JSON stores

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Motivation

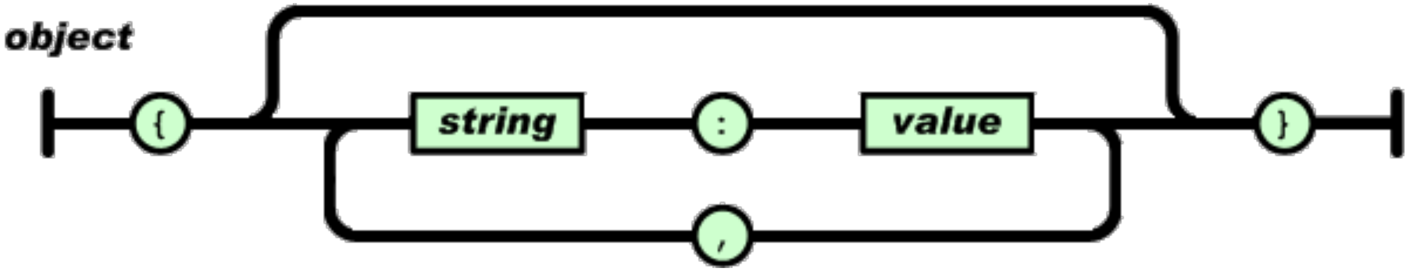
- JSON (JavaScript Object Notation) allows to describe nested, potentially heterogeneous data
  - Very flexible
  - Thus, a good idea for NoSQL!
- Less verbose than XML

Sample JSON document: Twitter

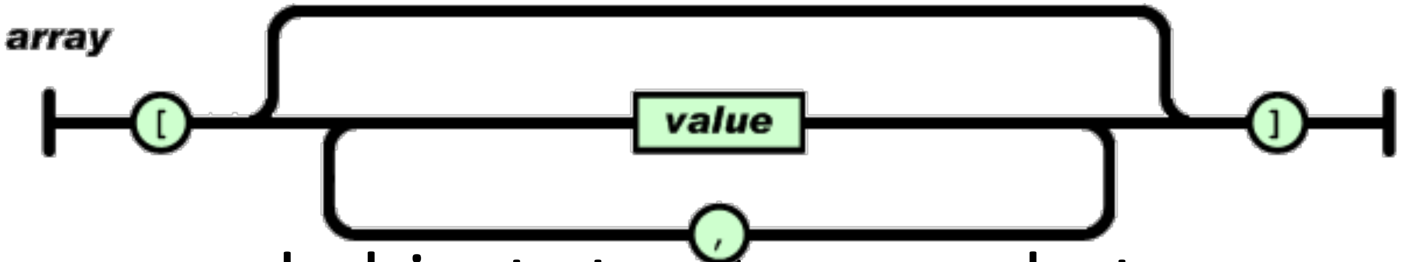
```
{ "results":[
     {"text":"@twitterapi  http://tinyurl.com/ctrefg",
     "to_user_id":396524,
     "to_user":"TwitterAPI",
     "from_user":"jkoum",
     "metadata":     {"result_type":"popular", "recent_retweets": 109 },
     "id":1478555574,
     "from_user_id":1833773,
     "iso_language_code":"nl",
     "source":"twitter< /a>",
     "profile_image_url":http://s3.amazonaws.com/twitter/a155_b_normal.jpg,
     "created_at":"Wed, 08 Apr 2009 19:22:10 +0000"},
     ... truncated ...],
    "refresh_url":"?since_id=1480307926&q=%40twitterapi",
    "results_per_page":15,
    "next_page":"?page=2&max_id=1480307926&q=%40twitterapi",
    "completed_in":0.031704,
    "page":1,
    "query":"%40twitterapi"}
}
```

