MongoDB Administrator Training

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Release 3.4

MongoDB, Inc.

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Contents

1 Introduction

1.1 Warm Up

Introductions

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

Note:

- Tell the students about yourself:
  - Your role
  - 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?

Note:

- Ask students to go around the room and introduce themselves.
- Make sure the names match the roster of attendees.
- Ask about what roles the students play in their organization and note on attendance sheet.
- Ask what software stacks students are using.
  - With MongoDB and in general.
  - Note this information as well.

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?

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

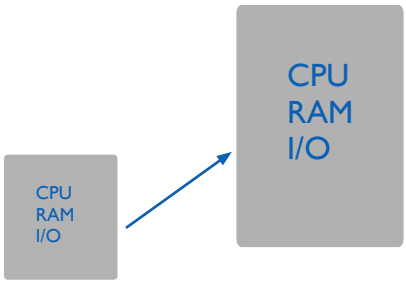
A MongoDB document expressed using JSON syntax.

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

Note:

- How would you represent this document in a relational database? How many tables, how many queries per page load?
- What are the pros/cons to this design? (hint: 1 million comments)
- Where relational databases store rows, MongoDB stores documents.
- Documents are hierarchical data structures.
- This is a fundamental departure from relational databases where rows are flat.

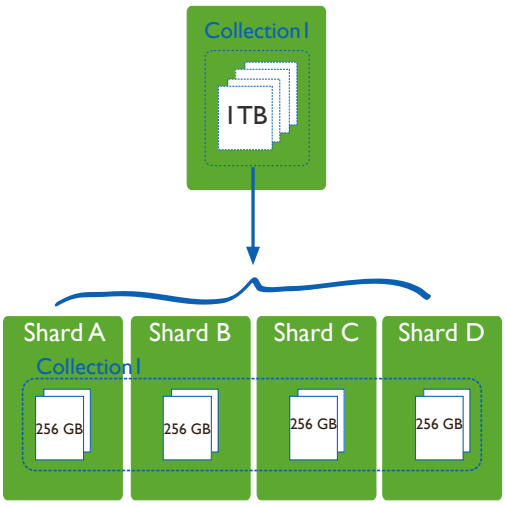
Vertical Scaling



Note: Another difference is in terms of scalability. With an RDBMS:

- If you need to support a larger workload, you buy a bigger machine.
- The problem is, machines are not priced linearly.
- The largest machines cost much more than commodity hardware.
- If your application is successful, you may find you simply cannot buy a large enough a machine to support your workload.

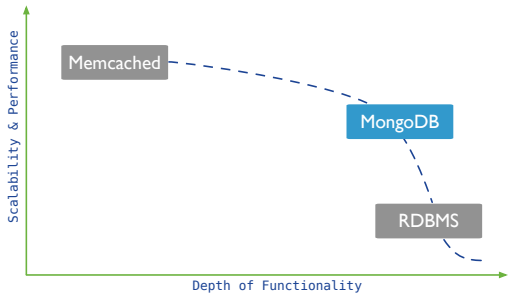
Scaling with MongoDB



Note:

- MongoDB is designed to be horizontally scalable (linear).
- MongoDB scales by enabling you to shard your data.
- When you need more performance, you just buy another machine and add it to your cluster.
- MongoDB is highly performant on commodity hardware.

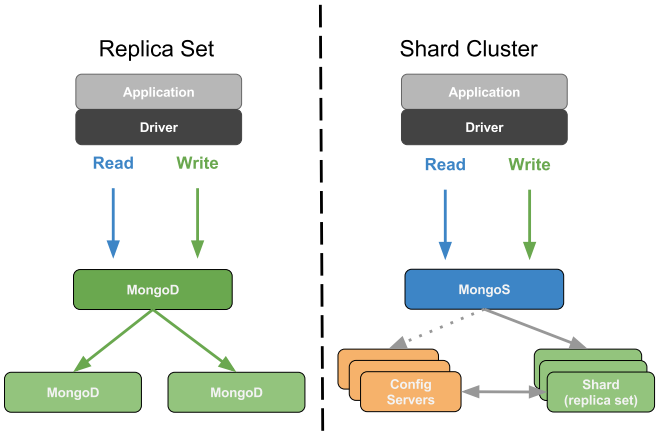
Database Landscape



Note:

- We've plotted each technology by scalability and functionality.
- At the top left, are key/value stores like memcached.
- These scale well, but lack features that make developers productive.
- At the far right we have traditional RDBMS technologies.
- These are full featured, but will not scale easily.
- Joins and transactions are difficult to run in parallel.
- MongoDB has nearly as much scalability as key-value stores.
- Gives up only the features that prevent scaling.
- We have compensating features that mitigate the impact of that design decision.

MongoDB Deployment Models



Note:

- MongoDB supports high availability through automated failover.
- Do not use a single-server deployment in production.
- Typical deployments use replica sets of 3 or more nodes.
  - The primary node will accept all writes, and possibly all reads.
  - Each secondary will replicate from another node.
  - If the primary fails, a secondary will automatically step up.
  - Replica sets provide redundancy and high availability.
- In production, you typically build a fully sharded cluster:
  - Your data is distributed across several shards.
  - The shards are themselves replica sets.
  - This provides high availability and redundancy at scale.

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[1].

Example Field Values

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

[1] http://json.org/

BSON

- MongoDB stores data as Binary JSON (BSON).
- MongoDB drivers send and receive data in this format.
- They map BSON to native data structures.
- BSON provides support for all JSON data types and several others.
- BSON was designed to be lightweight, traversable and efficient.
- See bsonspec.org[2].

Note: E.g., a BSON object will be mapped to a dictionary in Python.

BSON Hello World

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

// BSON
"\x16\x00\x00\x00\x02hello\x00
 \x06\x00\x00\x00world\x00\x00"
```

Note:

- \x16\x00\x00\x00 (document size)
- \x02 = string (data type of field value)
- hello\x00 (key/field name, \x00 is null and delimits the end of the name)
- \x06\x00\x00\x00 (size of field value including end null)
- world\x00 (field value)
- \x00 (end of the document)

A More Complex BSON Example

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

// BSON
"\x3b\x00\x00\x00\x04BSON\x00\x26\x00
 \x00\x00\x020\x00\x08\x00\x00
 \x00awesome\x00\x011\x00\x33\x33\x33\x33\x33\x33
 \x14\x40\x102\x00\xc2\x07\x00\x00
 \x00\x00"
```

[2] http://bsonspec.org/#/specification

Documents, Collections, and Databases

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

The `_id` Field

- All documents must have an `_id` field.
- The `_id` is immutable.
- If no `_id` is specified when a document is inserted, MongoDB will add the `_id` field.
- MongoDB assigns a unique ObjectId as the value of `_id`.
- Most drivers will actually create the ObjectId if no `_id` is specified.
- The `_id` field is unique to a collection (namespace).

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[3]

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”

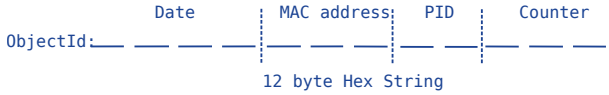
Note: Take the opportunity to show students how to query using `$type` operator:

```
use datatypes
db.sample.insertMany([
  {a: 1, b: "hello"},
  {a: 1.2, b: { c: "goodbye"}}
])
```

[3] http://bsonspec.org/

```
db.sample.find({b: {$type: 'string'}})
db.sample.find({b: {$type: 3}})
```

ObjectId




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

Note:

- An ObjectId is a 12-byte value.
- The first 4 bytes are a datetime reflecting when the ObjectID was created.
- The next 3 bytes are the MAC address of the server.
- Then a 2-byte process ID
- Finally, 3 bytes that are monotonically increasing for each new ObjectId created within a collection.

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[4].

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

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

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

Note: Using a double as the argument can lead to loss of precision. A string argument is preferred.

```
MongoDB Enterprise > NumberDecimal("999.4999999999999")
NumberDecimal("999.4999999999999")
MongoDB Enterprise > NumberDecimal(999.4999999999999)
NumberDecimal("999.500000000000")
```

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.

Note: Show the following example:

```
MongoDB Enterprise > use foo
MongoDB Enterprise > db.numbers.insertMany([
  { "_id" : 1, "val" : NumberDecimal( "9.99" ), "description" : "Decimal" },
  { "_id" : 2, "val" : 9.99, "description" : "Double" },
  { "_id" : 3, "val" : 10, "description" : "Double" },
  { "_id" : 4, "val" : NumberLong(10), "description" : "Long" },
  { "_id" : 5, "val" : NumberDecimal( "10.0" ), "description" : "Decimal" }
])
```

[4] https://docs.mongodb.com/ecosystem/drivers/

```
MongoDB Enterprise > db.numbers.find().sort({"val": 1})
{ "_id" : 1, "val" : NumberDecimal("9.99"), "description" : "Decimal" }
{ "_id" : 2, "val" : 9.99, "description" : "Double" }
{ "_id" : 3, "val" : 10, "description" : "Double" }
{ "_id" : 4, "val" : NumberLong(10), "description" : "Long" }
{ "_id" : 5, "val" : NumberDecimal("10.0"), "description" : "Decimal" }

MongoDB Enterprise > db.numbers.find({"val": NumberDecimal("10")}).sort({"val": 1})
{ "_id" : 3, "val" : 10, "description" : "Double" }
{ "_id" : 4, "val" : NumberLong(10), "description" : "Long" }
{ "_id" : 5, "val" : NumberDecimal("10.0"), "description" : "Decimal" }

MongoDB Enterprise > db.numbers.find({"val": NumberDecimal("9.99")}).sort({"val": 1})
{ "_id" : 1, "val" : NumberDecimal("9.99"), "description" : "Decimal" }

MongoDB Enterprise > db.numbers.find({"val": 9.99}).sort({"val": 1})
{ "_id" : 2, "val" : 9.99, "description" : "Double" }
```

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
- Solaris

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
```

Note:

- You might want to add the MongoDB bin directory to your path, e.g.
- Once installed, create the MongoDB data directory.
- Make sure you have write permission on this directory.

If you are using Koding these are a few instructions you can follow:

- Download MongoDB tarbal and setup the environment

```
wget http://downloads.mongodb.org/linux/mongodb-linux-x86_64-ubuntu1204-3.2.
↪1.tgz
tar xzvf mongodb-linux-x86_64-ubuntu1204-3.2.1.tgz
cd mongodb-linux-x86_64-ubuntu1204-3.2.1/bin
export PATH=`pwd`:$PATH
```

Install on Windows

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

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

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

Note: Can also install Windows as a service, but not recommended since we need multiple mongod processes for future exercises

---

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
```

Note: Optionally, talk about the –dbpath variable and specifying a different location for the data files

---

Launch a `mongod`

Explore the `mongod` command.

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

Launch a `mongod` with the MMAPv1 storage engine:

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

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

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

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

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

Note:

- Please verify that all students have successfully installed MongoDB.
- Please verify that all can successfully launch a mongod.

The MMAPv1 Data Directory

```
ls /data/db
```

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

Note: Files for a single database increase in size as follows:

- sample.0 is 64 MB
- sample.1 is 128 MB
- sample.2 is 256 MB, etc.
- This continues until sample.5, which is 2 GB
- All subsequent data files are also 2 GB.

The WiredTiger Data Directory

```
ls /data/db
```

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

Import Exercise Data

```
unzip usb_drive.zip

cd usb_drive

mongoimport -d sample -c tweets twitter.json

mongoimport -d sample -c zips zips.json

mongoimport -d sample -c grades grades.json

cd dump

mongorestore -d sample city

mongorestore -d sample digg
```

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

Note: For local installs

- Import the data provided on the USB drive into the *sample* database.

For Koding environment

- Download *sample* data from:

```
wget https://www.dropbox.com/s/54xsjwq59zoq1fe/sample.tgz
```

Launch a Mongo Shell

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

```
mongo
```

Display available commands.

```
help
```

Note: On Koding environment do the following:

- Create a new *Terminal* and rename it to **Client**

Explore Databases

Display available databases.

```
show dbs
```

To use a particular database we can type the following.

```
use <database_name>

db
```

Note:

- This assigns the variable `db` to a connection object for the selected database.
- We can display the name of the database we are currently using by evaluating `db` in the mongo shell.
- Highlight the power of the Mongo shell here.
- It is a fully programmable JavaScript environment.
  - To demonstrate this you can use the following code block

```
for(i=0;i<10;i++){ print("this is line "+i)}
```

Exploring Collections

```
show collections

db.<COLLECTION>.help()

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

Note:

- Show the collections available in this database.
- Show methods on the collection with parameters and a brief explanation.
- Finally, we can query for the documents in a collection.

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 CRUD

2.1 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()
```

Note:

- Make sure the students are performing the operations along with you.
- Some students will have trouble starting things up, so be helpful at this stage.

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()
```

Note:

- Note that you can assign an _id to be of almost any type.
- It does not need to be an ObjectId.

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" } )
```

Note:

- The following will fail because it attempts to use an array as an `_id`.

```
db.movies.insertOne( { "_id" : [ "Star Wars",
                                 "The Empire Strikes Back",
                                 "Return of the Jedi" ] } )
```

- The second insert with `_id : "Star Wars"` will fail because there is already a document with `_id` of "Star Wars" in the collection.
- The following will fail because it is a malformed document (i.e. no field name, just a value).

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

`insertMany()`

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

Note:

- In the case of an ordered bulk operation, every operation will be executed in the order they are added to the bulk operation.
- In the case of an unordered bulk operation however there is no guarantee what order the operations are executed.
- With an unordered bulk operation, the operations in the list may be reordered to increase performance.

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()
```

Note:

- This example has a duplicate key error.
- Only the first 3 documents will be inserted.

Unordered `insertMany()`

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

Example: Unordered `insertMany()`

Experiment with the following insert.

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

The Shell is a JavaScript Interpreter

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

Exercise: Creating Data in the Shell

Experiment with the following commands.

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

db.stuff.find()
```

Deleting Documents

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

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

Using `deleteOne()`

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

Using `deleteMany()`

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

Example: Deleting Documents

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

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

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

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

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

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

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

Dropping a Collection

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

Note: Mention that `drop()` is more performant than `deleteMany()`.

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.testcol1.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
```

2.2 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" } )
```

Note: Matching Rules:

- Any field specified in the query must be in each document returned.
- Values for returned documents must match the conditions specified in the query document.
- If multiple fields are specified, all must be present in each document returned.
- Think of it as a logical AND for all fields.

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.

Note: Students might find it helpful to think of an array field as having multiple values – one for each of its elements.

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" ] } )
```

Note: Later, we'll see operators that will allow us to do things like match all documents where an array field contains any of a set of values.

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
```

Note:

- This query finds documents where:
  - There is a `filming_locations` field.
  - The `filming_locations` field contains one or more embedded documents.
  - At least one embedded document has a field `country`.
  - The field `country` has the specified value (“USA”).
- In this collection, `filming_locations` is actually an array field.
- The embedded documents we are matching are held within these arrays.

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 } )
```

The last `find()` fails because MongoDB cannot determine how to handle unnamed fields such as `box_office`.

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
```

Note:

- With the `find()` above, the shell iterates over the first 20 documents.
- `it` causes the shell to iterate over the next 20 documents.
- Can continue issuing `it` commands until all documents are seen.

Example: Cursor Objects in the Mongo Shell

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

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

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

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

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

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

Cursor Methods

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

Example: Using `count()`

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

// all 100
db.testcol.count()

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

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

Note:

- You may pass a query document like you would to `find()`.
- `count()` will count only the documents matching the query.
- Will return the number of documents in the collection if you do not specify a query document.
- The last query in the above achieves the same result because it operates on the cursor returned by `find()`.

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 } )
```

Note:

- Sort can be executed on a cursor until the point where the first document is actually read.
- If you never delete any documents or change their size, this will be the same order in which you inserted them.
- Sorting two or more fields breaks the convention of javascript objects that key / value pairs are unordered.
- In some drivers you may need to take special care with this.
- For example, in Python, you would usually query with a dictionary.
- But dictionaries are unordered in Python, so you would use an array of tuples instead.

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" )
```

Note: Returns

```
{
    "values" : [ "Jaws", "Home Alone" ],
    "stats" : { ... },
    "ok" : 1
}
```

2.3 Query Operators

Learning Objectives

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

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

Comparison Query Operators

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

Example (Setup)

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

Example: Comparison Operators

```
db.movies.find()

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

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

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

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

Logical Query Operators

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

Example: Logical Operators

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

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

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

Note:

- `db.movies.find( { "imdb_rating" : { $not : { $gt : 7 } } } )` also returns everything that doesnt have an "imdb_rating"

Example: Logical Operators

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

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

Element Query Operators

- `$exists`: Select documents based on the existence of a particular field.
- `$type`: Select documents based on their type.
- See BSON types[5] for reference on types.

Example: Element Operators

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

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

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

Array Query Operators

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

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 : {
```

[5] http://docs.mongodb.org/manual/reference/bson-types

```
        "city" : "Florence",
        "country" : "Italy"
      } } } )
```

Note:

- Comparing the last two queries demonstrates `$elemMatch`.

2.4 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?

Note:

- 650

```
db.grades.find( { student_id: { $lt: 65 } } ).count()
```

Exercise: Inspection Result "Fail" & "Pass"

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

Note:

- 16808

```
db.inspections.find({ "result": { $in: [ "Pass", "Fail" ] } }).count()
```

Exercise: View Count > 1000

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

Note:

- Requires querying into subdocuments

```
db.stories.find( { "shorturl.view_count": { $gt: 1000 } } )
```

Exercise: Most comments

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

---

Note:

- You can .limit() with .sort()

```
db.stories.find({media:"news"}).sort({comments:-1}).limit(1)[0].comments
```

Exercise: Television or Videos

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

Note:

```
db.stories.find( { "$or": [ { "topic.name": "Television" },
                            { media: "videos" } ] } ).skip(5).limit(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.)

Note:

```
db.stories.find( { media: { $in: [ "news", "images" ] },
                   "topic.name": "Comedy" })
```

2.5 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

Note:

- By "simplest," we mean that it's simple conceptually – that replacing a document is a sort of basic idea of how an update happens.
- We will later see update methods that will involve only changing some fields.

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

Note:

- If they try to modify the _id, it will throw an error

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() } )
```

Note:

- Ask the students why the first replace killed the `title` field
- Ask why the final replace failed

The `updateOne()` Method

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

`$set` and `$unset`

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

Example (Setup)

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

Example: `$set` and `$unset`

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

Update Operators

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

Example: Update Operators

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

The `updateMany()` Method

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

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

Example: `updateMany()`

```
// let's start tracking the number of sequals 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,
      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 } } )
```

Note:

- Pattern for time series data
- Displaying charts is easy
  - Can change granularity to by the minute, hour, day, etc.

Array Operators

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

Note:

- These operators may be applied to array fields.

Example: Array Operators

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

Note:

- Pass $pop a value of -1 to remove the first element of an array and 1 to remove the last element in an array.

