Introduction to NoSQL and MongoDB

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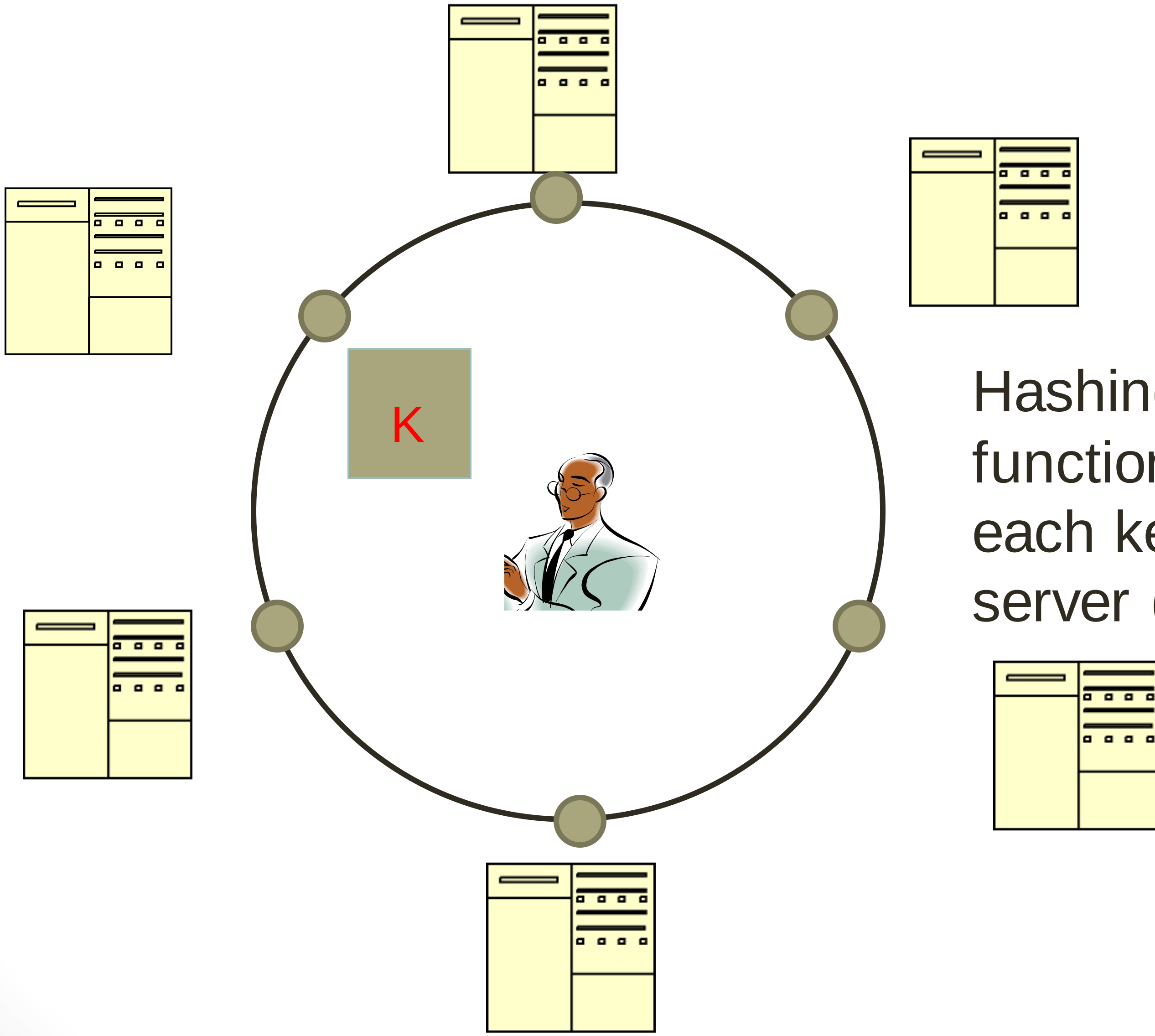
Outline for today

- Introduction to NoSQL
  - Architecture
    - Sharding
    - Replica sets
  - NoSQL Assumptions and the CAP Theorem
  - Strengths and weaknesses of NoSQL
- MongoDB
  - Functionality
  - Examples

Taxonomy of NoSQL

- **Key-value**
- **Graph database**
- **Document-oriented**
- **Column family**

Typical NoSQL architecture



Hashing function maps each key to a server (node)

CAP theorem for NoSQL

What the CAP theorem really says:

- If you cannot limit the number of faults and requests can be directed to any server and you insist on serving every request you receive then you cannot possibly be consistent

Eric Brewer 2001

How it is interpreted:

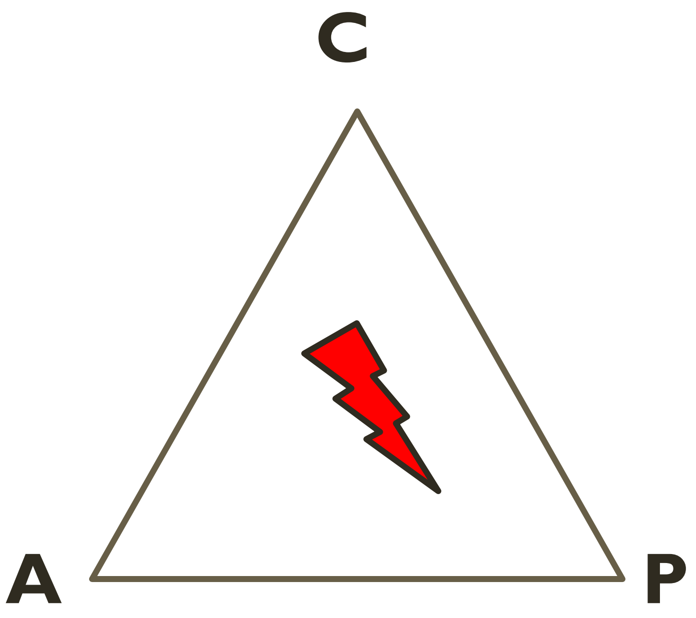
- You must always give something up: consistency, availability or tolerance to failure and reconfiguration

Theory of NOSQL: CAP

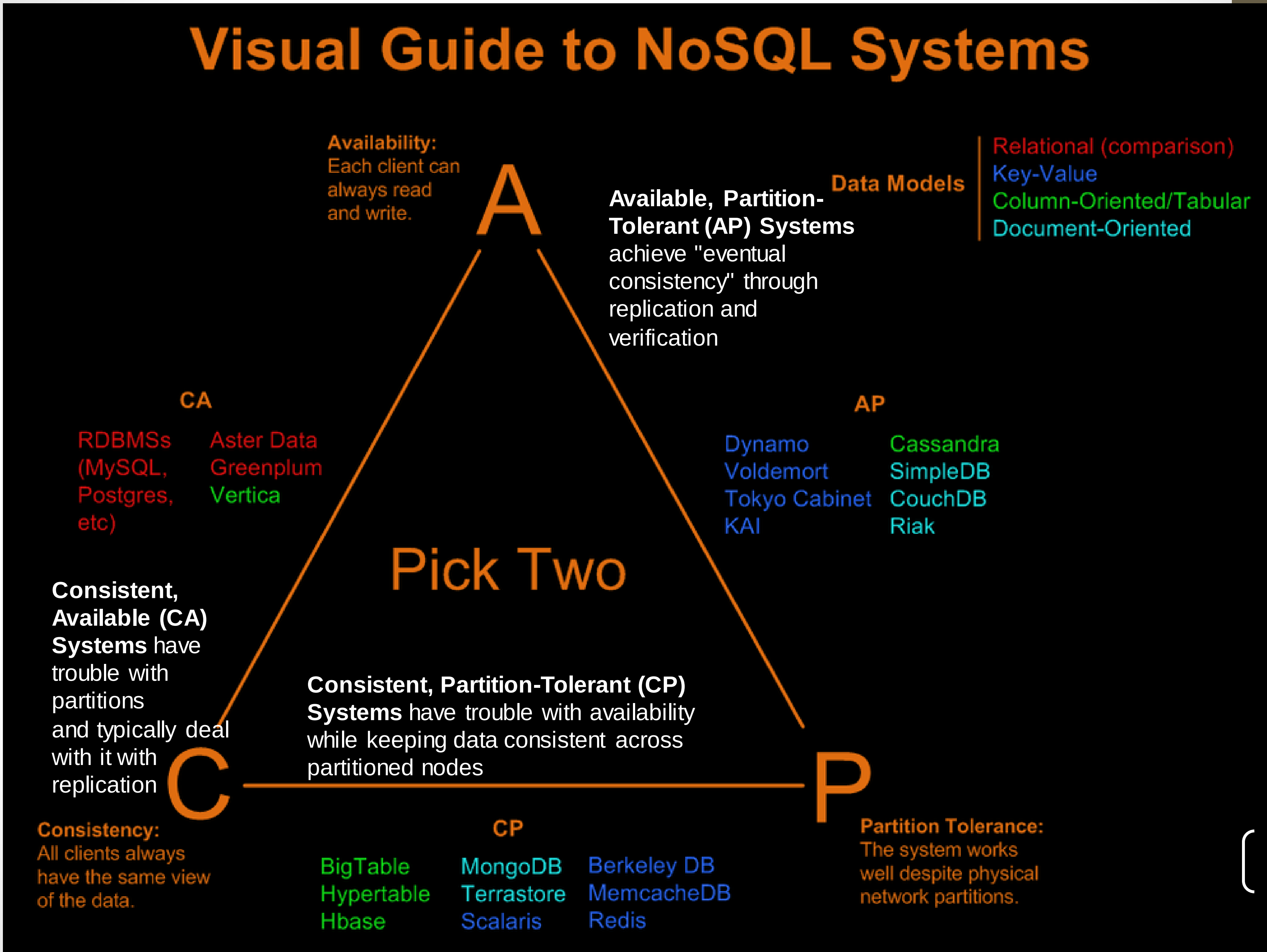
GIVEN:

- Many nodes
- Nodes contain ***replicas of partitions*** of the data

- **C**onsistency
  - All replicas contain the same version of data
  - Client always has the same view of the data (no matter what node)
- **A**vailability
  - System remains operational on failing nodes
  - All clients can always read and write
- **P**artition tolerance
  - multiple entry points
  - System remains operational on system split (communication malfunction)
  - System works well across physical network partitions



CAP Theorem: satisfying all three at the same time is impossible



http://blog.nahurst.com/visual-guide-to-nosql-systems

Sharding of data

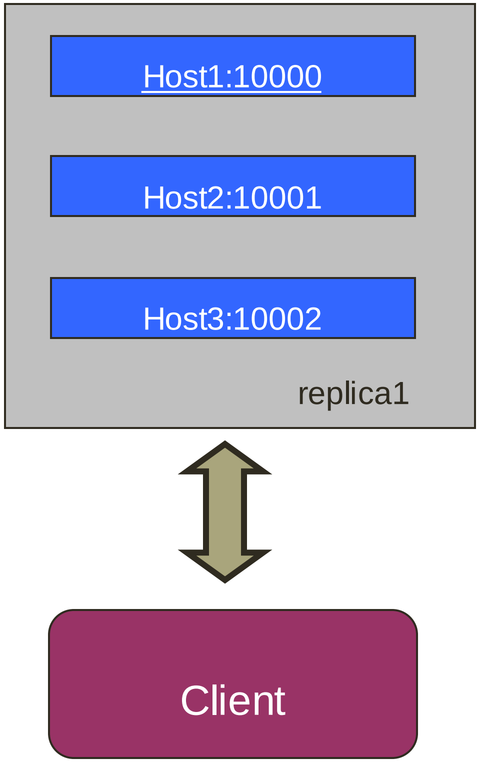
- Distributes a single logical database system across a cluster of machines
- Uses range-based partitioning to distribute documents based on a specific shard key
- Automatically balances the data associated with each shard
- Can be turned on and off per collection (table)

Replica Sets

- Redundancy and Failover
- Zero downtime for upgrades and maintenance

- Master-slave replication
  - Strong Consistency
  - Delayed Consistency

- Geospatial features



How does NoSQL vary from RDBMS?

- Looser schema definition
- Applications written to deal with specific documents/ data
  - Applications aware of the schema definition as opposed to the data
- Designed to handle distributed, large databases
- Trade offs:
  - No strong support for ad hoc queries but designed for speed and growth of database
    - Query language through the API
  - Relaxation of the ACID properties

Benefits of NoSQL

Elastic Scaling

- RDBMS scale up – bigger load , bigger server
- NO SQL scale out – distribute data across multiple hosts seamlessly

DBA Specialists

- RDMS require highly trained expert to monitor DB
- NoSQL require less management, automatic repair and simpler data models

Big Data

- Huge increase in data RDMS: capacity and constraints of data volumes at its limits
- NoSQL designed for big data

Benefits of NoSQL

Flexible data models

- Change management to schema for RDMS have to be carefully managed
- NoSQL databases more relaxed in structure of data
  - Database schema changes do not have to be managed as one complicated change unit
  - Application already written to address an amorphous schema

Economics

- RDMS rely on expensive proprietary servers to manage data
- No SQL: clusters of cheap commodity servers to manage the data and transaction volumes
- Cost per gigabyte or transaction/second for NoSQL can be lower than the cost for a RDBMS

Drawbacks of NoSQL

- Support
  - RDBMS vendors provide a high level of support to clients
    - Stellar reputation
  - NoSQL – are open source projects with startups supporting them
    - Reputation not yet established
- Maturity
  - RDMS mature product: means stable and dependable
    - Also means old no longer cutting edge nor interesting
  - NoSQL are still implementing their basic feature set

Drawbacks of NoSQL

- **Administration**
  - RDMS administrator well defined role
  - No SQL's goal: no administrator necessary however NO SQL still requires effort to maintain
- **Lack of Expertise**
  - Whole workforce of trained and seasoned RDMS developers
  - Still recruiting developers to the NoSQL camp
- **Analytics and Business Intelligence**
  - **RDMS designed to address this niche**
  - NoSQL designed to meet the needs of an Web 2.0 application - not designed for ad hoc query of the data
    - Tools are being developed to address this need

RDB ACID to NoSQL BASE

Atomicity

Consistency

Isolation

Durability

⟺

Basically

Available (CP)

Soft-state
(State of system may change over time)

Eventually consistent
(Asynchronous propagation)

Pritchett, D.: BASE: An Acid Alternative (queue.acm.org/detail.cfm?id=1394128)

First example:

What is MongoDB?

