode` implicitly enables authentication

## Solution 5: Enable SSL between the nodes (Advanced)

No downtime is achieved by changing all members to:

- first to: mode: allowSSL
- then to: mode: preferSSL
- then: mode: requireSSL

## Solution 6: Enable SSL with the client

- In ~/mongo-messenger/lib/messages.js

```
const fs = require('fs');

let ca = [fs.readFileSync('/etc/ssl/mongodb/messenger-CA.pem')];
let cert = fs.readFileSync('/etc/ssl/mongodb/mongomessenger.pem');
let key = fs.readFileSync('/etc/ssl/mongodb/mongomessenger.key');
let options = {
  sslValidate:true,
  sslCA:ca,
  sslCert:cert,
  sslKey:key
}
const url = 'mongodb://mongo-messenger:nodejs@node1:27017,node2:27017,node3:27017/
  ↵security-lab?authSource=admin&replicaSet=SECURED&ssl=true'
let messages = null;
MongoClient.connect(url, options, (err, db) => {
  assert.equal(null, err)
  messages = db.collection('messages')
})
```

## Solution 7: Encrypt Storage Layer

- Encryption at rest is also an Enterprise only feature
- Enable encryption on the storage engine

```
security:
  enableEncryption: true
  encryptionKeyFile: /etc/ssl/mongodb/mongodb-keyfile
```

- Different options to manage encryption keys, however for this lab a simple *keyfile* should have been enough

```
openssl rand -base64 32 > mongodb-keyfile
chmod 600 mongodb-keyfile
sudo chown mongod.mongod mongodb-keyfile
```

<https://docs.mongodb.com/manual/tutorial/configure-encryption/>

## Solution 8: Avoid any log leaks

By setting up log redaction

```
security:  
  redactClientLogData: true
```

```
db.adminCommand(  
  { setParameter: 1, redactClientLogData : true }  
)
```

- And you need a way to prove/show that redaction worked

## Solution 9: Enable Auditing

On each node of the replica set:

```
auditLog:  
  destination: file  
  format: JSON  
  path: /mongod-data/audit/SECURED/audit.json  
  filter: '{ roles: { role: "write", db: "admin" } }'  
  
setParameter: { auditAuthorizationSuccess: true }
```

```
sudo chmod 700 /mongod-data/audit/SECURED  
sudo chown mongod.mongod /mongod-data/audit/SECURED
```

## Solution 10 (optional): Revoked Certificates

Revoking a certificate is done in 2 steps:

- revoke it
- get the updated list of revoked certificates for your servers

```
openssl ca -revoke mongomessenger.pem -keyfile CA.key -cert CA.pem  
openssl ca -gencrl -out crl.pem -keyfile CA.key -cert CA.pem
```

However, that was already done in the file `crl.pem` we gave you.

## Solution 10 (optional): Revoked Certificates (con't)

To have the mongod processes being aware of the revoked certificates, restart one at the time, your mongod processes with this additional option:

```
net:  
  ssl:  
    ...  
    CRLFile: /etc/ssl/mongodb/crl.pem
```

This will also revoke the ~/client.pem we constructed, because it is derived from mongomessenger.pem

## Solution 11 (optional): Use x.509 authentication for users

We need to get the *subject* for our user, **in the right order**, by passing the `-nameopt RFC2253` parameter to openssl

```
openssl x509 -in mongomessenger.pem -inform PEM -subject -nameopt RFC2253 | grep _  
subject  
subject= C=US,ST>New York,L>New York City,O=MongoDB,OU=USERS,CN=localhost
```

Create the user in the \$external database

```
db.getSiblingDB("$external").runCommand(  
{  
  createUser: "C=US,ST>New York,L>New York City,O=MongoDB,OU=USERS,CN=localhost",  
  "roles": [  
    { "role": "readWrite", "db": "security-lab" }  
  ],  
  "authenticationRestrictions": [  
    { "serverAddress": ["10.0.0.0/24"] }  
  ]  
})
```

Test the user by connecting with the mongo shell

```
mongo --ssl --sslPEMKeyFile <path to CA signed client PEM file> \  
--sslCAFile <path to root CA PEM file> --authenticationDatabase '$external' \  
--authenticationMechanism MONGODB-X509
```

Use this user in the application

```
const url = 'mongodb://node1:27017,node2:27017,node3:27017/security-lab? \  
authSource=$external&mechanism="MONGODB-X509"&replicaSet=SECURED&ssl=true'
```

