Class Announcements

- Teams are up and running
  - Jaron Smith
  - Tapan Katipelli
- Project deliverable 1 was submitted
  - All teams did a good job
- Project deliverable 2 is due March 16
  - We will see some examples of complete projects
- Last class: 15 mins for each team to present the project
  - Peer-evaluation: each team votes for the other teams
  - Final score for team: 5 deliverables + peer vote

UMD DATA605 - Big Data Systems
NoSQL Document Stores
MongoDB
CouchDB

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with thanks to Profs
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Kathleen Durant (Northeastern U.)

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UMD DATA605 - Big Data Systems

NoSQL Document Stores

MongoDB

Couchbase

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Key-Value Store vs Document DBs

- **Key-value stores**
  - Basically a map or a dictionary
    - E.g., HBase, Redis
  - Typically only look up values by key
    - Sometimes can do search in value field with a pattern
  - Uninterpreted value (e.g., binary blob) associated with a key
  - Typically one namespace for all key-values

- **Document DBs**
  - Collect sets of key-value pairs into *documents*
    - E.g., MongoDB, CouchDB
  - Documents typically represented in JSON, XML, or BSON (binary JSON)
  - Documents organized into *collections*, similar to tables in relational DBs
    - Large collections can be partitioned and indexed

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NoSQL Document Stores

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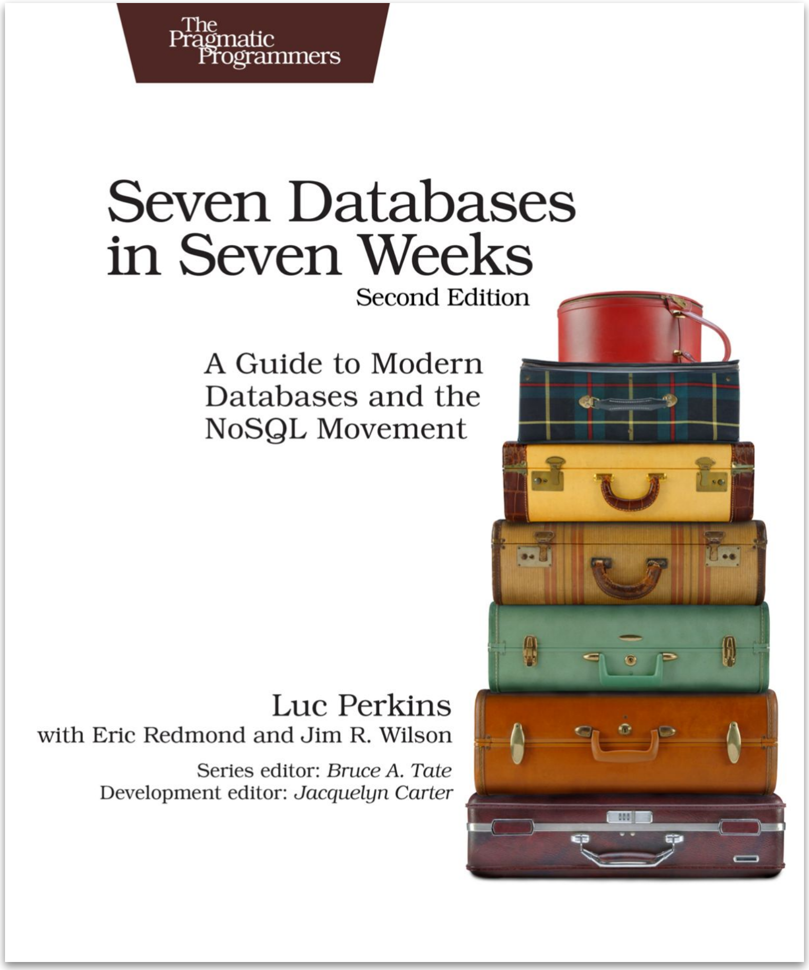
Resources

- All concepts in slides
- MongoDB tutorial
- Web
  - https://www.mongodb.com/
  - Official docs
  - pymongo
- Book
  - Seven Databases in Seven Weeks, 2e



MongoDB

- Developed by MongoDB Inc.
  - Founded in 2007
  - Based on DoubleClick experience with large-scale data
  - Mongo comes from "hu-mongo-us"
- One of the most used NoSQL DBs (if not the most used)
- **Document-oriented NoSQL database**
  - Schema-less
    - No Data Definition Language (DDL), like for SQL
    - In practice, you can store maps with any keys and values
    - Application tracks the schema, mapping between documents and their meaning
  - Keys are hashes stored as strings
    - Document Identifiers `_id` created for each document (field name reserved by system)
  - Values use BSON format
    - Based on JSON (B stands for Binary)
- Written in C++
- Supports APIs (drivers) in many languages
  - E.g., JavaScript, Python, Ruby, Java, Scala, C++, ...