The Positional $ Operator

- $[6] is a positional operator that specifies an element in an array to update.
- It acts as a placeholder for the first element that matches the query document.
- $ replaces the element in the specified position with the value given.
- Example:

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

Example: The Positional $ Operator

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

[6] http://docs.mongodb.org/manual/reference/operator/update/postional

Upserts

- If no document matches a write query:
  - By default, nothing happens
  - With `upsert: true`, inserts one new document
- 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 } )
```

Note:

- Note that an updateMany works just like updateOne when no matching documents are found.
- First query updates the document with “title” = “Jaws” by incrementing “budget”
- Second query: 1) creates a new document, 2) assigns an _id, 3) sets “title” to “Jaws II” 4) performs the update
- Third query: 1) creates a new document, 2) sets “title” : “Jaws III”, 3) Set budget to 1

`save()`

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

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

Example: `save()`

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

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

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

Note:

- A lot of users prefer to use update/insert, to have more explicit control over the operation

---

Be careful with `save()`

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

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

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

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

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

doc.imdb_rating = 7.4


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

`findOneAndUpdate()` and `findOneAndReplace()`

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

`findOneAndUpdate()` and `findOneAndReplace()` Options

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

Example: `findOneAndUpdate()`

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

`findOneAndDelete()`

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

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

2.6 Lab: Updating Documents

Exercise: Pass Inspections

In the sample.inspections namespace, 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.

Note:

```
db.inspections.updateMany({result: "Completed"},
                          {$set: {result: "No Violation Issued"}})
{
  "acknowledged": true,
  "matchedCount": 20,
  "modifiedCount": 20
}
```

Exercise: Set `fine` value

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

Note:

```
db.inspections.updateMany({result: "Fail"},
                          {$set: {fine: 100}})
{
  "acknowledged": true,
  "matchedCount": 1120,
  "modifiedCount": 1120
}
```

Exercise: Increase `fine` in ROSEDALE

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

Note:

```
db.inspections.updateMany({"address.city": "ROSEDALE", result: "Fail" },
                          {$inc: {fine: 150}})
{
  "acknowledged": true,
  "matchedCount": 1120,
  "modifiedCount": 1120
}
```

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"
- MongoDB's address is

```
{city: 'New York', zip: 10036, street: '43', number: 229}
```

Note:

```
db.inspections.updateOne({business_name: "MongoDB"},
                         {$set: {
                           address: {
                               city: "New York",
                               zip: 10036,
                               street: "43",
                               number: 229 },
                           result: "AWESOME",
                           id: "XXXXXXX",
                           certificate_number: 140021221},
                          $currentDate: {date: {$type: "date"}}},
                          {upsert: true})
{
        "acknowledged" : true,
        "matchedCount" : 0,
        "modifiedCount" : 0,
        "upsertedId" : ObjectId("573f29d8dc8e6b0ba6e8f594")
}
```

We can also add a variation to see if students can determine how to sort results so they can look at certificate numbers granted in sequence. Kudos to students that recognize the need to filter for certificate_number values that are integers and also do some form of projection.

```
db.inspections.find(
    {certificate_number: {$type:16}},
    {certificate_number: 1,
     id:1}).sort({certificate_number:-1}).limit(1)
```

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.

Note:

- Talk about how this can be used for time series data, real-time graphs/charts

```
db.product_metrics.updateOne(
    {name: "backpack" },
    {$inc: { "purchases_past_7_days.4" : 200 } } )
```

3 Indexes

3.1 Index Fundamentals

Learning Objectives

Upon completing this module students should understand:

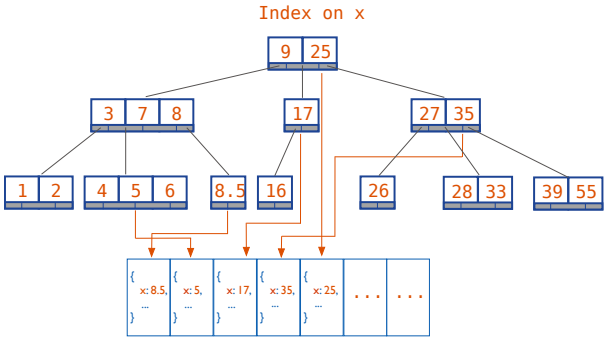
- The impact of indexing on read performance
- The impact of indexing on write performance
- How to choose effective indexes
- The utility of specific indexes for particular query patterns

---

Note:

- Ask how many people in the room are familiar with indexes in a relational database.
- If the class is already familiar with indexes, just explain that they work the same way in MongoDB.

Why Indexes?



Note:

- Without an index, in order to find all documents matching a query, MongoDB must scan every document in the collection.
- This is murder for read performance, and often write performance, too.
- If all your documents do not fit into memory, the system will page data in and out in order to scan the entire collection.
- An index enables MongoDB to locate exactly which documents match the query and where they are located on disk.
- MongoDB indexes are based on B-trees.

Types of Indexes

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

Note:

- There are also hashed indexes and TTL indexes.
- We will discuss those elsewhere.

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()
```

Note:

- Make sure the students are using the sample database.
- Review the structure of documents in the tweets collection by doing a find().
- We'll be looking at the user subdocument for documents in this collection.

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

---

Note:

- Default will be helpful if you're worried running the query could cause sever performance problems
- executionStats will be the most common verbosity level used
- allPlansExecution is for trying to determine WHY it is choosing the index it is (out of other candidates)

`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 returened 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

---

Note:

- By documents "touched", we mean that they had to be in memory (either already there, or else loaded during the query)
- By "better" index, we mean one that matches the query more closely.

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()`

Note:

- Has not yet been implemented for the new CRUD API.
  - No `updateOne()`, `replaceOne()`, `updateMany()`, `deleteOne()`, `deleteMany()`, `findOneAndUpdate()`, `findOneAndDelete()`, `findOneAndReplace()`, `insertMany()`

`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()
```

Note:

- This will get confusing for students, may want to spend extra time here with more examples

---

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 } )
```

Note:

- Walk through the "nWouldModify" field in the output to show how many documents would have been updated

---

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.

Note:

- nscannedObjects should now be a much smaller number, e.g., 8.
- Operations teams are accustomed to thinking about indexes.
- With MongoDB, developers need to be more involved in the creation and use of indexes.

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

Note:

- For mmapv1, all indexes will be modified whenever the document moves on disk
  - i.e., When it outgrows its record space

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.

Note:

- If your system has limited RAM, then using the index will force other data out of memory.
- When you need to access those documents, they will need to be paged in again.

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 } )
```

Note:

- Partial indexes are now preferred to sparse.
- You can create the functional equivalent of a sparce index with `{ field : { $exists : true } }` for your partialFilterExpression.

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 } )
```

Note:

- Unique indexes do not work well with multikey indexes
- The following would produce a collision and return an error

```
db.test.insertMany([
  {a: [1, 2, 3]},
  {a: [2, 4, 6]}
])
db.test.createIndex({a: 1}, {unique: true})
```

- Unique indexes do not evaluate subdocument contents
- The following would **not** produce an error

```
db.test.insertMany([
  {a: {b: 2, c: 3}},
  {a: {c: 3, b: 2}}
])
db.test.createIndex({a: 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 } )
```

3.2 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")
```

Note:

- Help students understand the output from explain
- Specifically highlight:
  - That this required a COLLSCAN
  - `totalDocsExamined` vs `nReturned`
  - Note `executionTimeMillisEstimate`

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

Note:

- Highlight and discuss the following:
  - That this was an IXSCAN
  - `totalDocsExamined`, `totalKeysExamined`, and `nReturned`
  - `executionTimeMillisEstimate`

```
db.routes.createIndex({"airlines.id": -1})
```

3.3 Compound Indexes

Learning Objectives

Upon completing this module students should understand:

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

Introduction to Compound Indexes

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

The Order of Fields Matters

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

- Equality tests, e.g.,

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

- Range queries, e.g.,

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

- Sorting, e.g.,

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

Note:

- The order in which the fields are specified is of critical importance.
- It is especially important to consider query patterns that require two or more of these operations.

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"

Note:

- The index we have created stores the range values before the equality values.
- The documents with timestamp values 2, 3, and 4 were found first.
- Then the associated anonymous values had to be evaluated.

A Different Compound Index

Drop the index and build a new one with user.

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

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

`totalKeysExamined` is 2. `n` is 2.

`totalKeysExamined == n`

username	timestamp
“anonymous”	1
“anonymous”	2
“anonymous”	4
“sam”	2
“martha”	5

Note:

- This illustrates why.
- There is a fundamental difference in the way the index is structured.
- This supports a more efficient treatment of our query.

Let Selectivity Drive Field Order

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

Adding in the Sort

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

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

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

In-Memory Sorts

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

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

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

Avoiding an In-Memory Sort

Rebuild the index as follows.

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

- We no longer have an in-memory sort, but need to examine more keys.
- `totalKeysExamined` is 3 and 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

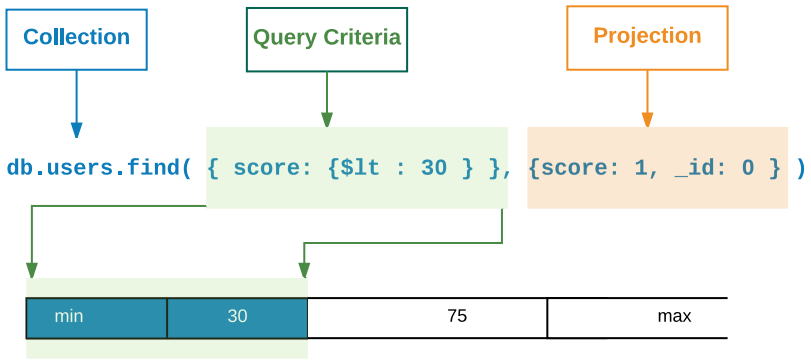
Note:

- general index illustration
- we can see that the returned results are already sorted.
- no need to perform an in-memory sort

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")
```

3.4 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)
```

Note:

- Work through method of explaining query with .explain("executionStats")
- Look at differences between (timestamp, active) and (active, timestamp)

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 } )
```

Note:

- { active: 1, 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 })
```

Note:

- Trick question, the answer most students will give is { x: 1, tstamp: 1 }, however, the $in will require an in-memory sort
- (tstamp) or (tstamp, x) are the only indexes that will prevent an in-memory sort, but aren't selective at all

---

3.5 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 })
```

Note:

- Note: JSON is a dictionary and doesn't guarantee order, indexing the top level array (comments array) won't work

---

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 } )
```

Note:

```
// Never do this, won't give you the results expected
// JSON is a dictionary, and won't preserve ordering, second query will return no␣
↪results

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

Note:

```
// 3 documents
db.player.find( { "last_moves" : [ 3, 4 ] } )
// Uses the multi-key index
db.player.find( { "last_moves" : [ 3, 4 ] } ).explain()

// No documents
db.player.find( { "last_moves" : 3 } )

// Does not use the multi-key index, because it is naive to position.
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 } )
```

Note:

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

// x : [ 1, 11 ] array still comes first, because it 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 ] } )
```

3.6 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[7] for more details.
- We discuss sharding in detail in another module.

Limitations

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

Note:

- For a field on which there is both a hashed index and a non-hashed index, MongoDB will use the non-hashed index for range queries.

---

[7] 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" } )
```

3.7 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.

Note:

- Instructor, please draw a 2d coordinate system with axes for lat and lon.
- Draw a red (or some other color) x to represent the query document.

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.

Note:

- Draw several Xs to represent other documents.

Find Nearby Documents

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

Flat vs. Spherical Indexes

There are two types of geospatial indexes:

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

Flat Geospatial Index

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

Spherical Geospatial Index

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

Creating a 2d Index

Creating a 2d index:

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

Possible options key-value pairs:

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

Exercise: Creating a 2d Index

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

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

Note: Answer:

```
db.testcol.createIndex( { xy : "2d" }, { min : -20, max : 20, bits : 10 } )
```

Inserting Documents with a 2d Index

There are two accepted formats:

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

Exercise: Inserting Documents with 2d Fields

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

Note: Answer:

```
db.twoD.insert( { xy : [ -3, 0 ] } )  // legacy coordinate pairs
db.twoD.insert( { xy : { lng : 3, lat : 0.4 } } )  // document with lng, lat
db.twoD.find()  // both went in OK
db.twoD.insert( { xy : 5 } )  // insert works fine
// Keep in mind that the index doesn't apply to this document.
db.twoD.insert( { xy : [ 0, -500 ] } )
// Generates an error because -500 isn't between +/-20.
db.twoD.insert( { xy : [ 0, 0.00003 ] } )
db.twoD.find()
// last insert worked fine, even though the position resolution is below
// the resolution of the Geohash.
```

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.

Note:

- A geodesic may not go where you think.
- E.g., the LineString that joins the points [90, 5] and [-90, 5]:
  - Does NOT go through the point [0, 5]
  - DOES go through the point [0, 90] (i.e., the North Pole).

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> ] ] } }
```

Note:

- Legacy coordinate pairs are treated as Points by a 2dsphere index.

Polygons

Simple Polygon:

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

Polygon with One Hole:

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

Other Types of 2dsphere Objects

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

Exercise: Inserting geoJSON Objects (1)

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

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

Note:

```
laguardia = [ -73.8726, 40.7772 ]
jfk = [ -73.7789, 40.6397 ],
newark = [ -74.1686, 40.6925 ]
heathrow = [ -0.4614, 52.4775 ]
gatwick = [ -0.1903, 51.1481 ]
stansted = [ 0.2350, 51.8850 ]
luton = [-0.4333, 51.9000 ]
```

- Remember, we use [latitude, longitude].
- In this example, we have made North (latitude) and East (longitude) positive.
- West and South are negative.

Exercise: Inserting geoJSON Objects (2)

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

Note:

```
nyPorts = [ laguardia, jfk, newark ]
londonPorts = [ heathrow, gatwick, stansted, luton ]
flightNumbers = [ "AA4453", "VA3333", "UA2440" ]
```

Exercise: Inserting geoJSON Objects (3)

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

Note:

```
for (takeoff in ny_ports) {
    for (landing in london_ports) {
        db.flights.insert(
            { origin : { type : "Point",
                         coordinates : ny_ports[takeoff] },
              destination : { type : "Point",
                              coordinates : london_ports[landing] },
              flightNumber : flightNumbers[takeoff] } )
     }
}
```

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.

Note:

```
db.flights.createIndex( { origin : "2dsphere",
                          destination : "2dsphere",
                          flightNumber : 1 } )

db.flights.createIndex( { destination : "2dsphere" } )

db.flights.getIndexes() // see the indexes.
```

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.

3.8 Using Compass with Indexes

Learning Objectives

Upon completing this module, students should understand:

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

Introduction

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

/modules/compass

Execute a geoJSON query with Compass

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

Execute Query (cont)

- Importing the data

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

- In Compass, executing the query

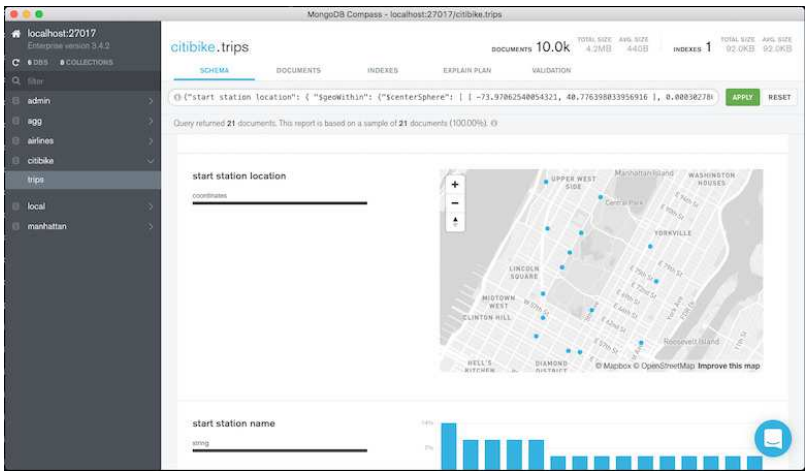
```
{
 "start station location": { "$geoWithin": { "$centerSphere": [
 [ -73.97062540054321, 40.776398033956916 ], 0.000302786 ] } },
 "end station location": { "$geoWithin": { "$centerSphere": [
 [ -73.9879247077942, 40.742201076382784 ], 0.00006308 ] } }
}
```

Note:

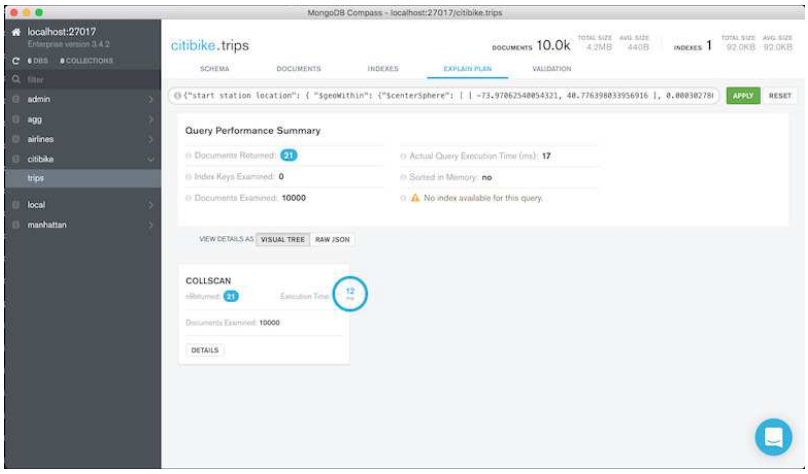
- The equatorial radius of the earth is 6378.2 kilometers, or 3963.2 miles
- How did we calculate the radians we wanted?
  - desired distance / equatorial radius
  - 1.93 / 6378.2 and .40/6378.2 for kilometers
  - 1.2 / 3963.2 and .25/3963.2 for miles

---

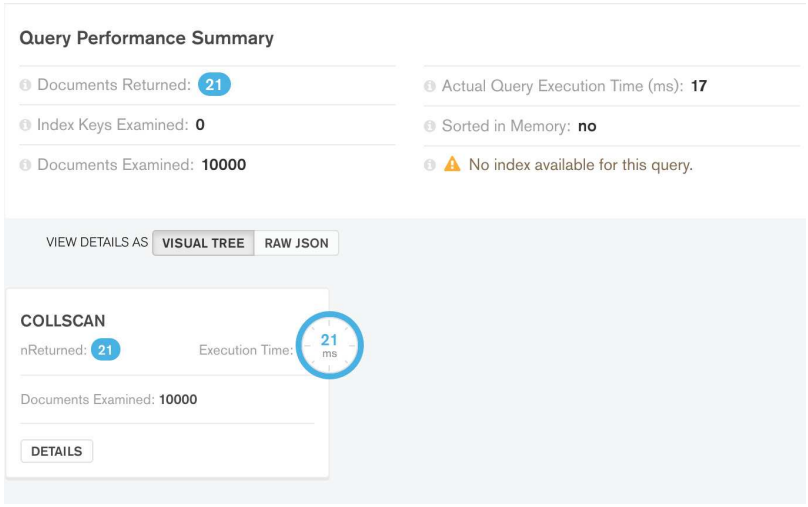
geoJSON Query Example



geoJSON Query Explain Plan



geoJSON Query Explain Detail



Query Explain (cont)

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

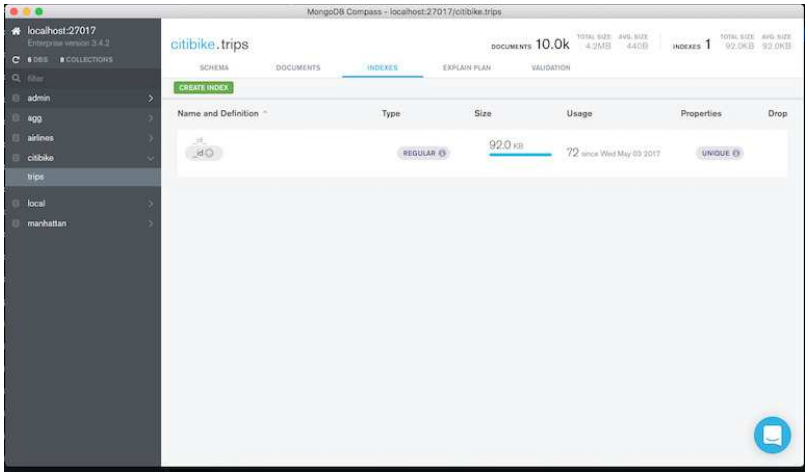
Creating an Index Using Compass

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

Note:

- The index view shows helpful information about the indexes
- The index name and type
- Size, usage, and index properties

The Index Tab

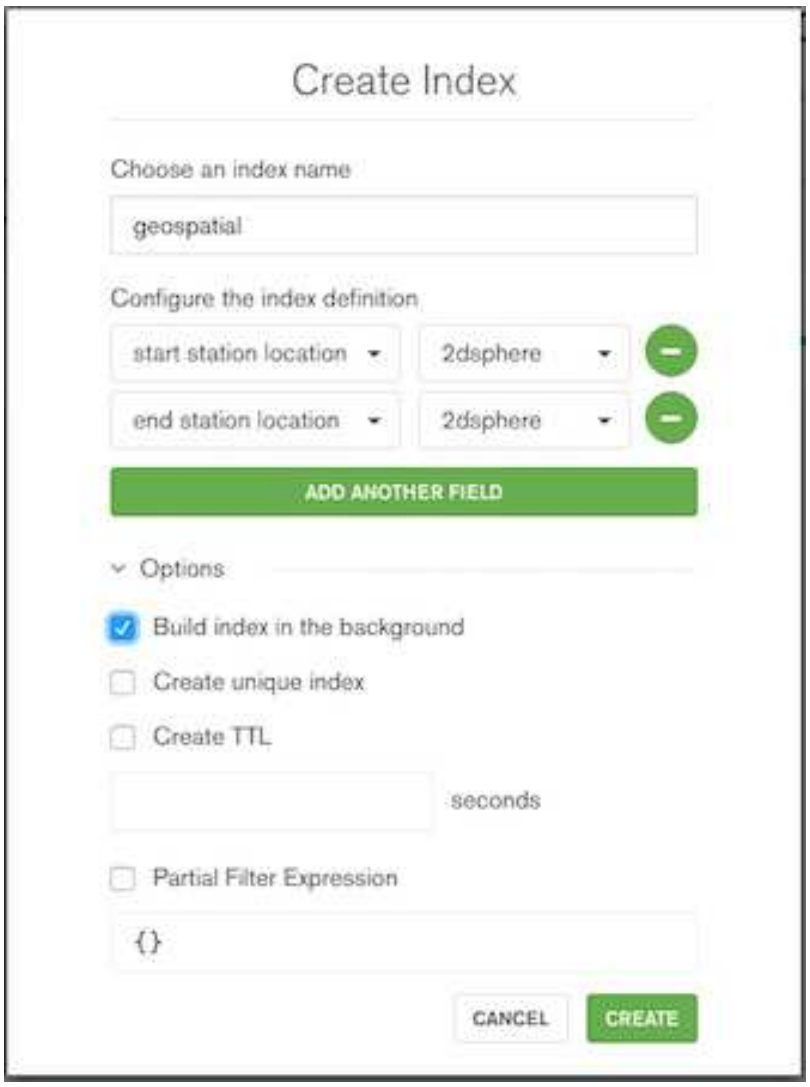


Creating an Index Example

Verifying the Index

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

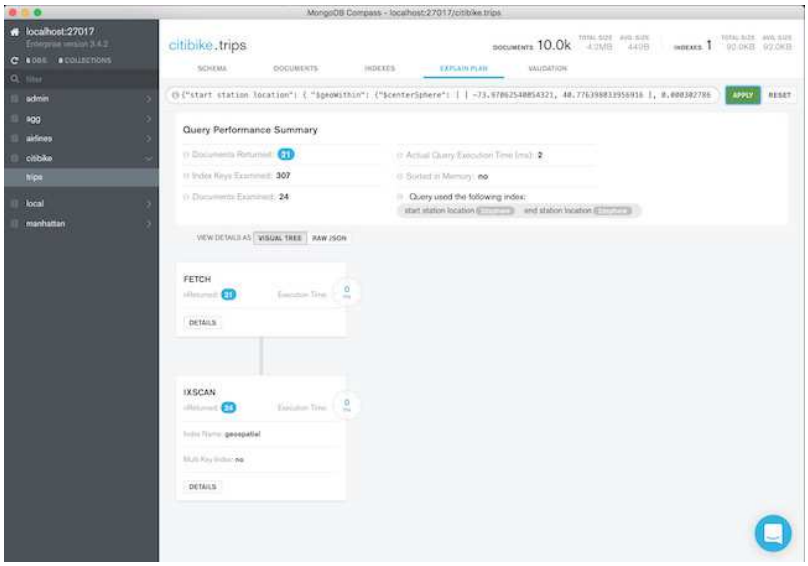
```
{
 "start station location": { "$geoWithin": { "$centerSphere": [
 [ -73.97062540054321, 40.776398033956916 ], 0.000302786 ] } },
 "end station location": { "$geoWithin": { "$centerSphere": [
 [ -73.9879247077942, 40.742201076382784 ], 0.00006308 ] } }
}
```



Index Performance

Note:

- Highlight the differences now that our index is being used
- Actual Query Time is dramatically reduced
- The view detail now shows the stages
- *Query used the following index* shows the index used



3.9 TTL Indexes

Learning Objectives

Upon completing this module students should understand:

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

TTL Index Basics

- TTL is short for "Time To Live".
- TTL indexes must be based on a field of type `Date` (including `ISODate`) or `Timestamp`.
- Any `Date` field older than `expireAfterSeconds` 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);
}
```