### **Solution 12 (optional): External Access**

- The first thing to understand is that we will have a less secure solution
- At least, try to restrict the IPs from which connections can happen
  - reflect those info in the “bindIp” setting
  - reflect those in the user account
- Allowing clients without certs is done by starting the mongod with `allowConnectionsWithoutCertificates`
- Use the `preferSSL` option instead of `requireSSL`

## 13 Backup and Recovery

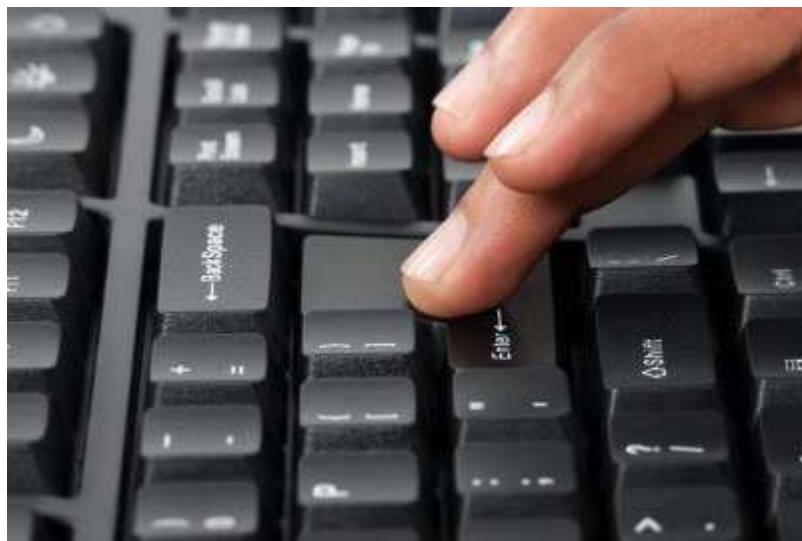
*Backup and Recovery (page 248)* An overview of backup options for MongoDB

### 13.1 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
                         server port. Can also use --host hostname
  --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

# 14 Reporting Tools and Diagnostics

*Performance Troubleshooting (page 253)* An introduction to reporting and diagnostic tools for MongoDB

*Lab: Finding and Addressing Slow Operations (page 260)* Lab on finding and addressing slow queries

*Lab: Using explain() (page 261)* Lab: Finding and Addressing Slow Operations

## 14.1 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* (page 117) 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.

## 14.2 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.

## 14.3 Lab: Using `explain()`

Before getting started, let's make sure we drop all indexes from `sensor_readings` collection has no indexes:

```
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")
```

# 15 MongoDB Atlas, Cloud & Ops Manager Fundamentals

*MongoDB Cloud & Ops Manager (page 262)* Learn about what Cloud & Ops Manager offers

*Automation (page 264)* Cloud & Ops Manager Automation

*Lab: Cluster Automation (page 267)* Set up a cluster with Cloud Manager Automation

*Monitoring (page 268)* Monitor a cluster with Cloud Manager

*Lab: Create an Alert (page 270)* Create an alert on Cloud Manager

*Backups (page 270)* Use Cloud Manager to create and administer backups

## 15.1 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

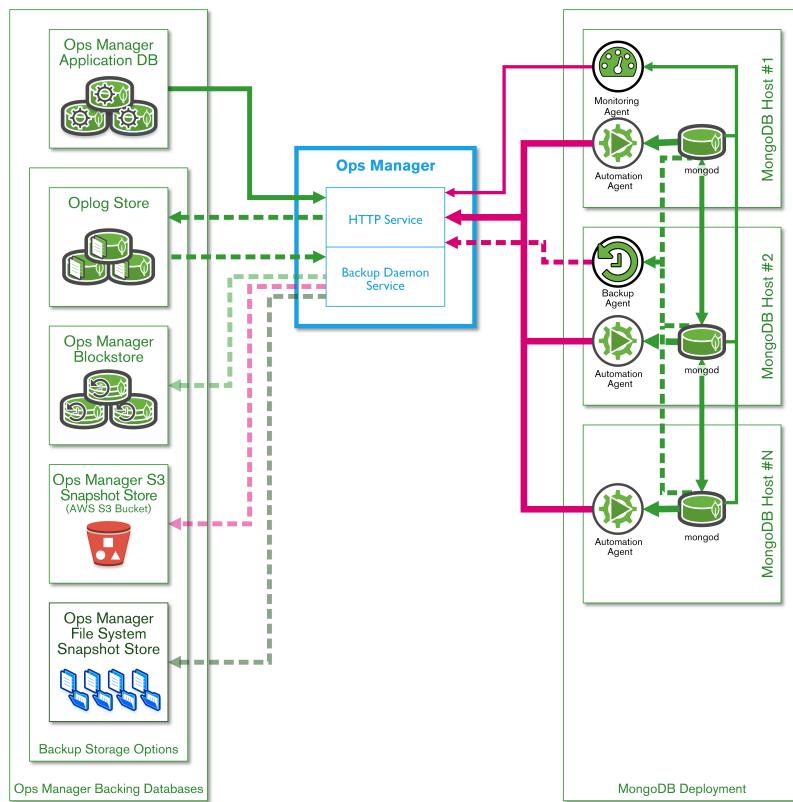
All services for managing a MongoDB cluster or group of clusters:

- 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>

## **15.2 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?**

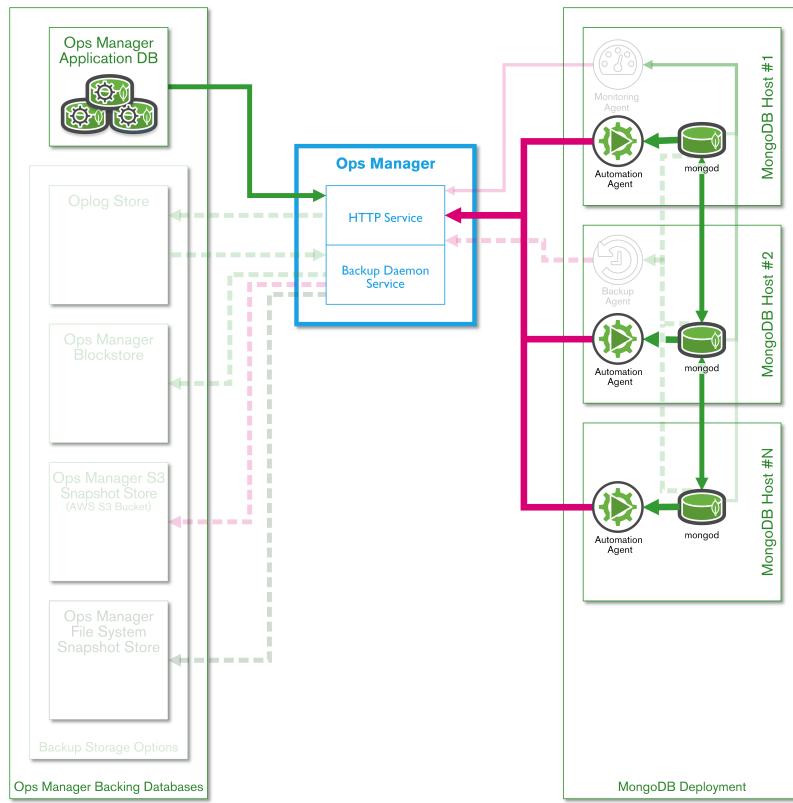
Fully managed MongoDB deployment on your own servers:

- 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<sup>63</sup>](#)
  - [The Automation API<sup>64</sup>](#)
  - [Configuring the Automation Agent<sup>65</sup>](#)

## 15.3 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**

<sup>63</sup> <https://docs.cloud.mongodb.com/tutorial/nav/automation-agent/>

<sup>64</sup> <https://docs.cloud.mongodb.com/api/>

<sup>65</sup> <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)

