
MongoDB Developer Training

Release 3.0

MongoDB, Inc.

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1 Introduction

Warm Up (page 3) Activities to get the class started

MongoDB Overview (page 4) MongoDB philosophy and features

MongoDB Stores Documents (page 7) The structure of data in MongoDB

Storage Engines (page 10) MongoDB storage engines

Lab: Installing and Configuring MongoDB (page 15) Install MongoDB and experiment with a few operations.

1.1 Warm Up

Introductions

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

Getting to Know You

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

MongoDB Experience

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

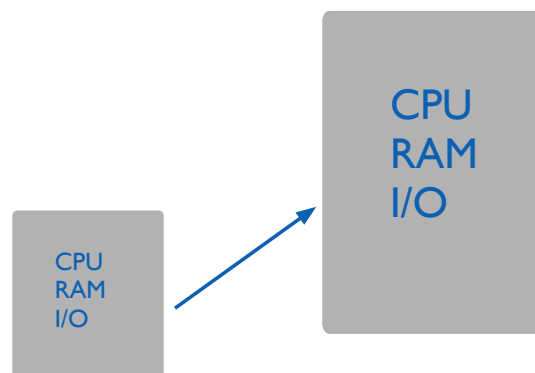
- Python dictionaries
- Ruby hashes
- PHP arrays
- JSON objects

An Example MongoDB Document

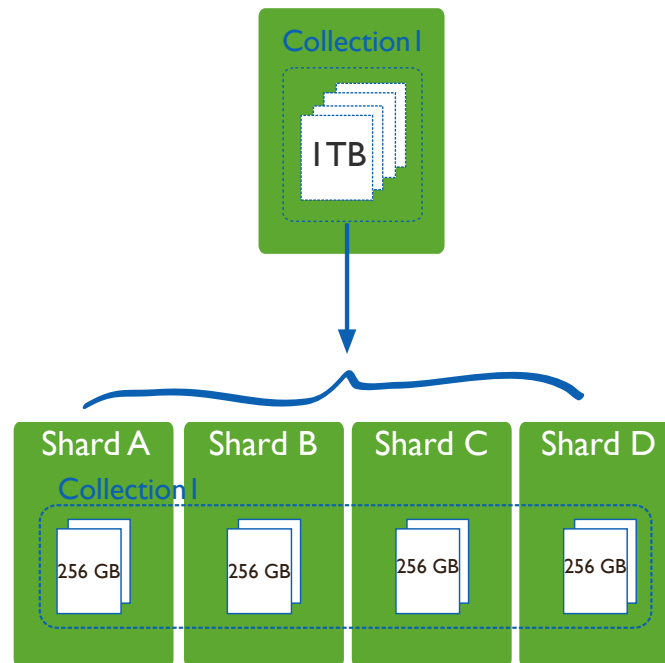
A MongoDB document expressed using JSON syntax.

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

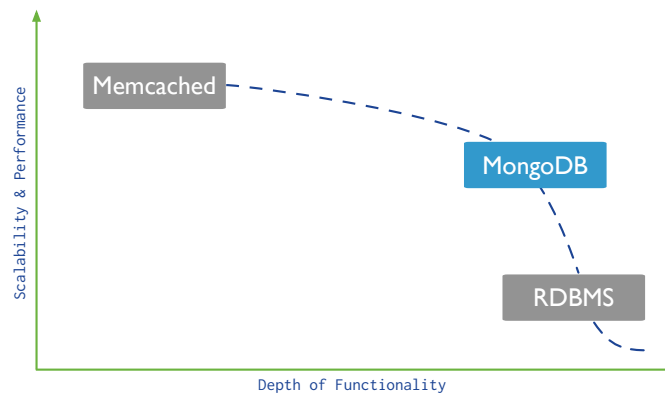
Vertical Scaling



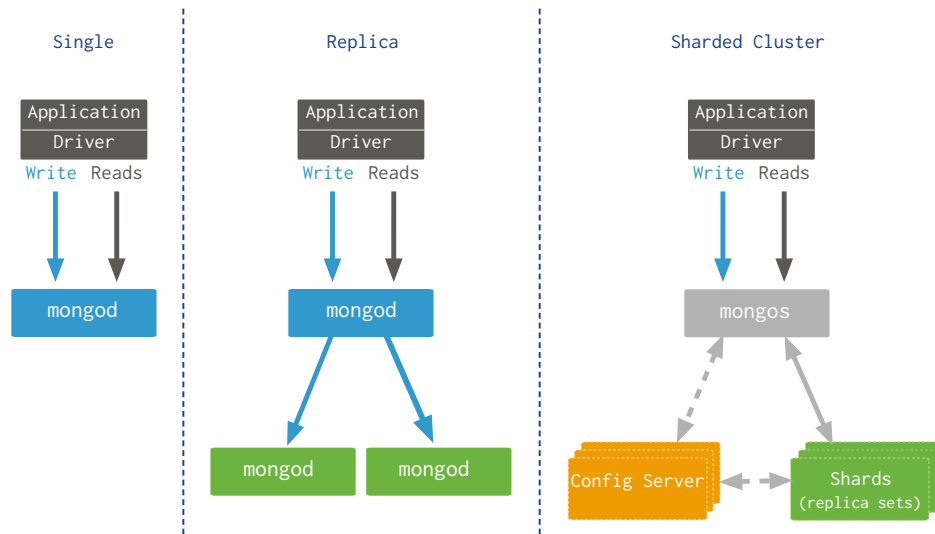
Scaling with MongoDB



Database Landscape



MongoDB Deployment Models



1.3 MongoDB Stores Documents

Learning Objectives

Upon completing this module, students should understand:

