Data Management using

mongoDB®

Outline

1. Introduction to MongoDB
2. Insert and Update API
3. Query API
4. Collection Modeling
5. Aggregation Queries
6. Database Scalability Solutions
7. MongoDb Sharding & Replication

Introduction to

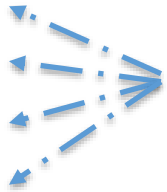
What is MongoDB?

- MongoDB is an open-source **Document Oriented Database**
  - Uses a document data model: Stores data as JSON documents (instead of rows and columns as done in a relational database)
  - Arrange documents in collections (documents can vary in structure)
    - with dynamic schemas (schemaless)
  - API to query and manage documents

- Better alternative data management solution for Web applications compared to using a Relational Database

Document

```
{
  "isbn" : "123",
  "title": "Mr Bean and the Forty Thieves",
  "category": "Fun",
  "pages": 250
  "authors": ["Mr Bean", "Juha Dahak"],
  "publisher": {
               "name": "MrBeanCo",
               "country": "UK“
               }
}
```



property : value

property : array

property : document

- **Document = JSON** object
- **Document = set of key-value pairs**
- **Basic unit of data** in MongoDB
- Analogous to **row** in a relational database

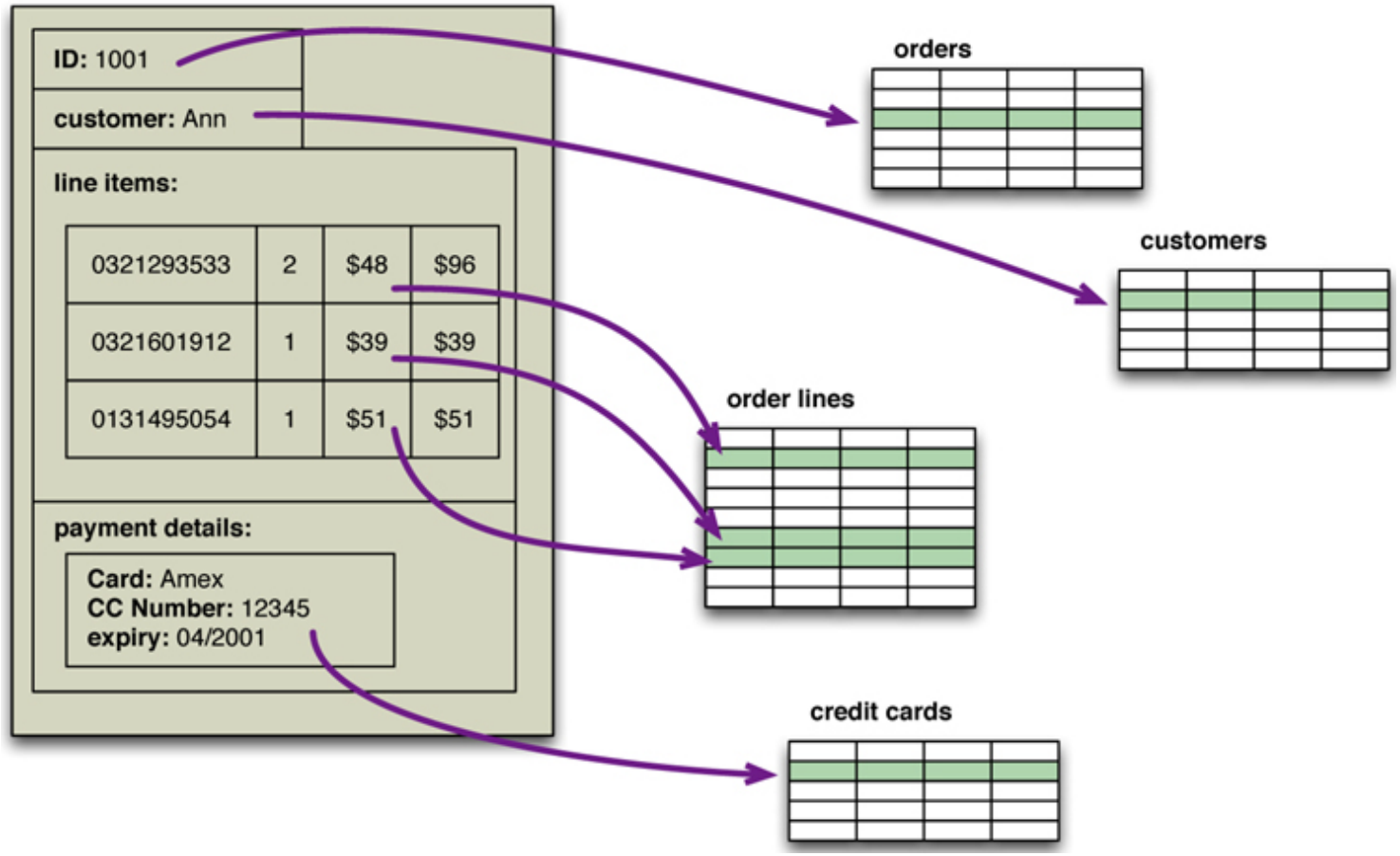
Document Data Model

Relational

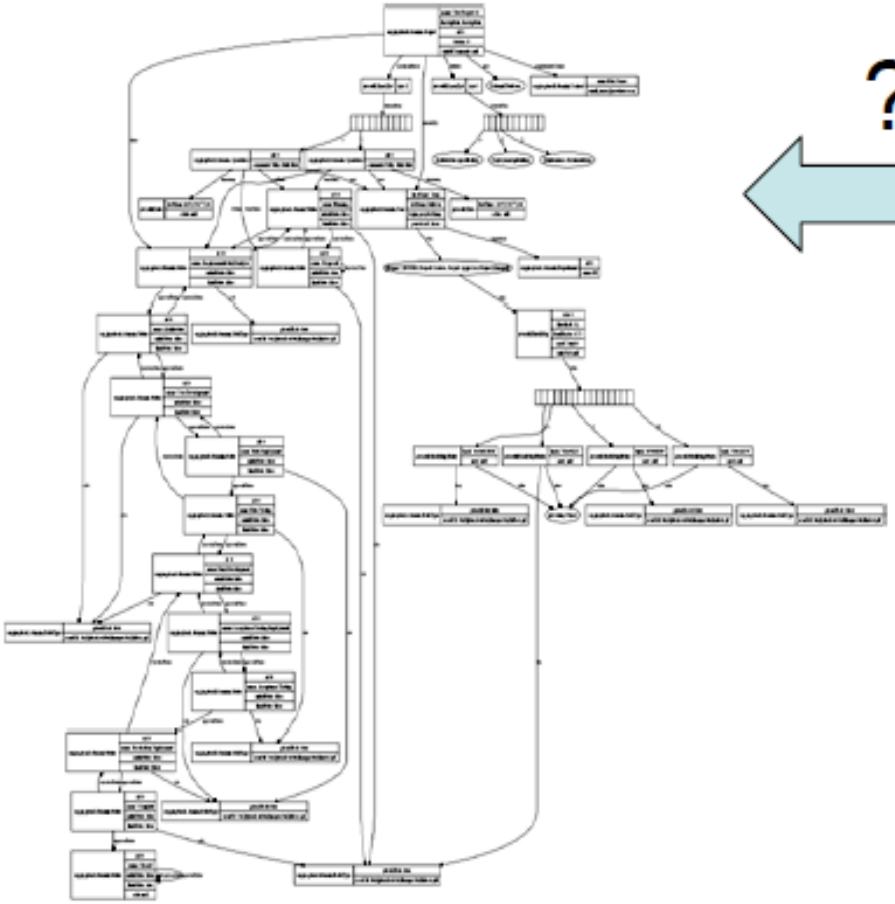
MongoDB

```
{
  first_name: 'Paul',
  surname: 'Miller',
  city: 'London',
  location:
[45.123,47.232],
  cars: [
    { model: 'Bentley',
      year: 1973,
      value: 100000, … },
    { model: 'Rolls Royce',
      year: 1965,
      value: 330000, … }
  ]
}
```