## **15.4 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

## 15.5 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.

## 15.6 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**

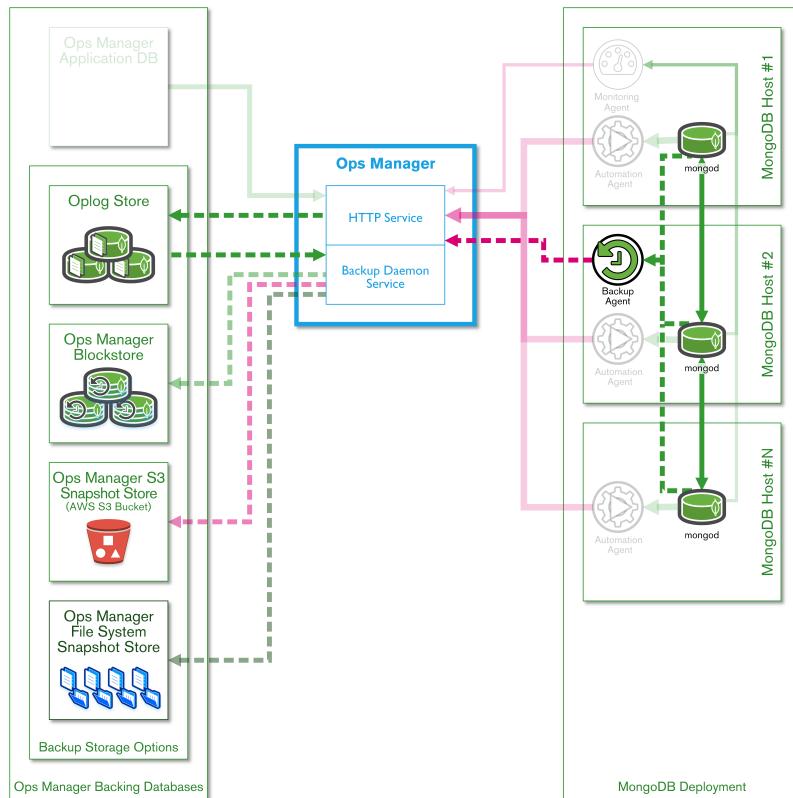
## Cloud / Ops Manager Backups

- Based off oplogs (even for the config servers)
- Point-in-time recovery for replica sets, snapshots for sharded clusters
- Oplog 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

# 16 MongoDB Cloud & Ops Manager Under the Hood

*API (page 273)* Using the Cloud & Ops Manager API

*Lab: Cloud Manager API (page 274)* Cloud & Ops Manager API exercise

*Architecture (Ops Manager) (page 275)* Ops Manager

*Security (Ops Manager) (page 277)* Ops Manager Security

*Lab: Install Ops Manager (page 278)* Install Ops Manager

## 16.1 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.

## **16.2 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.

## **16.3 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

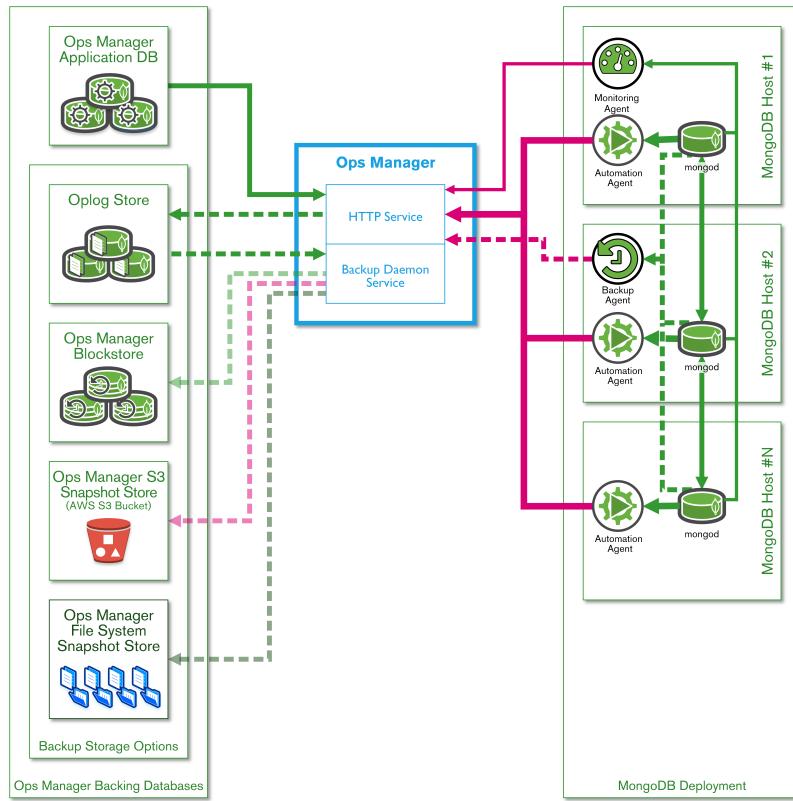
### **Components**

- 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)

## **16.4 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:

- SCRAM-SHA256
- LDAP
- Kerberos

### **Authenticating Between an Ops Manager Agent and Cluster**

- LDAP
- 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

## **16.5 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](https://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

# 17 Introduction to MongoDB BI Connector

*MongoDB Connector for BI (page 281)* An introduction to MongoDB Connector for BI