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

JSON

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

A Simple JSON Object

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

JSON Keys and Values

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

Example Field Values

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

¹<http://json.org/>

BSON

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

BSON Hello World

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

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

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
\x14\x40\x102\x00\xc2\x07\x00\x00
\x00\x00"
```

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

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

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



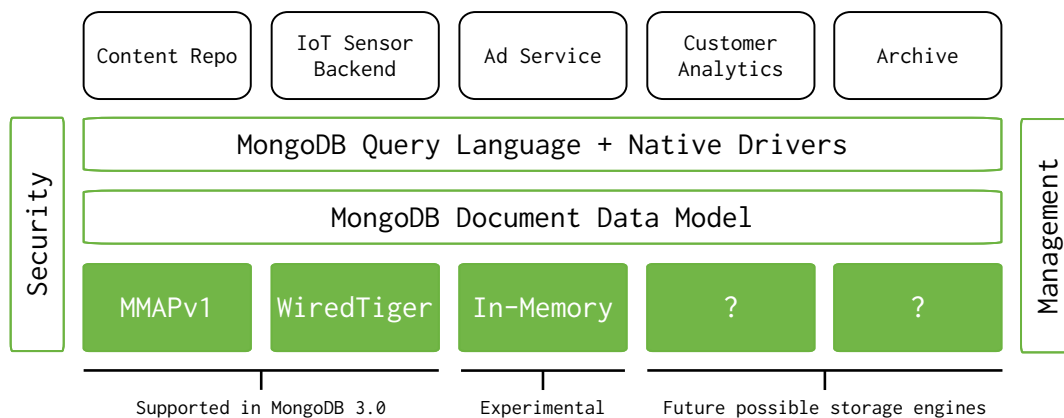
1.4 Storage Engines

Learning Objectives

Upon completing this module, students should be familiar with:

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

What is a Database Storage Engine?



How Storage Engines Affect Performance

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

Storage Engine Journaling

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

MongoDB Storage Engines

With the release of MongoDB 3.0, two storage engine options are available:

- MMAPv1 (default)
- WiredTiger

Specifying a MongoDB Storage Engine

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

```
mongod --storageEngine wiredTiger
```

Specifying a Location to Store Data Files

- Use the `dbpath` parameter

```
mongod --dbpath /data/db
```
- Other files are also stored here. E.g.,
 - `mongod.lock` file
 - `journal`
- See the MongoDB docs for a complete list of [storage options](http://docs.mongodb.org/manual/reference/program/mongod/#storage-options)³.

³<http://docs.mongodb.org/manual/reference/program/mongod/#storage-options>

MMAPv1 Storage Engine

- MMAPv1 is MongoDB's original storage engine and currently the default.

```
mongod
```

- This is equivalent to the following command:

```
mongod --storageEngine mmapv1
```

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

MMAPv1 Workloads

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

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

Power of 2 Sizes Allocation Strategy

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

Compression in MongoDB

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

WiredTiger Storage Engine

- The WiredTiger storage engine excels at all workloads, especially write-heavy and update-heavy workloads.
- Notable features of the WiredTiger storage engine that do not exist in the MMAPv1 storage engine include:
 - Compression
 - Document-level concurrency
- Specify the use of the WiredTiger storage engine as follows.

```
mongod --storageEngine wiredTiger
```

WiredTiger Compression Options

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

Configuring Compression in WiredTiger

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

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

Configuring Memory Usage in WiredTiger

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

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

Journaling in MMAPv1 vs. WiredTiger

- MMAPv1 uses write-ahead journaling to ensure consistency.
- WiredTiger uses a write-ahead transaction log in combination with checkpoints to ensure durability.
- With WiredTiger, the replication process may provide sufficient durability guarantees.

MMMAPv1 Journaling Mechanics

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

MMAPv1 Journaling Mechanics (Continued)

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

WiredTiger Journaling Mechanics

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

Storage Engine API

MongoDB 3.0 introduced a storage engine API:

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

Conclusion

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

1.5 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 <http://docs.mongodb.org/manual/installation/>.
- 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 777 /data/db
```

Install on Windows

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

```
C:\Program Files\MongoDB\Server\<VERSION>\bin
```
- It is helpful to add the location of the MongoDB binaries to your path.
- To do this, from “System Properties” select “Advanced” then “Environment Variables”

Create a Data Directory on Windows

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

```
md \data\db
```


Launch a mongod

Explore the mongod command.

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

Launch a mongod with the MMAPv1 storage engine:

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

Alternatively, launch with the WiredTiger storage engine.

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

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

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

The MMAPv1 Data Directory

```
ls /data/db
```

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

The WiredTiger Data Directory

```
ls /data/db
```

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

Import Exercise Data

```
cd usb_drive

unzip sampledata.zip

cd sampledata

mongoimport -d sample -c tweets twitter.json

mongoimport -d sample -c zips zips.json

cd dump

mongorestore -d sample training

mongorestore -d sample digg
```

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

Launch a Mongo Shell

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

```
mongo
```

Display available commands.

```
help
```

Explore Databases

Display available databases.

```
show dbs
```

To use a particular database we can type the following.

```
use <database_name>
```

```
db
```

Exploring Collections

```
show collections
```

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

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

Admin Commands

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

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

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

2 CRUD

Creating and Deleting Documents (page 20) Inserting documents into collections, deleting documents, and dropping collections

Reading Documents (page 25) The `find()` command, query documents, dot notation, and cursors

Query Operators (page 32) MongoDB query operators including: comparison, logical, element, and array operators

Lab: Finding Documents (page 36) Exercises for querying documents in MongoDB

Updating Documents (page 36) Using `update()` and associated operators to mutate existing documents

Lab: Updating Documents (page 43) Exercises for updating documents in MongoDB

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 remove 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 `insert()`.
- For example:

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

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

Example: Inserting a Document

Experiment with the following commands.

```
use sample

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

db.movies.find()
```

Implicit `_id` Assignment

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

Example: Assigning `_ids`

Experiment with the following commands.

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

db.movies.find()
```

Inserts will fail if...

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

Example: Inserts will fail if...

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

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

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

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

Bulk Inserts

- MongoDB 2.6 introduced bulk inserts.
- You may bulk insert using an array of documents.
- The API has two core concepts:
 - Ordered bulk operations
 - Unordered bulk operations
- The main difference is in the way the operations are executed in bulk.

Ordered Bulk Insert

- 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>.insert` is an ordered insert.
- See the next exercise for an example.

Example: Ordered Bulk Insert

Experiment with the following bulk insert.

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

Unordered Bulk Insert

- Pass `{ ordered : false }` to insert to perform unordered inserts.
- If any given insert fails, MongoDB will still attempt the others.
- The inserts may be executed in a different order from the way in which you specified them.
- 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 Bulk Insert

Experiment with the following bulk insert.