JSON document structure

- Object: collection of (name, value) pairs



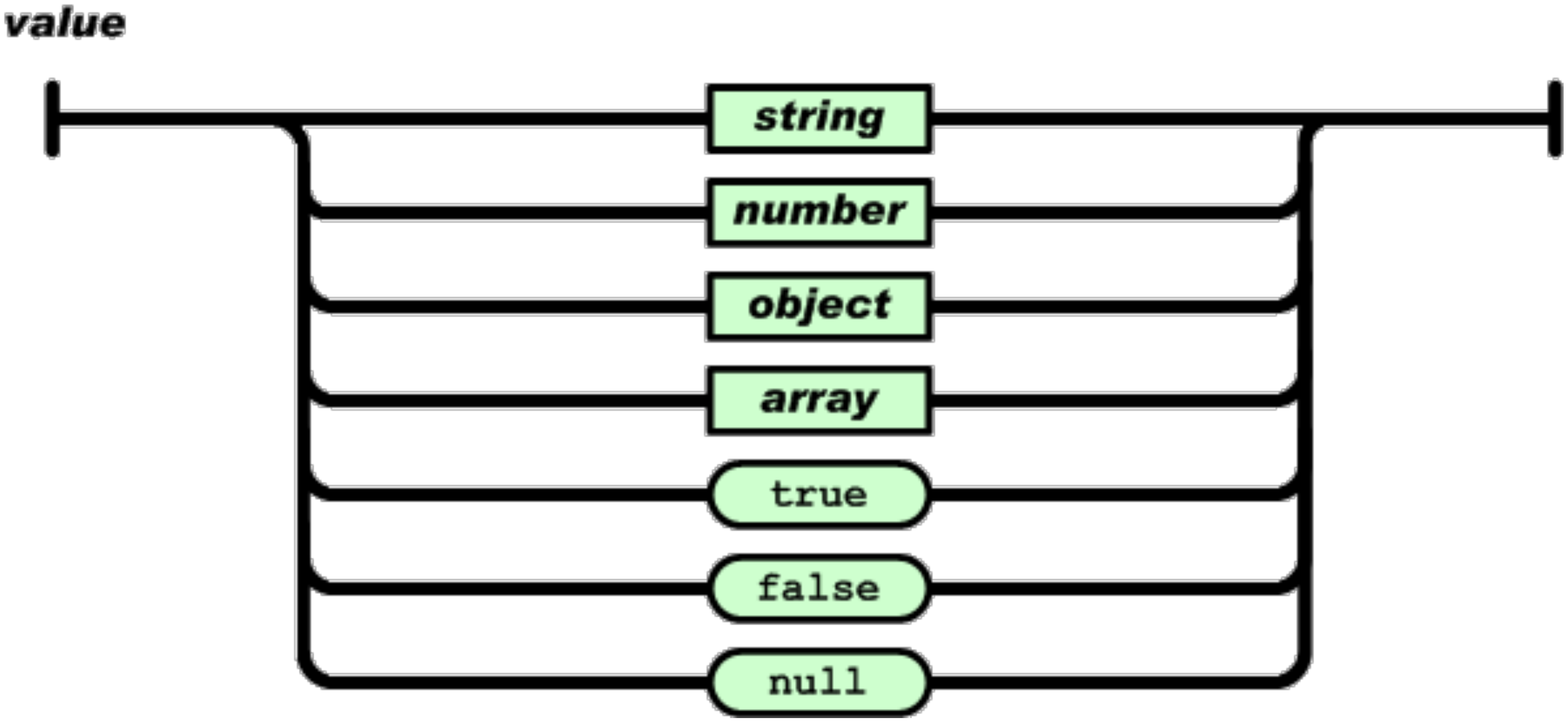
- Array: collection of values



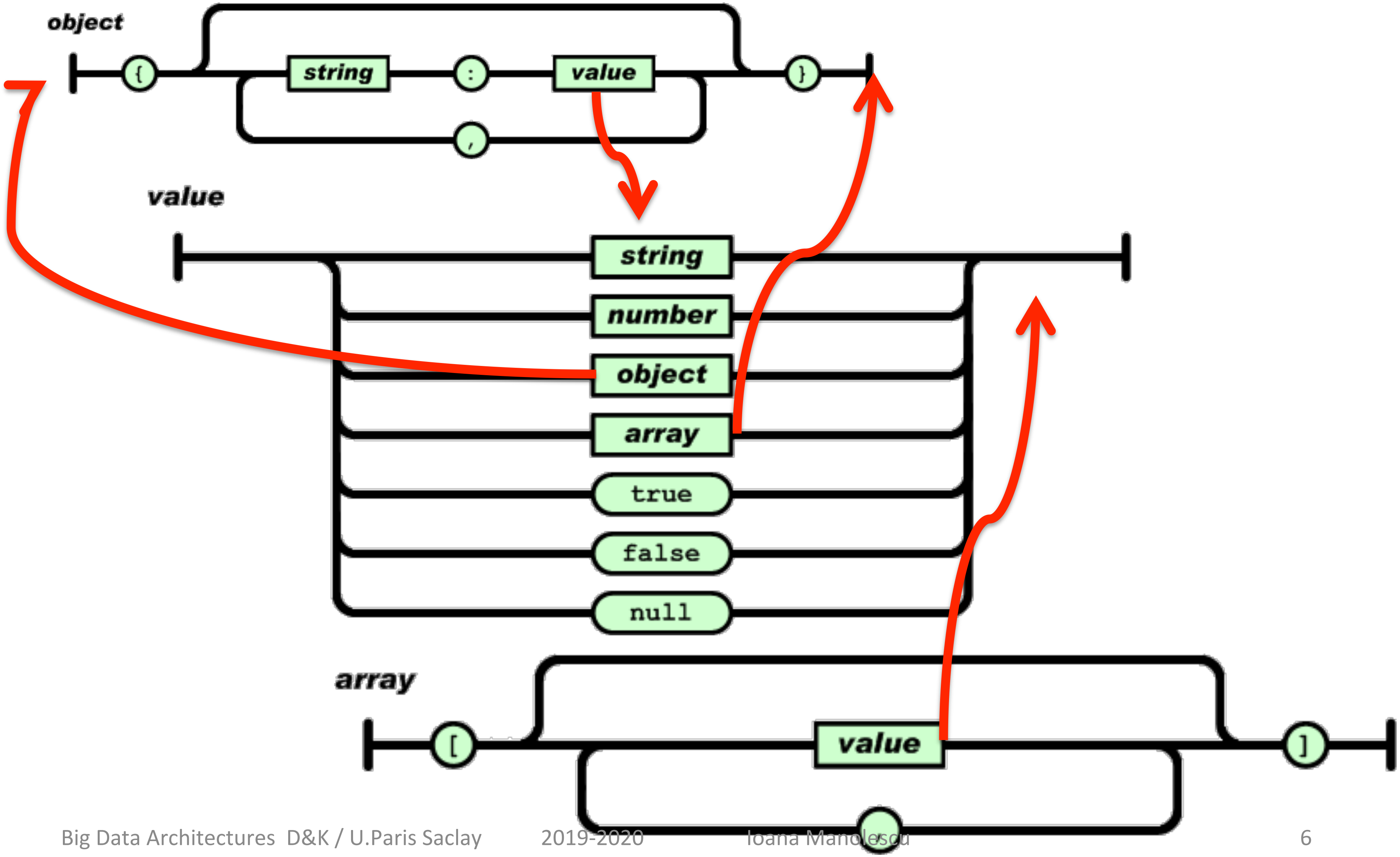
- Arrays and object structure are hetegeneous (no schema)

JSON document structure

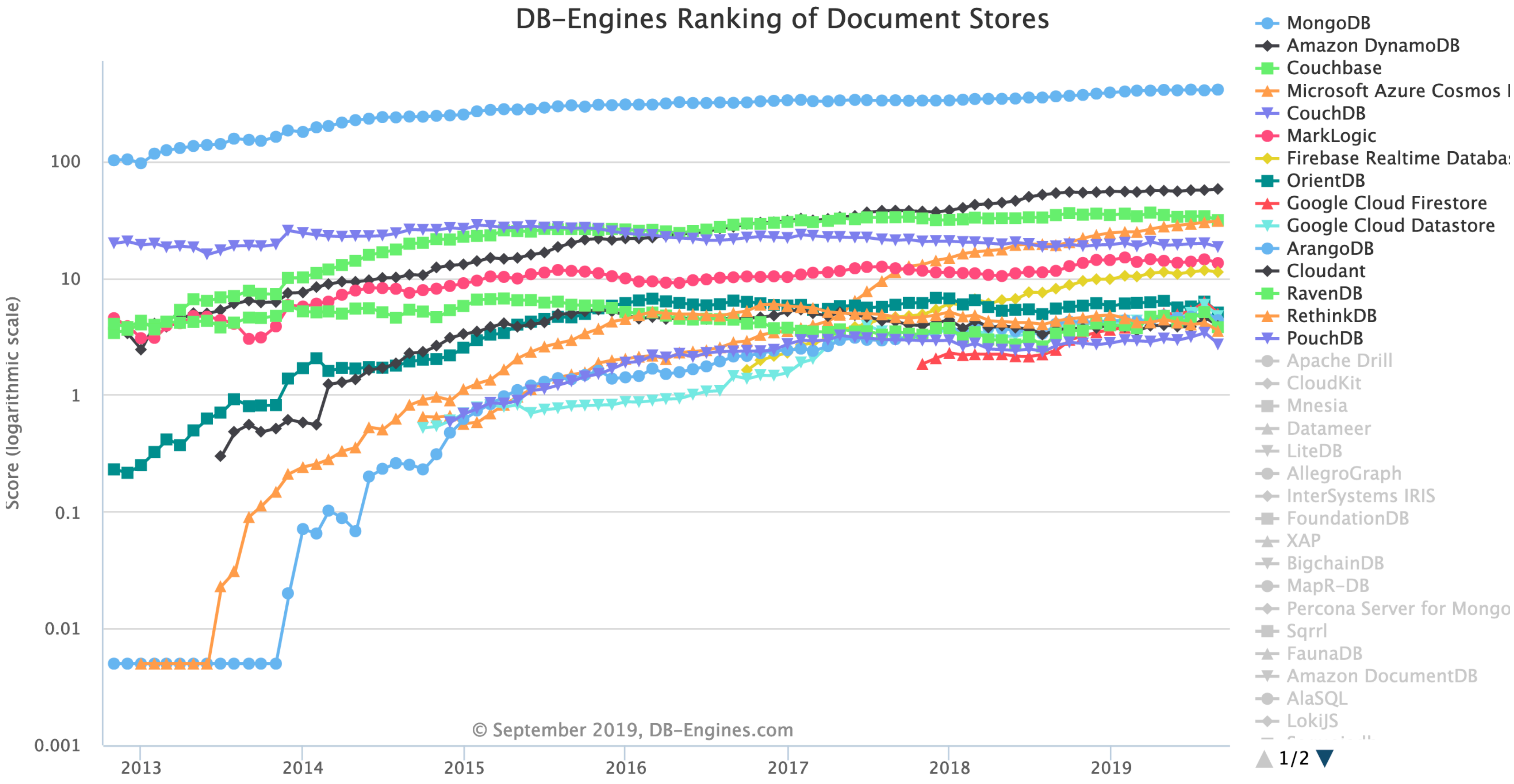
- Values (allow nesting):