Reduces the Impedance mismatch between the relational model and the in-memory data structures



Avoids - Complex object graphs need to be Mapped to the Relational Model



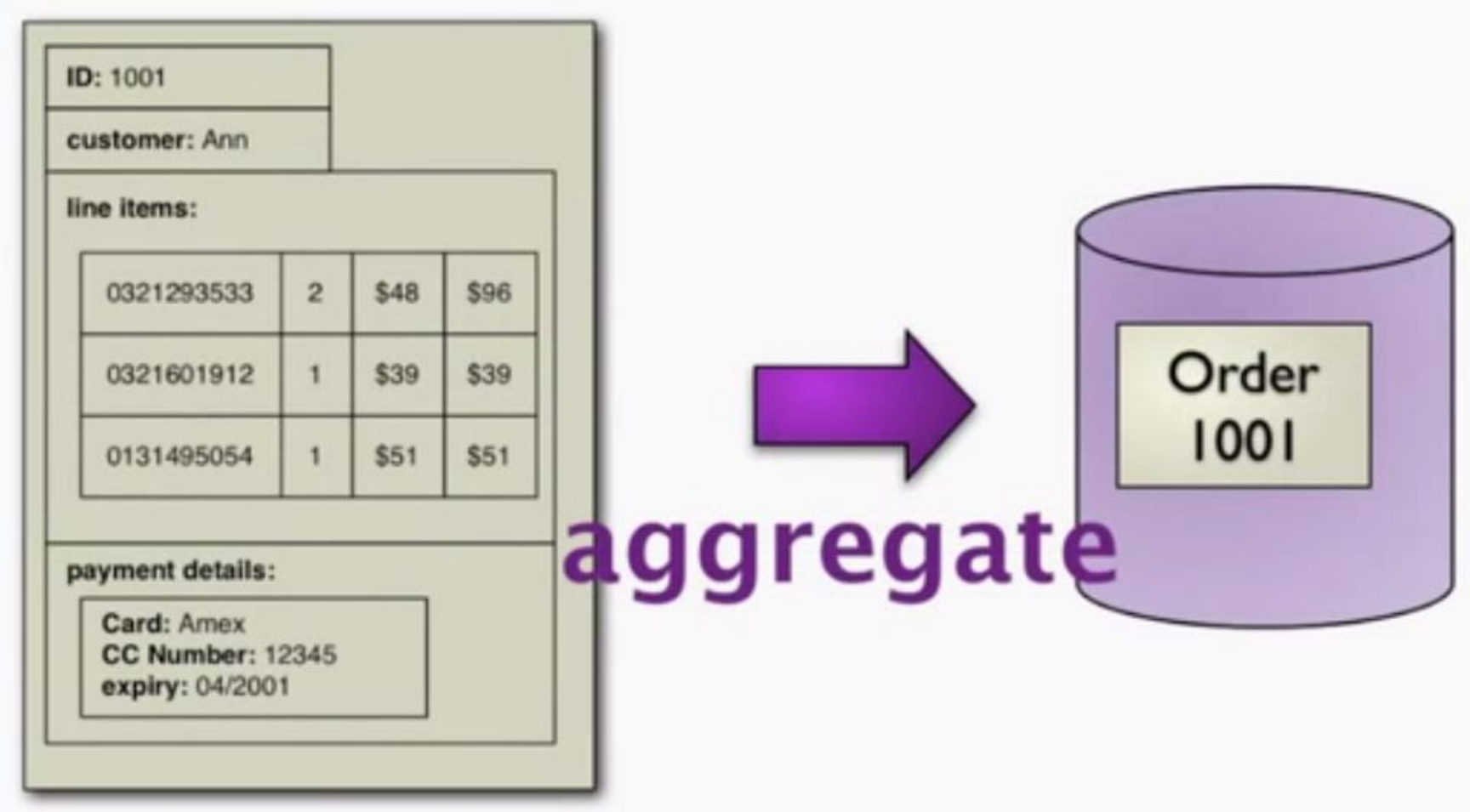
?!

ID	COL1	COL2	COL...

Poor performance

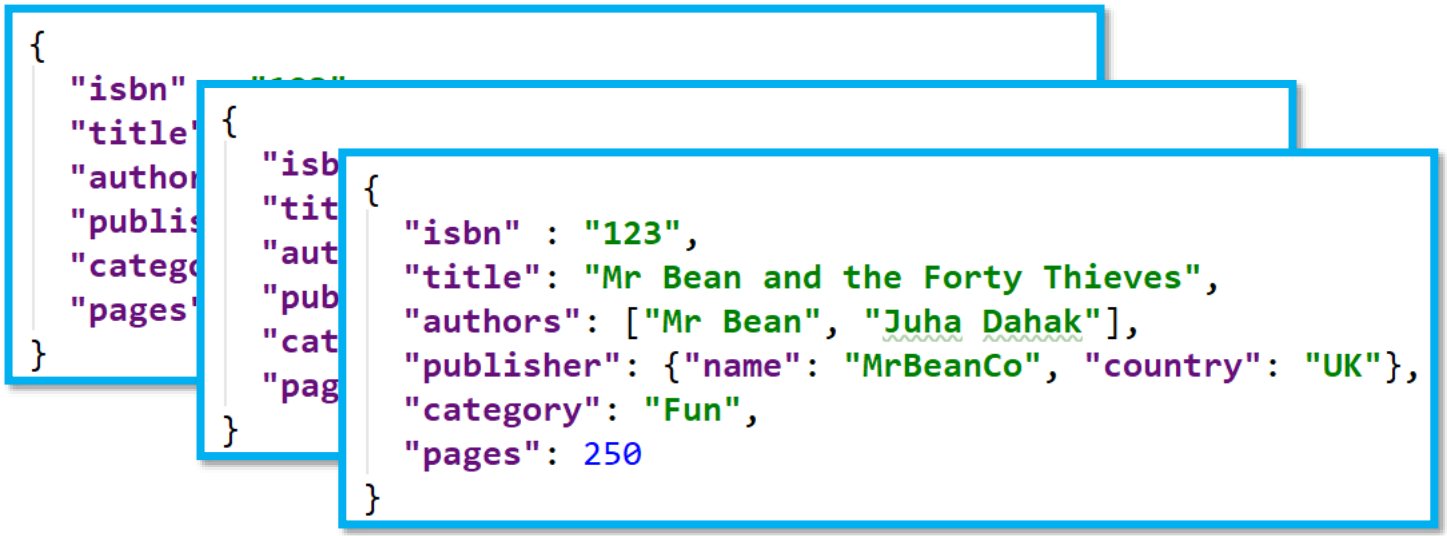
- Many inserts
- Many joins

Aggregate-Oriented



- Aggregate brings **cluster friendliness** as a whole aggregate can be stored in one node of the cluster

Collection



- **Collection = Group** of documents
  - Analogous to **table** in a relational database
  - **Does not enforce** a schema
  - Documents in a collection usually **have similar purpose** but they may have slightly different schema