```
db.movies.insert( [ { "_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 `remove()` to delete documents matching a specific set of conditions.
- Drop an entire collection.
- Drop a database.

Using `remove()`

- Remove documents from a collection using `remove()`.
- This command has one required parameter, a query document.
- All documents in the collection matching the query document will be removed.
- Pass an empty document to remove all documents.
- Prior to MongoDB 2.6 calling `remove()` with no parameters would remove all documents.
- Limit `remove()` to one document using `justOne`.

Example: Removing Documents

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

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

db.testcol.remove( { a : 1 } ) // Remove 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.remove( { a : { $lt : 5 } } ) // Remove three more

db.testcol.remove( { a : { $lt : 10 } },
                  { justOne : true } ) // Remove one more

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

db.testcol.remove( { } ) // 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.
- More on meta data later.

Example: Dropping a Collection

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

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

Dropping a Database

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

Example: Dropping a Database

```
use tempDB
db.testcoll1.insert( { a : 1 } )
db.testcoll2.insert( { 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.insert([ { "title" : "Jaws", "year" : 1975, "imdb_rating" : 8.1 },
                   { "title" : "Batman", "year" : 1989, "imdb_rating" : 7.6 },
                   ] )
db.movies.find()

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

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

Querying Arrays

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

Example: Querying Arrays

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

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

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

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

Querying with Dot Notation

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

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

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

Example: Querying with Dot Notation

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

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

Projections

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

Projection: Example (Setup)

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

Cursors

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

Example: Introducing Cursors

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

it
it
```

Example: Cursor Objects in the Mongo Shell

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

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

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

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

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

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

Cursor Methods

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

Example: Using `count()`

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

// all 100
db.testcol.count()

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

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

Example: Using sort ()

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

db.testcol.find()

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

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

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

The skip () Method

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

The limit () Method

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

The distinct () Method

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

Example: Using distinct ()

```
db.movie_reviews.drop()
db.movie_reviews.insert( [ { "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" )
```

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: Comparison Operators (Setup)

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

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

```

Example: Logical Operators

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

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

Element Query Operators

- `$exists`: Select documents based on the existence of a particular field.
- `$type`: Select documents based on their type.
- See [BSON types](#)⁴ 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

⁴<http://docs.mongodb.org/manual/reference/bson-types>

Example: Array Operators

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

db.movies.find( { "category" : { $size : 3 } } )
```

Example: \$elemMatch

```
db.movies.insert( {
  "title" : "Raiders of the Lost Ark",
  "filming_locations" : [
    { "city" : "Los Angeles", "state" : "CA", "country" : "USA" },
    { "city" : "Rome", "state" : "Lazio", "country" : "Italy" },
    { "city" : "Florence", "state" : "SC", "country" : "USA" }
  ] } )
```

// This query is incorrect, it won't return what we want

```
db.movies.find( {
  "filming_locations.city" : "Florence",
  "filming_locations.country" : "Italy"
} )
```

// \$elemMatch is needed, now there are no results, this is expected

```
db.movies.find( {
  "filming_locations" : {
    $elemMatch : {
      "city" : "Florence",
      "country" : "Italy"
    } } } )
```

2.4 Lab: Finding Documents

Exercise: Scores < 65

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

Exercise: Exams and Quizzes

In the sample database, how many documents in the scores collection have the type “exam” or “quiz”?

Exercise: Highest Quiz Score

Find the highest quiz score.

Exercise: View Count > 1000

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

Exercise: Television or Videos

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

Exercise: News or Images

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

2.5 Updating Documents

Learning Objectives

Upon completing this module students should understand

- The `update()` method
- The required parameters for `update()`
- Field update operators
- Array update operators
- The concept of an upsert and use cases.
- The `findAndModify` method

The update () Method

- Mutate documents in MongoDB using `update()`.
- `update()` requires two parameters:
 - A query document used to select documents to be updated
 - An update document that specifies how selected documents will change
- `update()` cannot delete a document.

Parameters to update ()

- Keep the following in mind regarding the required parameters for `update()`
- The query parameter:
 - Use the same syntax as with `find()`.
 - By default only the first document found is updated.
- The update parameter:
 - Take care to simply modify documents if that is what you intend.
 - Replacing documents in their entirety is easy to do by mistake.

\$set and \$unset

- Update one or more fields using the `$set` operator.
- If the field already exists, using `$set` will change its value.
- If the field does not exist, `$set` will create it and set it to the new value.
- Any fields you do not specify will not be modified.
- You can remove a field using `$unset`.

Example: \$set and \$unset (Setup)

```
db.movies.insert( [
  {
    "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.update( { "title" : "Batman" }, { $set : { "imdb_rating" : 7.7 } } )  
  
db.movies.update( { "title" : "Godzilla" }, { $set : { "budget" : 1 } } )  
  
db.movies.update( { "title" : "Home Alone" },  
                  { $set : { "budget" : 15, "imdb_rating" : 5.5 } } )  
  
// how will this query behave?  
db.movies.update( { "title" : "Batman" }, { "imdb_rating" : 7.7 } )  
  
db.movies.update( { "title" : "Home Alone" }, { $unset : { "budget" : 1 } } )
```

Example: Update Array Elements by Index

```
// add a sample document to track mentions per hour  
db.movie_mentions.insert( { "title" : "E.T.",  
                             "day" : ISODate("2015-03-27T00:00:00.000Z"),  
                             "mentions_per_hour" : [ 0, 0, 0, 0, 0, 0, 0,  
                                                       0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,  
                                                       0, 0 ]  
                           } )  
  
// update all mentions for the fifth hour of the day  
db.movie_mentions.update( { "title" : "E.T." },  
                          { $set : { "mentions_per_hour.5" : 2300 } } )
```

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.
- `$unset`: Delete a field.
- `$min`: Update only if value is smaller than specified quantity
- `$max`: Update only if value is larger than specified quantity
- `$currentDate`: Set the value of a field to the current date or timestamp.