- Developed by 10gen
  - Founded in 2007
- A document-oriented, NoSQL database
  - Hash-based, *schema-less database*
    - No Data Definition Language
    - In practice, this means you can store hashes with any keys and values that you choose
      - Keys are a basic data type but in reality stored as strings
      - Document Identifiers (_id) will be created for each document, field name reserved by system
    - Application tracks the schema and mapping
    - Uses BSON format
      - Based on JSON – B stands for Binary
- Written in C++
- Supports APIs (drivers) in many computer languages
  - JavaScript, Python, Ruby, Perl, Java, Java Scala, C#, C++, Haskell, Erlang

Functionality of MongoDB

- Dynamic schema
  - No DDL
- Document-based database
- Secondary indexes
- Query language via an API
- Atomic writes and fully-consistent reads
  - If system configured that way
- Master-slave replication with automated failover (replica sets)
- Built-in horizontal scaling via automated range-based partitioning of data (sharding)
- No joins nor transactions

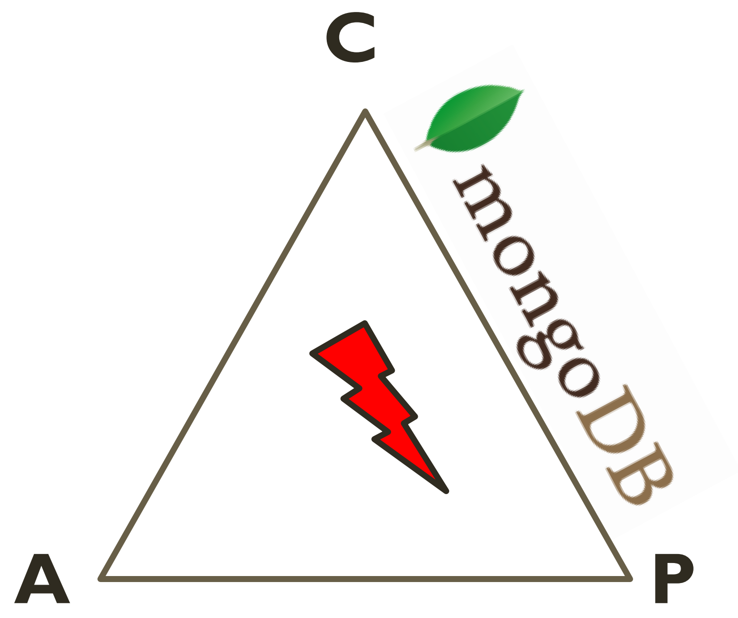
Why use MongoDB?

- Simple queries
- Functionality provided applicable to most web applications
- Easy and fast integration of data
  - No ERD diagram
- Not well suited for heavy and complex transactions systems