JSON document structure



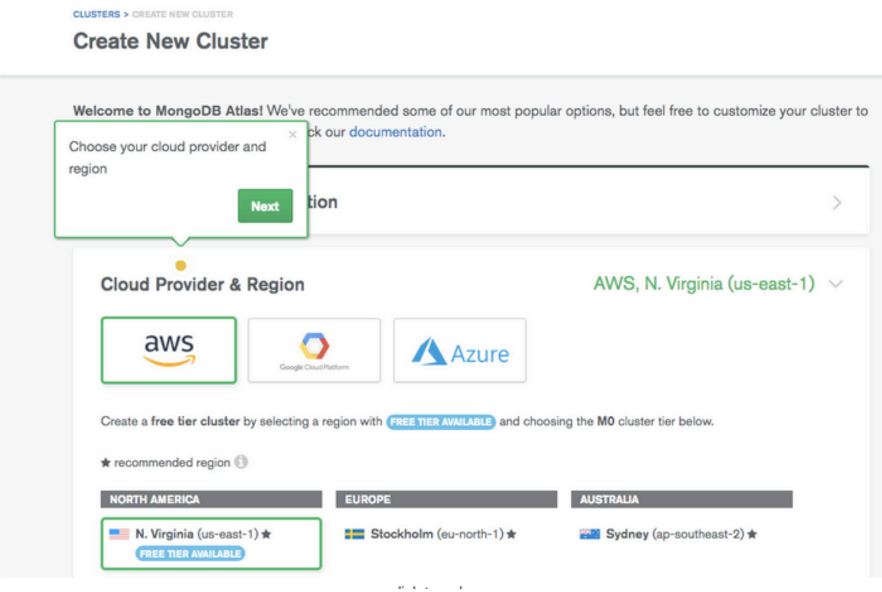
MongoDB: a JSON document store



Computed based on: popularity in search engine results, queries, job offers, social networks, questions on StackOverflow…

MongoDB tools

- MongoDB **server (mongod)**
  - Installed on top of an operating system (e.g., on a PC); assumes a file system and regular OS support
  - Accessed through (potentially concurrent) clients (mongo)
- MongoDB **Atlas** (or **cloud** edition)
  - Meant to deploy easily in the cloud (e.g. Amazon, Google, Azure...)
  - Assumes the respective cloud infrastructure services
- Other MongoDB tools:
  - Data lake
  - Charts to generate reporting images
  - Compass to visualize the data
  - Spark connector



CLUSTERS > CREATE NEW CLUSTER

Create New Cluster

Welcome to MongoDB Atlas! We've recommended some of our most popular options, but feel free to customize your cluster to ck our documentation.

Choose your cloud provider and region

Cloud Provider & Region: AWS, N. Virginia (us-east-1)

Create a **free tier cluster** by selecting a region with FREE TIER AVAILABLE and choosing the **M0** cluster tier below.

★ recommended region

NORTH AMERICA	EUROPE	AUSTRALIA
N. Virginia (us-east-1) ★ FREE TIER AVAILABLE	Stockholm (eu-north-1) ★	Sydney (ap-southeast-2) ★

MongoDB server

- The server data can be:
  - Replicated
    - Several identical copies of the same data
  - Partitioned (sharded)
    - Distributed across the machines of a cluster in order to take advantage of the storage and processing capacity
- Document processing
  - Selective access, or
  - Map-Reduce mode

MongoDB storage organization

- **Documents** are stored in **collections** (which may have **indexes**)
- Collections are part of **databases**

```
> mongo myExample              // Creates the database myExample
> db.towns.insert({            // Creates the collection towns
   name: "New York",           // and inserts a document into it
   population: 22200000,
   last_census: ISODate("2009-07-31"),
   famous_for: [ "statue of liberty", "food" ],
   mayor : {
      name : "Michael Bloomberg”,
      party : "I”
   }
}
```

MongoDB object IDs

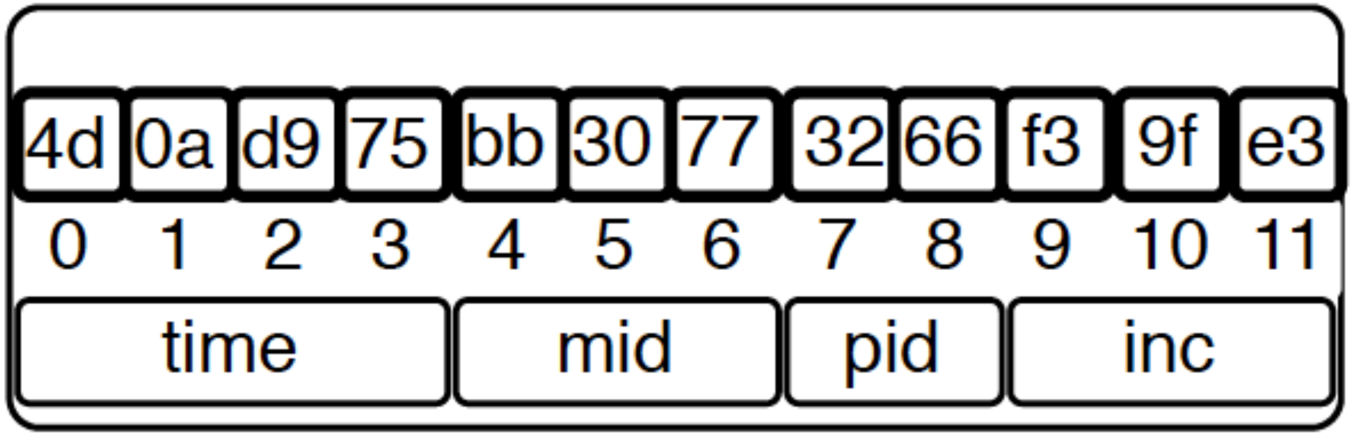
```
> db.towns.find()
{
    "_id" : ObjectId("4d0ad975bb30773266f39fe3"),
    "name" : "New York",
    "population": 22200000,
    "last_census": "Fri Jul 31 2009 00:00:00 GMT-0700
    (PDT)",
    "famous_for" : [ "statue of liberty", "food" ],
    "mayor" : { "name" : "Michael Bloomberg", "party" : "I" }
}
```

_id is implicitly added by the system

Each object ID is different

MongoDB object IDs

12 bytes:



4d	0a	d9	75	bb	30	77	32	66	f3	9f	e3
0	1	2	3	4	5	6	7	8	9	10	11
time				mid			pid		inc		

Timestamp; client machine ID; process ID; incremented counter

→

IDs are unique across machines and databases

MongoDB: information about data

It is possible to ask questions about objects, functions etc.

```
> typeof db
object
> typeof db.towns
object
> typeof db.towns.insert
function
```