Example: Update Operators

```
db.movies.update( { "title" : "Batman" }, { $inc : { "imdb_rating" : 2 } } )

db.movies.update( { "title" : "Home Alone" }, { $inc : { "budget" : 5 } } )

db.movies.update( { "title" : "Batman" }, { $mul : { "imdb_rating" : 4 } } )

db.movies.update( { "title" : "Batman" },
                  { $rename : { "budget" : "estimated_budget" } } )

db.movies.update( { "title" : "Home Alone" }, { $min : { "budget" : 5 } } )

db.movies.update( { "title" : "Home Alone" },
                  { $currentDate : { "last_updated" : { $type : "timestamp" } } } )

// increment movie mentions by 10
db.movie_mentions.update( { "title" : "E.T." },
                          { $inc : { "mentions_per_hour.5" : 10 } } )
```

update () Defaults to one Document

- By default, update () modifies the first document found that matches the query.
- The default use case is one where there is only one document that fits the query.
- This is to reduce the chances of unintended collection scans for updates.

Updating Multiple Documents

- In order to update multiple documents, we use the third (optional) parameter to update () .
- The third parameter is an options document.
- Specify multi: true as one field in this document.
- Bear in mind that without an appropriate index, you may scan every document in the collection.

Example: Multi-Update

Use db.testcol.find() after each of these updates.

```
// let's start tracking the number of sequels for each movie
db.movies.update( { }, { $set : { "sequels" : 0 } } )

// we need { multi : true } to change all documents
db.movies.update( { }, { $set : { "sequels" : 0 } },
                  { multi : true } )
```

Array Operators

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

Example: Array Operators

```
db.movies.update( { "title" : "Batman" },
  { $push : { "category" : "superhero" } } )
db.movies.update( { "title" : "Batman" },
  { $pushAll : { "category" : [ "villain", "comicbased" ] } } )

db.movies.update( { "title" : "Batman" },
  { $pop : { "category" : 1 } } )

db.movies.update( { "title" : "Batman" },
  { $pull : { "category" : "action" } } )
db.movies.update( { "title" : "Batman" },
  { $pullAll : { "category" : [ "villain", "comicbased" ] } } )

db.movies.update( { "title" : "Batman" }, { $addToSet : { "category" : "action" } } )
db.movies.update( { "title" : "Batman" }, { $addToSet : { "category" : "action" } } )
```

The Positional \$ Operator

- `$5` is a positional operator that specifies an element in an array to update.
- It acts as a placeholder for the first element that matches the query document.
- `$` replaces the element in the specified position with the value given.
- Example:

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

⁵<http://docs.mongodb.org/manual/reference/operator/update/positional>

Example: The Positional \$ Operator

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

Upserts

- By default, if no document matches an update query, the `update()` method does nothing.
- By specifying `upsert: true`, `update()` will insert a new document if no matching document exists.
- The `db.<COLLECTION>.save()` method is syntactic sugar that performs an upsert if the `_id` is not yet present
- Syntax:

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

Upsert Mechanics

- Will update as usual if documents matching the query document exist.
- Will be an upsert if no documents match the query document.
 - MongoDB creates a new document using equality conditions in the query document.
 - Adds an `_id` if the query did not specify one.
 - Performs an update on the new document.

Example: Upserts

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

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

db.movies.update( { "title" : "Jaws III", "category" : [ "horror" ] },
                  { $set : { "budget" : 1 } },
                  { upsert: true } )
```

save ()

- Updates the document if the `_id` is found, inserts it otherwise
- Syntax:

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

Example: save ()

- If the document does not contain an `_id` field, then the `save ()` method calls the `insert ()` method. During the operation, the mongo shell will create an `ObjectId` and assign it to the `_id` field.
- If the document contains an `_id` field, then the `save ()` method is equivalent to an update with the `upsert` option set to `true` and the query predicate on the `_id` field.

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

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

Be Careful with save ()

Be careful that you are not modifying stale data when using `save ()`. For example:

```
db.movies.drop()
db.movies.insert( { "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.update( { "title" : "Jaws" }, { $inc: { "imdb_rating" : 2 } } )
db.movies.find()

doc.imdb_rating = 7.4
doc

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

findAndModify()

Modify a document and return either:

- The pre-modification document
- If “new:true” is set, the modified document

Helpful for making changes to a document and reading the document in the state before or after the update occurred.

findAndModify() Example

```
db.worker_queue.findAndModify({
  "query" : { "state" : "unprocessed" },
  "update" : { $set: { "worker_id" : 123, "state" : "processing" } },
})
```

2.6 Lab: Updating Documents

Exercise: Letter Grades

- Using the `sample.scores` namespace, set the proper “grade” attributes.
- For example, users with scores greater than 90 get an “A”.
- Set the grade to “B” for scores falling between 80 and 90 and so on for grades “C”, “D”, and “F”.

Exercise: 10 Extra-Credit Points

- You’re being nice, so you decide to add 10 points to every score on every exam where the score is lower than 60.
- How do you do this update?