MongoDB: CAP approach

Focus on Consistency and Partition tolerance

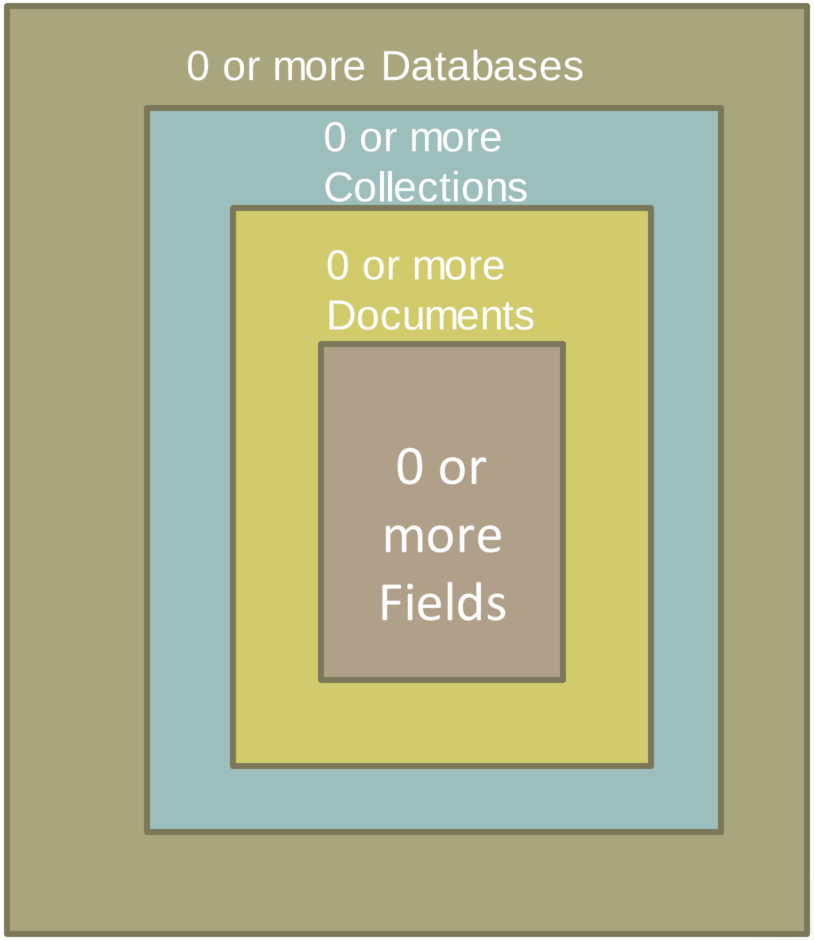
- **C**onsistency
  - all replicas contain the same version of the data
- **A**vailability
  - system remains operational on failing nodes
- **P**artition tolarence
  - multiple entry points
  - system remains operational on system split



CAP Theorem:
satisfying all three at the same time is impossible

MongoDB: Hierarchical Objects

- A MongoDB instance may have zero or more 'databases'
- A database may have zero or more 'collections'.
- A collection may have zero or more 'documents'.
- A document may have one or more 'fields'.
- MongoDB 'Indexes' function much like their RDBMS counterparts.



RDB Concepts to NO SQL

RDBMS		MongoDB
Database	⇨	Database
Table, View	⇨	Collection
Row	⇨	Document (BSON)
Column	⇨	Field
Index	⇨	Index
Join	⇨	Embedded Document
Foreign Key	⇨	Reference
Partition	⇨	Shard

Collection is not strict about what it Stores

Schema-less

Hierarchy is evident in the design

Embedded Document ?

MongoDB Processes and configuration

- Mongod – Database instance
- Mongos - Sharding processes
  - Analogous to a database router.
  - Processes all requests
  - Decides how many and which *mongods* should receive the query
  - *Mongos* collates the results, and sends it back to the client.
- Mongo – an interactive shell (a client)
  - Fully functional JavaScript environment for use with a MongoDB
- You can have one *mongos* for the whole system no matter how many mongods you have
- OR you can have one local *mongos* for every client if you wanted to minimize network latency.

Choices made for Design of MongoDB

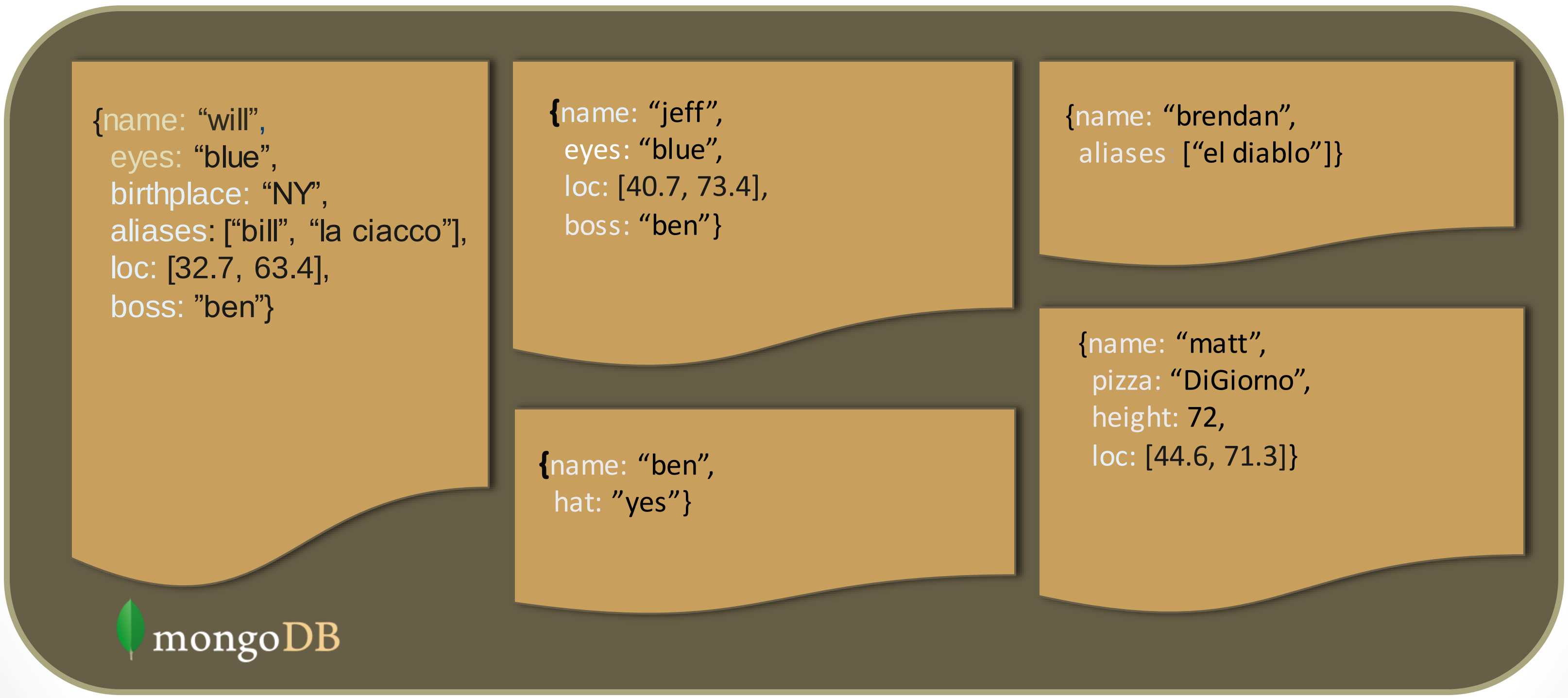
- Scale horizontally over commodity hardware
  - Lots of relatively inexpensive servers
- Keep the functionality that works well in RDBMSs
  - Ad hoc queries
  - Fully featured indexes
  - Secondary indexes
- What doesn’t distribute well in RDB?
  - Long running multi-row transactions
  - Joins
  - Both artifacts of the relational data model (row x column)