3.10 Text Indexes

Learning Objectives

Upon completing this module, students should understand:

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

What is a Text Index?

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

Creating a Text Index

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

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

Exercise: Creating a Text Index

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

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

Creating a Text Index with Weighted Fields

- Default weight of 1 per indexed field.
- Weight is relative to other weights in 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.

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" } }
) )
```

3.11 Partial Indexes

Learning Objectives

Upon completing this module, students should be able to:

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

What are Partial Indexes?

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

Creating Partial Indexes

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

Example: Creating Partial Indexes

- Consider the following schema:

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

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

Example: Creating Partial Indexes (Continued)

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

Note:

- We are choosing to name this index; the name is optional
- This is a single-field index, but other index types work the same
- The filter can be on fields other than the index keys

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
```

Note:

- Using `{ $exists: true }` is how to create sparse index functionality for a single field using a partial index
- Sparse indexes still work, but we now recommend people use partial indexes going forward

---

Quiz

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

Note:

- Correct answer: only those documents that match the `partialFilterExpression`
- Wrong answers:
  - All documents. This is the case for standard indexes.
  - Only those documents where the field exists. This is the case for sparse indexes.

Identifying Partial Indexes

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

Note:

- You can identify a partial index from the output of getIndexes()
- The presence of of a partialFilterExpression indicates a partial index
- This also allows you to identify the coverage of the index
- This index is on the “integer” field
- But the partialFilterExpression is on the “importance” field
  - Only indexing the documents with “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" }
```

Note:

- The first and last documents are the ones that will be indexed.

3.12 Lab: Finding and Addressing Slow Operations

Set Up

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

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

In the shell that launches execute the following method

```
performance.init()
```

Exercise: Determine Indexes Needed

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

Note:

- Look at the logs to find queries over 100ms
- { "active": 1 }
- { "str": 1, "x": 1 }

3.13 Lab: Using `explain()`

Exercise: explain("executionStats")

Drop all indexes from previous exercises:

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

Create an index for the "active" field:

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

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

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

4 Storage

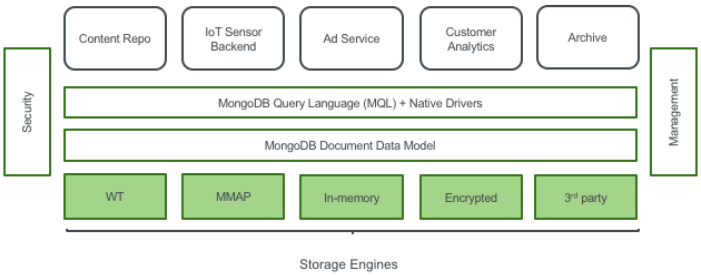
4.1 Introduction to Storage Engines

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?



Note:

- A database storage engine is the underlying software component that a database management system uses to create, read, update, and delete data from a database.
- Talk through the diagram and how storage engines are used to abstract access to the data

---

How Storage Engines Affect Performance

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

Note: Can use an extreme example, such as the difference between an in-memory storage engine and mmap/wiredtiger for write performance

---

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

With the release of MongoDB 3.2, three storage engine options are available:

- MMAPv1
- WiredTiger (default)
- In-memory storage (Enterprise only)

Specifying a MongoDB Storage Engine

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

```
mongod --storageEngine mmapv1
```

Note:

- wiredTiger is used if storageEngine parameter isn't specified

---

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[8].

MMAPv1 Storage Engine

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

```
mongod --storageEngine mmapv1
```

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

MMAPv1 Workloads

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

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

Note:

- None of the use cases above grow the documents (and potentially force them to move), one flaw with mmapv1

---

[8] http://docs.mongodb.org/manual/reference/program/mongod/#storage-options

Power of 2 Sizes Allocation Strategy

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

Compression in MongoDB

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

WiredTiger Storage Engine

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

```
mongod --storageEngine wiredTiger
```

WiredTiger Compression Options

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

Configuring Compression in WiredTiger

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

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

Configuring Memory Usage in WiredTiger

Use the `wiredTigerCacheSize` parameter to designate the amount of RAM for the WiredTiger storage engine.

- By default, this value is set to the maximum of half of physical RAM or 1GB
- If the database server shares a machine with an application server, it is now easier to designate the amount of RAM the database server can use

---

Note:

- Unlike MMAPv1, WiredTiger can be configured to use a finite amount of RAM.

Journaling in MMAPv1 vs. WiredTiger

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

MMMAPv1 Journaling Mechanics

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

MMAPv1 Journaling Mechanics (Continued)

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

WiredTiger Journaling Mechanics

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

Storage Engine API

MongoDB 3.0 introduced a storage engine API:

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

Conclusion

- MongoDB 3.0 introduces pluggable storage engines.
- Current options include:
  - MMAPv1 (default)
  - WiredTiger
- WiredTiger introduces the following to MongoDB:
  - Compression
  - Document-level concurrency
- The storage engine API enables third parties to develop storage engines. Examples include:
  - RocksDB
  - An HDFS storage engine

Note:

- Good time to draw what this replica set could look like on the board and talk through even more possibilities

---

5 Replica Sets

Introduction to Replica Sets **(page 106)** An introduction to replication and replica sets

Elections in Replica Sets **(page 110)** The process of electing a new primary (automated failover) in replica sets

Replica Set Roles and Configuration **(page 116)** Configuring replica set members for common use cases

The Oplog: Statement Based Replication **(page 118)** The process of replicating data from one node of a replica set to another

Lab: Working with the Oplog **(page 121)** A brief lab that illustrates how the oplog works

Write Concern **(page 124)** Balancing performance and durability of writes

Read Concern **(page 128)** Settings to minimize/prevent stale and dirty reads

Read Preference **(page 137)** Configuring clients to read from specific members of a replica set

Lab: Setting up a Replica Set **(page 138)** Launching members, configuring, and initiating a replica set

5.1 Introduction to Replica Sets

Learning Objectives

Upon completing this module, students should understand:

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

Use Cases for Replication

- High Availability
- Disaster Recovery
- Functional Segregation

High Availability (HA)

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

Note: If we lose a server and MongoDB is correctly configured:

- Our database system can still service reads and writes, but by default not during failover period when the election takes place and there is no primary.
- Without manual intervention as long as there is still a majority of nodes available.

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

Note:

- You may direct particular queries to specific nodes (which may have different indexes or hardware) to increase overall performance.
- Backup data from secondaries to avoid performance penalties on the primary, especially when using tools like `mongodump` which are I/O intensive and evict the working set from memory (significant when data size is larger than RAM and disks are slow).
- Dedicate secondaries for other purposes such as analytics jobs.

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)

Note:

- Sample use case: bank reference data distributed to 20+ data centers around the world, then consumed by the local application server

---

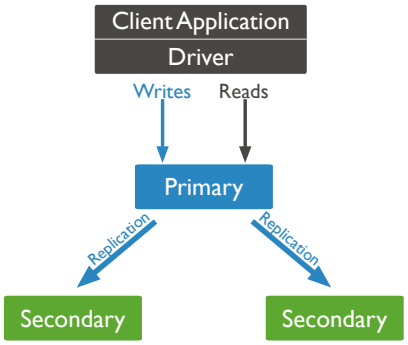
Replication is Not Designed for Scaling

- 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.

Note:

- Eventual consistency: This is often tricky to handle as most developers are used to the strong consistency that most databases (and MongoDB) have by default. It also raises the question of how stale the data can be, and what to do when it crosses the threshold (e.g. fall back to reading from the primary). As of MongoDB 3.4, queries can be executed with **readConcern: linearizable** to ensure non-stale reads under certain circumstances. More on this will be covered later.
- Potential system overload: For example, consider a 3 data node replica set using secondaries to scale reads. Each node is serving reads at 70% of its capacity, which is a reasonable utilization rate. What happens if one of the secondaries fail or is intentionally taken down for maintenance (e.g. upgrading the OS or MongoDB)? Even if the load splits evenly between the 2 remaining nodes, they will be at `70+(70/2)= 105%` capacity.

Replica Sets



Note:

- MongoDB implements replication in the form of replica sets. Don't use the term master-slave as that is what we had before replica sets. It still exists for some corner cases (e.g. > 12 replicas) but should otherwise be avoided.
- A replica set consists of one or more `mongod` servers. Maximum 50 nodes in total and up to 7 with votes.
- There is at most one `mongod` that is "primary" at any one time (though there are edge cases/bugs when there is more than one).
- There are usually two or more other `mongod` instances that are secondaries.
- Secondaries may become primary if there is a failover event of some kind.
- Failover is automatic when correctly configured and a majority of nodes remain.

- The secondaries elect a new primary automatically. A primary may also voluntarily step down, like when it can no longer reach the majority of nodes to avoid a potential split brain scenario.

Primary Server

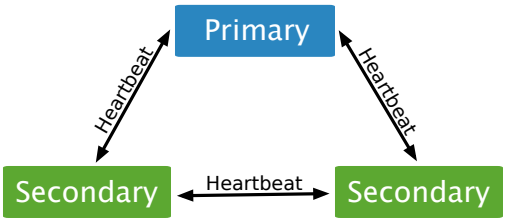
- Clients send writes to the primary only.
- MongoDB, Inc. maintains client drivers in many programming languages like Java, C#, Javascript, Python, Ruby, and PHP.
- MongoDB drivers are replica set aware.

Note: If the primary for a replica set changes from one node to another, the driver will automatically route writes to the correct `mongod`.

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



Note:

- The members of a replica set use heartbeats to determine if they can reach every other node.
- The heartbeats are sent every two seconds.
- If a node is unreachable, this may indicate server failure, a network partition, or simply too slow to respond. The heartbeat will timeout and retried several times before the state is updated.

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.

Note: Remind students that capped collections are collections that do not indefinitely expand. Once their maximum size is reached they were roll back to the beginning (oldest insert) and start overwriting data.

Initial Sync

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

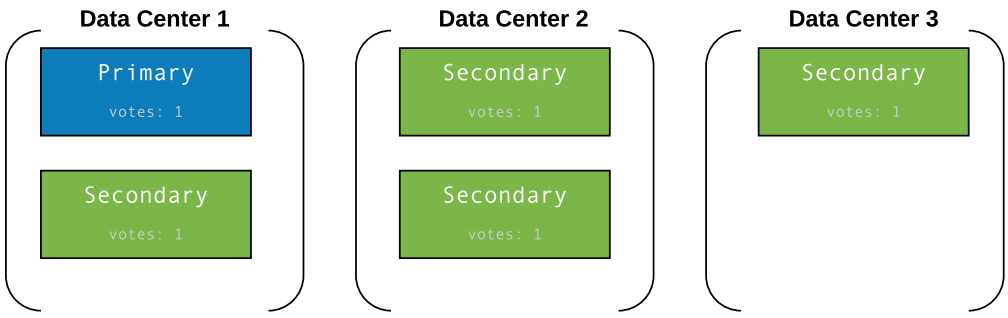
5.2 Elections in Replica Sets

Learning Objectives

Upon completing this module students should understand:

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

Members and Votes

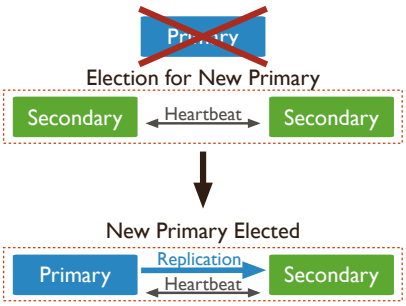


Note:

- In order for writes to occur, one member of a replica set must be primary.
- In the event the current primary becomes unavailable, the remaining members elect a new primary.
- Voting members of replica set each get one vote.

- Up to seven members may be voting members.
- This enables MongoDB to ensure elections happen quickly, but enables distribution of votes to different data centers.
- In order to be elected primary a server must have a true majority of votes.
- A member must have greater than 50% of the votes in order to be elected primary.

Calling Elections



Note:

- MongoDB uses a consensus protocol to determine when an election is required.
- Essentially, an election will occur if there is no primary.
- Upon initiation of a new replica set the members will elect a primary.
- If a primary steps down the set will hold an election.
- A secondary will call for an election if it does not receive a response to a heartbeat sent to the primary after waiting for 10 seconds.
- If other members agree that the primary is not available, an election will be held.

Selecting a New Primary

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

Priority

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

Note:

- Priority is a configuration parameter for replica set members.
- Use priority to determine where writes will be directed by default.
- And where writes will be directed in case of failover.
- Generally all identical nodes in a datacenter should have the same priority to avoid unnecessary failovers. For example, when a higher priority node rejoins the replica set after a maintenance or failure event, it will trigger a failover (during which by default there will be no reads and writes) even though it is unnecessary.
- More on this in a later module.
- PV1 does not factor priority into elections. However, after the replica set is stable, a secondary with higher priority will call for a new election to make itself the new primary. This increases the chance of there always being a primary, at the cost of potentially more elections.

Optime

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

Connections

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

Note: To be elected primary, a replica set member must be able to connect to a majority of the members in the replica set.

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.

Note:

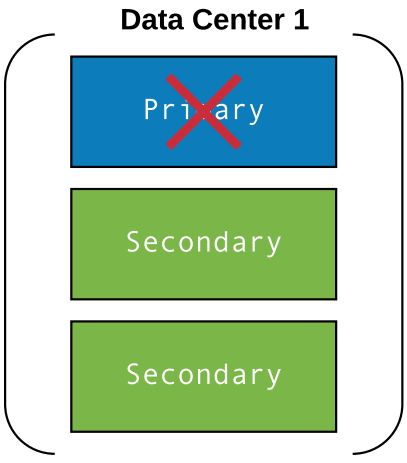
- Ask the class what the tradeoffs could be in setting secondaryCatchUpPeriodSecs to a very short amount of time (rollbacks could occur or operations not replicated)

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?

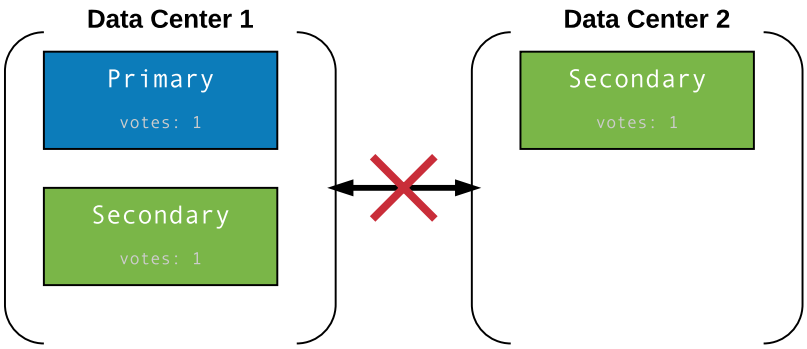


Note:

- It depends on the priorities of the secondaries.
- And on the optime.

Scenario B: 3 Data Nodes in 2 DCs

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

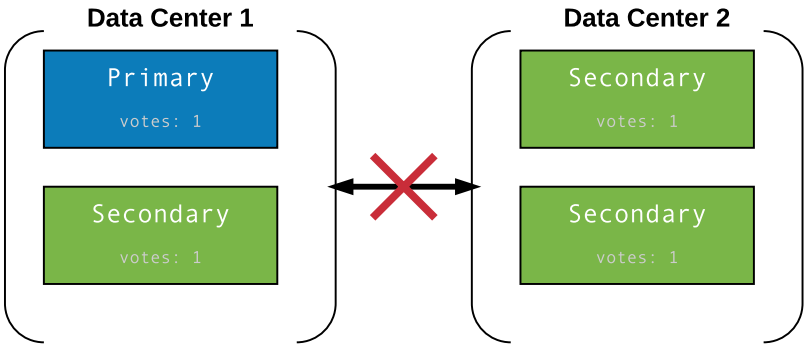


Note:

- The current primary is likely to remain primary.
- It probably has the highest priority.
- If DC2 fails, we still have a primary.
- If DC1 fails, we won't have a primary automatically. The remaining node in DC2 needs to be manually promoted by reconfiguring the replica set.

Scenario C: 4 Data Nodes in 2 DCs

What happens following this network partition?



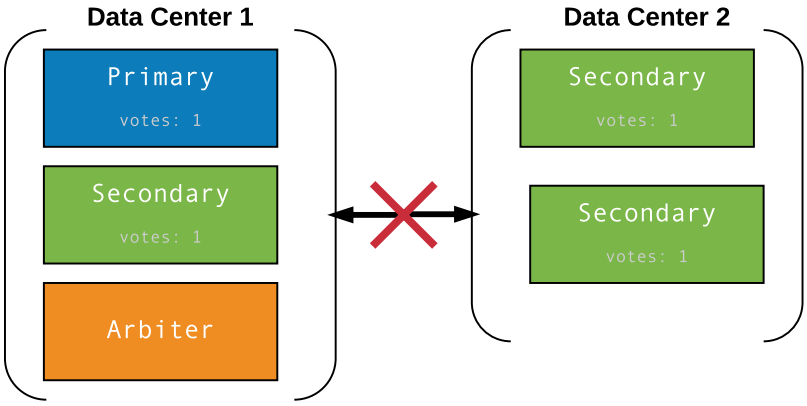
Note:

- We enter a state with no primary.
- Each side of the network partition has only 2 votes (not a majority).
- All the servers assume secondary status.
- This is avoidable.
- One solution is to add another member to the replica set.
- If another data node can not be provisioned, MongoDB has a special alternative called an arbiter that requires minimal resources.

- An arbiter is a `mongod` instance without data and performs only heartbeats, votes, and vetoes.

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?

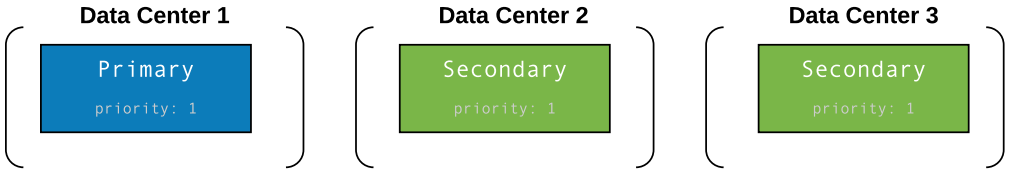


Note:

- The current primary is likely to remain primary.
- The arbiter helps ensure that the primary can reach a majority of the replica set.

Scenario E: 3 Data Nodes in 3 DCs

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

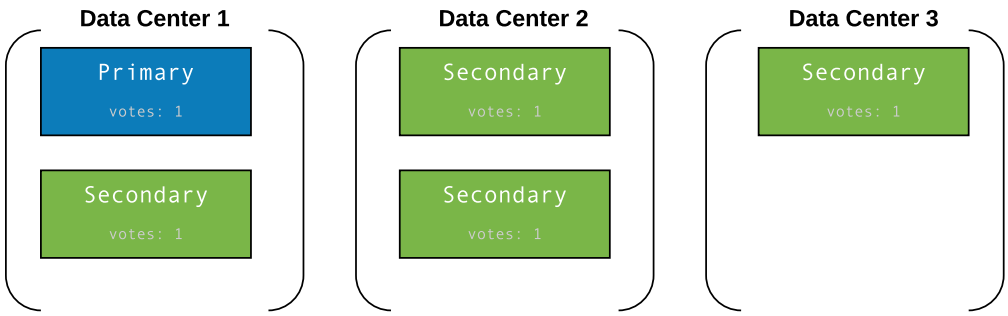


Note:

- The intent is to explain the advantage of deploying to 3 DCs - it's the minimum number of DCs in order for MongoDB to automatically failover if any one DC fails. This is generally what we recommend to customers in our consult and health check reports, though many continue to use 2 DCs due to costs and legacy reasons.
- To have automated failover in the event of single DC level failure, there must be at least 3 DCs. Otherwise the DC with the minority of nodes must be manually reconfigured.
- One of the data nodes can be replaced by an arbiter to reduce costs.

Scenario F: 5 Data Nodes in 3 DCs

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



Note:

- Adds another data node to each "main" DC to reduce typically slow and costly cross DC network traffic if an initial sync or similar recovery is needed, as the recovering node can pull from a local replica instead.
- Depending on the data sizes, operational budget, and requirements, this can be overkill.
- The data node in DC3 can be replaced by an arbiter to reduce costs.

5.3 Replica Set Roles and Configuration

Learning Objectives

Upon completing this module students should understand:

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

Example: A Five-Member Replica Set Configuration

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

Configuration

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

Principal Data Center

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

Note:

- The objective with the priority settings for these two nodes is to prefer to DC1 for writes.
- The highest priority member that is up to date will be elected primary.
- Up to date means the member's copy of the oplog is within 10 seconds of the primary.
- If a member with higher priority than the primary is a secondary because it is is not up to date, but eventually catches up, it will force an election and win.

Data Center 2

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

Note:

- Priority is not specified, so it is at the default of 1.
- `dc2-1` could become primary, but only if both `dc1-1` and `dc1-2` are down.
- If there is a network partition and clients can only reach DC2, we can manually failover to `dc2-1`.

What about `dc1-3` and `dc2-2`?

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

Note:

- Will replicate writes normally.
- We would use this node to pull reports, run analytics, etc.
- We can do so without paying a performance penalty in the application for either reads or writes.

What about `dc2-2`?

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

Note:

- `slaveDelay` permits us to specify a time delay (in seconds) for replication.
- In this case it is 7200 seconds or 2 hours.
- slaveDelay allows us to use a node as a short term protection against operator error:
  - Fat fingering – for example, accidentally dropping a collection in production.
  - Other examples include bugs in an application that result in corrupted data.
  - Not recommended. Use proper backups instead as there is no optimal delay value. E.g. 2 hours might be too long or too short depending on the situation.

5.4 The Oplog: Statement Based Replication

Learning Objectives

Upon completing this module students should understand:

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

Binary Replication

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

Tradeoffs

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

Note:

- Some deployments might need to run different versions of MongoDB on different nodes.
- Different versions of MongoDB might write to different file offsets.
- We might need to run a compaction or repair on a secondary.
- In many cases we want to do these types of maintenance tasks independently of other nodes.

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("-70461248769192690 8"),
  "v" : 2, "op" : "d", "ns" : "bar.foo", "b" : true, "o" : { "_id" : 65 } }
{ "ts" : Timestamp(1407159845, 1), "h" : NumberLong("601412634522501 9794"),
  "v" : 2, "op" : "d", "ns" : "bar.foo", "b" : true, "o" : { "_id" : 333 } }
{ "ts" : Timestamp(1407159845, 4), "h" : NumberLong("817879176423846 5439"),
  "v" : 2, "op" : "d", "ns" : "bar.foo", "b" : true, "o" : { "_id" : 447 } }
{ "ts" : Timestamp(1407159845, 3), "h" : NumberLong("-170739100170552 8381"),
  "v" : 2, "op" : "d", "ns" : "bar.foo", "b" : true, "o" : { "_id" : 1033 } }
{ "ts" : Timestamp(1407159845, 2), "h" : NumberLong("-681429739244240 6598"),
  "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.

Note:

- Can do maintenance without bringing the set down because statement-based replication does not depend on all nodes running the same version of MongoDB or other restrictions that may be imposed by binary replication.
- In the next exercise, we will see that the oplog is designed so that each statement is idempotent.
- This feature has several benefits for independent operation of nodes in replica sets.

Operations in the Oplog are Idempotent

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

Note: We need to be able to copy while accepting writes when:

- Doing an initial sync for a new replica set member.
- When a member rejoins a replica set after a network partition a member might end up writing operations it had already received prior to the partition.

The Oplog Window

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

Sizing the Oplog

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

5.5 Lab: Working with the Oplog

Create a Replica Set

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

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

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

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

Note: *mongo –nodb* command will start a MongoDB shell without connecting to a host.

This allows the user to perform a set of operations using the javascript handlers and helpers that the mongo shell allows.

A set of those helpers allow the creation of replica set nodes and sharded clusters running on the local machine. The only restriction is that a */data* folder exists and the user running *mongo* has write permission on that folder.

`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 } } }
```