MongoDB: Example of Document

- **A document is a JSON data structure**
- It corresponds to a row in a relational DB
  - Without schema
  - Values nested to an arbitrary depth
  - Primary key is `_id`

```
{
   "_id" : ObjectId("4d0b6da3bb30773266f39fea"),
   "country" : {
      "$ref" : "countries",
      "$id" : ObjectId("4d0e6074deb8995216a8309e")
   },
   "famous_for" : [
      "beer",
      "food"
   ],
   "last_census" : "Sun Jan 07 2018 00:00:00 GMT -0700 (PDT)",
   "mayor" : {
      "name" : "Ted Wheeler",
      "party" : "D"
   },
   "name" : "Portland",
   "population" : 582000,
   "state" : "OR"
}
```

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MongoDB: Functionalities

- **Design goals**
  - Performance
  - Availability / scalability
  - Rich data storage (not rich querying!)
- **Dynamic schema**
  - No DDL (Data Definition Language)
  - Secondary indexes
  - Query language via an API
- **Several levels of data consistency**
  - E.g., atomic writes and fully-consistent reads (at document level)
- **No joins nor transactions across multiple documents**
  - Makes distributed queries easy and fast
- **High availability through replica sets**
  - E.g., primary replication with automated failover
- **Built-in sharding**
  - Horizontal scaling via automated range-based partitioning of data
  - Reads and writes distributed over shards

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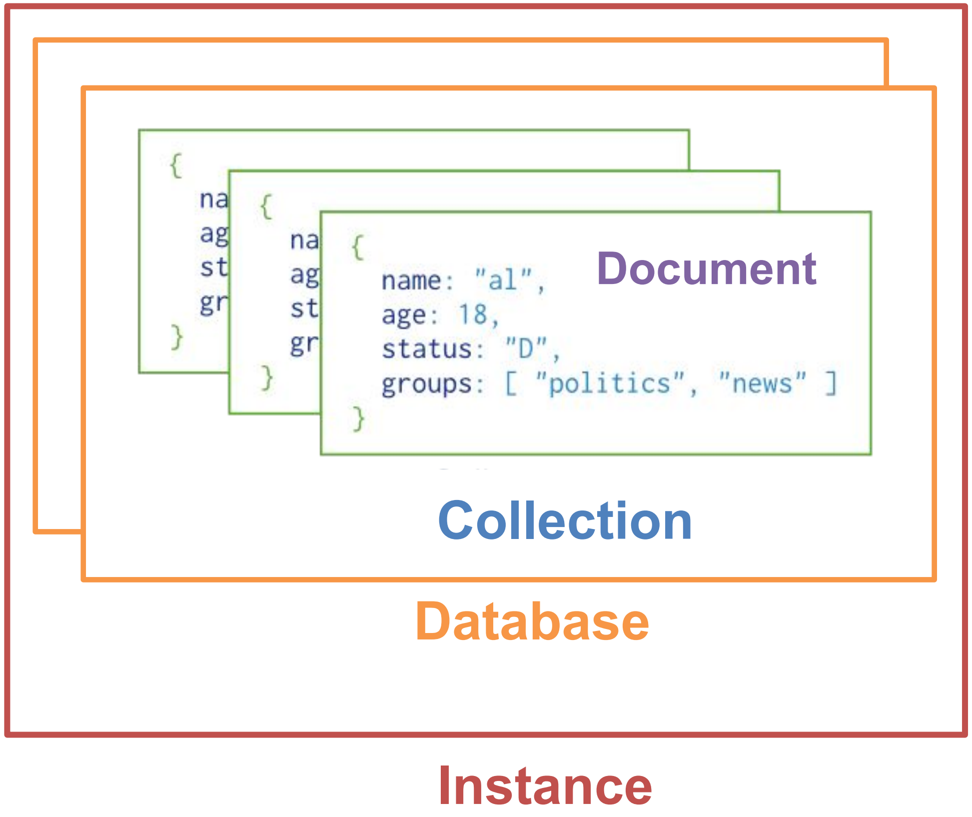
MongoDB: Hierarchical Objects

- A Mongo **instance** has:
  - Zero or more “databases”
  - Mongo instance same as Postgres
- A Mongo **database** has:
  - Zero or more “collections”
    - Mongo collection ~ Postgres tables
  - Mongo database ~ Postgres database
- A Mongo **collection** has:
  - Zero or more “documents”
    - Mongo document ~ Postgres rows
- A Mongo **document** has:
  - One or more “fields”
    - It has always primary key _id
    - Mongo field ~ Postgres columns



From https://www.mongodb.com/docs/manual/core/data-modeling-introduction

Relational DBs vs MongoDB: Terms and Concepts

RDBMS Concept	MongoDB Concept	Meaning in MongoDB
database	database	Container for collections
relation / table / view	collection	Group of documents
row / instance	document (BSON)	Group of fields
column / attribute	field	A name-value pair
index	index	
primary keys	*_id* field	Always the primary key
foreign key	reference	
table joins	embedded documents	

```
{
   "_id" : ObjectId("4d0b6da3bb30773266f39fea"),
   "country" : {
      "$ref" : "countries",
      "$id" : ObjectId("4d0e6074deb8995216a8309e")
   },
   "famous_for" : [
      "beer",
      "food"
   ],
   "last_census" : "Sun Jan 07 2018 00:00:00 GMT -0700 (PDT)",
   "mayor" : {
      "name" : "Ted Wheeler",
      "party" : "D"
   },
   "name" : "Portland",
   "population" : 582000,
   "state" : "OR"
}
```

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Relational vs Document DB: Workflows

- **Relational DBs**
  - E.g., PostgreSQL
  - Know what you want to store
    - Tabular data
  - Do not know how to use it
    - Static schema allows query flexibility (e.g., joins)
  - Complexity is at insertion time
    - Decide how to represent the data (i.e., schema)
- **Document DBs**
  - E.g., MongoDB
  - No assumptions on what to store
    - E.g., irregular JSON data
  - Know a bit how to access data
    - You want to access the data by key
    - E.g., it's a nested key-value map
  - Complexity is at access time
    - Get the data from the server
    - Process data on the client side