BSON format

- Binary-encoded serialization of JSON-like documents
- Zero or more key/value pairs are stored as a single entity
- Each entry consists of a field name, a data type, and a value
- Large elements in a BSON document are prefixed with a length field to facilitate scanning

Schema Free

- MongoDB does not need any pre-defined data schema
- Every document in a collection could have different data
  - Addresses NULL data fields



JSON format

- Data is in name / value pairs
- A name/value pair consists of a field name followed by a colon, followed by a value:
  - Example: “name”: “R2-D2”
- Data is separated by commas
  - Example: “name”: “R2-D2”, race : “Droid”
- Curly braces hold objects
  - Example: {“name”: “R2-D2”, race : “Droid”, affiliation: “rebels”}
- An array is stored in brackets []
  - Example [{“name”: “R2-D2”, race : “Droid”, affiliation: “rebels”},
  - {“name”: “Yoda”, affiliation: “rebels”}]

MongoDB Features

- Document-Oriented storage
- Full Index Support
- Replication & High Availability
- Auto-Sharding
- Querying
- Fast In-Place Updates
- Map/Reduce functionality

Agile

Scalable

Index Functionality

- B+ tree indexes
- An index is automatically created on the _id field (the primary key)
- Users can create other indexes to improve query performance or to enforce Unique values for a particular field
- Supports single field index as well as Compound index
  - Like SQL order of the fields in a compound index matters
  - If you index a field that holds an array value, MongoDB creates separate index entries for *every* element of the array
- Sparse property of an index ensures that the index only contain entries for documents that have the indexed field. (so ignore records that do not have the field defined)
- If an index is both unique and sparse – then the system will reject records that have a duplicate key value but allow records that do not have the indexed field defined

CRUD operations

- Create
  - db.collection.insert(<document>)
  - db.collection.save(<document>)
  - db.collection.update(<query>, <update>, { upsert: true })
- Read
  - db.collection.find(<query>, <projection>)
  - db.collection.findOne(<query>, <projection>)
- Update
  - db.collection.update(<query>, <update>, <options>)
- Delete
  - db.collection.remove(<query>, <justOne>)

Collection specifies the collection or the 'table' to store the document

Create Operations

Db.collection specifies the collection or the ‘table’ to store the document

- db.collection_name.insert(<document>)
  - Omit the _id field to have MongoDB generate a unique key
  - Example db.**parts**.insert({{type: “screwdriver”, quantity: 15 })
  - db.**parts**.insert({_id: 10, type: “hammer”, quantity: 1 })
- db.collection_name.update(<query>, <update>, { upsert: true })
  - Will update 1 or more records in a collection satisfying query
- db.collection_name.save(<document>)
  - Updates an existing record or creates a new record

Read Operations

- db.collection.find(<query>, <projection>).cursor modified
  - Provides functionality similar to the SELECT command
    - <query> where condition , <projection> fields in result set
  - Example: var PartsCursor = db.parts.find({parts: “hammer”}).limit(5)
  - Has cursors 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>)