Note:

- Note the last two entries in the oplog.
- These entries reflect the update command issued above.
- Note that there is one operation per document affected.
- More specifically, one operation for each of the documents with the _id values 2 and 5.

One can test students by asking them to insert data into the *store.notes* collection and then go find those writes in the oplog

```
use store
db.notes.insert({'note': 'oh my lord!'})
use local
db.rs.oplog.find({'ns': 'store.notes'})
```

5.6 Write Concern

Learning Objectives

Upon completing this module students should understand:

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

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

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

Balancing Durability with Performance

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

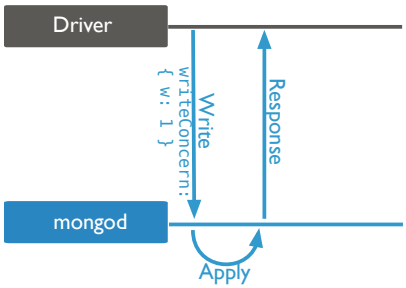
Note:

- MongoDB provides tunable write concern to better address the specific needs of applications.
- Clients may adjust write concern to ensure that the most important operations persist successfully to an entire MongoDB deployment.
- For other less critical operations, clients can adjust write concern to ensure faster performance.

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.

Write Concern: `{ w : 1 }`



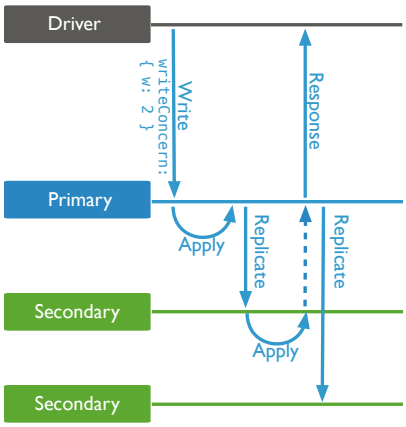
Note:

- We refer to this write concern as "Acknowledged".
- This is the default.
- The primary sends an acknowledgement back to the client that it received the write operation (in RAM).
- Allows clients to catch network, duplicate key, and other write errors.

Example: `{ w : 1 }`

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

Write Concern: `{ w : 2 }`



Note:

- Called "Replica Acknowledged"
- Ensures the primary completed the write.
- Ensures at least one secondary replicated the write.

Example: `{ w : 2 }`

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

Other 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 writes are also written to disk on the *primary* before being acknowledged
- When using PV1 (replication protocol version 1), writeConcernMajorityJournalDefault[9] is on by default for versions >= 3.4
  - so `w : majority` implies `j : true`

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

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

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

Example: `{ w : "majority" }`

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

Quiz: Which write concern?

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

- { w : 1 }
- { w : 2 }
- { w : 3 }
- { w : 4 }
- { w : “majority” }

Note: Answer: { w : “majority”}. This is the same as 4 for a 7 member replica set.

Further Reading

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

[10] http://docs.mongodb.org/manual/reference/write-concern
[11] http://docs.mongodb.org/manual/tutorial/configure-replica-set-tag-sets/#replica-set-configuration-tag-sets

5.7 Read Concern

Learning Objectives

Upon completing this module, students will be able to:

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

Read Concerns

- **Local**: *Default*
- **Majority**: Added in MongoDB 3.2, requires WiredTiger and election protocol version 1
- **Linearizable**: Added in MongoDB 3.4, works with MMAP or WiredTiger

Local

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

Majority

- Available only with WiredTiger.
- Reads majority acknowledged writes from a snapshot.
- Under certain circumstances (high volume, flaky network), can result in stale reads.

Linearizable

- Available with MongoDB versions > 3.4
- Will read latest data acknowledged with `w: 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

---

Note:

- For replica sets that run with **writeConcernMajorityJournalDefault** set to true, linearizable read concern returns data that will never be rolled back.

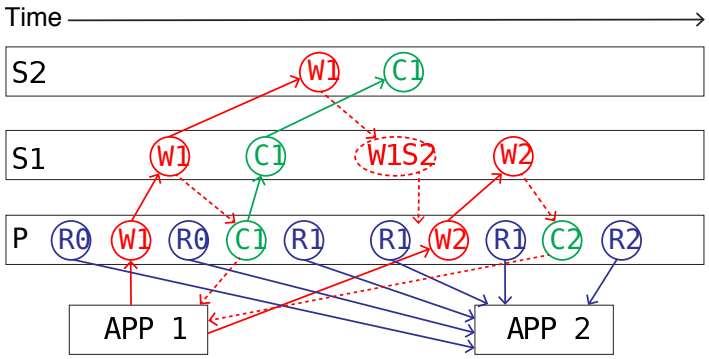
- With **writeConcernMajorityJournalDefault** set to false, MongoDB will not wait for *w: "majority"* writes to be durable before acknowledging the writes. As such, "majority" write operations could possibly roll back in the event of a loss of a replica set member.
- Only primary servers may be queried with **linearizable**.

Questions to ask:

- Can I avoid dirty reads if I write a document with write concern "majority" and read preference: "primary"?
  - Answer: No. Without using read concern level : "majority", reads can be dirty
- What can happen if I use a write concern of `{ w: 1 }` and read concern level of "majority"?
  - Answer: You will not have dirty reads ... but you may be unable to read your own writes

---

Example: Read Concern Level Majority



Note:

- This looks quite complicated, but all it's really showing is:
  - Two writes, both from App 1, and the associated replication and responses (red and green)
  - Several reads at various times all from App 2 (blue)
- Note that the applications are using w : "majority" and read concern level: "majority"
- The application doesn't read a write until after the secondary has confirmed to the primary that it has received the write
- Key:
  - Red W's are the writes: W1 and W2, as they propagate through
    - Dashed red lines are acknowledgments of the writes
      - W1S2 is the acknowledgment of write 1 from the S2 server
  - Green C's are the read commits from read concern "majority".
    - C1 marks the moment where W1 has been committed
    - C2 marks the moment where W2 has been committed
    - The primary also gets a write acknowledgement when a commit occurs on the primary
    - Note that the commits go from primary to the secondaries, along with the oplog.
  - Blue R's are the reads from App 2 at various points in time

    * R0 is the initial state
    * R1 is the state after W1 has been committed
    * R2 is the state after W2 has been committed

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

Note:

- Stale reads see a view of the data that was in place at some point recently

---

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

Note:

- The scenario described here might happen if, for example, the other primary freezes for some time, then resumes operation
- This slide is for the benefit of engineers who are very knowledgeable about isolation, and who are concerned about isolation levels
  - Telling them that primaries prevent stale reads is not completely accurate
  - With `linearizable`, the query will verify with the secondaries that the primary being queried can acknowledge `w: majority`.

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

Note:

- There is no way to know during a dirty read if its view of the data includes a write that will be rolled back
- Here is a good time to ask when writes can get rolled back
- Answers:
  - If a network partition isolates the primary, a new one will be elected
  - If the primary crashes, a new one will be elected and the old primary's writes will be 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

---

Note:

- Might be a good time to ask how many ways dirty reads can happen.
- Answers:
  - Primary gets a write, but crashes before the oplog sends data to the secondary
  - Primary and one secondary both get the write, but both crash before it gets to disk on either
  - Primary gets the write, but there is a network partition separating it from the secondaries; they elect a new primary
    - Write gets rolled back, so it's not in your data set unless manually added
- Don't let the students conflate read concern with read preference[12]

---

[12] https://docs.mongodb.com/manual/core/read-preference/

Quiz

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

Note:

- Dirty read means you see a write that may not persist
- Stale read means you don't see a write that has occurred

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

Note:

- If running with read concern level: "majority" but not write concern `{ w: "majority" }`, it would be possible to insert a document, get it acknowledged, and then try to read it back, but not see it.
- Obviously, users should not do this.

