MongoDB Developer Rapid Start Training

Release 3.4

MongoDB, Inc.

Mar 24, 2017

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 informaton 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 operations person?

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.

1.2 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

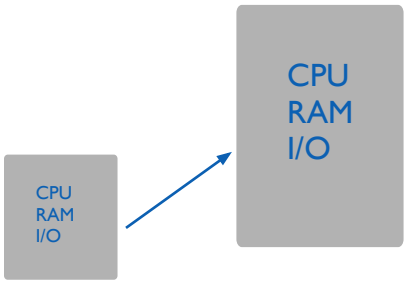
A MongoDB document expressed using JSON syntax.

```
{
  "_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.

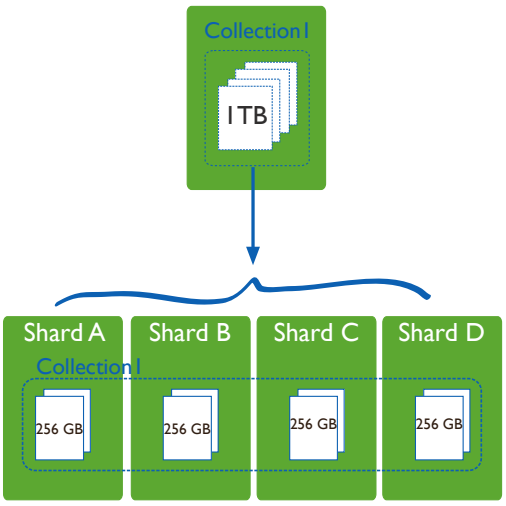
Vertical Scaling



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.

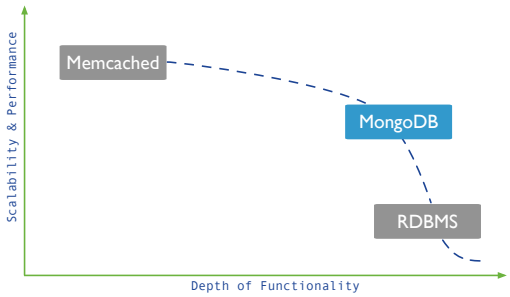
Scaling with MongoDB



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.

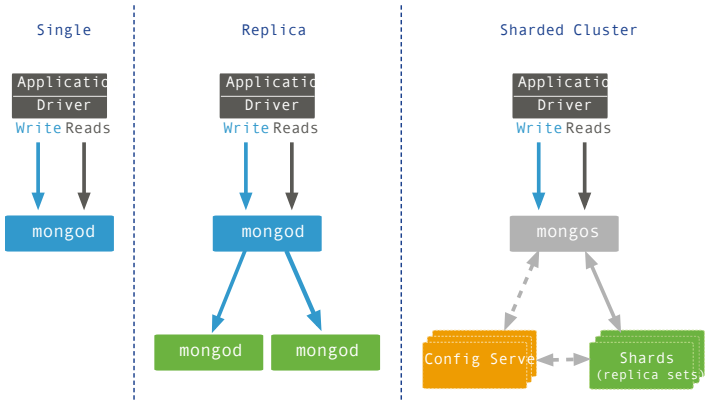
Database Landscape



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.

1.3 MongoDB Stores Documents

Learning Objectives

Upon completing this module, students should understand:

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

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" },
    [ "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).

ObjectIds

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.

1.4 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[3] 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 : {
```

[3] 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 mentions by 10
db.movie_mentions.updateOne( { title: "E.T." },
      { $inc:  { "mentions_per_hour.5" : 10 } } )
```

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

- $[4] 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" } } )
```

[4] 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:

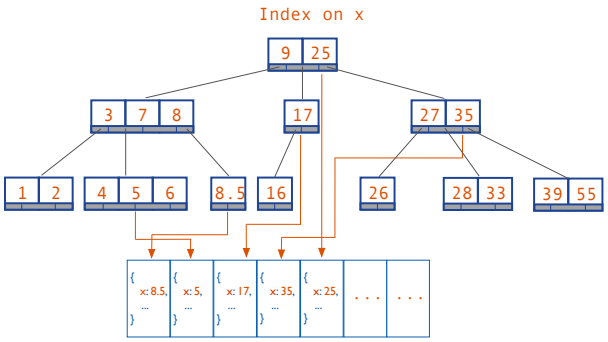
- The impact of indexing on read performance
- The impact of indexing on write performance
- How to choose effective indexes
- The utility of specific indexes for particular query patterns

---

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 } )
```

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 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

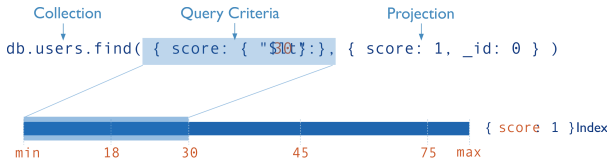
Note:

- 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")
```

3.3 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

---

3.4 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 x 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 ] } )
```

3.5 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[5] 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.

---

[5] 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" } )
```

3.6 Lab: Finding and Addressing Slow Operations

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 exercise.