Query Operators

Name	Description
$eq	Matches value that are equal to a specified value
$gt, $gte	Matches values that are greater than (or equal to a specified value
$lt, $lte	Matches values less than or (equal to) a specified value
$ne	Matches values that are not equal to a specified value
$in	Matches any of the values specified in an array
$nin	Matches none of the values specified in an array
$or	Joins query clauses with a logical OR returns all
$and	Join query clauses with a loginal AND
$not	Inverts the effect of a query expression
$nor	Join query clauses with a logical NOR
$exists	Matches documents that have a specified field

https://docs.mongodb.org/manual/reference/operator/query/

Update Operations

- db.collection_name.insert(<document>)
  - Omit the _id field to have MongoDB generate a unique key
  - Example 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
  - Example: db.parts.remove(type: /^h/ }) - remove all parts starting with h
  - Db.parts.remove() – delete all documents in the parts collections

CRUD examples

```
> db.user.insert({
      first: "John",
      last : "Doe",
      age: 39
})
```

```
> db.user.find ()
{ "_id" : ObjectId("51"),
      "first" : "John",
      "last" : "Doe",
      "age" : 39
}
```

```
> db.user.update(
      {"_id" : ObjectId("51")},
      {
          $set: {
              age: 40,
              salary: 7000}
      }
)
```

```
> db.user.remove({
      "first": /^J/
})
```

SQL vs. Mongo DB entities

My SQL	Mongo DB
START TRANSACTION; INSERT INTO **contacts** VALUES (NULL, ‘joeblow’); INSERT INTO **contact_emails** VALUES (NULL, ”joe@blow.com”, LAST_INSERT_ID()), (NULL, “joseph@blow.com”, LAST_INSERT_ID()); COMMIT;	db.contacts.save({ userName: “joeblow”, emailAddresses: [“joe@blow.com”, “joseph@blow.com”] }); Similar to IDS from the 70’s Bachman’s brainchild DIFFERENCE: MongoDB separates physical structure from logical structure Designed to deal with large &distributed

Aggregated functionality

Aggregation framework provides SQL-like aggregation functionality

- Pipeline documents from a collection pass through an aggregation pipeline, which transforms these objects as they pass through
- Expressions produce output documents based on calculations performed on input documents
- Example db.**parts**.aggregate ({$group : {_id: type, totalquantity : { $sum: quanity} } })

Map reduce functionality

- Performs complex aggregator functions given a collection of keys, value pairs
- Must provide at least a map function, reduction function and a 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> })
- More description of map reduce next lecture

Indexes: High performance read

- Typically used for frequently used queries
- Necessary when the total size of the documents exceeds the amount of available RAM.
- Defined on the collection level
  - Can be defined on 1 or more fields
    - Composite index (SQL) → Compound index (MongoDB)
- B-tree index
- Only 1 index can be used by the query optimizer when retrieving data
- **Index covers a query** - match the *query conditions* **and** return the results using only the index;
  - Use index to provide the results.

Replication of data

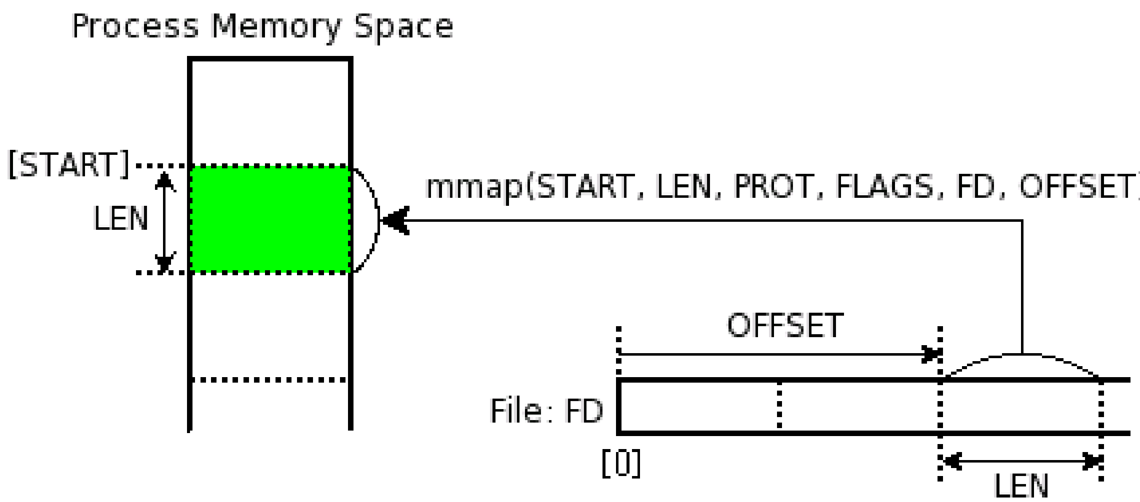
- Ensures redundancy, backup, and automatic failover
  - Recovery manager in the RDMS
- Replication occurs through groups of servers known as replica sets
  - Primary set – set of servers that client tasks direct updates to
  - Secondary set – set of servers used for duplication of data
  - At the most can have 12 replica sets
    - Many different properties can be associated with a secondary set i.e. secondary-only, hidden delayed, arbiters, non-voting
  - If the primary set fails the secondary sets 'vote' to elect the new primary set