## 17.1 MongoDB Connector for BI

### Learning Objectives

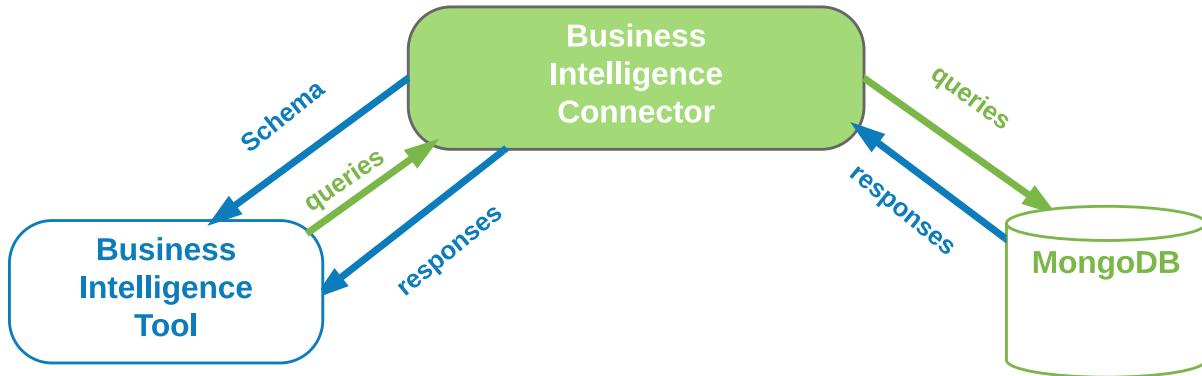
Upon completing this module students should understand:

- 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 generated, BI tools are able to request the corresponding 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 the following different authentication mechanisms:

- SCRAM-SHA-1
- SCRAM-SHA-256
- PLAIN (*LDAP Authentication*)
- GSSAPI(Kerberos)

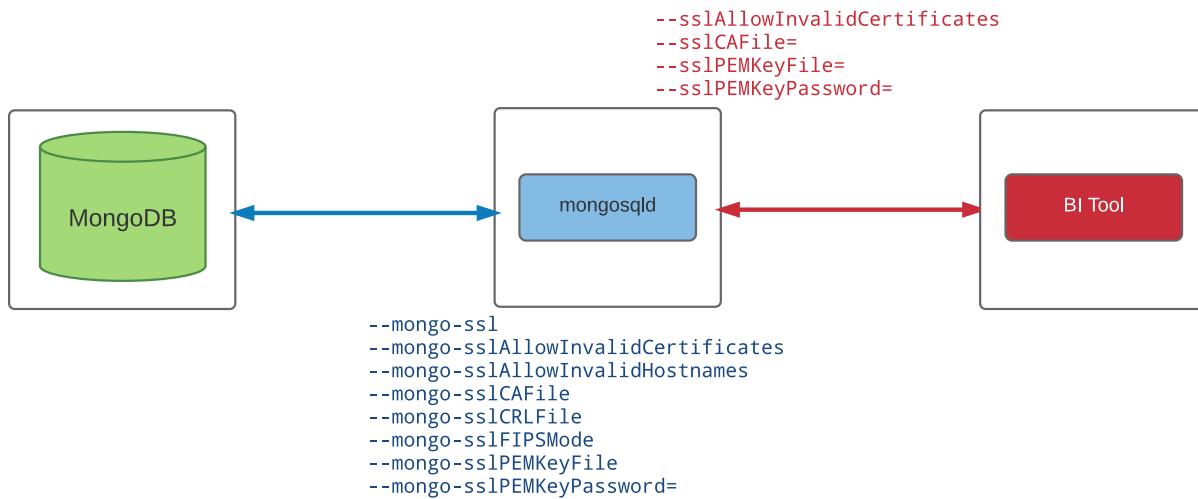
And external LDAP Authorization:

- 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 Compatibality

- BI Connector version 2.0 is compatible with **SQL-99 SELECT**<sup>66</sup> 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;
```

## ODBC Driver

- The MongoDB ODBC Driver for BI Connector provides connectivity between a SQL client and the MongoDB Connector for BI.
- Enables users to create a Data Source Name (DSN) and connect a variety of BI tools to the BI Connector.
- Includes an authentication plugin, which implements the client side of MongoDB-supported authentication mechanisms.

<sup>66</sup> <https://docs.mongodb.com/bi-connector/master/supported-operations/>

## **Supported Platforms**

- Windows (32-bit and 64-bit)
- macOS
- Ubuntu 14.04 and 16.04



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