Note:

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

3.7 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 Drivers

4.1 Introduction to MongoDB Drivers

Learning Objectives

Upon completing this module, students should understand:

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

MongoDB Supported Drivers

- C[6]
- C++[7]
- C#[8]
- Java[9]
- Node.js[10]
- Perl[11]
- PHP[12]
- Python[13]
- Ruby[14]
- Scala[15]

[6] http://docs.mongodb.org/ecosystem/drivers/c
[7] http://docs.mongodb.org/ecosystem/drivers/cpp
[8] http://docs.mongodb.org/ecosystem/drivers/csharp
[9] http://docs.mongodb.org/ecosystem/drivers/java
[10] http://docs.mongodb.org/ecosystem/drivers/node-js
[11] http://docs.mongodb.org/ecosystem/drivers/perl
[12] http://docs.mongodb.org/ecosystem/drivers/php
[13] http://docs.mongodb.org/ecosystem/drivers/python
[14] http://docs.mongodb.org/ecosystem/drivers/ruby
[15] http://docs.mongodb.org/ecosystem/drivers/scala

MongoDB Community Supported Drivers

35+ different drivers for MongoDB:

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

Driver Specs

To ensure drivers have a consistent functionality, series of publicly available specification documents[16] for:

- Authentication[17]
- CRUD operations[18]
- Index management[19]
- SDAM[20]
- Server Selection[21]
- Etc.

Driver Settings (Per Operation)

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

Driver Settings (Per Connection)

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

[16] https://github.com/mongodb/specifications
[17] https://github.com/mongodb/specifications/tree/master/source/auth
[18] https://github.com/mongodb/specifications/tree/master/source/crud
[19] https://github.com/mongodb/specifications/blob/master/source/index-management.rst
[20] https://github.com/mongodb/specifications/tree/master/source/server-discovery-and-monitoring
[21] https://github.com/mongodb/specifications/tree/master/source/server-selection

Insert a Document with the Java Driver

Connect to a MongoDB instance on localhost:

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

Access the test database:

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

Insert a myDocument Document into the test.blog collection:

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

Insert a Document with the Python Driver

Connect to a MongoDB instance on localhost:

```
client = MongoClient()
```

Access the test database:

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

Insert a myDocument Document into the test.blog collection:

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

Insert a Document with the C++ Driver

Connect to the "test" database on localhost:

```
mongocxx::instance inst{};
mongocxx::client conn{};

auto db = conn["test"];
```

Insert a myDocument Document into the test.blog collection:

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

4.2 Lab: Driver Tutorial (Optional)

Tutorial

Complete the Python driver tutorial[22] for a concise introduction to:

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

[22] http://api.mongodb.org/python/current/tutorial.html

5 Aggregation

5.1 Aggregation Tutorial

Learning Objectives

Upon completing this module students should understand:

- The concept of the aggregation pipeline
- The stages of the aggregation pipeline
- How to use aggregation operators
- The fundamentals of using aggregation for data analysis
- Group aggregation operators
- Using the same operator in multiple stages of an aggregation pipeline

Aggregation Basics

- Use the aggregation framework to transform and analyze data in MongoDB collections.
- For those who are used to SQL, aggregation can be similar to `GROUP BY`.
- 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:

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

Aggregation Stages

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

Aggregation Stages (continued)

- `$graphLookup`: Performs a recursive search on a collection
- `$indexStats`: Returns statistics regarding the use of each index for the collection
- `$out`: Creates a new collection from the output of an aggregation pipeline

For more information please check the aggregation framework stages[23] documentation page.

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.

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.

[23] https://docs.mongodb.com/manual/reference/operator/aggregation/#stage-operators

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[24].

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.

[24] 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 Unwind Stage

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

Example: User Mentions in a Tweet

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

```
    "hashtags" : [ ]
 },
 ...
```

Using $unwind

Who includes the most user mentions in their tweets?

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

Note:

- Many tweets contain multiple user mentions.
- We use unwind to produce one document for each user mention.
- Each of these documents is passed to the $group stage that follows.
- They will be grouped by the user who created the tweet and counted.
- As a result we will have a count of the total number of user mentions made by any one tweeter.

`$unwind` also supports this form:

```
{
  $unwind:
    {
      path: <field path>,
      includeArrayIndex: <string>,
      preserveNullAndEmptyArrays: <boolean>
    }
}
```

`$unwind` Behavior

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

Note:

- Nullish values are `null`, `undefined`, empty array, and missing fields

---

- the *preserveNullAndEmptyArrays* option (see next slide) can keep the nullish values around with the $unwind.