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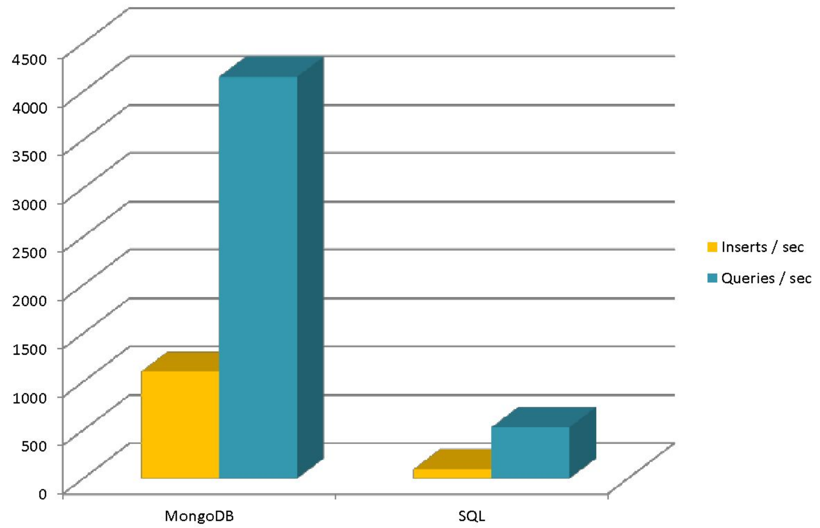
Why Use MongoDB?

- Simple to query
  - Do the work on client side
- It's fast
  - 2-10x faster than Postgres
- Data model / functionalities suitable for most web applications
  - Semi-structured data
  - Quickly evolving systems
- Easy and fast integration of data
- Not well suited for heavy and complex transactions systems
  - E.g., banking system



MongoDB: Data Model

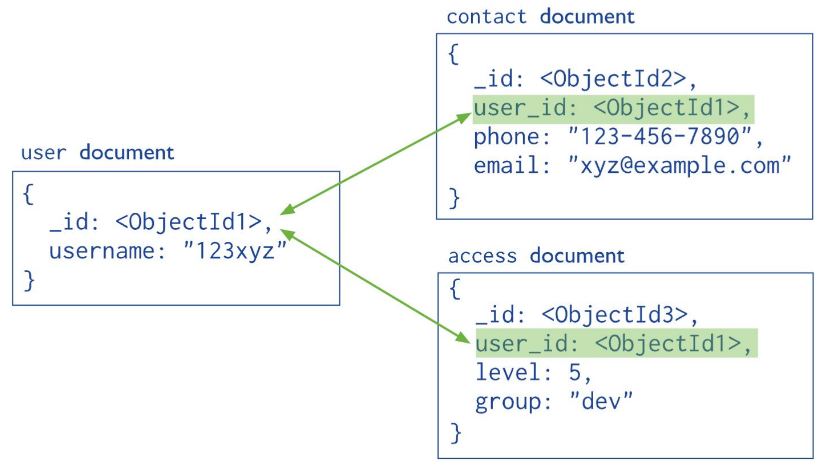
- **Documents** are composed of field and value pairs
  - **Field names** are strings
  - Each **value** is any BSON type
    - Arrays of documents
    - Native data types
    - Other documents
- E.g.,
  - `_id` holds an ObjectId
  - `name` holds a document that contains the fields `first` and `last`
  - `birth` and `death` are of Date type
  - `contribs` holds an array of strings
  - `views` holds a value of the NumberLong type

```
{
   name: "sue",                          ← field: value
   age: 26,                              ← field: value
   status: "A",                          ← field: value
   groups: [ "news", "sports" ]          ← field: value
}
```

```
{
   _id: ObjectId("5099803df3f4948bd2f98391"),
   name: { first: "Alan", last: "Turing" },
   birth: new Date('Jun 23, 1912'),
   death: new Date('Jun 07, 1954'),
   contribs: [ "Turing machine", "Turing test", "Turingery" ],
   views : NumberLong(1250000)
}
```

MongoDB: Data Model

- Documents can be nested
  - Embedded sub-document
- **Denormalized data models**
  - Store multiple related pieces of information in the same record
  - Conceptually is the result of a join operation
- **Normalized data models**
  - Eliminate duplication
  - Represent many-to-many relationships