Exercise: Updating Array Elements

Insert a document representing product metrics for a backpack:

```
db.product_metrics.insert(
  { 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.

3 Indexes

Index Fundamentals (page 44) An introduction to MongoDB indexes

Compound Indexes (page 50) Indexes on two or more fields

Lab: Optimizing an Index (page 55) Lab on optimizing a compound index

Multikey Indexes (page 56) Indexes on array fields

Hashed Indexes (page 59) Hashed indexes

Lab: Finding and Addressing Slow Operations (page 61) Lab on finding and addressing slow queries

Lab: Using explain() (page 61) Lab on using the explain operation to review execution stats

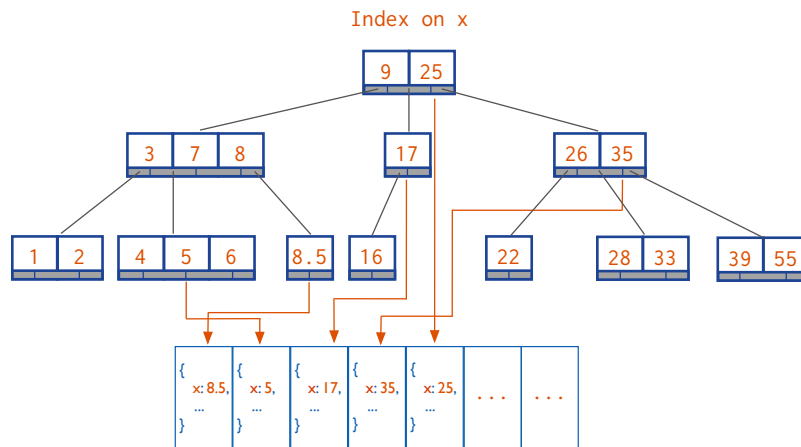
3.1 Index Fundamentals

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

Why Indexes?



Types of Indexes

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

Exercise: Using `explain()`

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

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

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

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

Results of `explain()`

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

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

Results of `explain()` - Continued

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

explain() Verbosity Can Be Adjusted

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

explain("executionStats")

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

Now we have query statistics:

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

explain("executionStats") - Continued

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

explain("executionStats") Output

- `nReturned` displays the number of documents that match the query.
- `totalDocsExamined` displays the number of documents the retrieval engine considered during the query.
- `totalKeysExamined` displays how many documents in an existing index were scanned.
- A `totalKeysExamined` or `totalDocsExamined` value much higher than `nReturned` indicates we need a different index.
- Given `totalDocsExamined`, this query will benefit from an index.

Other Operations

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

- `aggregate`
- `count`
- `group`
- `remove`
- `update`

db.<COLLECTION>.explain()

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

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

equivalent to

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

also equivalent to

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

Using explain() for Write Operations

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

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

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

Single-Field Indexes

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

Creating an Index

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

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

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

Listing Indexes

List indexes for a collection:

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

List index keys:

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

Indexes and Read/Write Performance

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

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 operation that touches an indexed field will require each index to be updated.
- Indexes require RAM.
- Be judicious about the choice of key.

Additional Index Options

- Sparse
- Unique
- Background

Sparse Indexes in MongoDB

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

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

Defining Unique Indexes

- Enforce a unique constraint on the index.
- Prevent duplicate values from being inserted into the database.
- 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 } )
```

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.insert(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()
```

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()
```

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()
```

totalKeysExamined is still > n. Why?

totalKeysExamined > n

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

A Different Compound Index

Drop the index and build a new one with user.

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

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

totalKeysExamined is 2. n is 2.

totalKeysExamined == n

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

Let Selectivity Drive Field Order

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

Adding in the Sort

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

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

- Note that the winningPlan includes a SORT stage.
- This means that MongoDB had to perform a sort in memory.
- In memory sorts for queries that retrieve large numbers of documents can degrade performance significantly.
- This is especially true if they are used frequently.

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();
```

- 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.

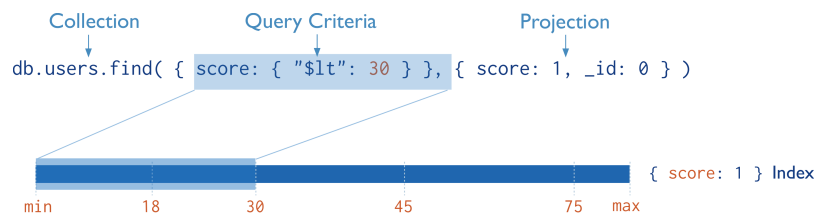
```
db.messages.dropIndex( "myindex" );
db.messages.createIndex( { username : 1, rating : 1, timestamp : 1 },
                        { name : "myindex" } );
db.messages.find( {
    timestamp : { $gte : 2, $lte : 4 },
    username : "anonymous"
} ).sort( { rating : -1 } ).explain();
```

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

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.insert({ "_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)
```

Exercise: Avoiding an In-Memory Sort

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

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

Exercise: Avoiding an In-Memory Sort, 2

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

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

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.insert( 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.insert(b)

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

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

Exercise: Array of Documents, Part 2

For each of the three queries below:

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

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

Exercise: Array of Arrays, Part 1

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

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

Exercise: Array of Arrays, Part 2

For each of the queries below:

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

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

How Multikey Indexes Work

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

Multikey Indexes and Sorting

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

Exercise: Multikey Indexes and Sorting

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

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

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

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

Limitations on Multikey Indexes

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

Example: Multikey Indexes on Multiple Fields

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

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

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

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

// Won't work
db.testcol.insert( { _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](#)⁶ 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.

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} .

⁶<http://docs.mongodb.org/manual/tutorial/shard-collection-with-a-hashed-shard-key/>

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.

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

Introduction to MongoDB Drivers (page 62) An introduction to the MongoDB drivers

Lab: Driver Tutorial (Optional) (page 64) A quick tour through the Python driver

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

- C⁷
- C++⁸
- C#⁹
- Java¹⁰
- Node.js¹¹
- Perl¹²
- PHP¹³
- Python¹⁴
- Ruby¹⁵
- Scala¹⁶

⁷<http://docs.mongodb.org/ecosystem/drivers/c>

⁸<http://docs.mongodb.org/ecosystem/drivers/cpp>

⁹<http://docs.mongodb.org/ecosystem/drivers/csharp>

¹⁰<http://docs.mongodb.org/ecosystem/drivers/java>

¹¹<http://docs.mongodb.org/ecosystem/drivers/node-js>

¹²<http://docs.mongodb.org/ecosystem/drivers/perl>

¹³<http://docs.mongodb.org/ecosystem/drivers/php>

¹⁴<http://docs.mongodb.org/ecosystem/drivers/python>

¹⁵<http://docs.mongodb.org/ecosystem/drivers/ruby>

¹⁶<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](#)¹⁷ for:

- [Authentication](#)¹⁸
- [CRUD operations](#)¹⁹
- [Index management](#)²⁰
- [SDAM](#)²¹
- [Server Selection](#)²²
- 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.

¹⁷<https://github.com/mongodb/specifications>

¹⁸<https://github.com/mongodb/specifications/tree/master/source/auth>

¹⁹<https://github.com/mongodb/specifications/tree/master/source/crud>

²⁰<https://github.com/mongodb/specifications/blob/master/source/index-management.rst>

²¹<https://github.com/mongodb/specifications/tree/master/source/server-discovery-and-monitoring>

²²<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](http://api.mongodb.org/python/current/tutorial.html)²³ for a concise introduction to:

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

²³<http://api.mongodb.org/python/current/tutorial.html>

5 Aggregation

Aggregation Tutorial (page 65) An introduction to the the aggregation framework, pipeline concept, and stages

Optimizing Aggregation (page 73) Resource management in the aggregation pipeline

Lab: Aggregation Framework (page 75) Aggregation labs

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

```
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
- `$group`: Used to aggregate field values from multiple documents
- `$out`: Creates a new collection from the output of an aggregation pipeline

The Match Stage

- The `$match` operator works like the query phase of `find()`, `update()`, and `remove()`.
- Documents in the pipeline that match the query document will be passed to subsequent stages.
- `$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.