MongoDB: Operations

- Can find meta-informations about data (e.g., type)
- Allows CRUD operations:
  - Insert / **C**reate
  - Query / **R**ead
  - **U**pdate
  - **D**elete

MongoDB: getting information about data

Calling a function with no parentheses shows the function code

```
db.towns.insert
   function (obj, _allow_dot) {
      if (!obj) { throw "no object passed to insert!"; }
      if (!_allow_dot) {  this._validateForStorage(obj); }
      if (typeof obj._id == "undefined") {
         var tmp = obj;
         obj = {_id:new ObjectId};
         for (var key in tmp) { obj[key] = tmp[key];}
      }
      this._mongo.insert(this._fullName, obj);
      this._lastID = obj._id;
   }
```

Working with (JavaScript) functions

Typing this into the client shell registers the function:

```
function insertCity(name, population, last_census,
                                   famous_for, mayor_info) {
    db.towns.insert(  {name:name, population:population,
                          last_census: ISODate(last_census),
                       famous_for:famous_for,
                        mayor : mayor_info}
                   );
}
```

Object implicitly created

Working with functions

Calling the function previously defined:

```
insertCity("Punxsutawney", 6200,
'2008-31-01',
["phil the groundhog"],{name:"Jim Wehrle" })
```

Array *Object*

```
insertCity("Portland", 582000, '2007-20-09’,
["beer", "food"],
{ name : "Sam Adams", party : "D" }  )
```

db.towns.find() returns three objects

Searching a MongoDB collection

```
db.towns.find({ "_id" :
ObjectId("4d0ada1fbb30773266f39fe4") })
```

returns the full object

```
db.towns.find({"_id" :
ObjectId("4d0ada1fbb30773266f39fe4") },
{ name : 1 })
    {
      "_id" : ObjectId("4d0ada1fbb30773266f39fe4"),
     "name" : "Punxsutawney"
    }
```

This is called a projection operator

The _id field is the only one always returned by default (unless excluded, see next)

Using exclusion in MongoDB projections

To exclude an attribute from a result, **set it to 0** in the find parameter

```
db.towns.find({ _id :
ObjectId("4d0ada1fbb30773266f39fe4") }, { name : 0 })
{
   "_id" : ObjectId("4d0ada1fbb30773266f39fe4"),
   "population" : 6200,
   "last_census" : "Thu Jan 31 2008 00:00:00 GMT-0800
(PST)",
   "famous_for" : [ "phil the groundhog" ]
}
```

A projection *cannot* contain *both* include and exclude specifications, except for the exclusion of the _id field.
In projections that *explicitly include* fields, only _id can be *excluded*.

More search patterns

```
db.towns.find(
    { name : /^P/, population : { $lt : 10000 } },
      //selection
    { name : 1, population : 1 })
      // projection
→
{"name" : "Punxsutawney", "population" : 6200 }

db.towns.find(
{ last_census : { $lte : ISODate('2008-31-01') } },
{ _id : 0, name: 1 })
→
{ "name" : "Punxsutawney" }
{ "name" : "Portland" }
```

Searching in nested structures

```
db.towns.find(
    { famous_for : "food" },
    { _id : 0, name : 1, famous_for : 1 })
→
{ "name" : "New York", "famous_for" : [ "statue of
liberty", "food" ] }
{ "name" : "Portland", "famous_for" : [ "beer", "food" ] }

db.towns.find(
    { famous_for : { $all : ["food", "beer"] } },
    { _id : 0, name:1, famous_for:1 )
→
    { "name" : "Portland", "famous_for" : [ "beer",
"food" ] }
```

$all matches an array containing all the specified values

Searching in nested structures

Nodes which *must not* have a match of the search condition:

```
db.towns.find(
    { famous_for : { $nin : ["food", "beer"] } },
    { _id : 0, name : 1, famous_for : 1 })
→
    { "name" : "Punxsutawney",
      "famous_for" : [ "phil the groundhog" ] }
```

Paths in conditions:

```
db.towns.find( { "mayor.party" : "I" }, { _id : 0, name : 1,
mayor : 1 })
→
{"name" : "New York",
  "mayor" : { "name" : "Michael Bloomberg", "party" : "I"}
}
```

Searching in nested structures

Countries that export **bacon and tasty food**:

```
db.countries.find(
 { "exports.foods.name" : "bacon",
   "exports.foods.tasty" : true }, { _id : 0, name : 1 } )
```

Countries that export **tasty bacon**:

```
db.countries.find(
   {"exports.foods" : { $elemMatch : { name : "bacon",
                                       tasty : true} } },
   { _id : 0, name : 1 } )
```

Matched by:

```
   {_id : "us", name : "United States",
    exports : { foods : [ { name : "bacon", tasty : true },
                          { name : "burgers" } ]}
   }
```

More search operators

- **$regex**: matches PCRE-compliant regexes within /... /
- PCRE: Perl-Compatible Regular Expressions
- **$ne, $lt, $lte, $gt, $gte**: arithmetics
- **$exists, $all, $in, $nin, $or, $nor, $not**: logical operators
- **$elemMatch**
- **$size**: matches array of given size
- **$type**: matches if field is of a given type

MongoDB updates

```
db.towns.update(
{ _id: ObjectID("4d0ada87bb30773266f39fe5") },
{ $set : { "state" : "OR" } } );
```

// updates state

```
db.towns.update(
{ _id: ObjectID("4d0ada87bb30773266f39fe5") },
{ { "state" : "OR" } } );
```

// replaces **the whole document**!

```
db.towns.delete(
{ _id: ObjectID("4d0ada87bb30773266f39fe5") })
```

// deletes the document

More operators used in updates

- **$set**, **$unset** (removes the field)
- **$inc** (increments)
- **$pop**, **$push**, **$pushall** for arrays
- **$addToSet** like push but avoids duplicates
- **$pull** removes a matching value from an array
- **$pullAll** removes all matching values

Other Operations: Aggregation

- **Aggregation** : can be applied as part of a pipeline consisting of several stages

```
db.collection.aggregate( [ { <stage> }, ... ] )
```

```
db.orders.aggregate([
    { $match: { status: "A" } },
    { $group: { _id: "$cust_id", total: { $sum: "$amount" } } }
 ]
)
```

Match stage

Aggregation stage

Combining information from several documents (1/3)

MongoDB is mostly document (collection)-oriented

- Ideally, data which should be used together is stored in the same document(s)

To **combine** data from several documents, several options:

1. Manual references: store the ID of a document within another:

```
original_id = ObjectId()
db.places.insert({ "_id": original_id,
                   "name": "Broadway Center",
                   "url": "bc.example.net" })
db.people.insert({ "name": "Erin",
                   "places_id": original_id,
                    "url": "bc.example.net/Erin" })
```

Combining information from several documents (2/3)

2. Use a **DBRef** (JSON object with "standard" attribute names). This is recognized as a pointer to another document:

```
{ "$ref" : <value>, "$id" : <value>, "$db" : <value> }
```

- "$ref" points to the collection
- "$id" points to the document
- "$db" points to the database

```
{ "_id" : ObjectId("5126bbf64aed4daf9e2ab771"),     // ..
  "creator" : { "$ref" : "creators",
                "$id" :  ObjectId("5126bc054aed4daf9e2ab772"),
                "$db" : "users" } }
```

Recognized in some language drivers, not in all

E.g. Java, Python, Perl, PHP OK

E.g. C, C++, Scala: not supported (as of 4.2)

Combining information from several documents (3/3)

Another way to combine data from several documents is a **lookup stage in a pipeline**.