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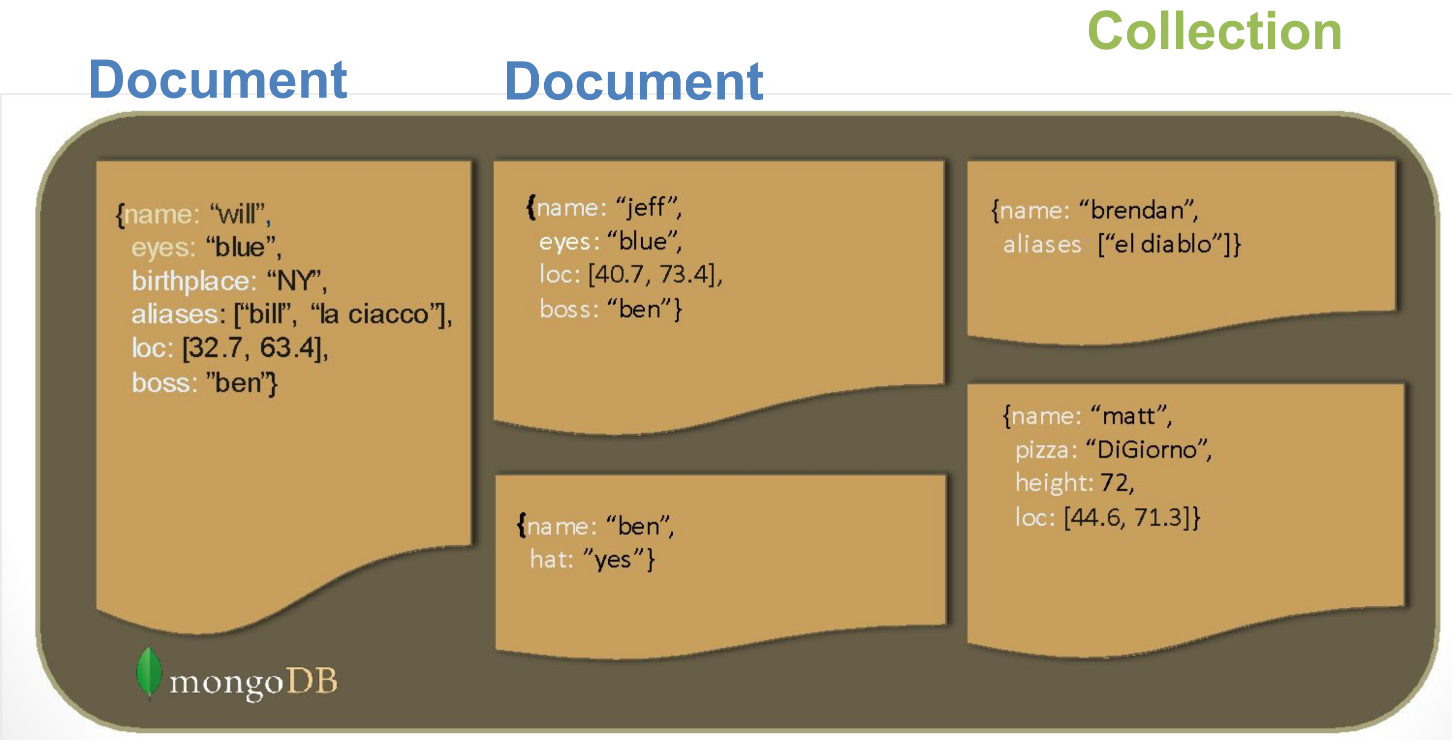
Schema Free

- MongoDB does not need any pre-defined data schema
- Every **document** in a **collection** can have different fields and values
  - No need for NULL values / union of fields like in relational DBs



JSON Format

- JSON = JavaScript Object Notation
- Data is stored in field / value pairs
- A field / value pair consists of:
  - A field name
  - Followed by a colon `:`
  - Followed by a value

```
“name”: “R2-D2”
```

- Data in documents is separated by commas `,`

```
“name”: “R2-D2”, race : “Droid”
```

- Curly braces `{}` hold documents

```
{“name”: “R2-D2”, race : “Droid”, affiliation: “rebels”}
```

- An array is stored in brackets `[]`

```
[{“name”: “R2-D2”, race: “Droid”, affiliation: “rebels”},
 {“name”: “Yoda”, affiliation: “rebels”}]
```

- Supports:
  - Embedding of nested objects within other objects
  - Just references

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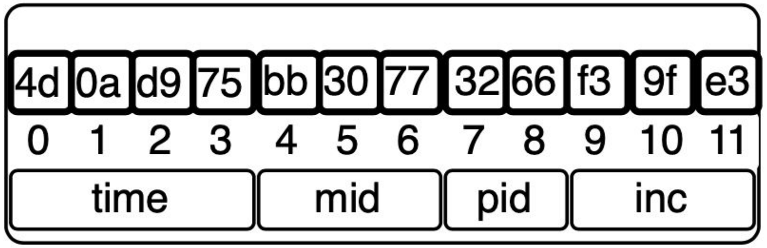
BSON Format

- Binary-encoded serialization of JSON-like documents
  - https://bsonspec.org
- Zero or more key/value pairs are stored as a single entity
  - Each entry consists of:
    - a field name (string)
    - a data type
    - a value
- Large elements in a BSON document are prefixed with a length field to facilitate scanning
- MongoDB understands the internals of BSON objects, even nested ones
  - Can build indexes and match objects against query expressions for BSON keys

ObjectID

- Each JSON data contains an `_id` field of type ObjectId
  - Same as a `SERIAL` constraint incrementing a numeric primary key in PostgreSQL
- An ObjectId is 12 bytes, composed of:
  - a timestamp
  - client machine ID
  - client process ID
  - a 3-byte auto-incremented counter
- Each Mongo process can handle its own ID generation without colliding
  - Mongo has a distributed nature
- Details [here]



Indexes

- Primary index automatically created on the `_id` field
  - B+ tree indexes
- Users can create secondary indexes to:
  - Improve query performance
  - Enforce unique values for a particular field
- Support single field index and compound index
  - Order of the fields in a compound index matters (like SQL)
- Sparse property of an index
  - The index contains only entries for documents that have the indexed field
  - Ignore records that do not have the field defined
- If an index is unique and sparse
  - Reject records that have a duplicate key value
  - Allow records that do not have the indexed field defined
- Details at https://www.mongodb.com/docs/manual/indexes/