Data Processing Pipelines

- The aggregation framework allows you to create a data processing pipeline.
- You can include as many stages as necessary to achieve your goal.
- For each stage consider:
  - What input that stage must receive
  - What output it should produce.
- Many tasks require us to include more than one stage using a given operator.

Most Unique User Mentions

- We frequently need multiple group stages to achieve our goal.
- We just looked at a pipeline to find the tweeter that mentioned the most users.
- Let's change this so that it is more of a question about a tweeter's active network.
- We might ask which tweeter has mentioned the most unique users in their tweets.

Same Operator ($group), Multiple Stages

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

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

Note:

- We begin as we did before by unwinding user mentions.
- Instead of simple counting them, we aggregate using $addToSet.
- This produces documents that include only unique user mentions.
- We then do another unwind stage to produce a document for each unique user mention.
- And count these in a second $group stage.

The Sort Stage

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

The Skip Stage

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

The Limit Stage

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

The Lookup Stage

- Pulls documents from a second collection into the pipeline
  - In SQL terms, performs a left outer join
    - If you `$lookup` then immediately `$unwind` the field, it becomes an inner join
  - 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`

Create a separate collection for `$lookup`

```
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,
      comment: "This isn't in the data set." }
    ] )
```

Example: Using `$lookup` (Continued)

```
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",
      foreignField: "employeeCount",
      as: "example_comments"
  } },
  { $sort : { number_of_employees: -1 } } ] )
```

The GraphLookup Stage

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

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

Note: $graphLookup Documentation[25]

`$graphLookup` Fields

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

`$graphLookup` Optional Fields

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

Note: You cannot use any aggregation expression in this filter. For example, a query document such as

```
{ lastName: { $ne: "$lastName" } }
```

will not work in this context to find documents in which the lastName value is different from the lastName value of the input document, because "$lastName" will act as a string literal, not a field path.

Query Documentation[26]

[25] https://docs.mongodb.com/manual/reference/operator/aggregation/graphLookup/
[26] https://docs.mongodb.com/manual/tutorial/query-documents/#read-operations-query-argument

`$graphLookup` Search Process

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

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

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

`$graphLookup` Search Process (continued)

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

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

`$graphLookup` Considerations

- The collection specified in `from` cannot be sharded.
- Setting `maxDepth` to 0 is equivalent to `$lookup`
- The `$graphLookup` stage must stay within the 100 megabyte memory limit. `$graphLookup` will ignore `allowDiskUse: true`
- If performing an aggregation that involves multiple views, the views must have the same collation.

Note: Although `$graphLookup` ignores the **allowDiskUse** argument, other stages in the aggregation pipeline will use it.

`$graphLookup` Example

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

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

`$graphLookup` Example (continued)

With the sample data inserted, perform the following aggregation:

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

`$graphLookup` Example Results

The previous `$graphLookup` operation will produce the following:

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

The Sample Stage

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

Note:

- The exact method is in the documentation.
  - Link here[27]

---

[27] https://docs.mongodb.com/manual/reference/operator/aggregation/sample/

Example: `$sample`

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

Note:

- Users will want their sample sizes to be large enough to be useful.
- 5 is too small for anything
- A statistician may be required for determining how much is enough; it depends on the distribution of data

---

The IndexStats Stage

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

---

Note:

- Doesn't include all internal operations
  - TTL deletions or .explain() queries, for example

Example: `$indexStats`

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

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

Note:

- Point out the "accesses" doc, with ops, is 0 for the new index initially.
- Ops incremented to 2 from the two find() queries.
- The `.next()` operations are to get the DB to actually execute the query.
- _id did not increment because we weren't using that index

- Neither query changed its “since” field in the “accesses” doc
- If using replication, the oplog will query on _id when replicating.

The Out Stage

- Used to create a new collection from the output of the aggregation pipeline.
- Can only be the last stage in the pipeline.
- If a collection by the name already exists, it replaces that collection.
- Syntax is { $out : “collection_name” }

5.2 Optimizing Aggregation

Learning Objectives

Upon completing this module students should understand:

- Aggregation pipeline options
- Key aspects of resource management during the aggregation pipeline
- How to order aggregation stages to maximize speed and minimize resource usage
- How MongoDB automatically reorders pipeline stages to improve efficiency
- Changes in the aggregation framework from MongoDB 2.4 to 2.6.

Aggregation Options

- You may pass an options document to `aggregate()`.
- Syntax:

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

- Following are some of the fields that may be passed in the options document.
  - `allowDiskUse : true` - permit the use of disk for memory-intensive queries
  - `explain : true` - display how indexes are used to perform the aggregation.