A Twitter Dataset

- Let's look at some examples that illustrate the MongoDB aggregation framework.
- These examples operate on a collection of tweets.
 - As with any dataset of this type, it's a snapshot in time.
 - It may not reflect the structure of Twitter feeds as they look today.

Tweets Data Model

```
{
  "text" : "Something interesting ...",
  "entities" : {
    "user_mentions" : [
      {
        "screen_name" : "somebody_else",
        ...
      }
    ],
    "urls" : [ ],
    "hashtags" : [ ]
  },
  "user" : {
    "friends_count" : 544,
    "screen_name" : "somebody",
    "followers_count" : 100,
    ...
  },
}
```

Analyzing Tweets

- Imagine the types of analyses one might want to do on tweets.
- It's common to analyze the behavior of users and the networks involved.
- Our examples will focus on this type of analysis

Friends and Followers

- Let's look again at two stages we touched on earlier:
 - `$match`
 - `$project`
- In our dataset:
 - `friends` are those a user follows.
 - `followers` are others that follow a 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 } ] )
```

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
}
```

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 }
] )
```

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 })
```

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 }
] )
```

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 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 Optimization](http://docs.mongodb.org/manual/core/aggregation-pipeline-optimization/)²⁵

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.

```
mongoimport -d blog -c posts --drop posts.json
```

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

Exercise: Repeated Aggregation Stages

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

```
mongoimport -d test -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.

²⁵<http://docs.mongodb.org/manual/core/aggregation-pipeline-optimization/>

Exercise: Projection

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

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

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

Exercise: Descriptive Statistics

From the `grades` collection, find the class (display the `class_id`) with the best average student performance.

If you have not already done so, import the `grades` collection as follows.

```
mongoimport -d test -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.

6 Introduction to Schema Design

Schema Design Core Concepts (page 77) An introduction to schema design in MongoDB

Schema Evolution (page 84) Considerations for evolving a MongoDB schema design over an application's lifetime

Common Schema Design Patterns (page 88) Common design patterns for representing 1-1, 1-M, and M-M relationships and tree structures in MongoDB

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 GridFS

- 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.update(
  { _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.update(
  { _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

```
cursor = db.reviews.update(
  { _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

Introduction to Replica Sets (page 93) An introduction to replication and replica sets

Replica Set Roles and Configuration (page 95) Configuring replica set members for common use cases

Write Concern (page 97) Balancing performance and durability of writes

Read Preference (page 101) Configuring clients to read from specific members of a replica set

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.

Disaster Recovery (DR)

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

Functional Segregation

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

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

Large Replica Sets

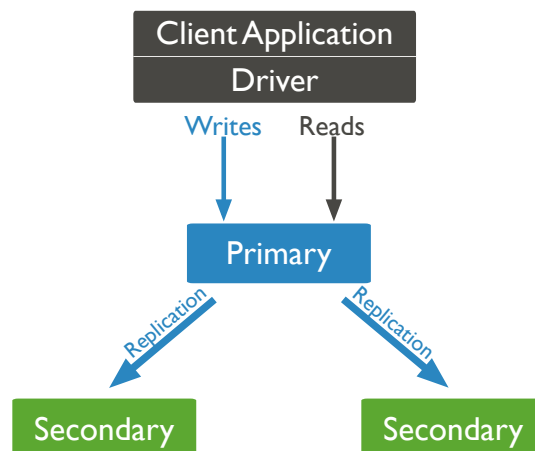
Functional segregation can be further exploited by using large replica sets.

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

Replication is Not Designed for Scaling

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

Replica Sets



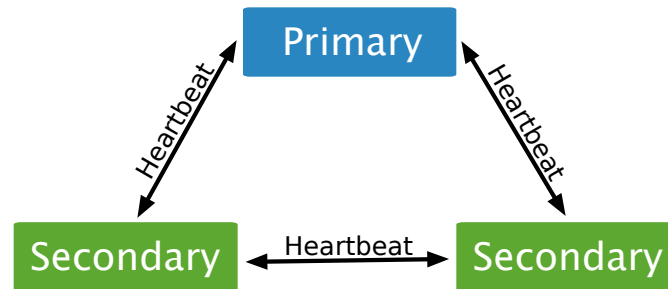
Primary Server

- Clients send writes 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.