CRUD Operations

- CRUD = Create, Read, Update, Delete

- **Create**

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

  Upsert = update (if exists) or insert (if it doesn't)

- **Read**

```
db.collection.find(<query>, <projection>)
db.collection.findOne(<query>, <projection>)
```

- **Update**

```
db.collection.update(<query>, <update>, <options>)
```

- **Delete**

```
db.collection.remove(<query>, <justOne>)
```

Details at https://www.mongodb.com/docs/manual/crud/

Create Operations

- `db.collection` specifies the collection (like an SQL table) to store the document

```
db.collection_name.insert(<document>)
```

  - Without `_id` field, MongoDB generates a unique key

```
db.parts.insert({type: “screwdriver”, quantity: 15})
db.parts.insert({_id: 10, type: “hammer”, quantity: 1})
```

- Update 1 or more records in a collection satisfying `query`

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

- Update an existing record or create a new record

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

Read Operations

- `find` provides functionality similar to `SQL SELECT` command
  `db.collection.find(<query>, <projection>).cursor`
  with:
  - <query> = where condition
  - <projection> = fields in result set

- `db.parts.find({parts: “hammer”}).limit(5)`
  - Return cursor to handle a result set
  - Can modify the query to impose limits, skips, and sort orders
  - Can specify to return the ‘top’ number of records from the result set

- `db.collection.findOne(<query>, <projection>)`

More Query Examples

SQL	Mongo
`SELECT * FROM users WHERE age>33`	`db.users.find({age: {$gt: 33}})`
`SELECT * FROM users WHERE age!=33`	`db.users.find({age: {$ne: 33}})`
`SELECT * FROM users WHERE name LIKE "%Joe%"`	`db.users.find({name: /Joe/})`
`SELECT * FROM users WHERE a=1 and b='q’`	`db.users.find({a: 1, b: 'q’})`
`SELECT * FROM users WHERE a=1 or b=2`	`db.users.find({$or: [{a: 1}, {b: 2}]})`
`SELECT * FROM foo WHERE name=‘bob’ and (a=1 or b=2 )`	`db.foo.find({name: "bob", $or: [{a: 1}, {b: 2}]})`
`SELECT * FROM users WHERE age>33 AND age<=40`	`db.users.find({'age': {$gt: 33, $lte: 40}})`

Query Operators

Command	Description
$regex	Match by any PCRE-compliant regular expression string (or just use the // delimiters as shown earlier)
$ne	Not equal to
$lt	Less than
$lte	Less than or equal to
$gt	Greater than
$gte	Greater than or equal to
$exists	Check for the existence of a field
$all	Match all elements in an array
$in	Match any elements in an array
$nin	Does not match any elements in an array
$elemMatch	Match all fields in an array of nested documents
$or	or
$nor	Not or
$size	Match array of given size
$mod	Modulus
$type	Match if field is a given datatype
$not	Negate the given operator check

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Update Operations

- `db.collection_name.insert(<document>)`
  - Omit the _id field to have MongoDB generate a unique key

```
db.parts.insert({{type: “screwdriver”, quantity: 15})
db.parts.insert({_id: 10, type: “hammer”, quantity: 1})
```

- `db.collection_name.save(<document>)`
  - Updates an existing record or creates a new record
- `db.collection_name.update(<query>, <update>, {upsert: true})`
  - Will update 1 or more records in a collection satisfying query
- `db.collection_name.findAndModify(<query>, <sort>, <update>, <new>, <fields>, <upsert>)`
  - Modify existing record(s) – retrieve old or new version of the record

Delete Operations

- `db.collection_name.remove(<query>, <justone>)`
  - Delete all records from a collection or matching a criterion
  - <justone> specifies to delete only 1 record matching the criterion
- Remove all parts starting with h

```
db.parts.remove(type: /^h/ })
```

- Delete all documents in the parts collections

```
db.parts.remove()
```

MongoDB Features

- Document-oriented NoSQL store
- Rich querying
  - Full index support
- Fast in-place updates
- Agile and scalable
  - Replication and high availability
  - Auto-Sharding
  - Map-reduce functionality
- Scale horizontally over commodity hardware
  - Lots of relatively inexpensive servers

MongoDB vs Relational DBs

- Keep the functionality that works well in RDBMSs
  - Ad-hoc queries
  - Fully featured indexes
  - Secondary indexes
- Do not offer RDBMS functionalities that don’t distribute
  - Long running multi-row transactions
  - Joins
  - ACID consistency

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MongoDB Tutorial

Tutorial is at GitHub

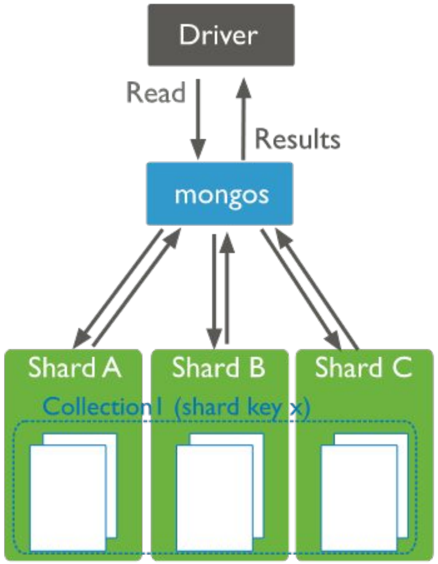
The instructions are here

> cd $GIT_REPO/tutorials/tutorial_mongodb

> vi tutorial_mongo.md

MongoDB Processes and Configuration

- **mongod**: database instance (i.e., the server process)
- **mongosh**: an interactive shell (i.e., a client)
  - Fully functional JavaScript environment for use with a MongoDB
- **mongos**: database router
  - Process all requests
  - Decide how many and which **mongod**s should receive the query (sharding / partitioning)
  - Collate the results
  - Send result back to the client
- You should have:
  - One **mongos** (router) for the whole system no matter how many **mongod**s you have; or
  - One local **mongos** for every client if you wanted to minimize network latency