Aggregation Limits

- An aggregation pipeline cannot use more than 100 MB of RAM.
- `allowDiskUse : true` allows you to get around this limit.
- The follow operators do not require the entire dataset to be in memory:
  - $match, $skip, $limit, $unwind, and $project
  - Stages for these operators are not subject to the 100 MB limit.
  - $unwind can, however, dramatically increase the amount of memory used.
- $group and $sort might require all documents in memory at once.

Limits Prior to MongoDB 2.6

- `aggregate()` returned results in a single document up to 16 MB in size.
- The upper limit on pipeline memory usage was 10% of RAM.

Optimization: Reducing Documents in the Pipeline

- These operators can reduce the number of documents in the pipeline:
  - $match
  - $skip
  - $limit:
- They should be used as early as possible in the pipeline.

Optimization: Sorting

- `$sort` can take advantages of indexes.
- Must be used before any of the following to do this:
  - `$group`
  - `$unwind`
  - `$project`
- After these stages, the fields or their values change.
- `$sort` requires a full scan of the input documents.

Automatic Optimizations

MongoDB will perform some optimizations automatically. For example:

- If a `$project` stage is used late in the pipeline it may be used to eliminate those fields earlier if possible.
- A `$sort` followed by a `$match` will be executed as a `$match` followed by a `$sort` to reduce the number of documents to be sorted.
- A `$skip` followed by a `$limit` will be executed as a `$limit` followed by a `$skip`, with the $limit parameter increased by the $skip amount to allow $sort + $limit coalescence.
- See: Aggregation Pipeline Optimation[28]

5.3 Lab: Aggregation Framework

Exercise: Working with Array Fields

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

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

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

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

Note:

```
use blog;
db.posts.aggregate([
  { "$unwind": "$comments" },
  { "$group":
    {
      _id: "$comments.author",
      num_comments: { $sum: 1 }
    }
  },
  { "$sort": { "num_comments": 1 } },
  { "$limit": 10 }
])
```

---

[28] http://docs.mongodb.org/manual/core/aggregation-pipeline-optimization/

Exercise: Repeated Aggregation Stages

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

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

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

Please note:

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

Note:

```
db.zips.aggregate( [
    { $match: { state: { $in: ["CA", "NY"] } } },
    { $group: { _id: { state: "$state", city: "$city" },
                pop: {$sum: "$pop"} } },
    { $match: { pop: {$gt: 25000} } },
    { $group: { _id: null,
                pop: {$avg: "$pop"} } }
] )
```

Exercise: Projection

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

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

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

Note:

```
db.zips.aggregate( [
   { $project : {
       first_char: { $substr: [ "$city", 0, 1] },
       pop: 1,
       city: "$city",
       zip: "$_id",
       state: 1
   } },
   { $match : {
       first_char: { $in: [ '0', '1', '2', '3', '4', '5', '6', '7', '8', '9'] }
   } },
   {
      "$group" : { _id: null,
```

```
                    population: { $sum : "$pop"} }
   }
] )
```

Exercise: Descriptive Statistics

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

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

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

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

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

Note: A solution should be something like them following:

- Unwind all the different scores
- Match based on a score type of "exam"
- Average the based on class_id and student_id
- Average per class
- Sort into descending order
- Limit to 1

```
db.grades.aggregate([
   {$unwind: "$scores"},
   {$match: {"scores.type": "exam"}},
   {$group: {_id: {student_id: "$student_id", class_id: "$class_id"},
             student_avg: {$avg: "$scores.score"}}},
   {$group: {_id: {class_id: "$_id.class_id"},
             class_avg: {$avg: "$student_avg"}}},
   {$sort: {class_avg: -1}}
])
```

5.4 Lab: Using `$graphLookup`

Exercise: Finding Airline Routes

For this exercise, incorporate the `$graphLookup` stage into an aggregation pipeline to find Delta Air Lines routes from JFK to BOI. Find all routes that only have one layover.

- Start by importing the necessary dataset

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

Note:

```
db.routes.aggregate([
  {
    $match: { "airline.alias": "DL", "dst_airport": "BOI" }
  }, {
    $graphLookup: {
      "startWith": "$dst_airport",
      "from": "routes",
      "connectFromField": "dst_airport",
      "connectToField": "src_airport",
      "as": "connections",
      "restrictSearchWithMatch": { "airline.alias": "DL" }
    }
  }, {
    $unwind: "$connections"
  }, {
    $match: { "connections.src_airport": "JFK" }
  }, {
    $project: {
      src_airport: 1,
      dst_airport: 1,
      connections: 1,
      is_equal: { $eq: ["$src_airport", "$connections.dst_airport"] }
    }
  }, {
    $match: { is_equal: true }
  }
]).pretty()
```

---

6 Introduction to Schema Design

6.1 Schema Design Core Concepts

Learning Objectives

Upon completing this module, students should understand:

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

What is a schema?