Naming conventions

- Here are some good **naming conventions**:
  - Database name is singular camelCase ending with DB e.g., bannerDB
  - Collections are lowercase plural e..g., students
  - Document fields: lowerCamelCase, e.g. firstName, age

Insert and Update API

CRUD

- **C**reate
  - db.collection.insert(<document>)
  - db.collection.save(<document>)
  - db.collection.update(<query>, <update>, { upsert: true })
- **R**ead
  - db.collection.find(<query>, <projection>)
  - db.collection.findOne(<query>, <projection>)
- **U**pdate
  - db.collection.update(<query>, <update>, <options>)
- **D**elete
  - db.collection.remove(<query>, <justOne>)

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/
})
```

Examples

In RDBMS

```
CREATE TABLE users (
    id MEDIUMINT NOT NULL
        AUTO_INCREMENT,
    user_id Varchar(30),
    age Number,
    status char(1),
    PRIMARY KEY (id)
)
```

```
DROP TABLE users
```

In MongoDB

Either insert the 1st document

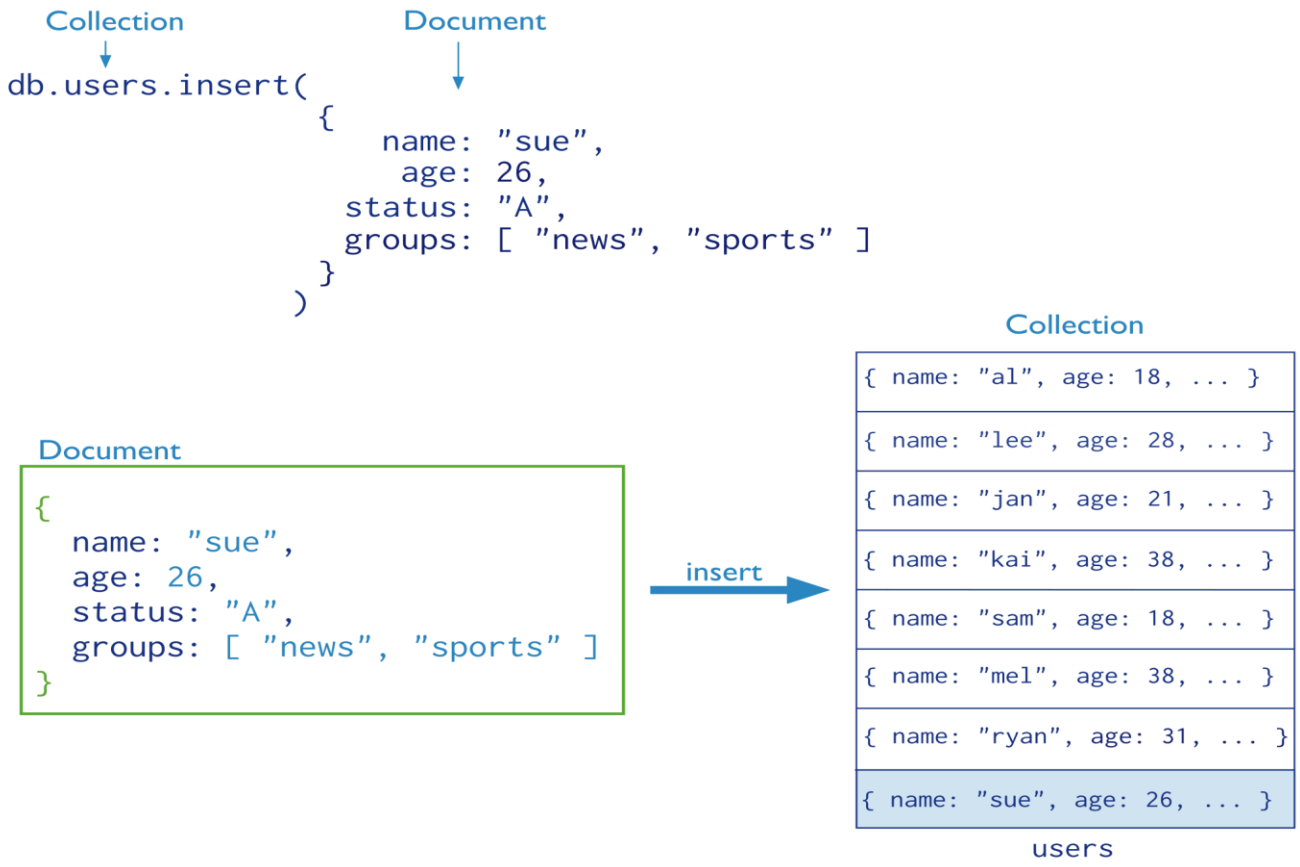
```
db.users.insert( {
    user_id: "abc123",
    age: 55,
    status: "A"
} )
```

Or create "Users" collection explicitly

```
db.createCollection("users")
```

```
db.users.drop()
```

Insertion



- The collection “users” is created automatically if it does not exist

Multi-Document Insertion (Use of Arrays)

```
var mydocuments =
    [
      {
        item: "ABC2",
        details: { model: "14Q3", manufacturer: "M1 Corporation" },
        stock: [ { size: "M", qty: 50 } ],
        category: "clothing"
      },
      {
        item: "MNO2",
        details: { model: "14Q3", manufacturer: "ABC Company" },
        stock: [ { size: "S", qty: 5 }, { size: "M", qty: 5 }, { size: "L", qty: 1 } ],
        category: "clothing"
      },
      {
        item: "IJK2",
        details: { model: "14Q2", manufacturer: "M5 Corporation" },
        stock: [ { size: "S", qty: 5 }, { size: "L", qty: 1 } ],
        category: "houseware"
      }
    ];
```

```
db.inventory.insert( mydocuments );
```

All the documents are inserted at once

Multi-Document Insertion (Bulk Operation)

- A temporary object in memory
- Holds your insertions and uploads them at once

There is also *Bulk Ordered* object

```
var bulk = db.inventory.initializeUnorderedBulkOp();
bulk.insert(
    {
      item: "BE10",
      details: { model: "14Q2", manufacturer: "XYZ Company" },
      stock: [ { size: "L", qty: 5 } ],
      category: "clothing"
    }
);
bulk.insert(
    {
      item: "ZYT1",
      details: { model: "14Q1", manufacturer: "ABC Company"  },
      stock: [ { size: "S", qty: 5 }, { size: "M", qty: 5 } ],
      category: "houseware"
    }
);

bulk.execute();
```

_id column is added automatically

Deletion
(Remove Operation)

- You can put condition on any field in the document (even ***_id***)

```
db.users.remove(          <-- collection
   { status: "D" }        <-- remove criteria
)
```

The following diagram shows the same query in SQL:

```
DELETE FROM users         <-- table
WHERE  status = 'D'       <-- delete criteria
```

`db.users.remove ( )` → Removes all documents from *users* collection

Update

```
db.users.update(                          <-- collection
   { age: { $gt: 18 } },                  <-- update criteria
   { $set: { status: "A" } },             <-- update action
   { multi: true }                        <-- update option
)
```

Otherwise, it will update only the 1st matching document

Equivalent to in SQL:

```
UPDATE users              <-- table
SET    status = 'A'       <-- update action
WHERE  age > 18           <-- update criteria
```

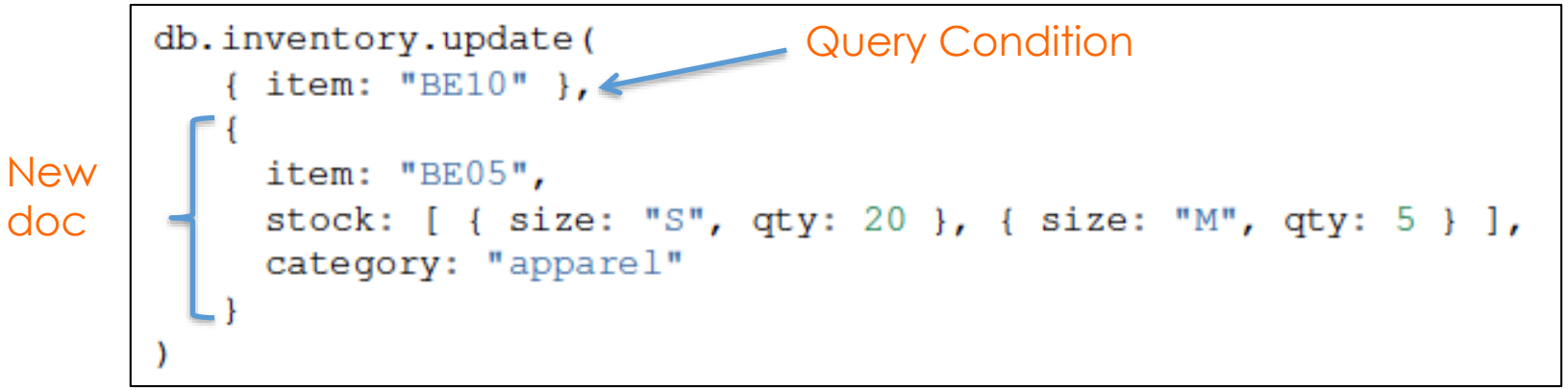
Update (Cont'd)

Two operators

```
db.inventory.update(
    { item: "MNO2" },
    {
      $set: {
        category: "apparel",
        details: { model: "14Q3", manufacturer: "XYZ Company" }
      },
      $currentDate: { lastModified: true }
    }
)
```

For the document with `item` equal to `"MNO2"`, use the `$set` operator to update the `category` field and the `details` field to the specified values and the `$currentDate` operator to update the field `lastModified` with the current date.

Replace a document



For the document having item = “BE10”, replace it with the given document

Insert or Replace

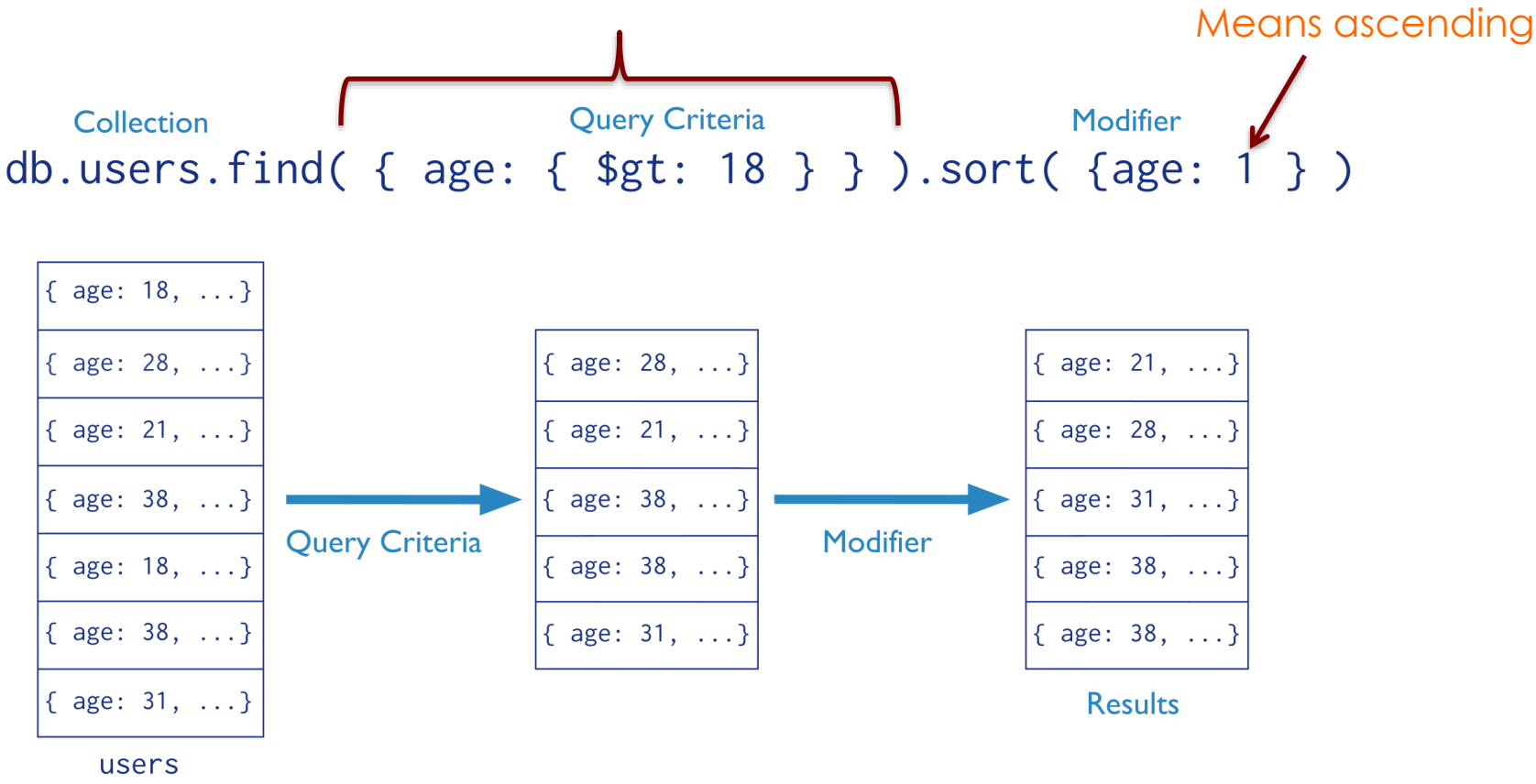
```
db.inventory.update(
    { item: "TBD1" },
    {
      item: "TBD1",
      details: { "model" : "14Q4", "manufacturer" : "ABC Company" },
      stock: [ { "size" : "S", "qty" : 25 } ],
      category: "houseware"
    },
    { upsert: true }
)
```

The ***upsert*** option

If the document having item = "TBD1" is in the DB, it will be replaced
Otherwise, it will be inserted.

Query API

Find() Operator



Find() + Projection