MapReduce Functionality

- Perform aggregator functions given a collection of (keys, value) pairs
- Must provide at least a map function, reduction function, and the name of the result set

```
db.collection.mapReduce(
    <mapfunction>,
    <reducefunction>,
    {
        out: <collection>,
        query: <document>,
        sort: <document>,
        limit: <number>,
        finalize: <function>,
        scope: <document>,
        jsMode: <boolean>,
        verbose: <boolean>
    })
```

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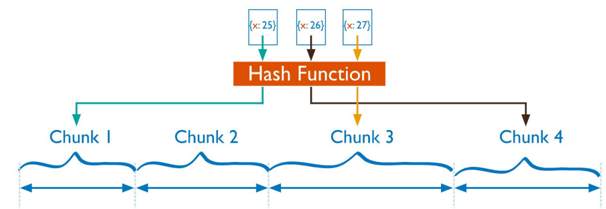
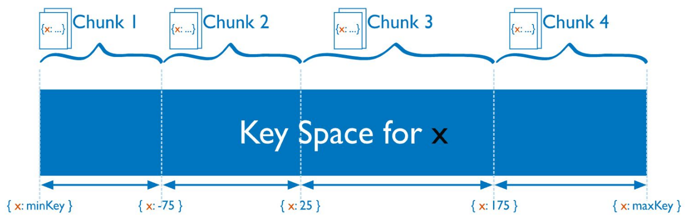
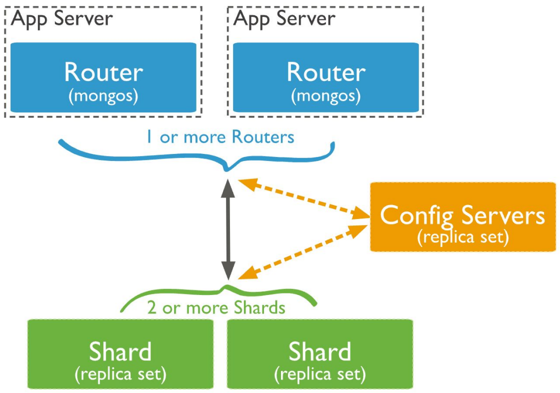
MongoDB: Sharding

- Sharding = method for distributing data across different machines
- Shard = subset of data
  - A collection is split in pieces based on the shard key
  - Data distributed based on has of shard key or intervals [a, b)
- Horizontal scaling achieved through sharding
  - Divide data and workload over multiple servers
  - Complexity in infrastructure and maintenance
- Each shard can be deployed as a replica set
- **`mongos`** acts as a query router interfacing clients and sharded cluster
- Config servers store metadata and configuration settings for cluster

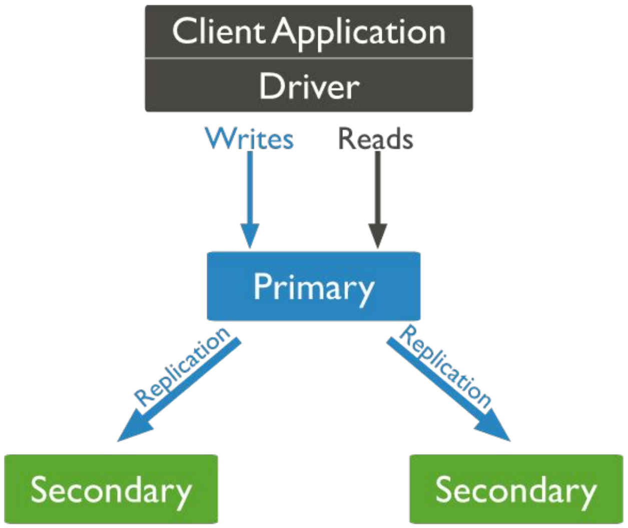


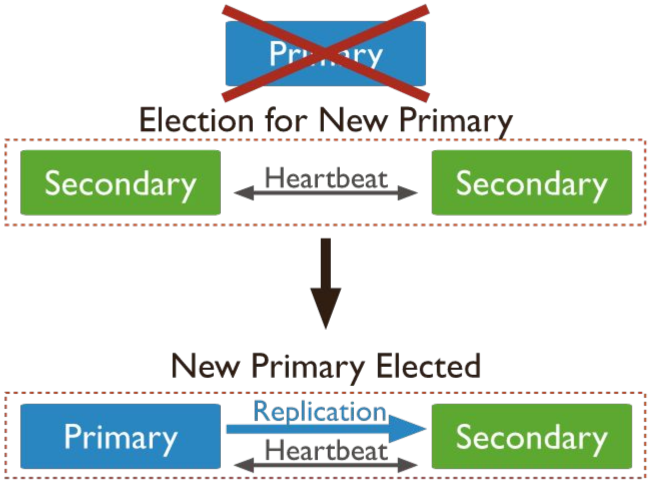




Data Replication

- **Data replication** ensure:
  - redundancy
  - backup
  - automatic failover
- Replication occurs through groups of servers known as **replica sets** (for each shard)
  - **Primary set**: set of servers that client asks direct updates to
  - **Secondary set**: set of servers used for duplication of data
  - Different properties can be associated with a secondary set, e.g., secondary-only, hidden delayed, arbiters, non-voting
- If the primary fails the secondary sets “vote” to elect the new primary set