A **$lookup** stage implements a *left-outer join,* where one can filter documents from an input collection based on another collection

Syntax of a lookup stage:

```
{
 $lookup: { from: <collection to join>,
                  localField: <field from the input documents>,
                  foreignField: <field from the documents of
                                         the "from" collection>,
                   as: <output array field> } }
}
```

Lookups performs an **equality match** between localField and foreignField

Lookups outputs the documents **from the local collection** that survived the join (left outer join semantics)

Global processing with custom code

One can define a JS function and run it

```
db.towns.find(
    ( function() { return this.population >
60000;} );
```

// runs the function over all the towns

Fails if one town has no population!

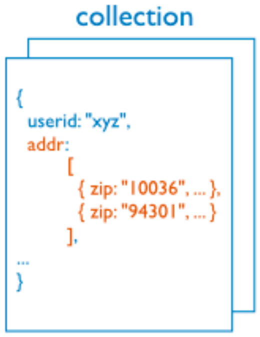
Contrast with XML/XQuery
"OK for extra, not OK for missing"

Indexing MongoDB data

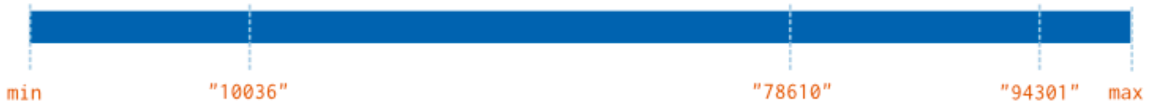
Indexes can be built on a collection calling collection.**createIndex**({attr…})

1. **B-trees** for exact and inequality search
   - May be built on a single attribute (simple) or several attributes (compound)
   - Collection.createIndex({"name": 1}) ; *// for ascending order, otherwise use -1*
   - B-tree index automatically built on _id

2. **Multikey indexes** allow indexing on an array attribute
   - Built by default when one requires the indexing of an array attribute



```
{
  userid: "xyz",
  addr:
      [
        { zip: "10036", ... },
        { zip: "94301", ... }
      ],
  ...
}
```



{ "addr.zip": 1 } Index

Indexing MongoDB data

3 **Geospatial indexes**: **2d** (planar geometry based on x,y), **2d sphere** (latitude, longitude)

- Operator: **$near, $nearsphere** (coordinates) returns the top k closest documents to the given coordinates
- Operators: **$geoWithin**, **$geoIntersects** (JSON rectangle)

4 **Text indexing** for full-text search

```
db.reviews.createIndex( { comments: "text" } )
db.collection.createIndex( { "$**": "text" } )
```

Inspect indexes: db.system.indexes.find()

Searching with and w/o an index

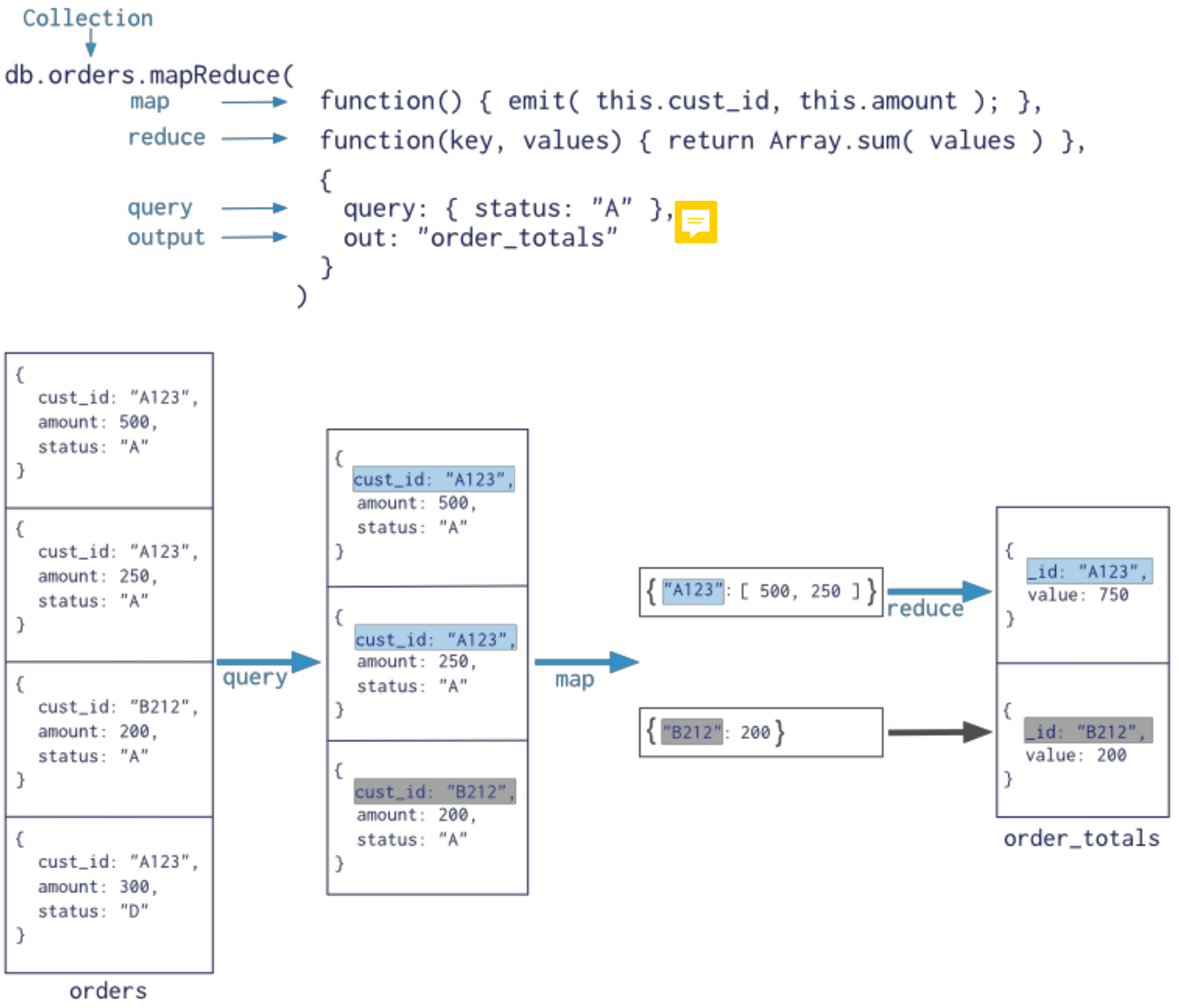
Without an index:

```
db.phones.find({display:
"+1800-5650001"})
.explain()

{"cursor" : "BasicCursor",
 "nscanned" : 109999,
 "nscannedObjects" :
  109999,
 "n" : 1,
 "millis" : 52,
 "indexBounds" : { }
}
```