```
db.users.find(
   { age: { $gt: 18 } },
   { name: 1, address: 1 }
).limit(5)
```

← collection
← query criteria
← projection
← cursor modifier

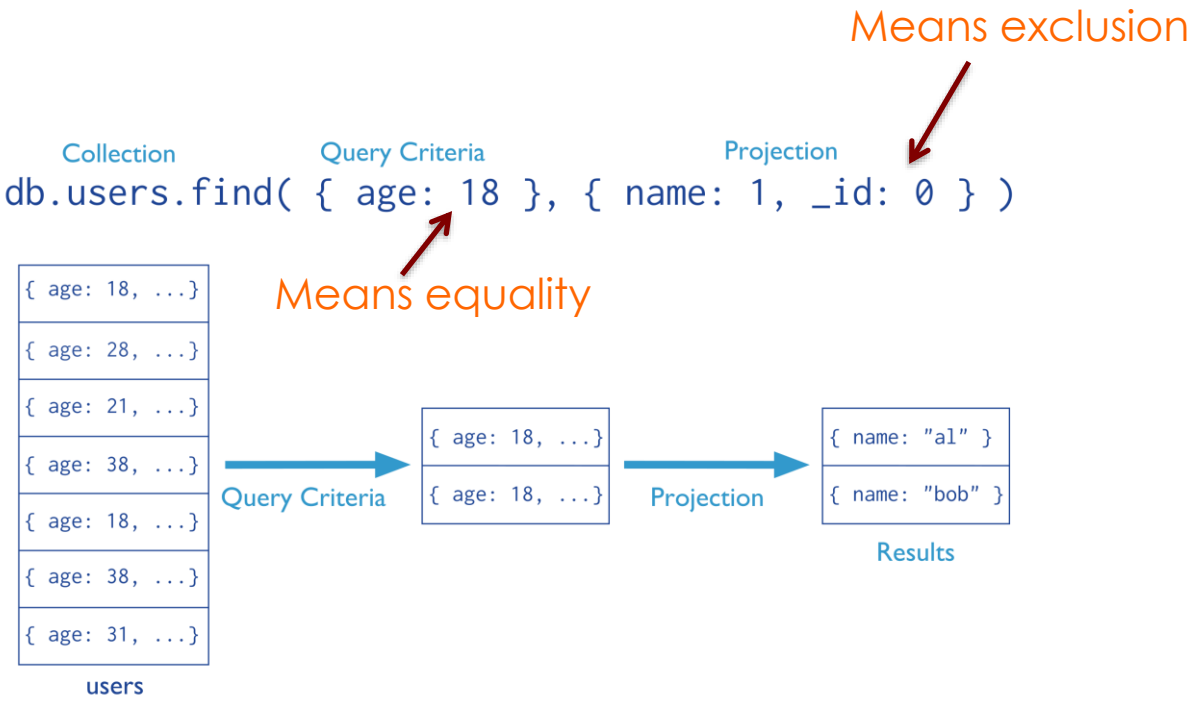
Means inclusion **+**
_id is always automatically included

Equivalent to in SQL:

```
SELECT _id, name, address
FROM   users
WHERE  age > 18
LIMIT  5
```

← projection
← table
← select criteria
← cursor modifier

Find(): Exclude Fields



Find() More Examples

Report all documents in the "inventory" collection

```
db.inventory.find( )
```

```
db.inventory.find( {} )
```

Equivalent to in SQL:

```
Select *
From inventory;
```

Report all documents in the "inventory" collection
Where type = 'food' or 'snacks'

```
db.inventory.find(
      {  type: { $in: [ 'food', 'snacks' ]  } }
)
```

Equivalent to in SQL:

```
Select *
From inventory
Where type in
      ('food',
'snacks');
```

Find(): AND & OR

AND Semantics

```
db.inventory.find( { type: 'food', price: { $lt: 9.95 } } )
```

OR Semantics

```
db.inventory.find(
    {
      $or: [ { qty: { $gt: 100 } }, { price: { $lt: 9.95 } } ]
    }
)
```

AND + OR Semantics

```
db.inventory.find(
    {
      type: 'food',
      $or: [ { qty: { $gt: 100 } }, { price: { $lt: 9.95 } } ]
    }
)
```

Type = 'food' and (qty > 100 or price < 9.95)

Queries Return Cursors

- All queries return a the results in a cursor
- If not assigned to a variable ➔ Printed to screen

  - Results are stored in a cursor
  - Many operators on top of that to manipulate the cursor

```
var myCursor = db.inventory.find();

var myFirstDocument = myCursor.hasNext() ? myCursor.next() : null;

myCursor.objsLeftInBatch();
```

Cursor's Methods:
http://docs.mongodb.org/manual/reference/method/js-cursor/

Cursor Manipulation

```
var myCursor =  db.inventory.find( { type: 'food' } );

myCursor.forEach(printjson);
```

```
var myCursor = db.inventory.find( { type: 'food' } );
var documentArray = myCursor.toArray();
var myDocument = documentArray[3];
```

Querying Complex Types

```
{
  "firstName": "John",
  "lastName": "Smith",
  "isAlive": true,
  "age": 25,
  "height_cm": 167.6,
  "address": {
    "streetAddress": "21 2nd Street",
    "city": "New York",
    "state": "NY",
    "postalCode": "10021-3100"
  },
  "phoneNumbers": [
    {
      "type": "home",
      "number": "212 555-1234"
    },
    {
      "type": "office",
      "number": "646 555-4567"
    }
  ],
  "children": [],
  "spouse": null
}
```

Documents can be complex, E.g.,
(Arrays, embedded documents, any nesting of these, many levels)

Queries get complex too !!!

Array Manipulation (Exact Match)

```
{ _id: 5, type: "food", item: "aaa", ratings: [ 5, 8, 9 ] }
{ _id: 6, type: "food", item: "bbb", ratings: [ 5, 9 ] }
{ _id: 7, type: "food", item: "ccc", ratings: [ 9, 5, 8 ] }
```

```
db.inventory.find( { ratings: [ 5, 8, 9 ] } )
```

The operation returns the following document:

```
{ "_id" : 5, "type" : "food", "item" : "aaa", "ratings" : [ 5, 8, 9 ] }
```

Array Manipulation (Search By Element)

```
{ _id: 5, type: "food", item: "aaa", ratings: [ 5, 8, 9 ] }
{ _id: 6, type: "food", item: "bbb", ratings: [ 5, 9 ] }
{ _id: 7, type: "food", item: "ccc", ratings: [ 9, 5, 8 ] }
```

```
db.inventory.find( { ratings: 5 } )
```

The operation returns the following documents:

```
{ "_id" : 5, "type" : "food", "item" : "aaa", "ratings" : [ 5, 8, 9 ] }
{ "_id" : 6, "type" : "food", "item" : "bbb", "ratings" : [ 5, 9 ] }
{ "_id" : 7, "type" : "food", "item" : "ccc", "ratings" : [ 9, 5, 8 ] }
```

Notice: if a document has "ratings" as an Integer field = 5, it will be returned

Array Manipulation (Search By Position)

```
{ _id: 5, type: "food", item: "aaa", ratings: [ 5, 8, 9 ] }
{ _id: 6, type: "food", item: "bbb", ratings: [ 5, 9 ] }
{ _id: 7, type: "food", item: "ccc", ratings: [ 9, 5, 8 ] }
```

```
db.inventory.find( { 'ratings.0': 5 } )
```

The operation returns the following documents:

```
{ "_id" : 5, "type" : "food", "item" : "aaa", "ratings" : [ 5, 8, 9 ] }
{ "_id" : 6, "type" : "food", "item" : "bbb", "ratings" : [ 5, 9 ] }
```

Another Example

```
{ _id: 5, type: "food", item: "aaa", ratings: [ 5, 8, 9 ] }
{ _id: 6, type: "food", item: "bbb", ratings: [ 5, 9 ] }
{ _id: 7, type: "food", item: "ccc", ratings: [ 9, 5, 8 ] }
```

```
db.inventory.find( { ratings: { $gt: 5, $lt: 9 } } )
```

```
{ "_id" : 5, "type" : "food", "item" : "aaa", "ratings" : [ 5, 8, 9 ] }
{ "_id" : 6, "type" : "food", "item" : "bbb", "ratings" : [ 5, 9 ] }
{ "_id" : 7, "type" : "food", "item" : "ccc", "ratings" : [ 9, 5, 8 ] }
```

Embedded Object Matching (Field Matching)