Secondaries

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

Heartbeats



The Oplog

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

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 },
```

Data Center 2

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

What about dc1-3 and dc2-2?

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


What about dc2-2?

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

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`.

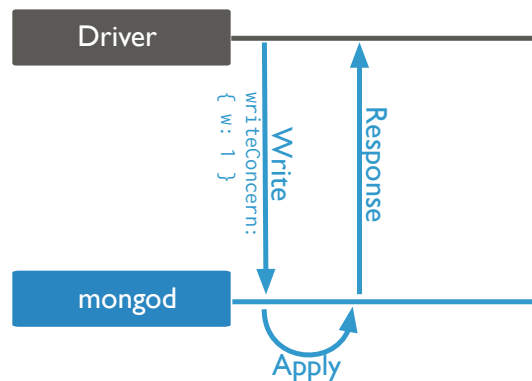
Balancing Durability with Performance

- 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.

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.

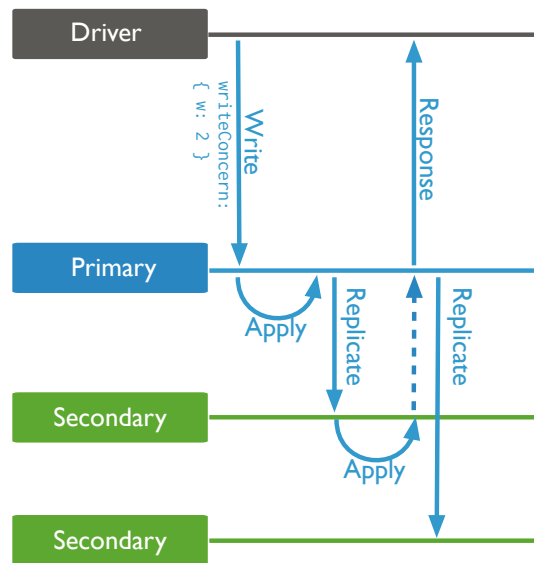
Write Concern: { w : 1 }



Example: { w : 1 }

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

Write Concern: { w : 2 }



Example: { w : 2 }

```
db.customer.update( { 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.update({ _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" }

Further Reading

See [Write Concern Reference](#)²⁶ for more details on write concern configurations, including setting timeouts and identifying specific replica set members that must acknowledge writes (i.e. [tag sets](#)²⁷).

²⁶<http://docs.mongodb.org/manual/reference/write-concern>

²⁷<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.

Not for Scaling

- In general, do *not* read from secondaries to provide extra capacity for reads.
- [Sharding](http://docs.mongodb.org/manual/sharding)²⁸ increases read and write capacity by distributing operations across a group of machines.
- Sharding is a better strategy for adding capacity.

Read Preference Modes

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

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

²⁸<http://docs.mongodb.org/manual/sharding>

Tag Sets

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

For example, in the mongo shell:

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

8 Sharding

Introduction to Sharding (page 103) An introduction to 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.

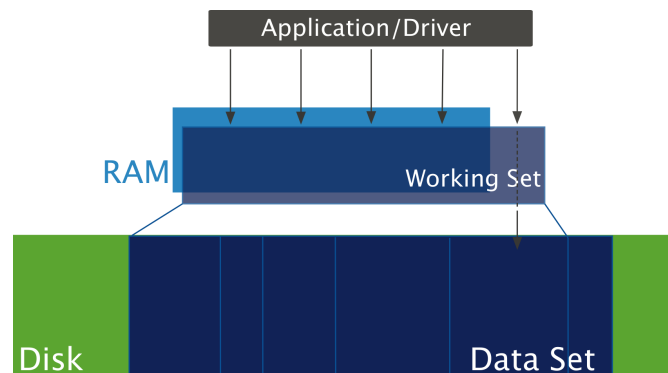
Sharding is Concerned with Scale

- 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



Limitations of Vertical Scaling

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

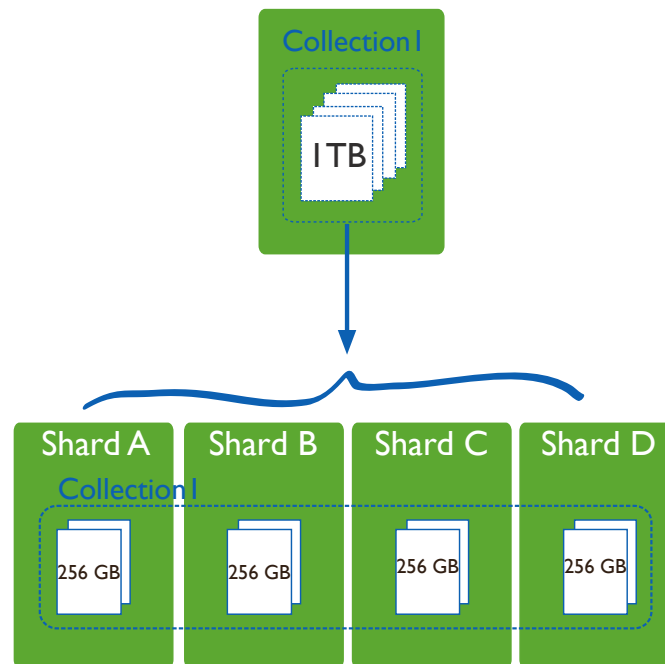
Sharding Overview

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

When to Shard

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

Dividing Up Your Dataset



Sharding Concepts

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

- Shard Keys
- Chunks

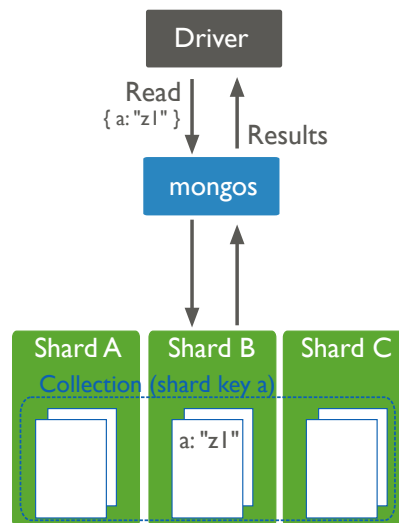
Shard Key

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

Shard Key Ranges

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

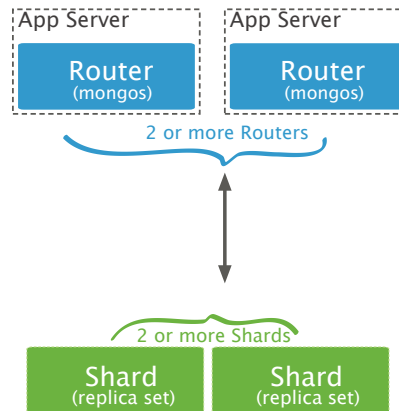
Targeted Query Using Shard Key



Chunks

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

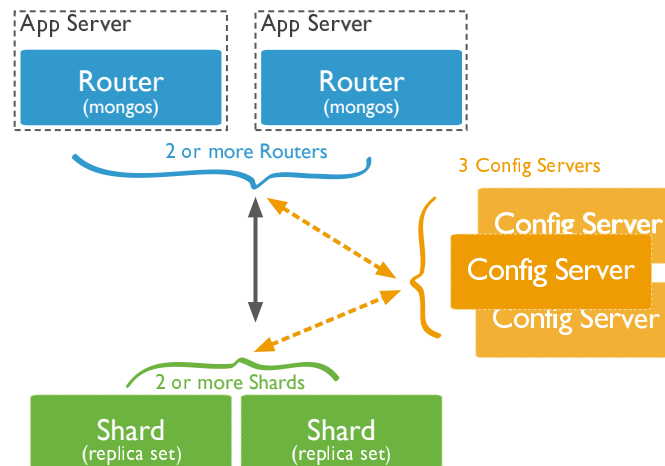
Sharded Cluster Architecture



Mongos

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

Config Servers



Config Server Hardware Requirements

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

Possible Imbalance?