With an index on display:

```
db.phones.find({ display:
"+1800-5650001" }).
explain()

{"cursor" : "BtreeCursor
display_1",
  "nscanned" : 1,
  "nscannedObjects" : 1,
  "n" : 1,
  "millis" : 0,
  "indexBounds" : {
  "display" : [ [ "+1 800-5650001",
"+1 800-5650001" ] ] }
}
```

MapReduce processing



```
db.orders.mapReduce(
           function() { emit( this.cust_id, this.amount ); },
           function(key, values) { return Array.sum( values ) },
           {
             query: { status: "A" },
             out: "order_totals"
           }
)
```

```
{
  cust_id: "A123",
  amount: 500,
  status: "A"
}
{
  cust_id: "A123",
  amount: 250,
  status: "A"
}
{
  cust_id: "B212",
  amount: 200,
  status: "A"
}
{
  cust_id: "A123",
  amount: 300,
  status: "D"
}
```

```
{
  cust_id: "A123",
  amount: 500,
  status: "A"
}
{
  cust_id: "A123",
  amount: 250,
  status: "A"
}
{
  cust_id: "B212",
  amount: 200,
  status: "A"
}
```

```
{"A123": [ 500, 250 ]}
{"B212": 200}
```

```
{
  _id: "A123",
  value: 750
}
{
  _id: "B212",
  value: 200
}
```

Execution order:

1. Query
2. Map
3. Reduce
4. [finalize] to wrap up reducer results, e.g. to take the max among all
5. [output]

Replica sets

Duplication (replication) to prevent against server failure and data loss

Example (three servers): mkdir ./mongo1 ./mongo2 ./mongo3

Create replication set:

```
mongod --replSet book --dbpath ./mongo1 --port 27011 –rest
mongod --replSet book --dbpath ./mongo2 --port 27012 --rest
mongod --replSet book --dbpath ./mongo3 --port 27013 –rest
```

Then in one of the servers initialize replication set:

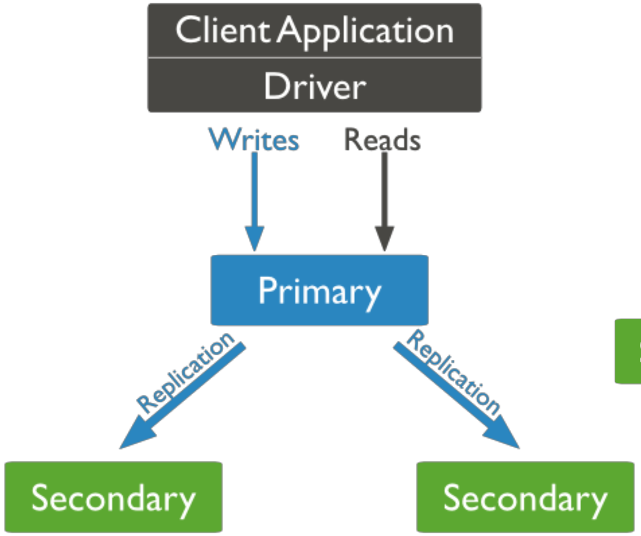
```
mongo localhost:27011
> rs.initiate({_id: 'book',
                    members: [ {_id: 1, host: 'localhost:27011'},
                               {_id: 2, host: 'localhost:27012'},
                               {_id: 3, host: 'localhost:27013'} ] })
```

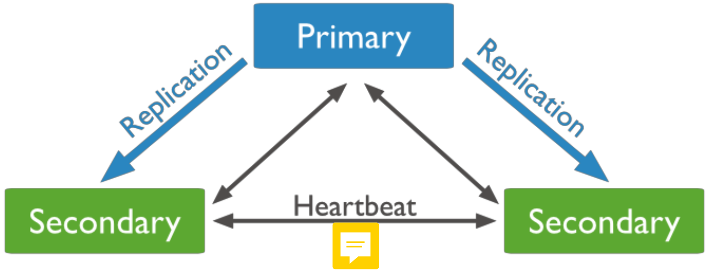
Then one server will output [rs Manager] replSet PRIMARY
while two will output [rs sync] replSet SECONDARY

Replica sets in MongoDB

The servers held a vote to determine who is the master (primary); the two others are replicas ("secondary")

By default, applications *read/write through the primary*, who pushes updates to secondary servers



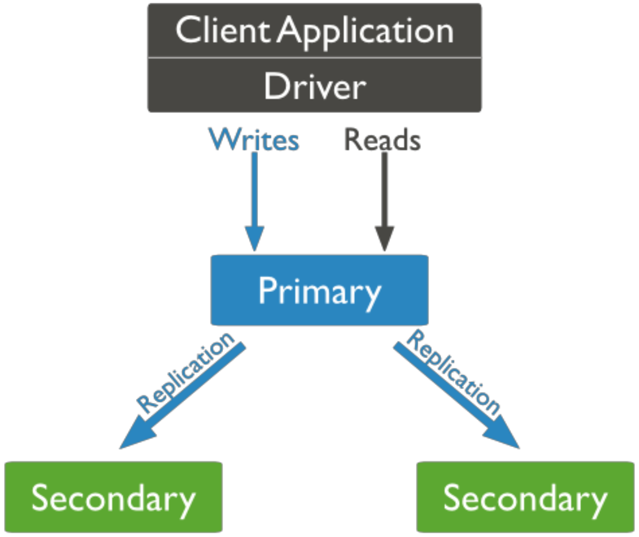


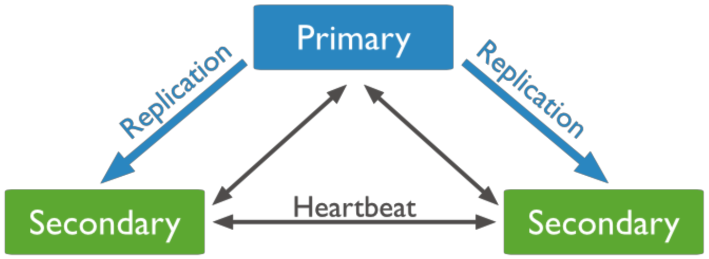
If the master is considered dead, there are new elections

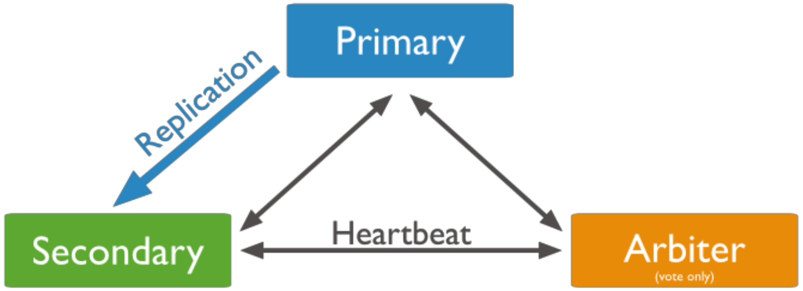
- *Only succeed if more than half of the original replication set votes*
- Operations attempted on a demoted (dead) master are lost
- *A write is considered successful only if > half of the replicas "saw" it*

Replica sets

By default, write to the primary, who pushes updates to secondary servers







MongoDB recommends an *odd number of servers in a replica set*, to allow a majority in case of network failure. One arbiter may be added to the replica set