```
{
        name: "Joe",
        address: {
                city: "San Francisco",
                state: "CA" } ,
        likes: [ 'scuba', 'math', 'literature' ]
}
```

Find the user documents where the address's state = 'CA'

db.persons.find({"address.state" : "CA"})

Using dot notation

Matching Arrays of Embedded Documents

```
{
  _id: 100,
  type: "food",
  item: "xyz",
  qty: 25,
  price: 2.5,
  ratings: [ 5, 8, 9 ],
  memos: [ { memo: "on time", by: "shipping" }, { memo: "approved", by: "billing" } ]
}

{
  _id: 101,
  type: "fruit",
  item: "jkl",
  qty: 10,
  price: 4.25,
  ratings: [ 5, 9 ],
  memos: [ { memo: "on time", by: "payment" }, { memo: "delayed", by: "shipping" } ]
}
```

Select all documents where the memos array contains a document written by 'shipping' department

db.inventory.find({ 'memos.by': 'shipping' }) // Returns both documents

Means any element in the array

Matching Arrays of Embedded Documents: Multiple Conditions

```
{
  _id: 100,
  type: "food",
  item: "xyz",
  qty: 25,
  price: 2.5,
  ratings: [ 5, 8, 9 ],
  memos: [ { memo: "on time", by: "shipping" }, { memo: "approved", by: "billing" } ]
}

{
  _id: 101,
  type: "fruit",
  item: "jkl",
  qty: 10,
  price: 4.25,
  ratings: [ 5, 9 ],
  memos: [ { memo: "on time", by: "payment" }, { memo: "delayed", by: "shipping" } ]
}
```

```
db.inventory.find(
   {
     memos:
       {
          $elemMatch:
            {
               memo: 'on time',
               by: 'shipping'
            }
       }
    }
)
```

Select all documents where the memos array contains a document written by 'shipping' department and the content "on time"

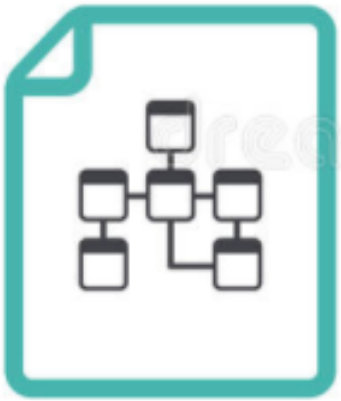
Query Operators: Comparison Op

Name	Description
`$eq`	Matches values that are equal to a specified value.
`$gt`	Matches values that are greater than a specified value.
`$gte`	Matches values that are greater than or equal to a specified value.
`$lt`	Matches values that are less than a specified value.
`$lte`	Matches values that are less than or equal to a specified value.
`$ne`	Matches all 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.

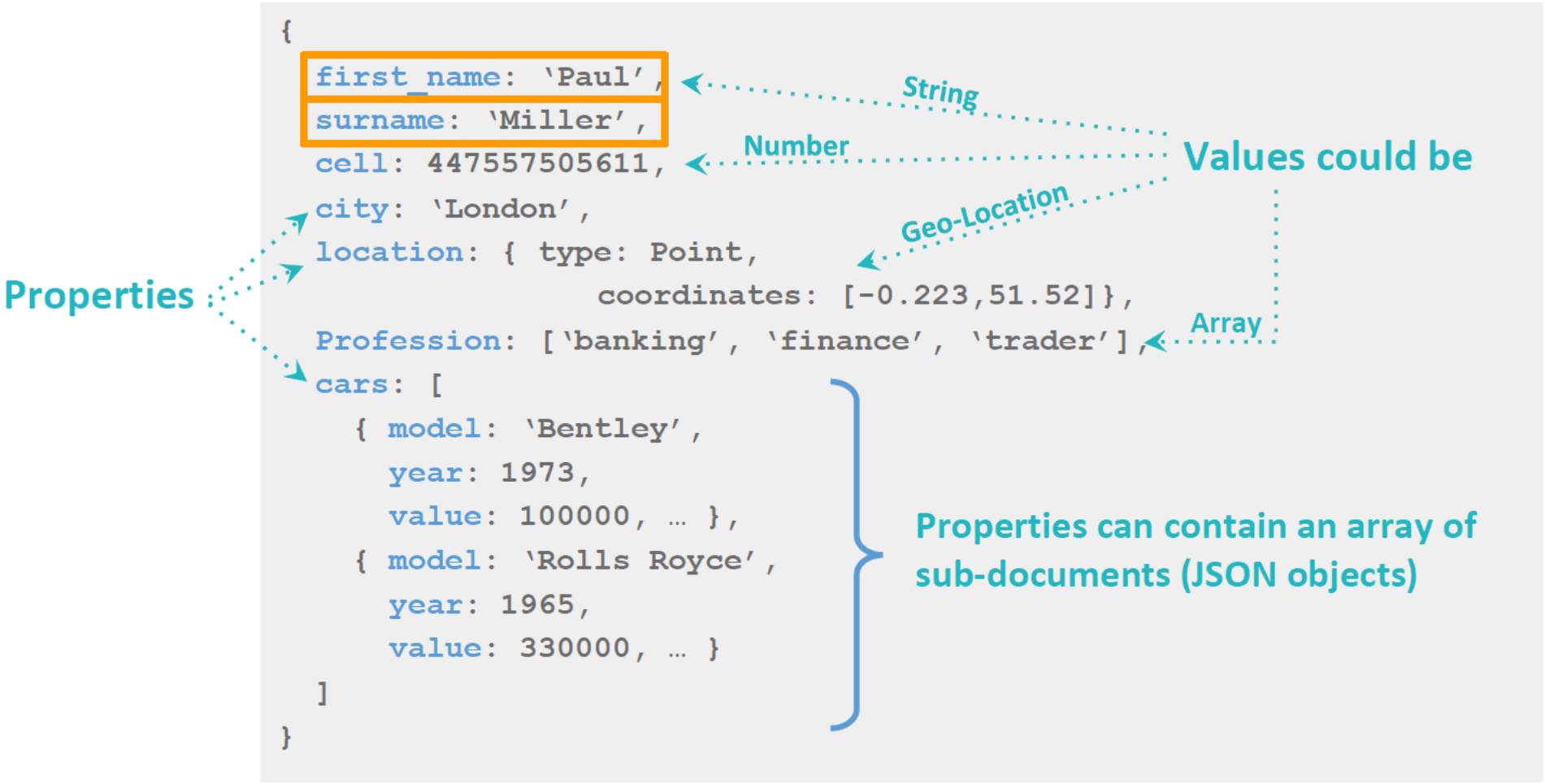
```
db.inventory.find( { qty: { $gte: 20 } } )
```