Consistency of data

- All read operations issued to the primary of a replica set are consistent with the last write operation
  - 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
  - If clients permit reads from secondary sets – then client may read a previous state of the database
  - Failure occurs before the secondary nodes are updated
    - System identifies when a rollback needs to occur
    - Users are responsible for manually applying rollback changes

Provides Memory Mapped Files

- „A memory-mapped file is a segment of virtual memory which has been assigned a direct byte-for-byte correlation with some portion of a file or file-like resource."[1]
- mmap()



[1]: http://en.wikipedia.org/wiki/Memory-mapped_file

Other additional features

- Supports geospatial data of type
  - Spherical
    - Provides longitude and latitude
  - Flat
    - 2 dimensional points on a plane
  - Geospatial indexes

Interactive session: query through API

C:\windows\system32\cmd.exe - c:\mongodb\bin\mongo

```
connecting to: test
> use learn
switched to db learn
>
> db.unicorns.insert({name: 'Aurora', dob: new Date(1991, 0, 24, 13, 0), loves:
... ['carrot', 'grape'], weight: 450, gender: 'f', vampires: 43});
> b.unicorns.insert({name: 'Unicrom', dob: new Date(1973, 1, 9, 22, 10), loves:
... ['energon', 'redbull'], weight: 984, gender: 'm', vampires: 182});
> db.unicorns.insert({name: 'Roooooodles', dob: new Date(1979, 7, 18, 18, 44),
... loves: ['apple'], weight: 575, gender: 'm', vampires: 99});
> db.unicorns.insert({name: 'Raleigh', dob: new Date(2005, 4, 3, 0, 57), loves:
... ['apple', 'sugar'], weight: 421, gender: 'm', vampires: 2});
> b.unicorns.insert({name: 'Nimue', dob: new Date(1999, 11, 20, 16, 15), loves:
... ['grape', 'carrot'], weight: 540, gender: 'f'});
>
> db.unicorns.find({gender: 'm', weight: {$gt: 700}})
{ "_id" : ObjectId("4f66c2114a3f7341b825b088"), "name" : "Unicrom", "dob" : ISOD
ate("1973-02-10T06:10:00Z"), "loves" : [ "energon", "redbull" ], "weight" : 984,
 "gender" : "m", "vampires" : 182 }
>
> db.unicorns.find({vampires: {$exists: false}})
{ "_id" : ObjectId("4f66c23e4a3f7341b825b08b"), "name" : "Nimue", "dob" : ISODat
e("1999-12-21T00:15:00Z"), "loves" : [ "grape", "carrot" ], "weight" : 540, "gen
der" : "f" }
>
> db.unicorns.find({gender: 'f', $or: [{loves: 'apple'}, {loves: 'orange'}, {
... weight: {$lt: 500}}]})
{ "_id" : ObjectId("4f66c2114a3f7341b825b087"), "name" : "Aurora", "dob" : ISODa
te("1991-01-24T21:00:00Z"), "loves" : [ "carrot", "grape" ], "weight" : 450, "ge
nder" : "f", "vampires" : 43 }
>
```

Summary

- NoSQL built to address a distributed database system
  - Sharding
  - Replica sets of data
- CAP Theorem: consistency, availability and partition tolerant
- MongoDB
  - Document oriented data, schema-less database, supports secondary indexes, provides a query language, consistent reads on primary sets
  - Lacks transactions, joins

Limited BNF of a BSON document

document	::=	int32 e_list "\x00"	BSON Document
e_list	::=	element e_list	Sequence of elements
element	::=	"\x01" e_name data type	Specific data type
e_name	::=	cstring	Key name
string	::=	int32 (byte*) "\x00"	String
cstring	::=	(byte*) "\x00"	CString
binary	::=	int32 subtype (byte*)	Binary
subtype	::=	"\x00"	Binary / Generic
	|	"\x01"	Function
	|	"\x02"	Binary (Old)
	|	"\x03"	UUID (Old)
	|	"\x04"	UUID
	|	"\x05"	MD5
	|	"\x80"	User defined
code_w_s	::=	int32 string document	Code w/ scope