- Strong consistency on read
- Resistence to some partitioning

MongoDB sharding

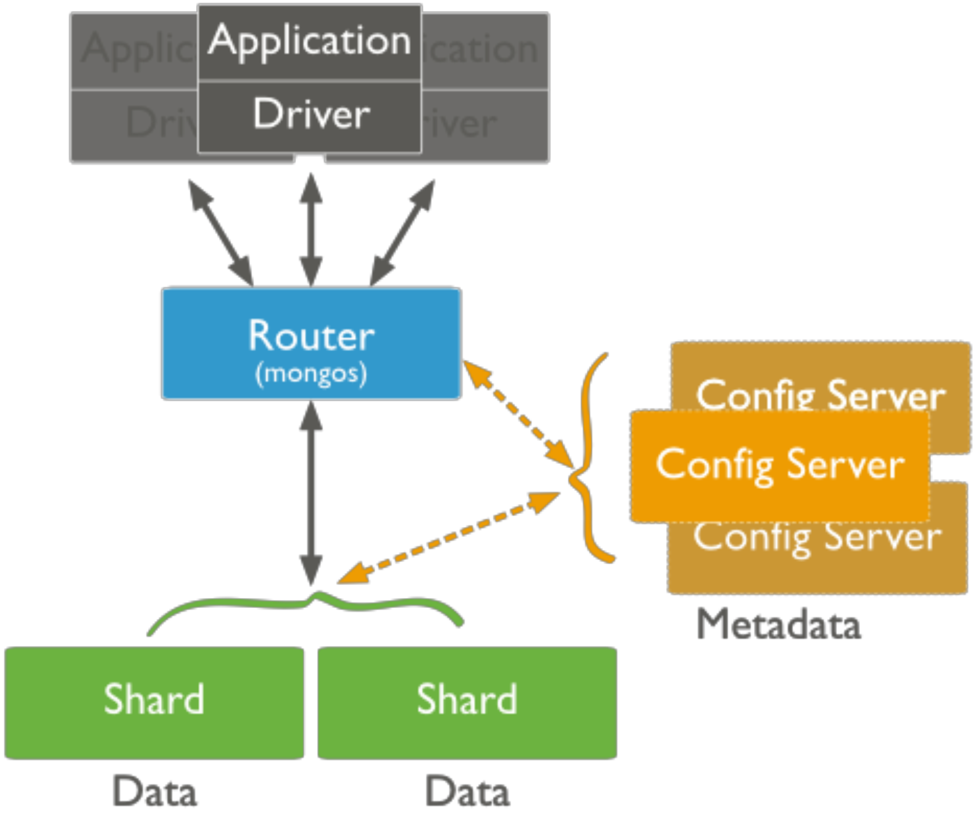
Sharding = partitioning

1 shard = 1 fragment

- To distribute a very large collection across several servers

Sharding is logically *on top of replication*

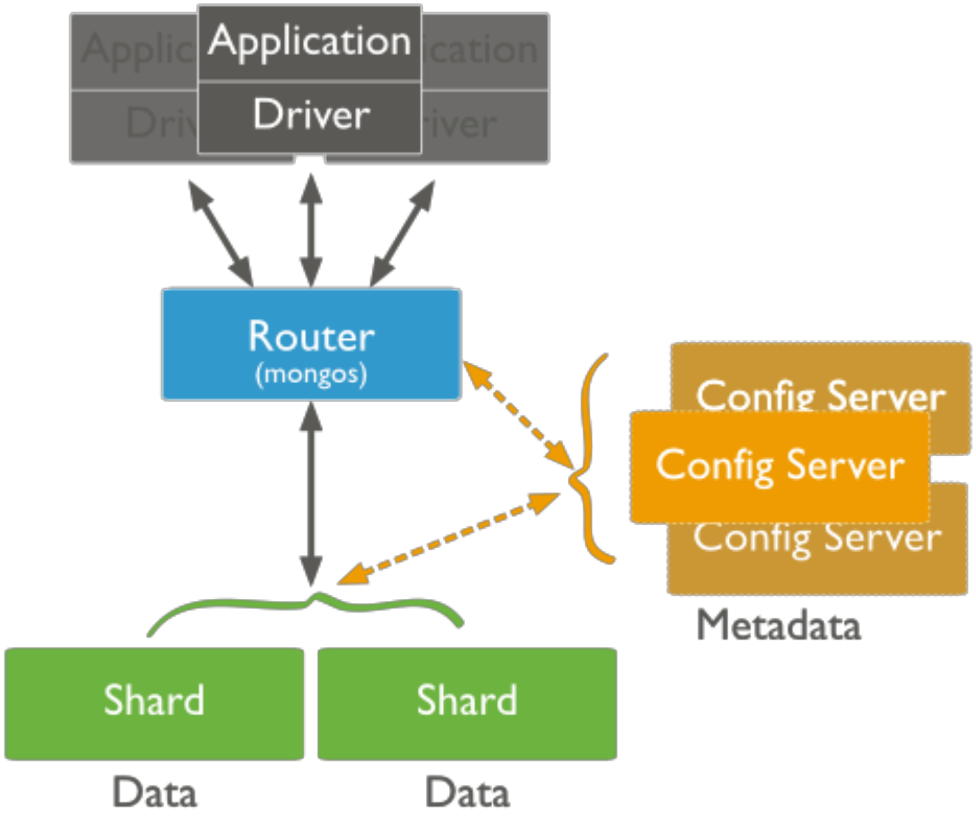
- Each shard server may participate to a replica set



MongoDB sharding

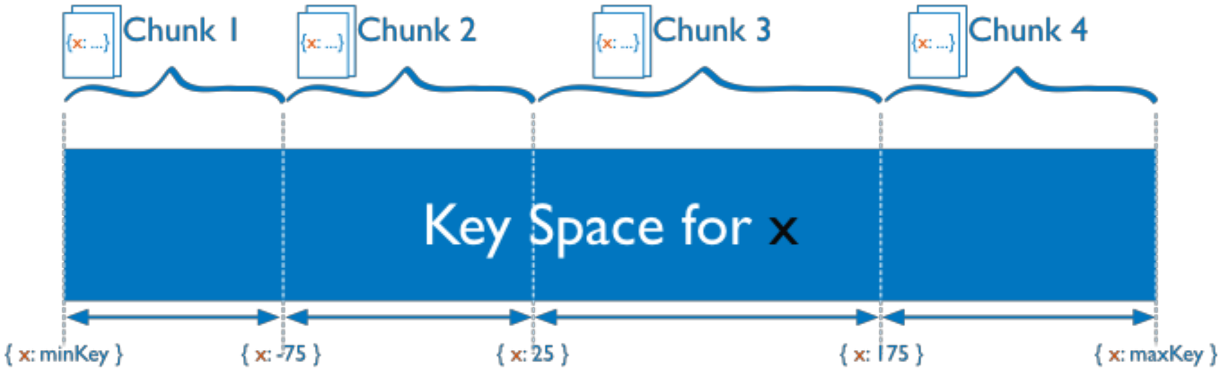
Roles:

- **Shard** (shard server): stores a collection fragment
- **Config server(s)**: store(s) information on which shard has what (~ catalog)
- **Single point of entry**: mongos



MongoDB sharding

- A data collection is partitioned into chunks based on the value of a shard key
- Each chunk covers a key range