Example: Using Read Concern

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

```
./launch_replset_for_majority_read_concern.sh
```

Note:

- This will allow them to launch a replica set that can use majority read concern.

```
#!/usr/bin/env bash

mkdir -p /data/replset/{1,2,3}
wait
mongod --replSet majrc --port 27017 --dbpath /data/replset/1 --logpath /data/replset/
↪1/mongod.log --wiredTigerCacheSizeGB 1 --enableMajorityReadConcern --fork
wait
mongod --replSet majrc --port 27018 --dbpath /data/replset/2 --logpath /data/replset/
↪2/mongod.log --wiredTigerCacheSizeGB 1 --enableMajorityReadConcern --fork
wait
mongod --replSet majrc --port 27019 --dbpath /data/replset/3 --logpath /data/replset/
↪3/mongod.log --wiredTigerCacheSizeGB 1 --enableMajorityReadConcern --fork
wait
echo 'cfg = { "_id" : "majrc", "members" : [ { "_id" : 0, "host" : "localhost:27017",␣
↪} ] }; rs.initiate(cfg)' | mongo
wait
echo 'rs.add("localhost:27018")' | mongo
wait
echo 'rs.add("localhost:27019")' | mongo
```

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
```

Note:

- In this example, students can see that one document will propagate to the secondaries.

- But the second document, while present on the primary, will not replicate.
- Encourage them to use their own example (with `db.fsyncLock` on secondaries).
  - They can use a driver, if they wish.

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?

Note: Answer:

- Invoke the mongod with `--enableMajorityReadConcern`
- Use `cursor.readConcern("majority")` on a read
  - Alternatively, use read concern level "majority" with a driver's connection pool

---

Replication Protocol Version 0

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

Replication Protocol Version 1

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

Replication Protocol Version 1 (continued)

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

Note:

- Previously, secondaries would acknowledge writes before those writes were journaled
- A short `electionTimeoutMillis` can result in lots of elections, especially with a flaky network
- A long `electionTimeoutMillis` can result in lower availability due to longer failover time
- When to use PV0 and PV1?
  - >= 3.4.2
    - Pv1: should always be recommended. All known issues with Arbiters, priorities, and rollbacks have been mitigated.
    - Pv0: No known cases where Pv0 is materially superior.
  - 3.2.12+
    - Pv1: Should be recommended if customer is primarily using w:majority writes. Can safely be used with Arbiters, Priorities, and other topologies with minimal impact on failover. Non-majority writes can still be rolled back on failover as there is no "catch up" period implemented in 3.2. However, priority take overs (a leading cause of large rollbacks) have been limited to only occur if the higher priority node is with 10 seconds of the current primary.
    - Pv0: Should be recommended if customer is primarily using non-majority writes.
  - 3.2.11/3.4.1 or lower
    - Pv1: Should only be recommended if an application is exclusively using w:majority writes without priorities or arbiters. This is due to rollback bugs and large rollbacks of non-majority writes caused by mishandling of priorities.
    - Pv0: Should be recommended whenever non-majority writes are being used. Particularly, if a customer is using priorities.

Quiz

What are the advantages of replication protocol 1?

Note:

- `electionTimeoutMillis` now tunable
- Secondaries write to the journal before acknowledging
- Enables read concern "majority"

Further Reading

See Read Concern Reference[13] for more details on read concerns.

[13] http://docs.mongodb.org/manual/reference/read-concern

5.8 Read Preference

What is Read Preference?

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

Use Cases

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

Note:

- If you have application servers in multiple data centers, you may consider having a geographically distributed replica set[14] and using a read preference of `nearest`.
- This allows the client to read from the lowest-latency members.
- Use `primaryPreferred` if you want an application to read from the primary under normal circumstances, but to allow possibly stale reads from secondaries during failover.

Not for Scaling

- In general, do *not* read from secondaries to provide extra capacity for reads.
- Sharding[15] increases read and write capacity by distributing operations across a group of machines.
- Sharding is a better strategy for adding capacity.

[14] http://docs.mongodb.org/manual/core/replica-set-geographical-distribution
[15] http://docs.mongodb.org/manual/sharding

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.

Tag Sets

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

For example, in the mongo shell:

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

5.9 Lab: Setting up a Replica Set

Overview

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

Create Data Directories

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

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

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

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

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

Launch Each Member

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

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

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

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

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

Status

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

Note:

- In production, each member would run on a different machine and use service scripts. For example on Linux, modify `/etc/mongod.conf` accordingly and run:

  ```
  sudo service mongod start
  ```

- To simplify this exercise, we run all members on a single machine.
- The same configuration process is used for this deployment as for one that is distributed across multiple machines.

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()
```

Note:

- `rs.initiate()` will use the FQDN. If we simply use `localhost` when adding the data node and arbiter, MongoDB will refuse to mix the two and return an error.

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)
```

Note:

- Note that `cfg["members"][1]["priority"] = 10` does not actually change the priority.
- `rs.reconfig(cfg)` does.

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[16]
- Replica States[17]

[16] http://docs.mongodb.org/manual/reference/replica-configuration/
[17] http://docs.mongodb.org/manual/reference/replica-states/

6 Sharding

6.1 Introduction to Sharding

Learning Objectives

Upon completing this module, students should understand:

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

Contrast with Replication

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

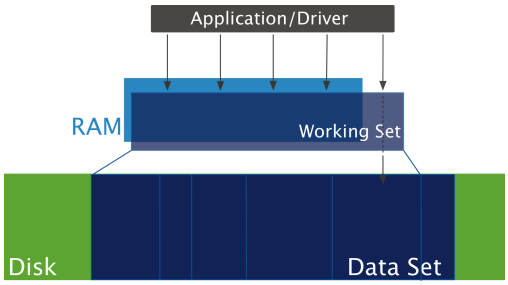
Sharding is Concerned with Scale

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

Vertical Scaling

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

The Working Set



Note:

- The working set for a MongoDB database is the portion of your data that clients access most often.
- Your working set should stay in memory, otherwise random disk operations will hurt performance.
- For the fastest processing, ensure that your indexes fit entirely in RAM so that the system can avoid reading the index from disk.
- In some cases, only recently indexed values must be in RAM.

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 possible support.
- This is when it is time to scale horizontally.

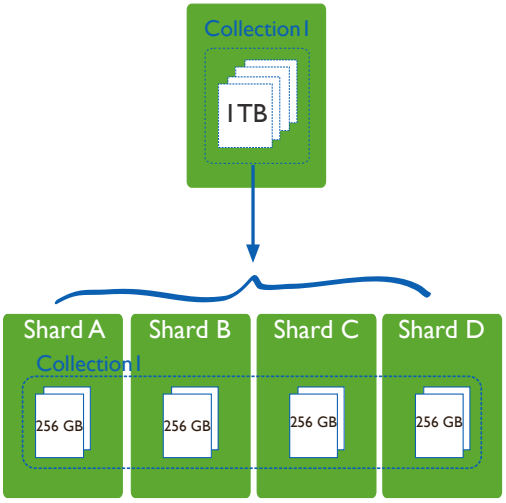
Sharding Overview

- 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



Note:

- When you shard a collection it is distributed across several servers.
- Each mongod manages a subset of the data.
- When you perform a read or write operation it will go to a router that will then direct the query to the appropriate server.
- Depending on the operation and how your cluster is configured you may need to touch only one server to complete the operation.

Sharding Concepts

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

- Shard Keys
- Chunks

Shard Key

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

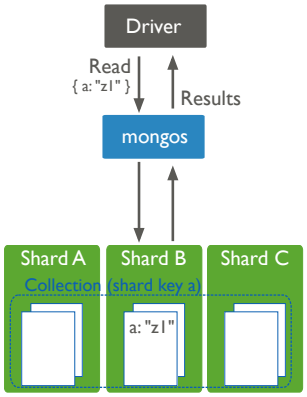
Shard Key Ranges

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

Note:

- For reads and updates, the shard key determines which shard holds the document and will handle the operation.
- When you insert a document, the shard key determines which server you will write to.

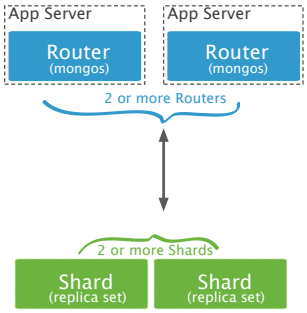
Targeted Query Using Shard Key



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



Note:

- This figure illustrates one possible architecture for a sharded cluster.
- Each shard is a self-contained replica set.
- Each replica set holds a partition of the data.
- As many new shards could be added to this sharded cluster as scale requires.
- At this point our cluster can handle a load approaching twice that of a single replica set using the same hardware.
- As mentioned, read/write operations go through a router.
- The server that routes requests is the mongos.

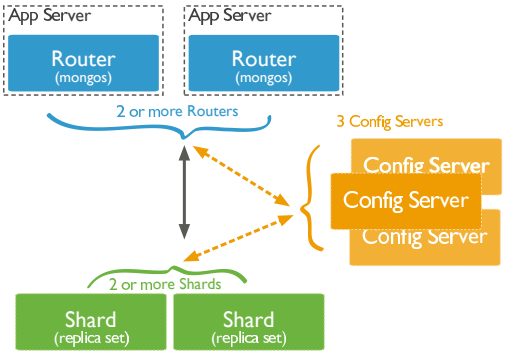
Mongos

- 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.

Note:

- A mongos is typically deployed on an application server.
- There should be one mongos per app server.
- Scale with your app server.
- Very little latency between the application and the router.

Config Servers



Note:

- The previous diagram was incomplete; it was missing config servers.
- Use three config servers in production.
- In MongoDB 3.2, support for config server replica set (CSRS) was introduced.
- In MongoDB 3.4, mirrored (SCCC) config servers were deprecated. Config servers must now be set up in CSRS.
- In MongoDB 3.4, the balancing process was moved from the `mongos` server and is the responsibility of the **primary** config server
- These hold only metadata about the sharded collections.
  - Where your mongos servers are
  - Any hosts that are not currently available
  - What collections you have
  - How your collections are partitioned across the cluster
- Mongos processes use them to retrieve the state of the cluster.

- You can access cluster metadata from a mongos by looking at the `config` db.

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.

Note:

- Documents will eventually move as chunks are balanced.
- But in the meantime one server gets hammered while others are idle.
- And moving chunks has its own performance costs.

Shards Should be Replica Sets

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

6.2 Balancing Shards

Learning Objectives

Upon completing this module students should understand:

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

Chunks and the Balancer

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

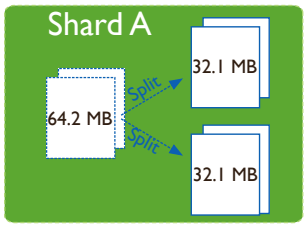
Chunks in a Newly Sharded Collection

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

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

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

Chunk Splits



Note:

- When a chunk grows larger than the chunk size it will be split in half.
- The default chunk size is 64MB.
- A chunk can only be split between two values of a shard key.
- If every document on a chunk has the same shard key value, it cannot be split.
- This is why the shard key's cardinality is important
- Chunk splitting is just a bookkeeping entry in the metadata.
- No data bearing documents are altered.

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

---

Note:

- A large data import will take time to split and balance without pre-splitting.

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 to 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.

Note: As of MongoDB 3.4, deployments using WiredTiger will see increased balancing speed. The default value **secondaryThrottle** is **false**, so the balancer will not wait for replication before proceeding to the next chunk during migration. This is the default now because MongoDB now has a dedicated balancing migration thread

---

Chunk Migration Steps

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

Concluding a Balancing Round

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

6.3 Shard Zones

Learning Objectives

Upon completing this module students should understand:

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

Note: MongoDB 3.4 introduced Zones, which supersedes tag-aware sharding available in earlier versions.

Zones - Overview

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

Example: DateTime

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

Example: Location

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

Example: Premium Tier

- You have customers who want to pay for a "premium" tier.
- The shard key permits you to distinguish one customer's documents from all others.
- Tag the document ranges for each customer so that their documents will be located on shards of the appropriate tier (zone).
- Shards tagged as premium tier run on high performance servers.
- Other shards run on commodity hardware.
- See Manage Shard Zone[18]

Note:

- As customers move from one tier to another it will be necessary to execute commands that either add a given customer's shard key range to the premium tag or remove that range from those tagged as "premium".
- During balancing rounds, if the balancer detects that any chunks are not on the correct shards per configured tags, the balancer migrates chunks in tagged ranges to shards associated with those tags.
- After re-configuring tags with a shard key range, and associating it with a shard or shards, the cluster may take some time to balance the data among the shards.
- See: Tiered Hardware for varying SLA or SLO[19].

---

[18] http://docs.mongodb.org/manual/tutorial/manage-shard-zone/
[19] https://docs.mongodb.com/manual/tutorial/sharding-tiered-hardware-for-varying-slas/

Zones - Caveats

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

6.4 Lab: Setting Up a Sharded Cluster

Learning Objectives

Upon completing this module students should understand:

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

Our Sharded Cluster

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

Sharded Cluster Configuration

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

Build Our Data Directories

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

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

On Windows, run the following commands instead:

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

Initiate a Replica Set (Linux/MacOS)

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

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

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

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

Initiate a Replica Set (Windows)

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

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

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

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

Note:

- Students should replace <HOSTNAME> by the local machine name

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

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

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

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

Spin Up a Second Replica Set (Windows)

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

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

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

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

Note:

- Students should replace <HOSTNAME> by the local machine name

A Third Replica Set (Linux/MacOS)

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

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

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

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

A Third Replica Set (Windows)

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

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

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

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

Note:

- Students should replace <HOSTNAME> by the local machine name

---

Status Check

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

Launch Config Servers (Linux/MacOS)

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

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

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

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

Launch Config Servers (Windows)

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

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

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

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

Launch the Mongos Processes (Linux/MacOS)

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

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

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

Note:

- Students should set `$HOSTNAME` by the local machine name
- echo $HOSTNAME

Launch the Mongos Processes (Windows)

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

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

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

Add All Shards

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

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

Enable Sharding and Shard a Collection

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

```
mongo --port 27017
```

```
sh.enableSharding("test")
sh.shardCollection("test.testcol", { a : 1, b : 1 } )

for (i=0; i<1000; i++) {
   docArr = [];
   for (j=0; j<1000; j++) {
     docArr.push(
     {
       a : i, b : j,
       c : "Filler String 000000000000000000000000000000000000000000000000000"
     } )
   };
db.testcol.insert(docArr)
};
```

Observe What Happens

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

```
sh.status()
```

Note:

- Point out to the students that you can see chunks get created and moved to different shards.
- Also useful to have students run a query or two.

  ```
  db.testcol.find( { a : { $lte : 100 } } ).explain()
  ```

---

7 Security

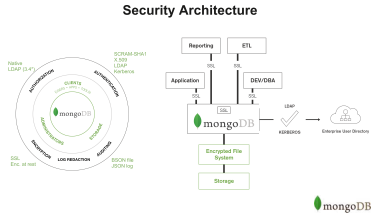
7.1 Security Introduction

Learning Objectives

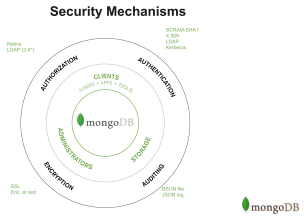
Upon completing this module students should understand:

- The high-level overview of security in MongoDB
- Security options for MongoDB
  - Authentication
  - Authorization
  - Transport Encryption
  - Enterprise only features

A High Level Overview



Security Mechanisms



Note:

- MongoDB provides numerous security features, to include:
  - Authentication
    - SCRAM-SHA-1
    - x.509 Certificate Authentication
  - Authorization
    - Role-Based Access Control
  - Transport Encryption
  - Enterprise Only Features
    - Kerberos Authentication
    - LDAP Proxy Authentication
    - Encryption at Rest
    - Auditing
  - Network Exposure Settings
- You should only run MongoDB in a trusted environment.
- You should run MongoDB from a non-root user.
- You are welcome to use any features you desire, or none.
- All security is off by default. This will change, and versions >= 3.6 will be restricted to localhost by default

---

Authentication Options

- Community
  - Challenge/response authentication using SCRAM-SHA-1 (username & password)
  - X.509 Authentication (using X.509 Certificates)
- Enterprise
  - Kerberos
  - LDAP

Note:

- Although there is a SCRAM-SHA-2 algorithm that addressed some vulnerabilities in SCRAM-SHA-1, it would not benefit MongoDB
- By cracking either algorithm an attacker would have to have access to the `db.users` collection and associated metadata

---

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)

Note:

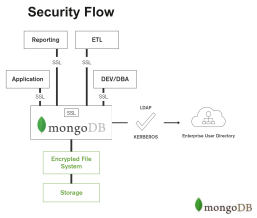
- FIPS (Federal Information Processing Standard)
- Users should use a certificate from a certificate authority in order for clients to verify the server's identity

---

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



Note:

- A robust and secure applicate architecture can be created by using the provided security features and following this checklist[20]
- The overall strength of the security protocols in place is only as strong as the weakest link.
  - Use authentication
  - Use role-based authorization; limit users to what they need
  - Transmit data using TLS/SSL
  - Encrypt data at rest
  - Use valid certificates signed by a trusted certificate authority
  - Ensure all `mongod` and `mongos` servers are configured properly

7.2 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

[20] https://docs.mongodb.com/manual/administration/security-checklist/

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

Note:

- You can bring up the following questions:
  - What are privileges?
  - What kind of resources can be found on a typical database?
- Have some open discussion about what defines an action.
- Also you can take the opportunity to give examples of different roles in a company and how they are organized in terms of procedures and resources.

What is a resource?

- Databases?
- Collections?
- Documents?
- Users?
- Nodes?
- Shard?
- Replica Set?

Note:

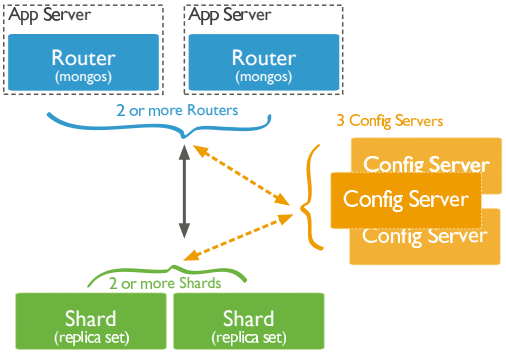
- A resource is a database, collection, set of collections, or the cluster.

- If the resource is the cluster, the affiliated actions affect the state of the system rather than a specific database or collection.

Authorization Resources

- Databases
- Collections
- Cluster

Cluster Resources



Note:

- Given the distributed nature of our database, MongoDB includes the cluster resource in the authorization module.
- Replica sets and shards comprise the cluster domain.

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

Note:

- Actions are the operations that one can perform on database resources.

- The actions above are grouped by purpose.
- This organization is logical, not operational.
- Here we can ask the students which common operations they are familiar with while operating with a database and how those translate to MongoDB operations.

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[21] in the MongoDB documentation.

Note: These are just a few examples of the list of actions available. The full list is available in MongoDB docs: https://docs.mongodb.org/v3.0/reference/privilege-actions/#privilege-actions

---

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"]
}
```

Note:

- We want to explain that we can set a privilege that enables multiple actions on a given resource.
- Also important to highlight that we can set *loose* resources like `all databases` or `all collections`

```
{
  resource: {"db": "", "collection": ""},
  actions: ["find", "insert"]
}
```

---

[21] https://docs.mongodb.com/manual/reference/privilege-actions/

Authorization Roles

MongoDB grants access to data through a role-based authorization system:

- Built-in roles: pre-canned roles that cover the most common sets of privileges users may require
- User-defined roles: if there is a specific set of privileges not covered by the existing built-in roles you are able to create your own roles

Built-in Roles

Database Admin	Cluster Admin	All Databases
dbAdmin	clusterAdmin	readAnyDatabase
dbOwner	clusterManager	readWriteAnyDatabase
userAdmin	clusterMonitor	userAdminAnyDatabase
	hostManager	dbAdminAnyDatabase

Database User	Backup & Restore
read	backup
readWrite	restore

Superuser	Internal
root	__system

Note: Built-in roles have been created given the generic users that interact with a database and their respective tasks.

- Database user roles: should be granted to application-side users;
- Database administrators: roles conceived for system administrator, DBAs and security officers
- Cluster Administrator roles: mostly for system administrators and DBAs; individuals that will deal with the overall administration of deployments
- Backup and Restore: for applications that perform only backup and restore operations (for example: Cloud and Ops Manager)
- All Database Roles: for global administrators of a deployment. If you want to avoid granting the same role for every single database
- Superuser: root level operations. Generally the first user that you create on any give system should probably have a root role and then add other specific users.
- Internal: it's documented, it's public but don't mention it too much. This a backdoor that only the cluster members (other replica set members, or a mongos) should have access to. Do not assign this role to user objects representing applications or human administrators.

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" }
  ]
)
```

Note: `grantRolesToUser` also allows to specify a `writeConcern` to ensure the durability of the operation, as any of the remaining authz methods.