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

Example: Normalized Data Model

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

Example: Denormalized Version

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

Schema Design in MongoDB

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

Three Considerations

- The data your application needs
- Your application's read usage of the data
- Your application's write usage of the data

Case Study

- A Library Web Application
- Different schemas are possible.

Author Schema

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

User Schema

```
{   "_id": int,
    "username": string,
    "password": string
}
```

Book Schema

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

Example Documents: Author

```
{   _id: 1,
    firstName: "F. Scott",
    lastName: "Fitzgerald"
}
```

Example Documents: User

```
{   _id: 1,
    username: "emily@10gen.com",
    password: "slsjfk4odk84k209dlkdj90009283d"
}
```

Example Documents: Book

```
{   _id: 1,
    title: "The Great Gatsby",
    slug: "9781857150193-the-great-gatsby",
    author: 1,
    available: true,
    isbn: "9781857150193",
    pages: 176,
    publisher: {
        name: "Everyman's Library",
        date: ISODate("1991-09-19T00:00:00Z"),
        city: "London"
    },
    subjects: ["Love stories", "1920s", "Jazz Age"],
    language: "English",
    reviews: [
        { user: 1, text: "One of the best..." },
        { user: 2, text: "It's hard to..." }
    ]
}
```

Embedded Documents

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

Example: Embedded Documents

```
{   ...
    publisher: {
        name: "Everyman's Library",
        date: ISODate("1991-09-19T00:00:00Z"),
        city: "London"
    },
    subjects: ["Love stories", "1920s", "Jazz Age"],
    language: "English",
    reviews: [
        { user: 1, text: "One of the best..." },
        { user: 2, text: "It's hard to..." }
    ]
}
```

Embedded Documents: Pros and Cons

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

Linked Documents

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

Example: Linked Documents

```
{    ...
     author: 1,
     reviews: [
          { user: 1, text: "One of the best..." },
          { user: 2, text: "It's hard to..." }
     ]
}
```

Linked Documents: Pros and Cons

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

Arrays

- Array of scalars
- Array of documents

Array of Scalars

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

Array of Documents

```
{   ...
    reviews: [
        { user: 1, text: "One of the best..." },
        { user: 2, text: "It's hard to..." }
    ]
}
```

Exercise: Users and Book Reviews

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

- Users
  - username (string)
  - email (string)
- Reviews
  - text (string)
  - rating (integer)
  - created_at (date)

Solution A: Users and Book Reviews

Reviews may be queried by user or book

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

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

Solution B: Users and Book Reviews

Optimized to retrieve reviews by user

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

Solution C: Users and Book Reviews

Optimized to retrieve reviews by book

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

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

Store Binary Files in MongoDB with GridFS

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

How GridFS Works

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

Schema Design Use Cases with GridsFS

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

6.2 Schema Evolution

Learning Objectives

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

- Development Phase
- Production Phase
- Iterative Modifications

Development Phase

Support basic CRUD functionality:

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

Development Phase: Known Query Patterns

```
// Find authors by last name.
db.authors.createIndex({ "lastName": 1 })

// Find books by slug for detail view
db.books.createIndex({ "slug": 1 })

// Find books by subject (multi-key)
db.books.createIndex({ "subjects": 1 })

// Find books by publisher (index on embedded doc)
db.books.createIndex({ "publisher.name": 1 })
```

Production Phase

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

Production Phase: Read Patterns

List books by author last name

```
authors = db.authors.find({ lastName: /^f.*/i }, { _id: 1 });

authorIds = authors.map(function(x) { return x._id; });

db.books.find({author: { $in: authorIds }});
```

Addressing List Books by Last Name

"Cache" the author name in an embedded document.

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

Queries are now one step

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

Production Phase: Write Patterns

Users can review a book.

```
review = {
    user: 1,
    text: "I thought this book was great!",
    rating: 5
};

db.books.updateOne(
    { _id: 3 },
    { $push: { reviews: review }}
);
```

Caveats:

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

Exercise: Recent Reviews

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

Solution: Recent Reviews, Schema

Store users' reviews in monthly buckets.