- 1 shard = a set of chunks
- Mongos routes writes to the appropriate chunk based on the shard key value
- Chunks are split when they grow beynd a fixed chunk size (64 MB default, can be split)
- MongoDB migrates chunks across shards for load balancing

MongoDB sharding

// starting the shard servers:

```
mkdir ./mongo4 ./mongo5
mongod --shardsvr --dbpath ./mongo4 --port 27014
mongod --shardsvr --dbpath ./mongo5 --port 27015
```

// starting the config server:

```
mkdir ./mongoconfig
mongod --configsvr --dbpath ./mongoconfig --port 27016
```

// starting mongos connected to the config

```
mongos --configdb localhost:27016 --chunkSize 1 --port 27020
```

// talking to mongos to configure sharding:

```
mongo localhost:27020/admin
> db.runCommand( { addshard : "localhost:27014" } ) -> { "shardAdded" :
"shard0000", "ok" : 1 }
> db.runCommand( { addshard : "localhost:27015" } ) -> { "shardAdded" :
"shard0001", "ok" : 1 }
> db.runCommand({ enablesharding: "test"}) -> { "ok" : 1 }
> db.runCommand( { shardcollection : "test.cities", key : {name : 1} } ) //
{ "collectionsharded" : "test.cities", "ok" : 1 }
```

Another JSON store: CouchDB

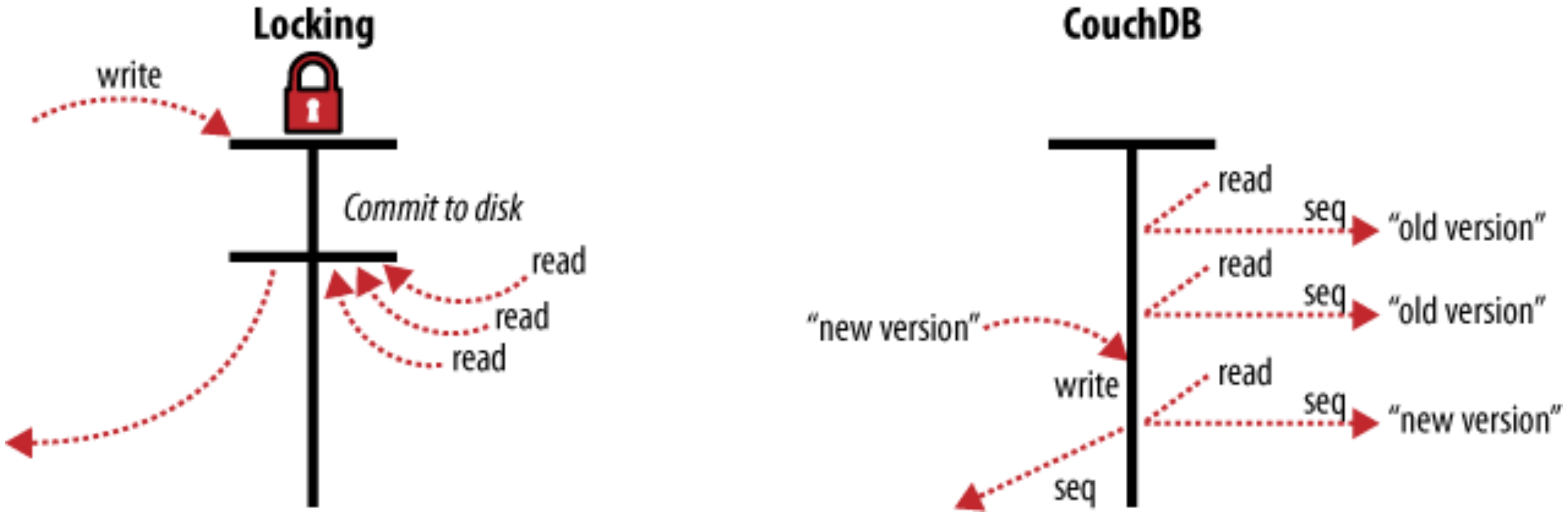
http://db-engines.com/en/system/CouchDB%3BMongoDB

Feature	CouchDB	MongoDB
Since	2005	2009
Ranking	#23 overall, #2 document store	#4 overall, #1 document store
From	Apache Software	MongoDB Inc
APIs and other access methods	RESTful HTTP/JSON API	proprietary protocol using JSON
Replication methods	Master-master replication Master-slave replication	Master-slave replication
MapReduce	yes	yes
Consistency concepts	Eventual Consistency	Eventual Consistency Immediate Consistency
Foreign keys	no	no

More document stores: http://db-engines.com/en/ranking_trend/document+store

Concurrency control in CouchDB

- Update granularity = document
- To change a document's attribute, rewrite the document!
- Multi-Version Concurrency Control: some requests may return "old" versions but they each return a version that was valid at some point



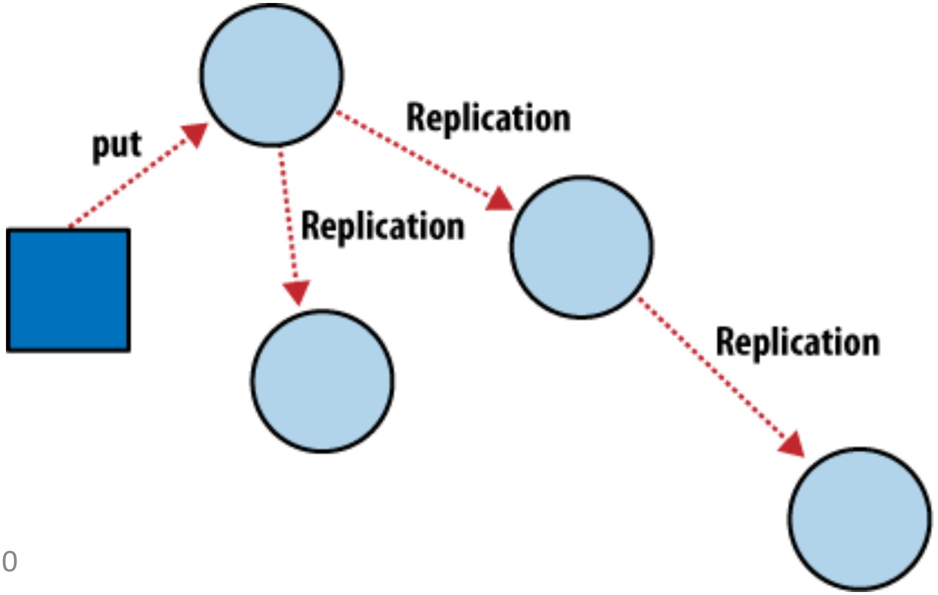
Synchronization in CouchDB

Each server can work independently

Incremental replication can be set to run in the background

Synchronization is on demand between any pair of servers

Diverging changes are flagged as **conflicts**; conflict resolution policy must be specified. One document version wins, the other is considered older.



Conclusion: JSON stores

- **JSON**: extremely popular data interchange format
- **MongoDB**: (by far) most popular JSON data management system
- **MongoDB query language**:
  – Rich matching within one document
  – This is declarative.
  – Pipeline processing for more complex operations
  – Non-declarative
- MongoDB **replication:**
  – replica group, voting, quorum
- MongoDB **distribution**: sharding

- Other JSON stores:
  – Amazon DynamoDB (also serves as K-V store)
  – CouchDB