```
db.grantRolesToUser(
  "reportsUser",
  [
    { role: "read", db: "accounts" }
  ],
  { w: "majority" , wtimeout: 4000 }
)
```

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})
```

Note: There are many other authorization and user management commands and options that you should get your students acquainted with. All of those can be found in the security reference[22]

The output of this slide command is should be similar to the following:

```
{
"role": "insertAndFindOnlyMyDB",
"db": "admin",
"isBuiltin": false,
"roles": [ ],
"inheritedRoles": [ ],
"privileges": [
  {
    "resource": {
      "db": "myDB",
      "collection": ""
    },
    "actions": [
      "find",
      "insert"
    ]
  }
],
"inheritedPrivileges": [
  {
    "resource": {
      "db": "myDB",
      "collection": ""
    },
    "actions": [
      "find",
      "insert"
    ]
  }
 ]
}
```

---

[22] https://docs.mongodb.org/manual/reference/security/

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
```

7.3 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" }
    ]
})
```

Note: Make sure that users understand the importance of this role:

- What happens when we need to add a new user?
- What happens when someone loses their password?
- What happens when we need to remove a user?

These are very specific operations. Also make note that we can be more granular if we want a specific user to administer only specific database users using role:

```
{ role: "userAdmin", db: "justthisdb" }
```

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 want to make sure this DBA can administer all databases of the system, which role(s) should he have? See the MongoDB documentation[23].

Note: The answer for this question is *dbAdminAnyDatabase*

In this section we should explore the existing built-in roles for database administrators. Raise the some of the following questions.

- What differences exist between `dbAdmin` and `dbOwner` roles?
- When should we apply one or another?

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

Note: This question requires a little more thought since the correct answer actually requires two different roles:

```
use admin
db.createUser(
{
  user: "theITguy",
  pwd: "i+love+networkprotocols",
  customData: { notes: ["admin", "the person admins machines"] },
  roles: ["clusterAdmin", "backup"]
})
```

Students can also come up with a custom user-defined role that should be given credit but discouraged given that we have a set of roles that perform the wanted operation.

---

[23] https://docs.mongodb.com/manual/reference/built-in-roles/

7.4 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.

Note: At this point its good moment to ask the question:

- Why can't we just have a `root` level user create the roles?
- Why should we first have a look to the 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.

Note: Students should create a JSON object that will contain all of the above privileges

```
privileges: [
  {resource: { db: "brands", collection: "*"},
   actions: ["viewUser", "listCollections", "update"]},
  {resource: { db: "brands", collection: "automotive"},
   actions: ["insert"] }
]
```

Here you can reference the set of available privileges that MongoDB has: https://docs.mongodb.org/manual/reference/privilege-actions/

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?

Note: Students should come up with something very similar to the following:

```
db.createRole({
  role: "carlover",
  privileges: [
    { resource: { db: "brands", collection: "*"}, actions: ["viewUser",
↪"listCollections", "update"]},
    { resource: { db: "brands", collection: "automotive"}, actions: ["insert"] }
  ],
  roles: []
})
```

Ask the students why we need the `roles` array and why it should be empty.

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.

Note: Students should come up with something similar to this command:

```
use brands
db.grantRolesToUser(
  "ilikecars",
  [
    { role: "dbOwner", db: "brands" }
  ]
)
```

Students can come up with other commands like `db.updateUser("ilikecars", {...})` which is also valid.

Revoke Role

- Let's assume that the role `carlover` is no longer valid for user `ilikecars`.
- How do we revoke this role?

Note: In this section the students should be able to indicate that the command for doing this operation is the following:

```
use brands
db.revokeRolesFromUser(
  "ilikecars",
  [
    { role: "carlover", db: "brands" }
  ]
)
```

7.5 Authentication

Learning Objectives

Upon completing this module, you should understand:

- Authentication mechanisms
- External authentication
- Native authentication
- Internal node authentication
- Configuration of authentication mechanisms

Authentication

- Authentication is concerned with:
  - Validating identities
  - Managing certificates / credentials
  - Allowing accounts to connect and perform authorized operations
- MongoDB provides native authentication and supports X509 certificates, LDAP, and Kerberos as well.

Authentication Mechanisms

MongoDB supports a number of authentication mechanisms:

- SCRAM-SHA-1 (default >= 3.0)
- MONGODB-CR (legacy)
- X509 Certificates
- LDAP (MongoDB Enterprise)
- Kerberos (MongoDB Enterprise)

Note:

- Native: SCRAM-SHA-1 and MongoDB-CR are native mechanisms in the sense that they are fully managed by MongoDB instances.
- External: LDAP and Kerberos are external authentication mechanisms and are only available with MongoDB Enterprise.
- X509 can also be considered native in terms of management but they rely on certificates generated by 3rd parties and only enforced by MongoDB.

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 -u user -p
 ↪
 ↪                                                    MongoDB shell version: 3.2.
 ↪5
Enter password:
```

Note:

- Using the `--auth` parameter will only cause mongod to enable authentication.
- You need to create users separately.
- the shell

- You can take the opportunity to ask:
  - Q: What happens if we just launch a mongod without having any users created?
  - A: Nothing happens, we just can't access the instance.
- cover localhost exception
- create a first user with the following, avoid using `root` as the role

```
db.createUser({user:'admin',pwd:'pwd',roles:[{role:'userAdminAnyDatabase',db:'admin'}
↪]})
```

- run the following to see who is authenticated:

```
db.runCommand({connectionStatus:1})
```

7.6 Lab: Secure mongod

Premise

It is time for us to get started setting up our first MongoDB instance with authentication enabled!

Note:

- Expected time: 5 minutes
- Prerequisites:
  - Students should have installed MongoDB Enterprise or compiled MongoDB community with –ssl flags.

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" } ]
} )
```

Note: *root* is a superuser role so make sure you mention the privileges.

https://docs.mongodb.org/manual/reference/built-in-roles/#superuser-roles

---

Enable Authentication

Launch `mongod` with `auth` enabled

```
mongo admin --port 28000 --eval 'db.shutdownServer()'
mongod --port 28000 --dbpath /data/secure_instance_dbpath --auth
```

Note: With these commands, you can mention that:

- *mongo admin –eval 'db.shutdownServer()'* is a clean shutdown of the server
- `timeoutSecs` is parameter that can be used to control the shutdown operation
- Especially w/ replica sets, which they'll be using, soon.

Connect using the recently created `maestro` user.

```
mongo --port 28000 admin -u maestro -p
```

7.7 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)

Note:

- Explain what DML and DDL operations are:
  - DML means data manipulation language (inserts, updates, removes, grant user role ...)
  - DDL means data definition language (create collection, index, drop database ...)
- Q: Why do we not enable DML by default?
- A: Due to the performance impact of logging all write operations
- Q: In what circumstances might we want to enable DML?

- A: On highly sensitive namespaces or for given set of users.

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
```

Note:

- We can define filters on any particular field of the audit message
- These will work as regular MongoDB query filter expressions, but not all operators will apply.
- Be creative and ask students to set different filters based on roles or incoming connections.

7.8 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)

Note:

- important to note to students that encryption at rest is an enterprise version feature

---

Network Encryption

- MongoDB enables TLS/SSL for transport layer encryption of traffic between nodes in a cluster.
- Three different network architecture options are available:
  - Encryption of application traffic connections
  - Full encryption of all connections
  - Mixed encryption between nodes

Note:

- mixed encryption means that we can have nodes in a replica set that communicate with some nodes not encrypted and others encrypted

---

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

Note:

- Important to raise awareness to this point
- Many students might get the impression that configuring encryption in one of the nodes would be enough when that's not the case
- Wire data needs to encrypted through TLS/SSL configuration
- Encrypted Storage Engine only provides encryption on data at rest
- We should use different encryption keys for different nodes.

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

Note:

- MongoDB offers some integration options for Key Management and Storage Encryption
- Key managers are recommended for good security practices like key expiration and rotation
- Key managers are important if we want to be complaint with HIPAA, PCI-DSS, and FERPA certifications

---

7.9 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)

Note:

- Diagnosing issues may be more difficult with log redaction enabled due to lack of data
- Enable log redaction on each `mongod` and `mongos`
- Log redaction will **not** redact information in the `system.profile` collection, or the oplog in a replica set
- Restrict access with collection-level access control[24]

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
})
```

[24] https://docs.mongodb.com/manual/core/collection-level-access-control/

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
```

Note:

- We could also set this up by enabling profiling or increasing the log level after a normal start.
- Starting with the verbose option easily sets the lab up for us.

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

Note:

- If enabling on a replica set, all members must be configured to redact log data
- If running a sharded cluster, the `mongos` must also be configured to redact information. The same arguments will work for both `mongod` and `mongos`
- There are several ways to turn on log redaction:

```
// restart server with the --redactClientLogData flag
mongod --dbpath <path> --port <port> --redactClientLogData ...

// connect via the shell and run the following
db.adminCommand({
  setParameter: 1, redactClientLogData: true
})

// via a configuration file parameter
security:
  redactClientLogData: true
```

7.10 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[25]

Note:

- This might be a good opportunity to have students work in groups.

[25] https://docs.mongodb.org/manual/reference/configuration-options/

- If we can guarantee:
  - connectivity between all students workstations
  - administration rights over the workstations
- Then we can go ahead and group students together to accomplish these tasks.

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[26] 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
```

[26] 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
```

Note: If not mentioned before this is a good opportunity to have the students review the configuration options that MongoDB configuration files have.

Make sure you emphasize the security options:

https://docs.mongodb.org/manual/reference/configuration-options/#security-options

---

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
```

Note:

- On this configuration we are focusing on getting the internal authentication to work with a keyfile.
- There are other options that you may want to bring up with the students.
- It's probably a good time to ask?
  - If I want to use x509 certificates what other settings would I need to be adding?
  - Once I configured the system to use keyfile is that immutable?

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

Note:

We expect the students to first draft a set of instructions that they need to complete:

- Add the replication configuration to the config file
- Connect with *pivot* user to initiate the replica set
- Instantiate the remaining nodes

- Add those nodes to the replica set

The end result should be something similar to the following:

```
> rs.isMaster()
{
"setName" : "VAULT",
"setVersion" : 3,
"ismaster" : true,
"secondary" : false,
"hosts" : [
  "node0:50000",
  "node1:50000",
  "node2:50000"
],
...
}
```

They will probably have something to add to their config files.

Here's the link[27]

and it looks like this:

```
replication:
  oplogSizeMB: 100
  replSetName: "VAULT"
  enableMajorityReadConcern: true
```

7.11 Lab: LDAP Authentication & Authorization (Optional)

Premise

- Authentication and authorization with an external service (like LDAP) is an important functionality for large organizations that rely on centralized user management tools.
- This lab is designed to get you familiar with the procedure to run a `mongod` with authentication and authorization enabled with an external LDAP service.

Note:

- Take this opportunity to setup your OpenLDAP VM which students will connect to.
  1. Download and extract ldapserver.tar.gz[28]
  2. Run the following commands:

     ```
     $ vagrant up
     $ vagrant ssh
     ```

  3. You can confirm that everything is up and running correctly by running:

     ```
     $ ldapwhoami -vvv -H ldapi:/// -D 'uid=alice,ou=Users,dc=mongodb,dc=com' -
     ↪x -w secret
     ```

---

[27] https://github.com/thatnerd/work-public/blob/master/mongodb_trainings/secure_replset_config_including_replset_options.yaml
[28] http://s3.amazonaws.com/mongodb-training/vms/ldapserver.tar.gz

Test Connection to LDAP

- An LDAP server is up and running for you to connect to.
- **Server Info**:
  - **Server Address**: `192.168.19.100:8389`
  - **User**: `uid=alice,ou=Users,dc=mongodb,dc=com`
  - **Password**: `secret`

Note:

- Make sure to update the IP above with your computer's own local IP address.
- We're using `8389` instead of the default LDAP port of `389` because we need to forward the port from our VM to our host machine so students can access the OpenLDAP server.

Test Connection to LDAP (cont'd)

- Your goal is to fill in the following configuration file and get `mongoldap` to successfully talk to the LDAP server with the following command:

```
$ mongoldap --config mongod.conf --user alice --password secret
```

```
...
security:
  authorization: "enabled"
  ldap:
    servers: "XXXXXXXXXXXXXX:8389"
    authz:
      queryTemplate: "XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX"
    userToDNMapping: '[{match: "XXXX", substitution:
↪"XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX"}]'
    transportSecurity: "none"
    bind:
      method: "simple"
setParameter:
    authenticationMechanisms: PLAIN
```

Note:

- The key to this exercise is to build a correct `queryTemplate` and `userToDNMapping`.
- The correct missing parts of the config are:

```
security:
  ldap:
    servers: "192.168.19.100" // students will update with your local IP,␣
↪currently this is the IP of the VM
    authz:
      queryTemplate: "ou=Users,dc=mongodb,dc=com??one?(member={USER})"
    userToDNMapping: '[{match: "(.+)", substitution: "uid={0},ou=Users,dc=mongodb,
↪dc=com"}]'
```

- Inside ldapserver.tar.gz[29] there is a sample `mongod.conf` that should be able to talk to the LDAP server.

Authentication with LDAP

- Once you've successfully connected to LDAP with `mongoldap` you should be able to use the same config file with `mongod`.

```
$ mongod --config mongod.conf
```

- From here you should be able to authenticate with `alice` and `secret`.

```
$ mongo --username alice \
        --password secret \
        --authenticationMechanism PLAIN \
        --authenticationDatabase '$external'
```

Note:

- The following command will test your connection to the OpenLDAP server

```
$ mongoldap --config mongod.conf --user alice --password secret
```

Authorization with LDAP

- After successfully *authenticating* with LDAP, you'll need to take advantage of the **localhost exception** to enable *authorization* with LDAP.
- Create a role that allows anyone who is apart of the **cn=admins,ou=Users,dc=mongodb,dc=com** LDAP group to be able to manage users (e.g., inheriting `userAdminAnyDatabase`).
- To confirm that you've successfully setup authorization the following command should execute without error if you're authenticated as `alice` since she's apart of the group.

```
> use admin
> db.getRoles()
```

Note:

- The following command will create the necessary role.

```
> db.createRole({
    role: 'cn=admins,ou=Users,dc=mongodb,dc=com',
    privileges: [],
    roles:['userAdminAnyDatabase']
  });
```

---

[29] http://s3.amazonaws.com/mongodb-training/vms/ldapserver.tar.gz

7.12 Lab: Security Workshop

Note:

- We assume you are familiar with the provisioning scripts. If not start with: https://docs.google.com/document/d/17asAf_1lrj5lUynl6RdyrRekQeGbvsAW5ZV3F3FM3cA
- You will provision 4 nodes per team or attendee using the provisioning script. For example, for a 9 team or attendee exercise, you would run:

```
./deploy.py --profile mdbw-security --teams 9 --instances 4 --noom --run␣
↪INSTRUCTOR-StetsonD
```

- 3 nodes for the replica set, 1 node for the client application
- Replace INSTRUCTOR with your name, and StetsonD with the room you are presenting in
- The attendees will have to:
  - Setup SSL with the client certificates
  - Setup auth
  - Enable encryption at rest
  - Enable log redaction
- Each successive objective of this workshop requires full completion of previous objectives. Ensure all participants have met the requirements of a specific section before proceeding.

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

Note: Describe to the students the different components of this workshop.

- The application code in "security-lab/mongo-messenger"
- The 3 AWS instances where the backend should be running
- The single AWS instance where the node app should run
- The set of available files in "/share/downloads":
  - mongodb_packages => MongoDB binaries
  - certs => X509 certificates
  - config => Configuration files
- How to install and start MongoDB on the instances using the package
- Provide the students with the following files:
  - AdvancedAdministrator.pem
  - Info per team about IPs, hostnames, ... from running "describe.py –run security_workshop"
  - certs.tgz

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[30]

Note: [TODO] fix agent forwarding.

You can convert .pem files on Mac by:

- brew install putty

[30] http://docs.aws.amazon.com/AWSEC2/latest/UserGuide/putty.html

- puttygen mykey.pem -o mykey.ppk

Exercise: Accessing your instances from Linux or Mac

- Get your .pem file and close the permissions on it

```
chmod 600 AdvancedAdministrator.pem
```

- Enable the keychain and `ssh` into `node1`, propagating your credentials

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

- SSH into `node2` from `node1`

```
ssh -A node2
```

Solution: Accessing your instances

In our machines we will have access to all nodes in the deployment:

```
cat /etc/hosts
```

A `/share/downloads` folder with all necessary software downloaded

```
ls /share/downloads
ls /etc/ssl/mongodb
```

Note:

- quickly describe the contents of the dirs under `downloads` Don't emphasize `validation`, this is where your validation scripts are
- necessary certificates can be found in both `/etc/ssl/mongodb` and `/share/downloads/certs`

Exercise: Starting MongoDB and configuring the replica set

- `/share/downloads/mongodb_packages` contains MongoDB 3.2 and 3.4
- Installation instructions are at:
  - https://docs.mongodb.com/manual/tutorial/install-mongodb-enterprise-on-red-hat/
- Configure the 3 nodes as a replica set named **SECURED**
- Use `node1`, `node2` and `node3` for your host names
- You *MUST* use a config file[31]

[31] https://docs.mongodb.com/manual/reference/configuration-options/

Starting MongoDB and configuring the replica set (cont)

- Installation

```
sudo yum install -y mongodb-enterprise-3.4.2-1.el7.x86_64.rpm
sudo vi /etc/mongod.conf
sudo service mongod start
```

- Configure the 3 nodes as a replica set named **SECURED**, change **bindIp** to the **10.0.0.X** address, plus **127.0.0.1**

```
replication:
    replSetName: SECURED
net:
    bindIp: 10.0.0.101,127.0.0.1
```

Initiating The Replica Set

```
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()
```

Exercise: Check the Connection to MongoDB

Let's try to connect to our running MongoDB cluster.

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

Note:

- Here we want to make sure everyone can connect correctly to the MongoDB cluster.
- A student may ask why there are no primaries in the replica set. This is most likely because they've reached this step quickly and an election is still taking place

---

Exercise: 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
```

- Connect to the public ip of your `node4` instance, port 8080
  - `http://NODE4-public-IP:8080`

Note: The sample application code should be available in the AWS instance. In case students cannot find it, they can download using this instruction:

```
curl -O https://s3.amazonaws.com/mongodb-training/security_lab/security_lab.tgz
```

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"
```

- This will work, for now...

WARNING: Spying your deployment!

Throughout the lab, the instructor will be spying on your deployment!

This checking is done by running a few scripts on your machines that will verify whether or not you have completely secured your deployment.

We will come back to this later on.

Note: At this point you should run the lab validation scripts against one of the students environment to test which things are not yet secured.

- run any arbitrary command. Try the following first, as that first run may fail due to the fact that is has to add the hostname to `known_hosts`.

```
./manage.py --run NathanL-StetsonD --teams all \
--roles node1,node2,node3 --cmd "/bin/hostname -f"

./manage.py --run NathanL-StetsonD --teams all  \
--roles node1,node2,node3 \
--cmd "sudo python /share/downloads/validation/validate_log_redaction.py"

./manage.py --run NathanL-StetsonD --teams all \
--roles node1,node2,node3 \
--cmd "sudo python /share/downloads/validation/validate_se_encryption.py"
```

Exercise: Set up Authentication

Once we have our sample application up an running is time to start securing the system.

You should start by enabling MongoDB authentication[32]

To do this, you will have to decide:

- Which authentication mechanism to use
- Which authorization support will you use
- Set of users required to operate this system

Note: At this stage we will have the students making decisions regarding the authentication and authorization mechanisms available, and which better suits their needs.