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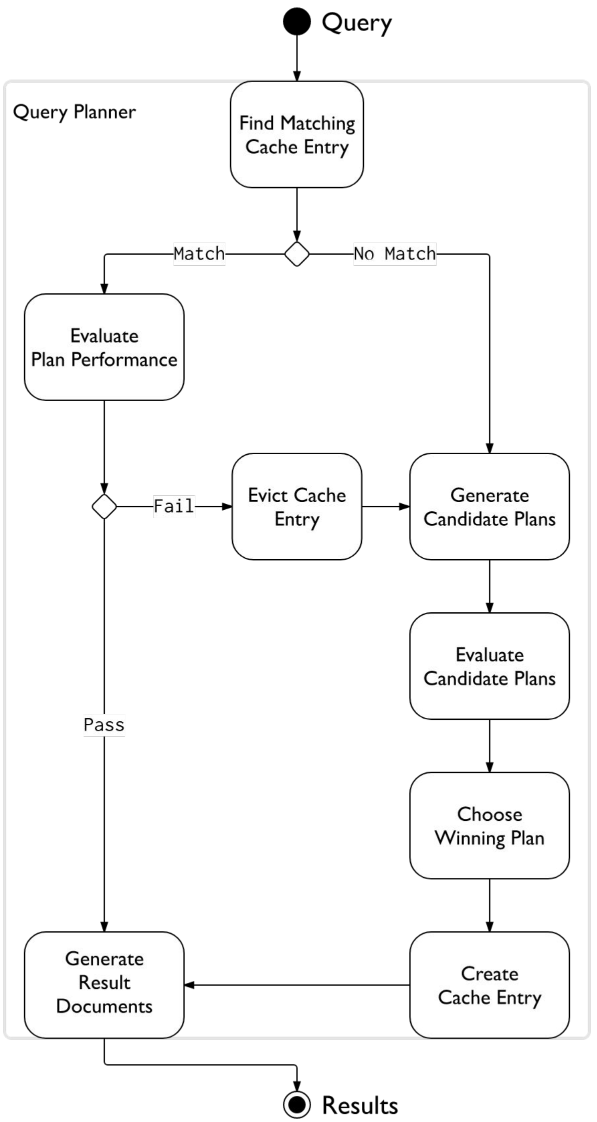
Data Consistency

- **Client decides how to enforce consistency for reads**
  - All writes and *consistent* reads go to the primary
  - All *eventually consistent* reads are distributed among the secondaries
- Reads to a primary have strict consistency
  - Reads reflect the latest changes to the data
- Reads to a secondary have eventual consistency
  - Updates propagate gradually
  - Client may read a previous state of the database

Query Optimizer

- Different from static and cost-based optimizer (like in RDBMSs)
- MongoDB optimizer is dynamic
  – Try different query plans and learns which ones perform well
  – The space of query plans is not so large, because there are no joins
  – When testing new plans
    - Execute multiple query plans in parallel
    - As soon as one plan finishes, terminate the other plans
  – If a plan that was working well starts performing poorly try again different plans
    - E.g, data in the DB has changed, parameter values to a query are different

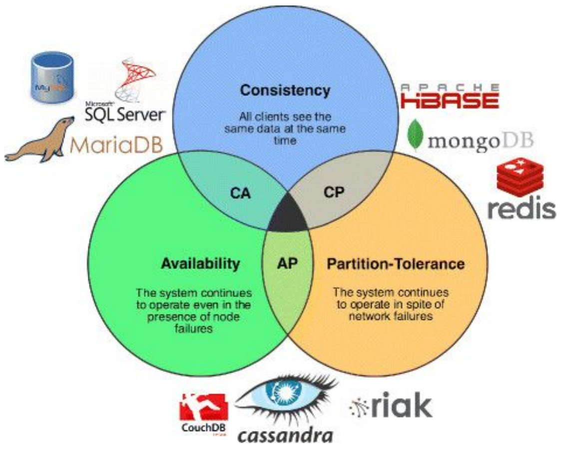


MongoDB: Strengths

- Provide a query language
- High-performance
  - Implemented in C++
- Very rapid development, open source
  - Support for many platforms
  - Many language drivers
- Built to address a distributed database system
  - Sharding
  - Replica sets of data
- Tunable consistency
- Useful when working with a huge quantity of data not requiring a relational model
  - The relationships between the elements does not matter
  - What really matters is the ability to store and retrieve great quantities of data

MongoDB: Limitations

- No referential integrity
- Lack of transactions and joins
- High degree of denormalization
  - Need to update data in many places instead of one
- Lack of predefined schema is a double-edged sword
  - You must have a data model in your application
  - Objects within a collection can be completely inconsistent in their fields
- CAP Theorem: targets consistency and partition tolerance, giving up on availability