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

Balancing Shards

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

With a Good Shard Key

You might easily see that:

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

With a Bad Shard Key

You might see that:

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

Choosing a Shard Key

Generally, you want a shard key:

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

More Specifically

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

Cardinality

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

Non-Monotonic

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

Shards Should be Replica Sets

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

9 MongoDB Cloud & Ops Manager

MongoDB Cloud & Ops Manager (page 111) Learn about what Cloud & Ops Manager offers

Automation (page 113) Cloud & Ops Manager Automation

Lab: Cluster Automation (page 116) Set up a cluster with Cloud & Ops Manager Automation

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

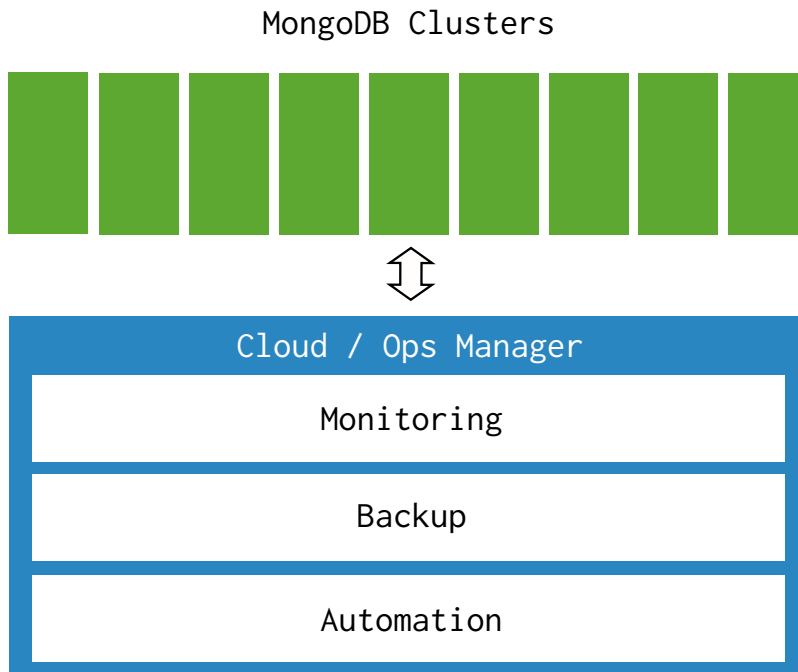
Deployment Options

- 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)

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?

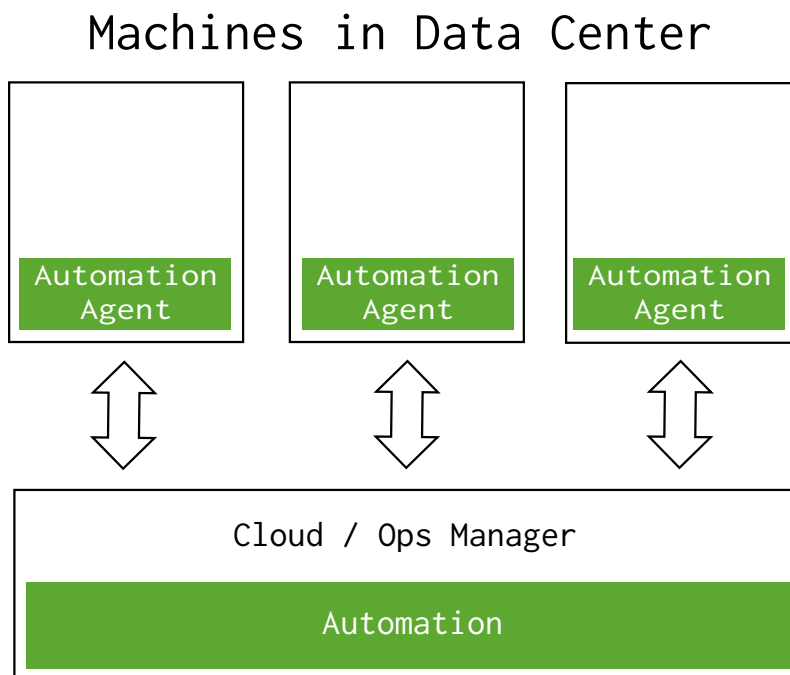
Fully managed MongoDB deployment on your own servers:

- 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 moa 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](#)²⁹ - [The Automation API](#)³⁰ - [Configuring the Automation Agent](#)³¹

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

Cloud Manager Automation Support

Windows machines are not supported at this time. You may use either your personal computer or Linux instances we have provided in order to complete this lab. Your instructor will provide you with instructions for access.

Exercise #1

Create a cluster using Cloud Manager automation with the following topology:

- 3 shards
- Each shard is a 3 node replica set (2 data bearing nodes, 1 arbiter)
- Version 2.6.8 of MongoDB
- **To conserve space, set “smallfiles” = true and “oplogSize” = 10**

²⁹<https://docs.cloud.mongodb.com/tutorial/nav/automation-agent/>

³⁰<https://docs.cloud.mongodb.com/api/>

³¹<https://docs.cloud.mongodb.com/reference/automation-agent/>

Exercise #2

Modify the cluster topology from Exercise #1 to the following:

- 4 shards (add one shard)
- Version 3.0.1 of MongoDB (upgrade from 2.6.8 -> 3.0.1)