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

Solution: Recent Reviews, Update

Adding a new review to the appropriate bucket

```
myReview = {
    _id: ObjectId("..."),
    rating: 3,
    text: "An average read.",
    created_at: ISODate("2012-10-13T12:26:11.502Z")
};

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

Solution: Recent Reviews, Read

Display the 10 most recent reviews by a user

```
cursor = db.reviews.find(
    { _id: /^bob-/ },
    { reviews: { $slice: -10 }}
).sort({ _id: -1 }).batchSize(5);

num = 0;

while (cursor.hasNext() && num < 10) {
    doc = cursor.next();

    for (var i = 0; i < doc.reviews.length && num < 10; ++i, ++num) {
        printjson(doc.reviews[i]);
    }
}
```

Solution: Recent Reviews, Delete

Deleting a review

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

6.3 Common Schema Design Patterns

Learning Objectives

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

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

One-to-One Relationship

Let's pretend that authors only write one book.

One-to-One: Linking

Either side, or both, can track the relationship.

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

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

One-to-One: Embedding

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

One-to-Many Relationship

In reality, authors may write multiple books.

One-to-Many: Array of IDs

The "one" side tracks the relationship.

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

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

One-to-Many: Single Field with ID

The "many" side tracks the relationship.

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

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

One-to-Many: Array of Documents

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

Many-to-Many Relationship

Some books may also have co-authors.

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

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

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

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

Query for all books by a given author.

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

Query for all authors of a given book.

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

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

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

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

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

Query for all books by a given author.

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

Query for all authors of a given book.

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

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

Tree Structures

E.g., modeling a subject hierarchy.

Allow users to browse by subject

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

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

Alternative: Parents and Ancestors

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

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

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

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

```
    parent: "Jazz Age"
}
```

Find Sub-Categories

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

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

Summary

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

7 Replica Sets

7.1 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
- 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

---

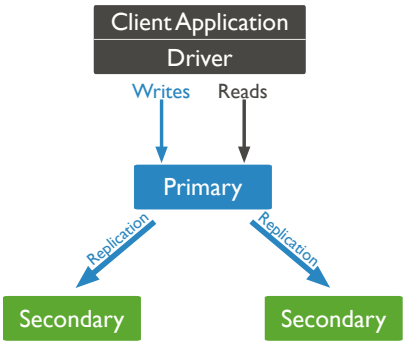
Replication is Not Designed for Scaling

- 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).
- 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

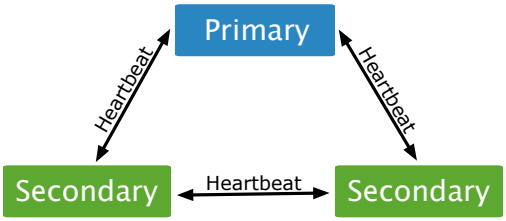
- Clients send writes the primary only.
- MongoDB, Inc. maintains client drivers in many programming languages like Java, C#, Python, Ruby, and PHP.
- MongoDB drivers are replica set aware.

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.

7.2 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.

7.3 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.

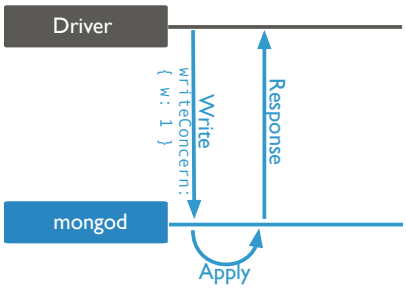
Note:

- 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

- 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 }`



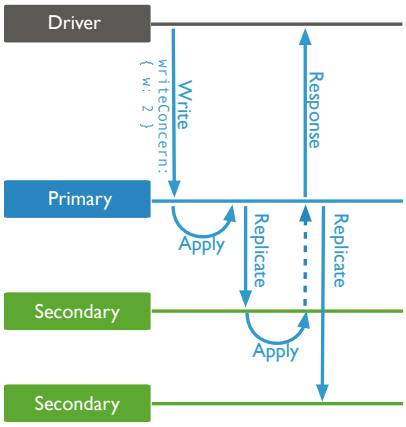
Note:

- 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

- You may specify any integer as the value of the `w` field for write concern.
- This guarantees that write operations have propagated to the specified number of members.
- E.g., `{ w : 3 }`, `{ w : 4}`, etc.

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

- Ensures the primary completed the write (in RAM).
- Ensures write operations have propagated to a majority of a replica set's **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[29] for more details on write concern configurations, including setting timeouts and identifying specific replica set members that must acknowledge writes (i.e. tag sets[30]).

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

7.4 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[31] 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[32] increases read and write capacity by distributing operations across a group of machines.
- Sharding is a better strategy for adding capacity.

[31] http://docs.mongodb.org/manual/core/replica-set-geographical-distribution
[32] 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)
```

8 Sharding

8.1 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.

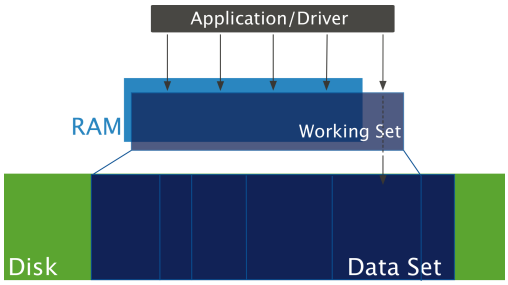
Sharding is Concerned with Scale

- 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.