Ask questions like:

- Which authentication mechanisms should we be setting up?
  - Remind students that we will want the application to be fully encrypted
- Which systems should we have in place to manage users?
  - What happens if we decide to have more than one application in this system?
  - What will happen if we need to remove

Solution: Enable authorization

- Using the localhost exception, create the first user

```
use admin
db.createUser({
  user: "foo",
  pwd: "bar",
  roles: [{role: "root", db: "admin"}]
})
db.createUser({
  user: "bar",
  pwd: "baz",
  roles: [{role: "userAdminAnyDatabase", db: "admin"}]
})
db.createUser({
  user: "mongo-messenger",
  pwd: "nodejs",
  roles: [{role: "readWrite", db: "security-lab"}]
})
```

- Must be able to create other users
- Need to change “Mongo Messenger” to auth with a given user

[32] https://docs.mongodb.com/manual/core/authentication/

Authorization questions

Some suggested questions for authorization and role-based access control[33]

- What built-in roles are available?
- Remind the students about user-defined roles
- What roles should be given?
- Based on the users created previously, what are some potential weaknesses?

Exercise: 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/`
- http://mongodb.github.io/node-mongodb-native/2.2/tutorials/connect/ssl/

Solution: Enable SSL between the nodes

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

- Restart all running mongod's
- Connect with the client
- Why no `authorization: enabled` in the config file?
  - Enabling clusterAuth implicity enables authorization

[33] https://docs.mongodb.com/manual/core/authorization/

Testing our SSL Connection from the mongo shell

```
mongo --ssl --host node1 --sslCAFile /etc/ssl/mongodb/ca.pem --sslPEMKeyFile /etc/ssl/
↪mongodb/node1.pem
```

Solution: Enable SSL with the client

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

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

let ca = [fs.readFileSync('/etc/ssl/mongodb/ca.pem')];
let cert = fs.readFileSync('/etc/ssl/mongodb/node1.pem');
let key = fs.readFileSync('/etc/ssl/mongodb/node1.pem');
let options = {
  sslValidate:true,
  sslCA:ca,
  sslCert:cert,
  sslKey:key
}
const url = `mongodb://mongo-messenger:node-js@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")
})
```

Troubleshooting

- Student receives an error that the primary can't be found
  - Their connection url is most likely malformed.
- Student receives an error that they don't have permission on the collection
  - If they've correctly set up authorization and role-based access control, they need to add the application user credentials and specify an `authSource`

Exercise: 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!!!

Solution: Encrypt Storage Layer

- Remind students that encryption at rest is only available for WiredTiger
- 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
```

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

Exercise: 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

Note: At this point students should enable log redaction in their cluster nodes.

To accomplish this students should do the following:

- relaunch all nodes enabling client log data redaction
- Give "extra kudos" to students that managed to do this and also clearing any information on previous logs

---

Solution: 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

Auditing

At this point we have a secured MongoDB deployment hardened against outside attacks, and used Role-Based Access Control to limit the access of users.

- The final step is to enable auditing, giving us a clear record of **who** performed an auditable action.

Exercise: Enable Auditing

- Enable auditing for all operations, to include CRUD operations, for your mongo-messenger user
- Output the log file in JSON format
- Output the log file to `/mongod-data/audit/SECURED`
- There are many filter options[34]

Note:

- Outputting to a BSON file will preserve the most information with the best performance, however we are outputting in JSON so participants can more easily parse the audit log.
- Take care when auditing CRUD operations, they are not redacted in the audit log
- Talk to the students about the different audit formats and destinations, touching on the pros and cons (e.g. readability, log truncation, and performance implications)
  - JSON, BSON
  - File, syslog, console
- Logging successful authentication actions is slower than logging just failed authentication actions
- Auditable actions can be fine-tuned in the audit filter parameter

---

Solution: Enable Auditing

```
setParameter: { auditAuthorizationSuccess: true }

auditLog:
  destination: "file"
  format: "JSON"
  path: /var/log/SECURED/audit.json
  filter: '{ users: { user: "mongo-messenger", db: "security-lab" } }'
```

[34] https://docs.mongodb.com/manual/tutorial/configure-audit-filters/

Putting it together

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

security:
  clusterAuthMode: x509
  enableEncryption : true
  encryptionKeyFile : /etc/ssl/mongodb/mongodb-keyfile
  redactClientLogData: true

setParameter: { auditAuthorizationSuccess: true }

auditLog:
  destination: "file"
  format: "JSON"
  path: /mongod-data/audit/SECURED/audit.json
  filter: '{ users: { user: "mongo-messenger", db: "security-lab" } }'
```

Summary

What we did:

- Enabled basic authorization
- Used SSL certificates
- Encrypted the database at rest
- Redacted the mongod logs
- Configured auditing for a specific user

Note: Ask what else could be done?

- MongoDB
  - Link authorization and authentication to outside system like LDAP or Kerberos
  - Enable redaction of results
- Infrastructure
  - Use security groups if in AWS
  - Use firewall
- Application
  - Security at the application level

---

8 Aggregation

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

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

Aggregation Stages

- There are many aggregation stages.
- In this introductory lesson, we'll cover:
  - `$match`: Similar to `find()`
  - `$project`: Shape documents
  - `$sort`: Like the cursor method of the same name
  - `$group`: Used to aggregate field values from multiple documents
  - `$limit`: Used to limit the amount of documents returned
  - `$lookup`: Replicates an SQL left outer-join

Aggregation Expressions and Variables

- Used to refer to data within an aggregation stage
- Expressions
  - Use field path to access fields in input documents, *e.g.* `"$field"`
- Variables
  - Can be both user-defined and system variables
  - Can hold any type of BSON data
  - Accessed like expressions, but with two $, *e.g.* `"$$<variable>"`
  - For more information about variables in aggregation expressions, click here[35]

Note:

- Explain to students that this is a brief overview
- Point out the use of expressions during the examples in this module

---

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.

[35] 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

Note:

- We should also mention that our tweet documents actually contain many more fields.
- We are showing just those fields relevant to the aggregations we'll do.

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 users.
- 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 } ] )
```

Note:

- Discuss the $match stage
- Discuss the $project stage as a whole
- Remember that with project we can pull a value out of an embedded document and put it at the top level.
- Discuss the ratio projection
- Discuss screen_name projection
- Give an overview of other operators we might use in projections

---

Exercise: $match and $project

- Of the users in the "Brasilia" timezone who have tweeted 100 times or more, who has the largest number of followers?
- Time zone is found in the "time_zone" field of the user object in each tweet.
- The number of tweets for each user is found in the "statuses_count" field.
- A result document should look something like the following:

```
{ _id         : ObjectId('52fd2490bac3fa1975477702'),
  followers   : 2597,
  screen_name: 'marbles',
  tweets      : 12334
}
```

Note:

```
[ { "$match" : { "user.time_zone" : "Brasilia",
                 "user.statuses_count" : {"$gte" : 100} } },
  { "$project" : { "followers" : "$user.followers_count",
                   "tweets" : "$user.statuses_count",
                   "screen_name" : "$user.screen_name" } },
  { "$sort" : { "followers" : -1 } },
  { "$limit" : 1 } ]
```

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[36].

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.

[36] http://docs.mongodb.org/manual/meta/aggregation-quick-reference/#accumulators

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

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 }
] )
```

Note:

- $group operations require that we specify which field to group on.
- In this case, we group documents based on the user's screen name.
- With $group, we aggregate values using arithmetic or array operators.
- Here we are counting the number of documents for each screen name.
- We do that by using the $sum operator
- This will add 1 to the count field for each document produced by the $group stage.
- Note that there will be one document produced by $group for each screen name.
- The $sort stage receives these documents as input and sorts them by the value of the count field

---

The Sort Stage

- Uses the $sort operator
- Works like the `sort()` cursor method
- 1 to sort ascending; -1 to sort descending
- E.g, db.testcol.aggregate([{ $sort : { b : 1, a : -1 } }])

The Skip Stage

- Uses the $skip operator
- Works like the `skip()` cursor method.
- Value is an integer specifying the number of documents to skip.
- E.g, the following will pass all but the first 3 documents to the next stage in the pipeline.
  - db.testcol.aggregate([{ $skip : 3 }, ...])

The Limit Stage

- Used to limit the number of documents passed to the next aggregation stage.
- Works like the `limit()` cursor method.
- Value is an integer.
- E.g., the following will only pass 3 documents to the stage that comes next in the pipeline.
  - db.testcol.aggregate([{ $limit: 3 }, ...])

The Lookup Stage

- Pulls documents from a second collection into the pipeline
  - The second collection must be in the same database
  - The second collection cannot be sharded
- Documents based on a matching field in each collection
- Previously, you could get this behavior with two separate queries

The Lookup Stage (continued)

- Documents based on a matching field in each collection
- Previously, you could get this behavior with two separate queries
  - One to the collection that contains reference values
  - The other to the collection containing the documents referenced

---

Note:

- When following with `$unwind`, if you use `preserveNullAndEmptyArrays: true` then it remains a left outer join.

Example: Using `$lookup`

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

```
// lookup example insert
db.commentOnEmployees.insertMany( [
    { employeeCount: 405000,
      comment: "Biggest company in the set." },
    { employeeCount: 405000,
      comment: "So you get two comments." },
    { employeeCount: 100000,
      comment: "This is a suspiciously round number." },
    { employeeCount: 99999,
      comment: "This is a suspiciously accurate number." },
    { employeeCount: 99998,
```

Example: Using `$lookup` (Continued)

```
      comment: "This isn't in the data set." }
    ] )
// end lookup example insert
// lookup example aggregation
db.companies.aggregate( [
  { $match: { number_of_employees: { $in:
      [ 405000, 388000, 100000, 99999, 99998 ] } } },
  { $project: { _id :0, name: 1, number_of_employees: 1 } },
  { $lookup: {
      from: "commentOnEmployees",
      localField: "number_of_employees",
```

9 Views

9.1 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>

Note:

- Views do not have any data, nor do they cache their data.
- Views can only be created from another view or single collection. In order to combine data from multiple collections, users can use the familiar aggregation operator *$lookup*

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()
```

Note:

- Views do have limits and there are certain operators that can't be used.
  - MapReduce
  - $text
  - Certain Projection operators
    - $
    - $slice
    - $elemMatch
    - $meta

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

---

Note:

- The aggregation to create the view is ran every time the view is queried
- Creating views from views can be slow, as we are cascading aggregations.
- Views are shown just like other collections via `show collections`
  - MongoDB will neither check collection fields nor existence before creating a view.
  - If there is no collection, the view will return an empty cursor

---

9.2 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.

Note:

```
use companies;
db.complaints.count() // 404816
```

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" : ""
}
```

Note:

```
use companies;
db.createView("companyComplaintsInNY", "complaints", [
  { $match: { "state": "NY" } },
  { $sort: { "date_received": -1 } }
])
```

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" : ""
})
```

9.3 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.

Note:

```
use companies;
db.complaints.count() // 404816
```

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"
}
```

Note:

```
use companies;
db.createView("productComplaints", "complaints", [
  { $project: { _id: 0, product: 1, state: 1, company: 1 } }
])
```

9.4 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 219)

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
          }
        ]
}
```

Note:

```
use companies;
db.createView("companyComplaintsByState", "productComplaints", [
  {
```

```
    $group: {
      "_id": {
          company: "$company",
          state: "$state"
      },
      count: {
          $sum: 1
      }
    }
  }, {
    $group: {
      "_id": "$_id.company",
      "byState": {
        "$push": {
          "state": "$_id.state",
          "count": "$count"
        }
      }
    }
  }, {
    $project: {
      _id: 0,
      "company": "$_id",
      "states": "$byState"
    }
  }
])
```

10 Reporting Tools and Diagnostics

Performance Troubleshooting **(page 222)** An introduction to reporting and diagnostic tools for MongoDB

10.1 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)
}
```

Note: Direct the students to the fact that you can see the activity on the server for reads/writes/total.

`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)
}
```

Note: Point out to students that the running time gets longer & longer, on average.

`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()
```

Note:

- Mention to the students what the fields mean.
- Things to keep in mind:

- op can be command, query, or update
- ns is sometimes the db.<COLLECTION> namespace
  - but sometimes db.$cmd for commands
- key updates refers to index keys
- ts (timestamp) is useful for some queries if problems cluster.

`db.serverStatus()`

- Takes a snapshot of server status.
- By taking diffs, you can see system trends.
- Most of the data that MMS gets is from here.

Exercise: Using `db.serverStatus()`

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

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

- In the second window, type periodically:

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

Analyzing Profiler Data

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

Performance Improvement Techniques

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

Performance Tips: Write Concern

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

Bulk Operations

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

Exercise: Comparing `insertMany` with `mongostat`

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

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

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

mongostat, insertOne with {w: 1}

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

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

Run mongostat and see how fast that happens.

Multiple insertOne s with {w: 3}

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

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

Again, run mongostat.

mongostat, insertMany with {w: 3}

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

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

Schema Design

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

Shard Key Considerations

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

Indexes and Performance

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

11 Backup and Recovery

11.1 Backup and Recovery

Disasters Do Happen

Human Disasters

Terminology: RPO vs. RTO

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

Terminology: DR vs. HA

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

Quiz

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

Backup Options

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

Document Level: `mongodump`

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

`mongodump`

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

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

File System Level

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

Ensure Consistency

Flush RAM to disk and stop accepting writes:

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

File System Backups: Pros and Cons

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

Document Level: `mongorestore`

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

File System Restores

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

Backup Sharded Cluster

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

Restore Sharded Cluster

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

Tips and Tricks

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

12 MongoDB Atlas, Cloud & Ops Manager Fundamentals

12.1 MongoDB Cloud & Ops Manager

Learning Objectives

Upon completing this module students should understand:

- Features of Cloud & Ops Manager
- Available deployment options
- The components of Cloud & Ops Manager

Cloud and Ops Manager

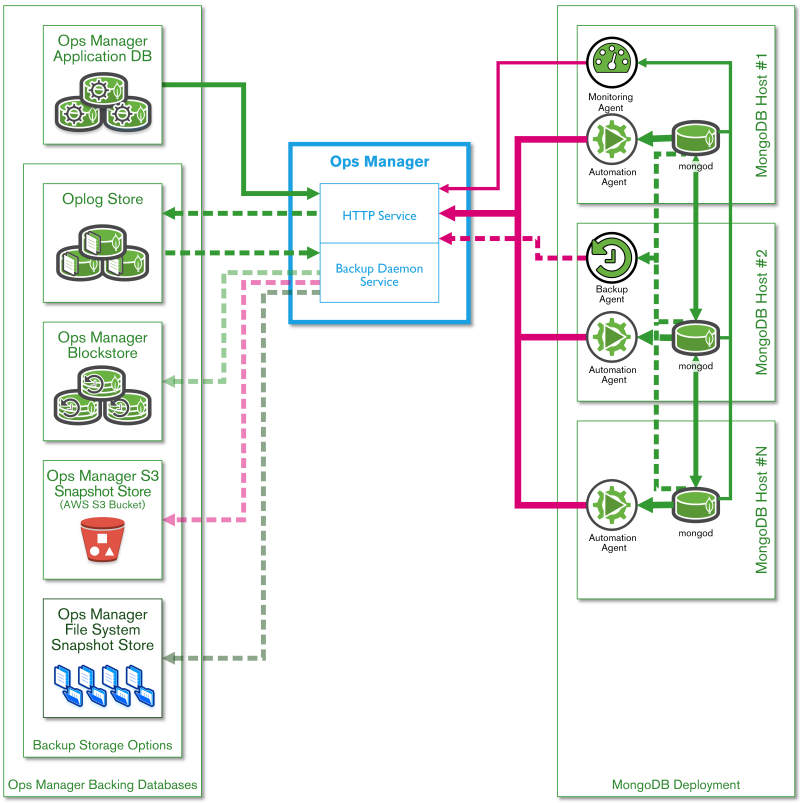
All services for managing a MongoDB cluster or group of clusters:

- Monitoring
- Automation
- Backups

Deployment Options

- Cloud Manager: Hosted, https://www.mongodb.com/cloud
- Ops Manager: On-premises

Architecture



Cloud Manager

- Manage MongoDB instances anywhere with a connection to Cloud Manager
- Option to provision servers via AWS integration

Ops Manager

On-premises, with additional features for:

- Alerting (SNMP)
- Deployment configuration (e.g. backup redundancy across internal data centers)
- Global control of multiple MongoDB clusters

Cloud & Ops Manager Use Cases

- Manage a 1000 node cluster (monitoring, backups, automation)
- Manage a personal project (3 node replica set on AWS, using Cloud Manager)
- Manage 40 deployments (with each deployment having different requirements)

Note:

- Use these use cases to get students interested in how Cloud Manager can save them a lot of time

---

Creating a Cloud Manager Account

Free account at https://www.mongodb.com/cloud

12.2 Automation

Learning Objectives

Upon completing this module students should understand:

- Use cases for Cloud / Ops Manager Automation
- The Cloud / Ops Manager Automation internal workflow

Note:

- Ops Manager can only be installed on 64-bit architecture

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

---

Note:

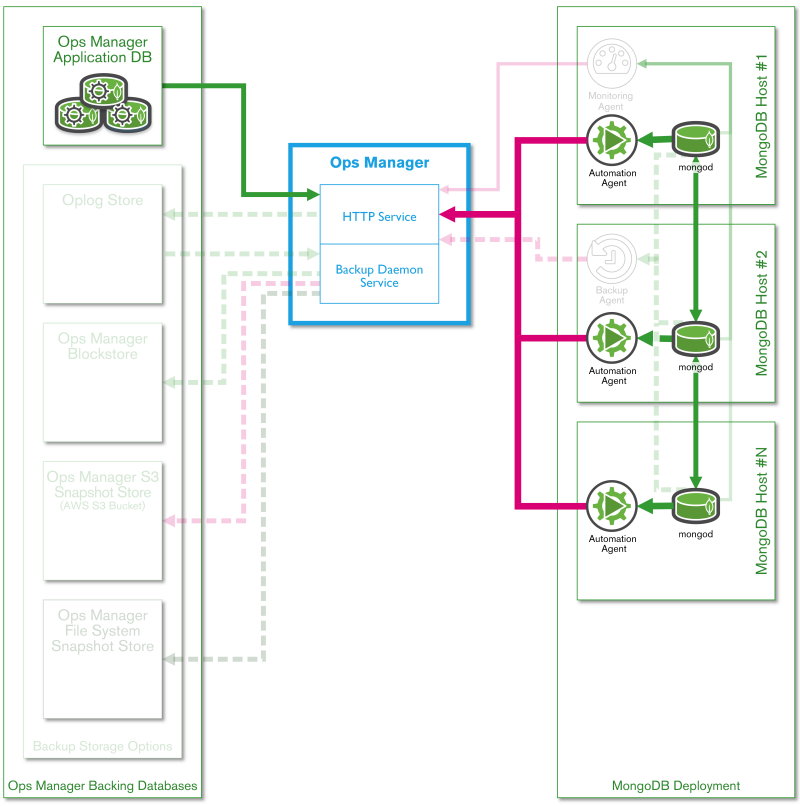
- Pings from automation agents occur at 10 second intervals in "goal state" mode
- Pings occur at 1 second intervals while performing an environment/topology change
- Automation agents **only** communicate with Ops/Cloud Manager.
  - Automation agents query the other machines in their cluster and perform predicate checks to ensure they can begin the process of an environment/topology change
  - In the case of failure, agents will continue to retry the operation indefinitely. Administrators must investigate the automation agent logs and fix the problem manually
  - In failure mode pings occur at 10 second intervals

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

Note:

- Administrators never edit the raw JSON document. Configuration is performed exclusively through an easy to use intuitive interface and the document is generated by the application.