```
db.inventory.update(
        { "carrier.fee": { $gte: 2 } },
        { $set: { price: 9.99 } }
)
```

Collection Modeling



Document can have a Complex Structure



Embedded vs Referenced documents

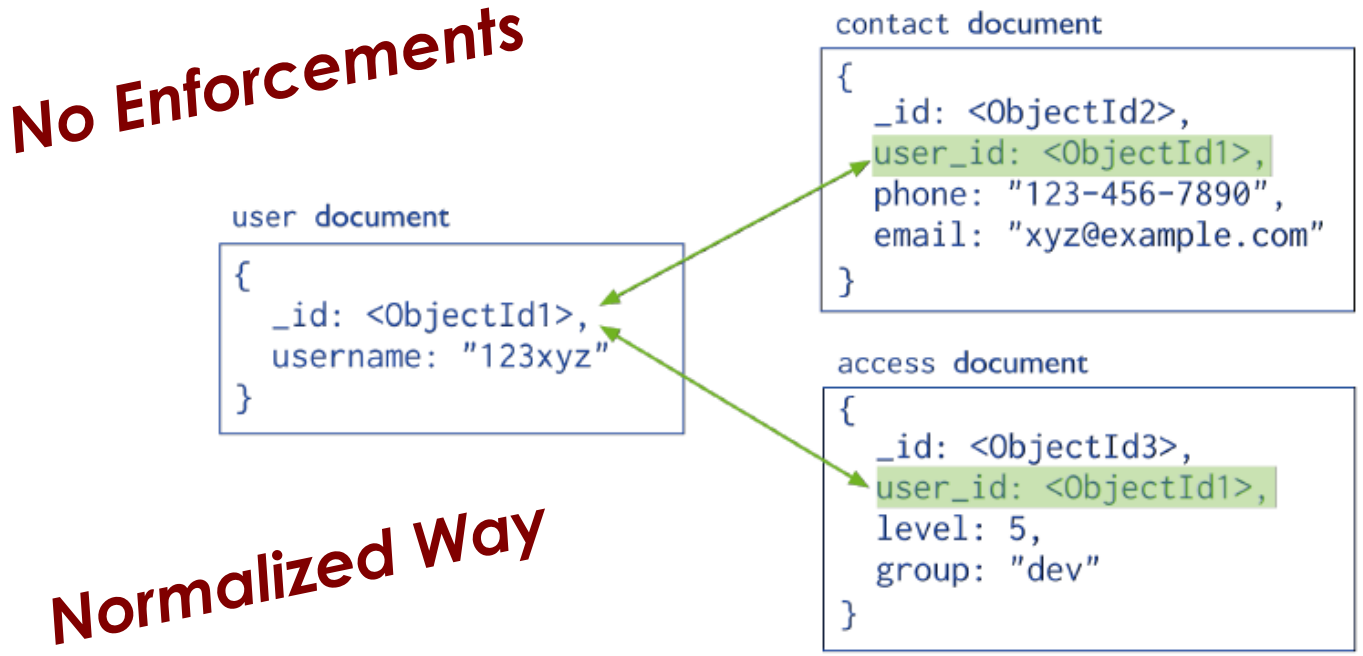
- Modeling multiple collections that reference each other
- In Relational DBs ➔ FK-PK Relationships
- Major design decision when designing a Document Schema is to decide **Embedded** vs **Referenced** subdocuments
- Decision should consider:
  - How the data will be used
  - Size of the document

In MongoDB

- ***Referencing*** between two collections
  - Use Id of one and put in the other
  - Very similar to FK-PK in Relational DBs
  - **Does not come with enforcement mechanism**

- ***Embedding*** between two collections
  - Put the document from one collection inside the other one

Referencing



- Have three collections in the DB: “User”, “Contact”, “Access”
- Link them by _id (or any other field(s))

Embedding

- Have one collection in DB: “User”
- The others are embedded inside each user’s document

Embedding

- **Advantages**
  - Retrieve all relevant information in a single query/document
  - Avoid implementing joins in application code => fast data retrieval
  - Update related information as a single atomic operation
- **Limitations**
  - Large documents mean more overhead if most fields are not relevant
  - 16 MB document size limit

Referencing

- **Advantages**
  - Smaller documents
  - Less likely to reach 16 MB document limit
  - Infrequently accessed information not accessed on every query
  - No duplication of data
- **Limitations**
  - Two queries required to retrieve information
  - Cannot update related information atomically (in one atomic operation)

1 to 1 Relationships => Better to Embed

Medical Procedures

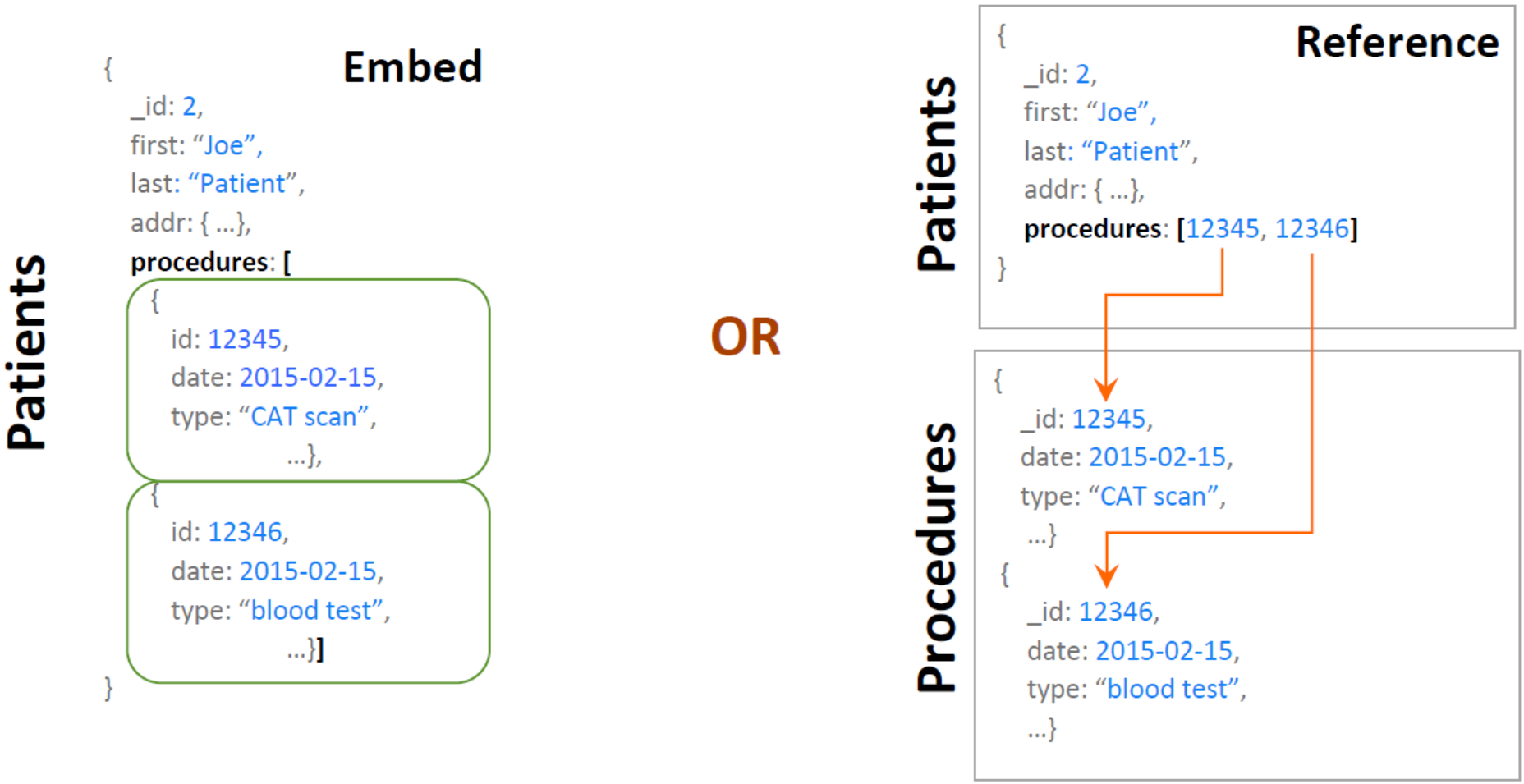
```
{
    "_id": 333,
    "date": "2003-02-09T05:00:00",
    "hospital": "County Hills",
    "patient": "John Doe",
    "physician": "Stephen Smith",
    "procedure": "Glucose",
    "result": {
        "value": 97,
        "measurement": "mg/dl"
    }
}
```

← Embed – *weak entity*

Embed:

- No data duplication
- Data that are read/written together lives together

One to Many Relationships



One to Many : General Recommendations

- **Embed when:**
  - **One-to-few** (e.g. customer - addresses)
  - **Often queried/updated together** in a single query (e.g., book - chapters)
  - No need to access the embedded object outside the context of the parent object (e.g., order – order items)
  - No additional data duplication introduced

- **Reference when:**
  - **1 to a large number of related items** (e.g. customer orders , book – reviews, video - comments)
  - Related data changes frequently (e.g., video – viewCount)
  - Referenced entity that is used by many others (e.g., session - **room**)
  - Document size is > 16 MB
  - Subdocument has a large number of infrequently accessed fields

1 to M Example 1

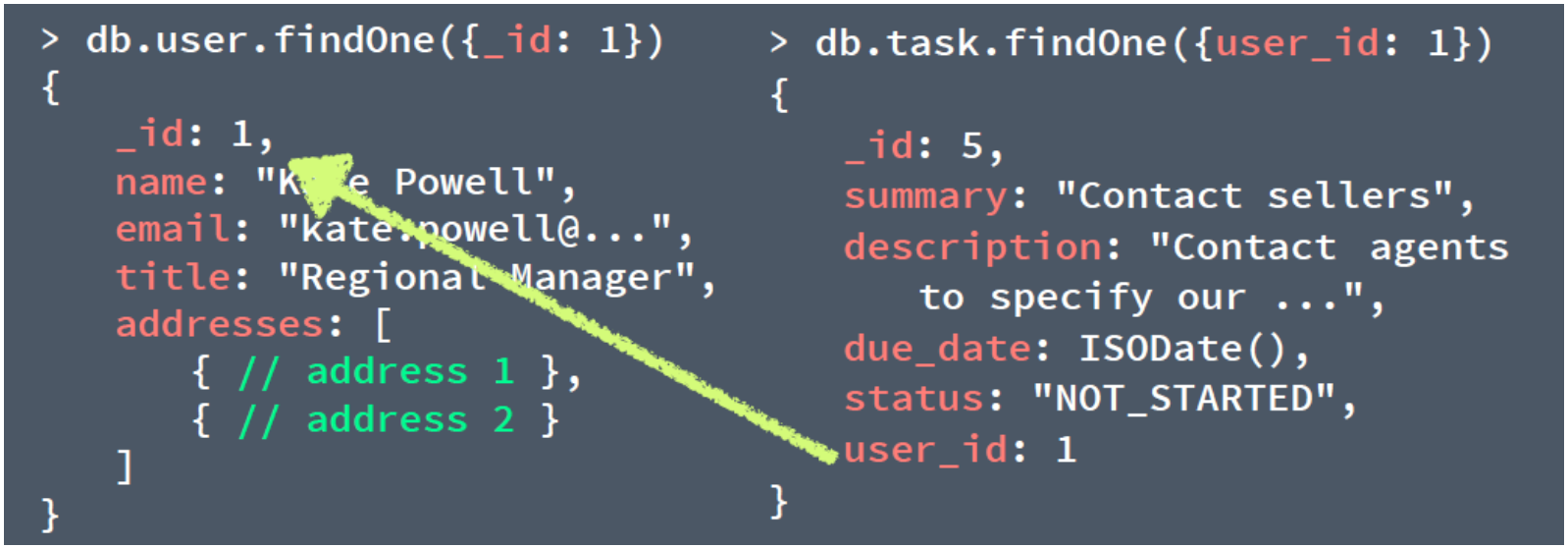
- *"We need to store user information like name, email and their addresses… yes they can have more than one."*