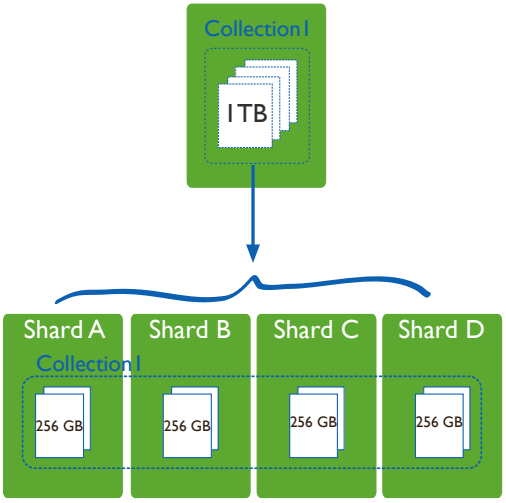
Sharding Overview

- 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

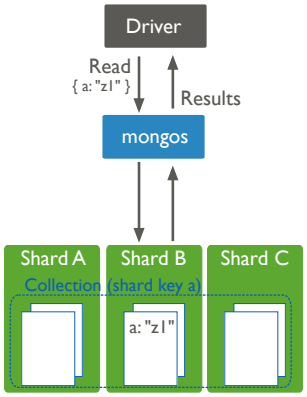
Shard Key Ranges

- 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.

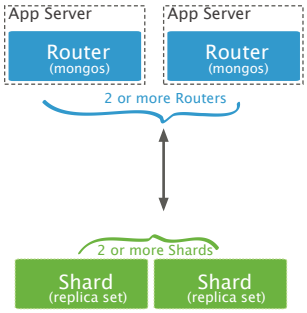
Targeted Query Using Shard Key



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.

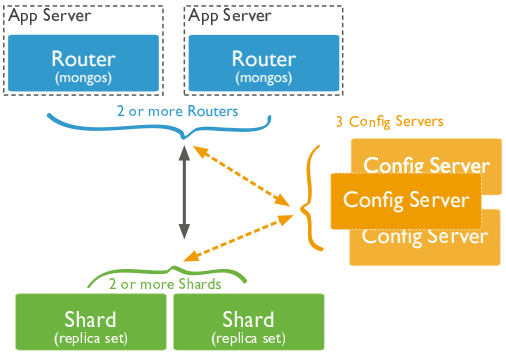
Mongos

- 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.
- 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.

9 MongoDB Cloud & Ops Manager

9.1 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

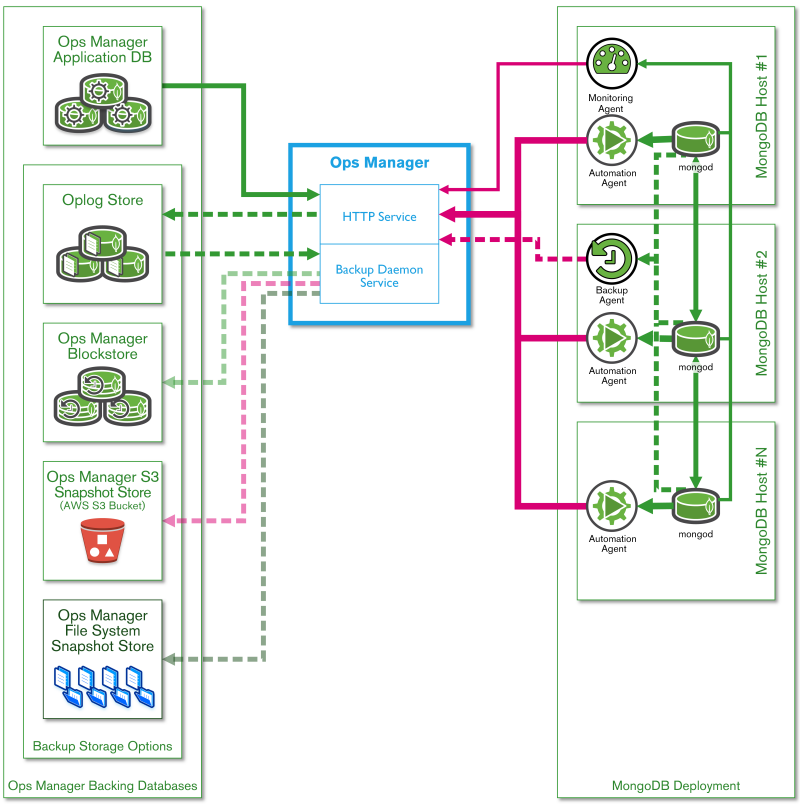
Deployment Options

- 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

9.2 Automation

Learning Objectives

Upon completing this module students should understand:

- Use cases for Cloud / Ops Manager Automation
- The Cloud / Ops Manager Automation internal workflow

What is Automation?