```
{
    "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[37]
- The Automation API[38]
- Configuring the Automation Agent[39]

Note:

- Go to your Admin page (within Cloud Manager) -> My groups, create a new group, and walk through the process of setting up a small cluster on your laptop

---

[37] https://docs.cloud.mongodb.com/tutorial/nav/automation-agent/
[38] https://docs.cloud.mongodb.com/api/
[39] https://docs.cloud.mongodb.com/reference/automation-agent/

12.3 Lab: Cluster Automation

Learning Objectives

Upon completing this exercise students should understand:

- How to deploy, dynamically resize, and upgrade a cluster with Automation

Exercise #1

Create a cluster using Cloud Manager automation with the following topology:

- 3 shards
- Each shard is a 3 node replica set (2 data bearing nodes, 1 arbiter)
- Version 2.6.8 of MongoDB
- **To conserve space, set "smallfiles" = true and "oplogSize" = 10**

Note:

- Windows is not supported, Windows users should work with another person in the class or work on a remote Linux machine
- The entire cluster should be deployed on a single server (or the students laptop)
- Registration is free, and won't require a credit card as long as the student stays below 8 servers

---

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)

Note:

- Students may complete this in one or two steps
- Cluster configuration should be modified, then redeployed

12.4 Monitoring

Learning Objectives

Upon completing this module students should understand:

- Cloud / Ops Manager monitoring fundamentals
- How to set up alerts in Cloud / Ops Manager

Monitoring in Cloud / Ops Manager

- Identify cluster performance issues
- Identify individual nodes in cluster with performance issues
- Visualize performance through graphs and overlays
- Configure and set alerts

Monitoring Use Cases

- Alert on performance issues, to catch them before they turn into an outage
- Diagnose performance problems
- Historical performance analysis
- Monitor cluster health
- Capacity planning and scaling requirements

Monitoring Agent

- Requests metrics from each host in the cluster
- Sends those metrics to Cloud / Ops Manager server
- Must be able to contact every host in the cluster (agent can live in a private network)
- Must have access to contact Cloud / Ops Manager website with metrics from hosts

Agent Configuration

- Can use HTTP proxy
- Can gather hardware statistics via munin-node
- Agent can optionally gather database statistics, and record slow queries (sampled)

Agent Security

- SSL certificate for SSL clusters
- LDAP/Kerberos supported
- Agent must have “clusterMonitor” role on each host

Monitoring Demo

Visit https://www.mongodb.com/cloud

Note:

- The 10gen mongo-perf group may be interesting for demo’ing to the class

---

Navigating Cloud Manager Charts

- Add charts to view by clicking the name of the chart at the bottom of the host’s page
- “i” icon next to each chart title can be clicked to learn what the chart means
- Holding down the left mouse button and dragging on top of the chart will let you zoom in

Metrics

- Minute-level metrics for 48 hours
- Hourly metrics for about 3 months
- Daily metrics for the life of the cluster

Alerts

- Every chart can be alerted on
- Changes to the state of the cluster can trigger alerts (e.g. a failover)
- Alerts can be sent to email, SMS, HipChat, or PagerDuty

12.5 Lab: Create an Alert

Learning Objectives

Upon completing this exercise students should understand:

- How to create an alert in Cloud Manager

Exercise #1

Create an alert through Cloud Manager for any node within your cluster that is down.

After the alert has been created, stop a node within your cluster to verify the alert.

Note:

- This alert can be created by going to Activity -> Alert Settings -> Create

---

12.6 Backups

Learning Objectives

Upon completing this module students should understand:

- How Cloud / Ops Manager Backups work
- Advantages to Cloud / Ops Manager Backups

Methods for Backing Up MongoDB

- mongodump
- File system backups
- Cloud / Ops Manager Backups

Comparing MongoDB Backup Methods

Considerations	Mongodump	File System	Cloud Backup	Ops Manager
Initial Complexity	Medium	High	Low	High
Replica Set PIT	Yes**	Yes**	Yes	Yes
Sharded Snapshot	No	Yes**	Yes	Yes
Restore Time	Slow	Fast	Medium	Medium

****Requires advanced scripting**

Note:

- Instructors should spend a lot of time on this chart, lots of considerations here

---

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

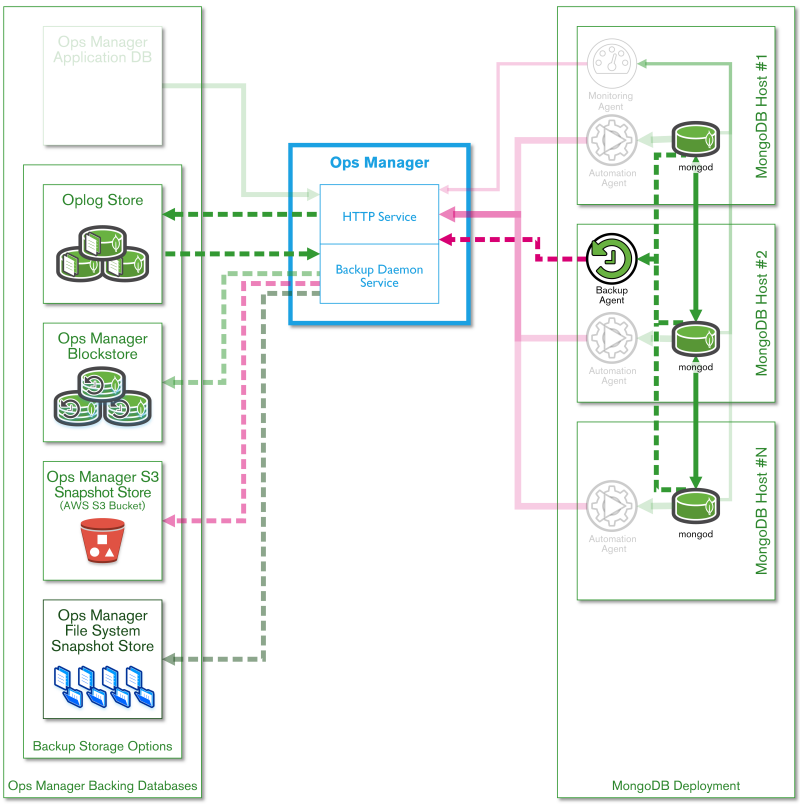
- Specify which backup to restore
- SCP push or HTTPS pull (one time use link) for data files

Architecture

Note:

- Can talk about the daemon process, HEAD database, and backup database with this diagram

---



Snapshotting

- Local copy of every replica set stored by Cloud / Ops Manager
- Oplog entries applied on top of local copy
- Local copy is used for snapshotting
- Very little impact to the cluster (equivalent to adding another secondary)

Backup Agent

- Backup agent (can be managed by Automation agent)
- Backup agent sends oplog entries to Cloud / Ops Manager service to be apply on local copy

13 MongoDB Cloud & Ops Manager Under the Hood

13.1 API

Learning Objectives

Upon completing this module students should understand:

- Overview of the Cloud / Ops Manager API
- Sample use cases for the Cloud / Ops Manager API

What is the Cloud / Ops Manager API?

Allows users to programmatically:

- Access monitoring data
- Backup functionality (request backups, change snapshot schedules, etc.)
- Automation cluster configuration (modify, view)

API Documentation

https://docs.mms.mongodb.com/core/api/ <https://docs.mms.mongodb.com/core/api/>

Note:

- Open the link in a browser and walk through some of the API calls, such as monitoring stats for a group

---

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.

Note:

- Most large companies use other systems for monitoring, point out how the API can help here

---

Programatically Restore Environments

Use the backup API to programmatically restore an integration or testing environment based on the last production snapshot.

Note:

- Fairly common practice for DBAs, except a lot of them are doing this manually

---

Configuration Management

Use the automation API to integrate with existing configuration management tools (such as Chef or Puppet) to automate creating and maintaining environments.

13.2 Lab: Cloud Manager API

Learning Objectives

Upon completing this exercise students should understand:

- Have a basic understanding of working with the Cloud Manager API (or Ops Manager if the student chooses)

Using the Cloud Manager API

If Ops Manager is installed, it may be used in place of Cloud Manager for this exercise.

Exercise #1

Navigate the Cloud Manager interface to perform the following:

- Generate an API key
- Add your personal machine to the API whitelist

Note:

- Admin -> API Keys and Whitelists

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"
```

Note:

- Make sure the group id matches a group within the student's account
- Ensure the IP address the request was coming from is whitelisted
- Ensure the username/apiKey is correct

Exercise #3

How would you find metrics for a given host within your Cloud Manager account? Create an outline for the API calls needed.

Note:

- First, query the API for a list of hosts: https://docs.mms.mongodb.com/reference/api/hosts/
- Next, query the metrics API call with the host is and name of the metric (or for all metrics): https://docs.mms.mongodb.com/reference/api/hosts/

13.3 Architecture (Ops Manager)

Learning Objectives

Upon completing this module students should understand:

- Ops Manager overview
- Ops Manager components
- Considerations for sizing an Ops Manager environment

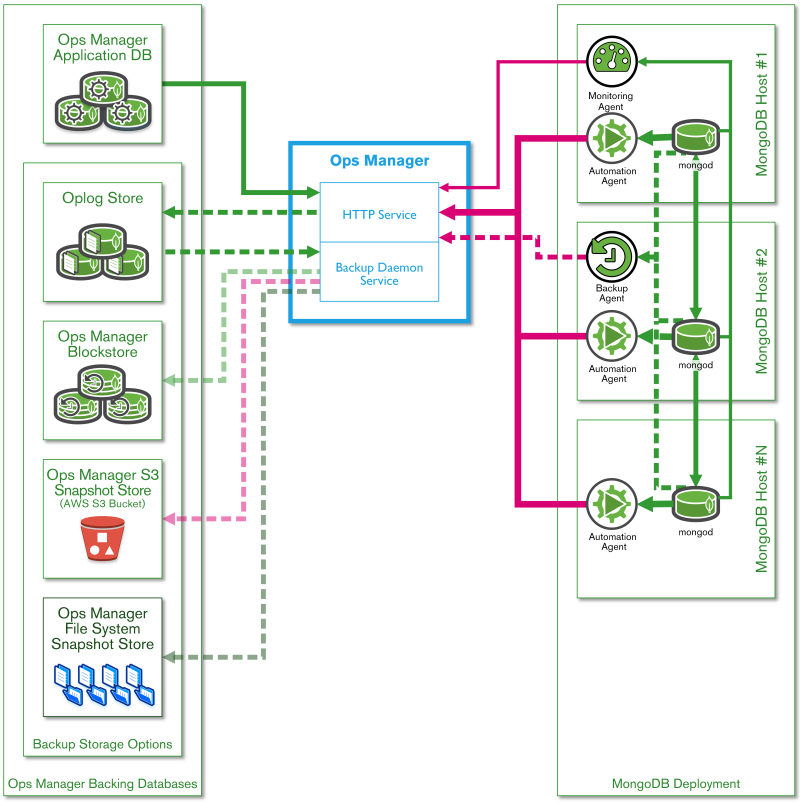
MongoDB Ops Manager

- On-premises version of Cloud Manager
- Everything stays within private network

Components

- Application server(s): web interface
- Ops Manager application database: monitoring metrics, automation configuration, etc.
- Backup infrastructure: cluster backups and restores

Architecture



Note:

- These deployments can get complex, talk about all the pieces
- Multiple backup daemons/backup DBs for large clusters

Application Server

- 15GB RAM, 50GB of disk space are required
- Equivalent to a m3.xlarge AWS instance

Application Database

- All monitoring metrics, automation configurations, etc. stored here
- Replica set, however, a standalone MongoDB node can also be used

Backup Infrastructure

- Backup database (blockstore, oplog, sync)
- Backup daemon process (manages applying oplog entries, creating snapshots, etc.)

Backup Database

- 3 sections: - blockstore for blocks - oplog - sync for initial sync slices
- Replica set, a standalone MongoDB node can also be used
- Must be sized carefully
- All snapshots are stored here
- Block level de-duping, the same block isn't stored twice (significantly reduces database size for deployment with low/moderate writes)

Backup Daemon Process

- The "workhorse" of the backup infrastructure
- Creates a local copy of the database it is backing up (references "HEAD" database)
- Requires 2-3X data space (of the database it is backing up)
- Can run multiple daemons, pointing to multiple backup databases (for large clusters)

13.4 Security (Ops Manager)

Learning Objectives

Upon completing this module students should understand:

- Ops Manager security overview
- Security and authentication options for Ops Manager

Ops Manager User Authentication

- Two-Factor authentication can be enabled (uses Google Authenticator)
- LDAP authentication option

Authentication for the Backing Ops Manager Databases

Ops Manager application database and backup database:

- MongoDB-CR (SCRAM-SHA1)
- LDAP
- Kerberos

Authenticating Between an Ops Manager Agent and Cluster

- LDAP
- MongoDB-CR
- Kerberos (Linux only)

Note:

- This is a good time to draw a diagram on the whiteboard to work through the various authentication options between the Ops Manager components

---

Encrypting Communications

- All communications can be encrypted over SSL.

Ops Manager Groups

- Users can belong to many different groups
- Users have different levels of access per group

User Roles By Group

- Read Only
- User Admin
- Monitoring Admin
- Backup Admin
- Automation Admin
- Owner

Global User Roles

- Global Read Only
- Global User Admin
- Global Monitoring Admin
- Global Backup Admin
- Global Automation Admin
- Global Owner

13.5 Lab: Install Ops Manager

Learning Objectives

Upon completing this exercise students should understand:

- The components needed for Ops Manager
- How to successfully install Ops Mananger

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

---

Note:

- This is sometimes the hardest part of setting up Ops Manager for users, ensuring everything has been set up correctly behind the scenes

---

Exercise #2

Install the Ops Manager application

- Ops Manager application requires a license for commercial use
- Download the Ops manager application (after completing form): http://www.mongodb.com/download
- Installation instructions (from above): docs.opsmanager.mongodb.com
- Verify Ops Manager is running successfully

Note:

- The Ops Manager application can be installed via an RPM, once the configuration file is updated, the application can be started (that is pretty much it to installing Ops Manager monitoring/automation)

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`

Note:

- Users sometimes get caught on permissions issues, especially for the HEAD directory

---

Exercise #4

Verify the Ops Manager installation was successful:

https://docs.opsmanager.mongodb.com/current/tutorial/test-new-deployment/

Exercise #5

Use Ops Manager to backup a test cluster:

- Create a 1 node replica set via Ops Manager automation
- Add sample data to the replica set:

```
> for (var i=0; i<10000; i++) { db.blog.insert( { "name" : i } )}
WriteResult({ "nInserted" : 1 })
> db.blog.count()
10000
```

- Use Ops Manager to backup the test cluster
- Perform a restore via Ops Manager of the test cluster

14 Introduction to MongoDB BI Connector

MongoDB Connector for BI **(page 256)** An introduction to MongoDB Connector for BI

14.1 MongoDB Connector for BI

Learning Objectives

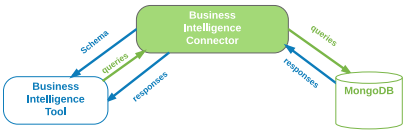
Upon completing this module students should understand:

- The different tools included in the MongoDB BI Connector package
- The different configuration files required by the BI Connector
- The supported SQL statements version
- How to launch `mongosqld`
- Run SQL statements in a MongoDB server instance

MongoDB BI Connector: Introduction

MongoDB Connector for BI enables the execution of SQL statements in a MongoDB server.

It's a native connector implementation that enables Business Intelligence tools to read data from a MongoDB server.



Note: This a good opportunity to show the students how to download the bi connector:

- BI Connector download[40]
- It's available with Enterprise subscription
- Free download for evaluation

---

[40] https://www.mongodb.com/download-center#bi-connector

How it works

The MongoDB Connector for BI executes in the following mode:

- Generates a Document-Relational Definition Language (DRDL) file that defines a map between a given collection shape to a relational schema
- Once the `drdl` file is generate, BI tools are able to request the correspondant relational sql and express queries
- After receiving and processing a SQL statement, provides back results in tabular format, native to BI Tools.
- The BI connector also functions as a pass-through authentication proxy.

Note: You can simplify the lingo by defining the connector as a sql proxy that understand SQL and is able to map it back to a collection shape.

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 colletions in MongoDB

Note:

- First we connect to a MongoDB instance using mongodrdl to generate the `drdl` file
- Them we launch `mongosqld` using the previously generated `drdl` file

The `mongodrdl`

`mongodrdl` generates a Document-Relation Definition Language file.

- The `drdl` file is a mapping between a given collection(s) shape and it's 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>
```

Note: Make sure students are aware of:

- drdl file is a YAML base file defining the mapping structure
- the name of the fields exposed to the sql client can be edited
  - by default we will keep the same naming

- for subdocuments and arrays, reference tables will be defined in the sql mapping

`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
    ...
```

Note:

`mongodrdl` implements all authentication mechanisms supported by mongodb

- By default, `mongodrdl` analyses **1000** documents of the target collection, to determine the shapes of your documents
- a larger sample size can be defined by setting `--sample` option

- If no collection `-c` is defined, the output file will contain all collections of the database.

```
mongodrdl -d training -o zips.drdl
```

- `mongodrdl` will expose all fields of a given collection or view
  - We can remove any given field from being exposed to the SQL client by manually editing the *drdl* file

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]}}"
```

Note: We can express any arbitrary MongoDB query. This feature becomes extremely useful when combined with non-standard SQL functionality, like geospatial queries that are natively supported by MongoDB.

```
db.zips.createIndex({'loc': '2d'})

db.zips.find({'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`

Note: We can overide the default configurations like:

- `--addr` : host address
- `--schemaDirectory` : defines a directory istead of a single *drdl* file
- Different socket permissions
- Different authentication mechanisms

`mongosqld` Authentication & Authorization

The BI Connector offers integration for three different authentication mechanisms:

- SCRAM-SHA-1
- MONGODB-CR
- PLAIN *(LDAP Authentication)*

And external LDAP Authorization:

- requires defining the **source** attribute in the user name string

```
grace?mechanism=PLAIN&source=$external
```

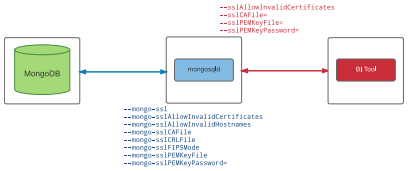
Note: Note that Kerberos is currently not supported.

- internal authentication and external LDAP authz are supported

---

`mongosqld` Encryption

BI Connector supports network encrytpion on all segments of the connection.



Note:

Make sure to reinforce that:

- we can encrypt all network segments
- from BI tool <-> mongosqld
- from mongosqld <-> mongod

- Although they should be set together, we can choose to encrypt only one network segment.

SQL Compatibalility

- BI Connector version 2.0 is compatible with SQL-99 SELECT[41] 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;
```

Note:

Demonstrate these instructions to students:

- run `mongod`
- import `zips.json` dataset
- generate *drdl* file

```
mkdir connector
mongod --dbpath connector --logpath connector/mongod.log --fork
mongoimport -d training -c zips usb_drive/zips.json
mongodrdl -d training -c zips -o zips.drdl
```

- run `mongosqld` using the *zips.drdl* file
- connect to `mongosqld` from a `mysql` client

```
mongosqld --schema zips.drld
mysql --host 127.0.0.1:3307
```

[41] https://docs.mongodb.com/bi-connector/master/supported-operations/

- run the following SQL query (and others)

```
use training;
DESC ZIPS;
SELECT zip, pop, state FROM zips WHERE state = "NY";
```

Find out more
mongodb.com | mongodb.org
university.mongodb.com

Having trouble?
File a JIRA ticket:
jira.mongodb.org

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