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NoSQL document stores

MongoDB

Couchbase

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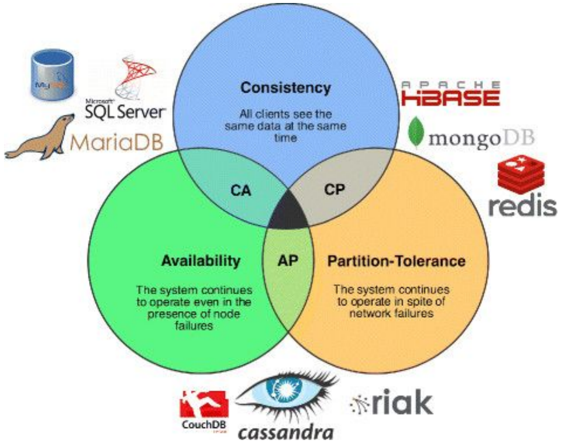
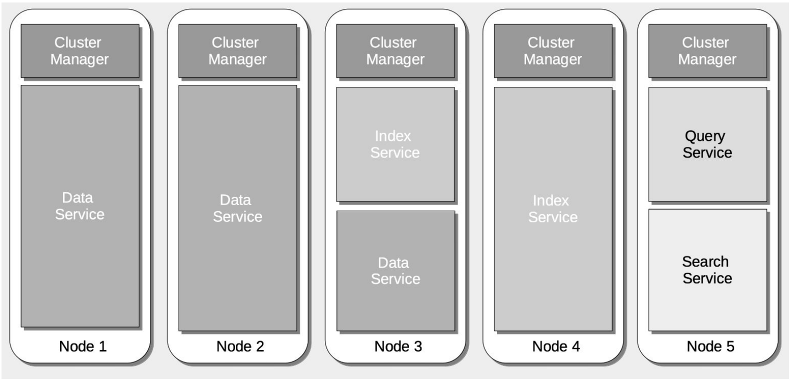
Couchbase

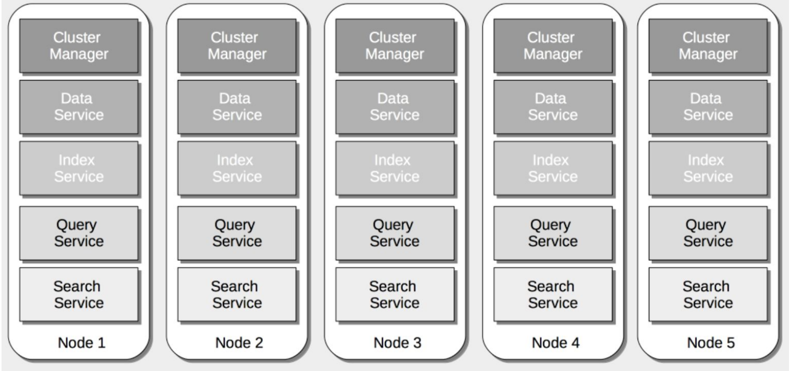
- NoSQL document-oriented DB (like MongoDB)
- [Couchbase](#) = merge of CouchDB and membase
  - *CouchDB*
    - Open source document store
    - HTTP RESTful API for reading and updating (add, edit, delete) documents
    - Support all 4 ACID properties
  - *membase*
    - Distributed key-value store (like Redis)
    - Designed to scale both up and down
    - Highly available and partition tolerant
- Couchbase
  - Uses HTTP protocol to query and interact with objects in the DB
    - No query language
  - Objects stored in *buckets*
    - Just a collection of documents (in JSON), with no special relation to one another
- From CAP point of view:
  - Get consistency and partition tolerance
  - High availability instead of consistency through use of multiple clusters



Architecture

- Every Couchbase node consists of different services:
  - Data service
  - Index service
  - Query service
  - Cluster manager component
- Services can run on separate nodes of the cluster, if needed
- Data replication across nodes of a cluster (and across data centers)
- Data manager *asynchronously* writes data to disk after acknowledging to the client
  - Optionally can ensure data is written to more than one server before acknowledging a write (synchronous)





Queries

- Can create multiple views over documents
  - Views are optimized/indexed by Couchbase for fast queries
  - Only re-indexed when underlying documents change a lot
- Perform well when:
  - There are infrequent changes to the structure of documents
  - Know in advance what kinds of queries you want to execute
- Uses a custom query language called N1QL (“nickel”), based on SQL
  - Extends SQL to JSON documents
  - And queries over multiple documents using joins
- Can do full-text searches using the indexes
- Map-reduce support
  - First define a view with the columns of the document your are interested in
    - Called the *map*
  - Optionally define aggregate functions over the data
    - The *reduce* step

Couchbase vs MongoDB

- According to Couchbase advocates
- **MongoDB**: hard to scale from single replica set to fully distributed environment
- **MongoDB**: performance degrades with increasing numbers of clients/users
  - **Couchbase**: Scales seamlessly, with an in-memory architecture, and able to scale across multiple nodes
- **MongoDB**: susceptible to data loss from failures
  - **Couchbase**: no master, no single point of failure
  - During failover, prevents different nodes from accepting simultaneous reads of writes of same data (maintains consistency)
- **MongoDB**: require a 3rd party cache to help it perform well
  - **Couchbase**: has integrated in-memory cache (memcached)
  - Keeps frequently accessed documents, metadata, and indexes in RAM, yielding high read/write throughput at low latency

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