Fully managed MongoDB deployment on your own servers:

- Automated provisioning
- Dynamically add capacity (e.g. add more shards or replica set nodes)
- Upgrades
- Admin tasks (e.g. change the size of the oplog)

How Does Automation Work?

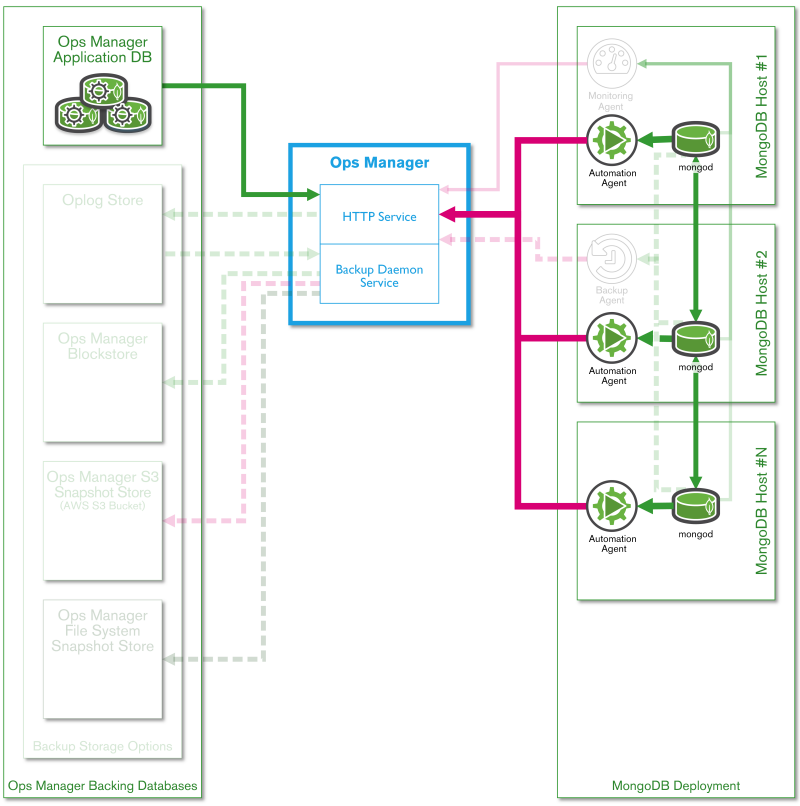
- Automation agent installed on each server in cluster
- Administrator creates design goal for system (through Cloud / Ops Manager interface)
- Automation agents periodically check with Cloud / Ops Manager to get new design instructions
- Agents create and follow a plan for implementing cluster design
- Minutes later, cluster design is complete, cluster is in goal state

Automation Agents

Sample Use Case

Administrator wants to create a 100 shard cluster, with each shard comprised of a 3 node replica set:

- Administrator installs automation agent on 300 servers
- Cluster design is created in Cloud / Ops Manager, then deployed to agents
- Agents execute instructions until 100 shard cluster is complete (usually several minutes)



Upgrades Using Automation

- Upgrades without automation can be a manually intensive process (e.g. 300 servers)
- A lot of edge cases when scripting (e.g. 1 shard has problems, or one replica set is a mixed version)
- One click upgrade with Cloud / Ops Manager Automation for the entire cluster

Automation: Behind the Scenes

- Agents ping Cloud / Ops Manager for new instructions
- Agents compare their local configuration file with the latest version from Cloud / Ops Manager
- Configuration file in JSON
- All communications over SSL

```
{
    "groupId": "55120365d3e4b0cac8d8a52a737",
    "state": "PUBLISHED",
    "version": 4,
    "cluster": { ...
```

Configuration File

When version number of configuration file on Cloud / Ops Manager is greater than local version, agent begins making a plan to implement changes:

```
"replicaSets": [
{
    "_id": "shard_0",
    "members": [
        {
            "_id": 0,
            "host": "DemoCluster_shard_0_0",
            "priority": 1,
            "votes": 1,
            "slaveDelay": 0,
            "hidden": false,
            "arbiterOnly": false
        },
    ...
```

Automation Goal State

Automation agent is considered to be in goal state after all cluster changes (related to the individual agent) have been implemented.

Demo

- The instructor will demonstrate using Automation to set up a small cluster locally.
- Reference documentation:
- The Automation Agent[33]
- The Automation API[34]
- Configuring the Automation Agent[35]

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

---

[33] https://docs.cloud.mongodb.com/tutorial/nav/automation-agent/
[34] https://docs.cloud.mongodb.com/api/
[35] https://docs.cloud.mongodb.com/reference/automation-agent/

9.3 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