```
{
    _id: 1,
    name: "Kate Powell",
    email: "kate.powell@somedomain.com",
    title: "Regional Manager",
    addresses: [
        { street: "123 Sesame St", city: "Boston" },
        { street: "123 Evergreen St", city: "New York" }
    ]
}
```

One-to-few ： embedding is the best design

1 to M Example 2

- *"We have to be able to store tasks, assign them to users and track their progress…"*



Referencing is the best design:

• Tasks are unbounded items: initially we do not know how many tasks we are going to have

- A user can end with thousands of tasks
- Maximum document size in MongoDB: 16 MB !

• Tasks can be queried without needing the retrieve the user details

Example 3

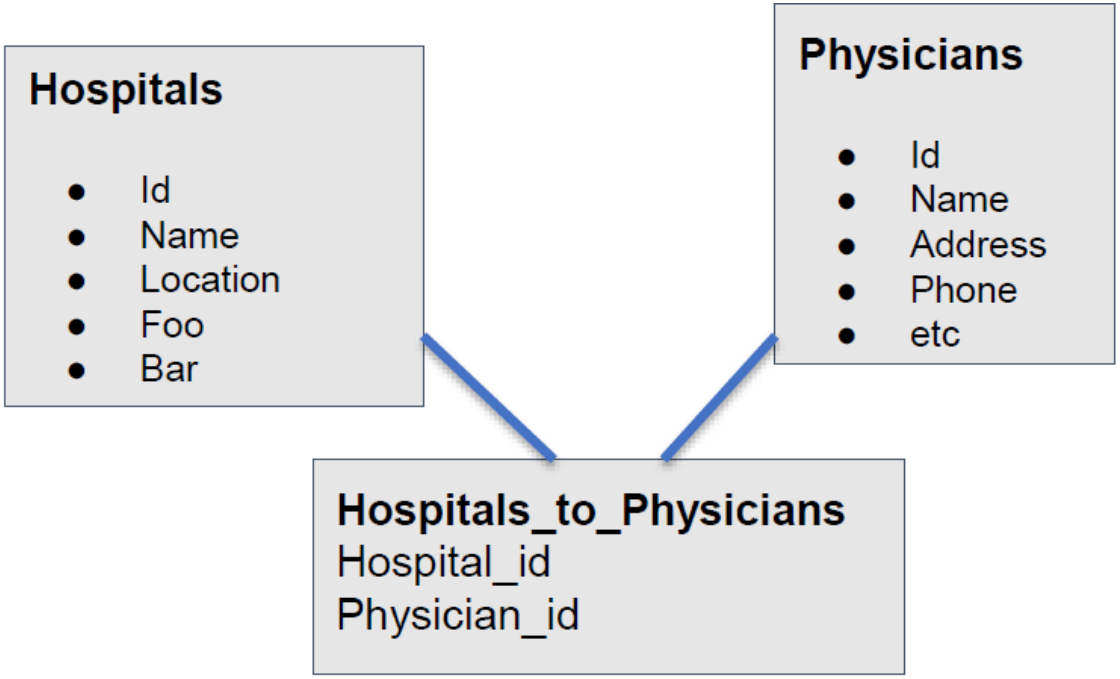
- **One-to-Many "Book", "Publisher"**
  - A book has one publisher
  - A publisher publishes many books
- **If embed "Publisher" inside "Book"**
  - Repeating publisher info inside each of its books
  - Very hard to update publisher's info
- **If embed "Book" inside "Publisher"**
  - Book becomes an array (many)
  - Frequently update and increases in size

Referencing is better in this case

Many to Many Relationship

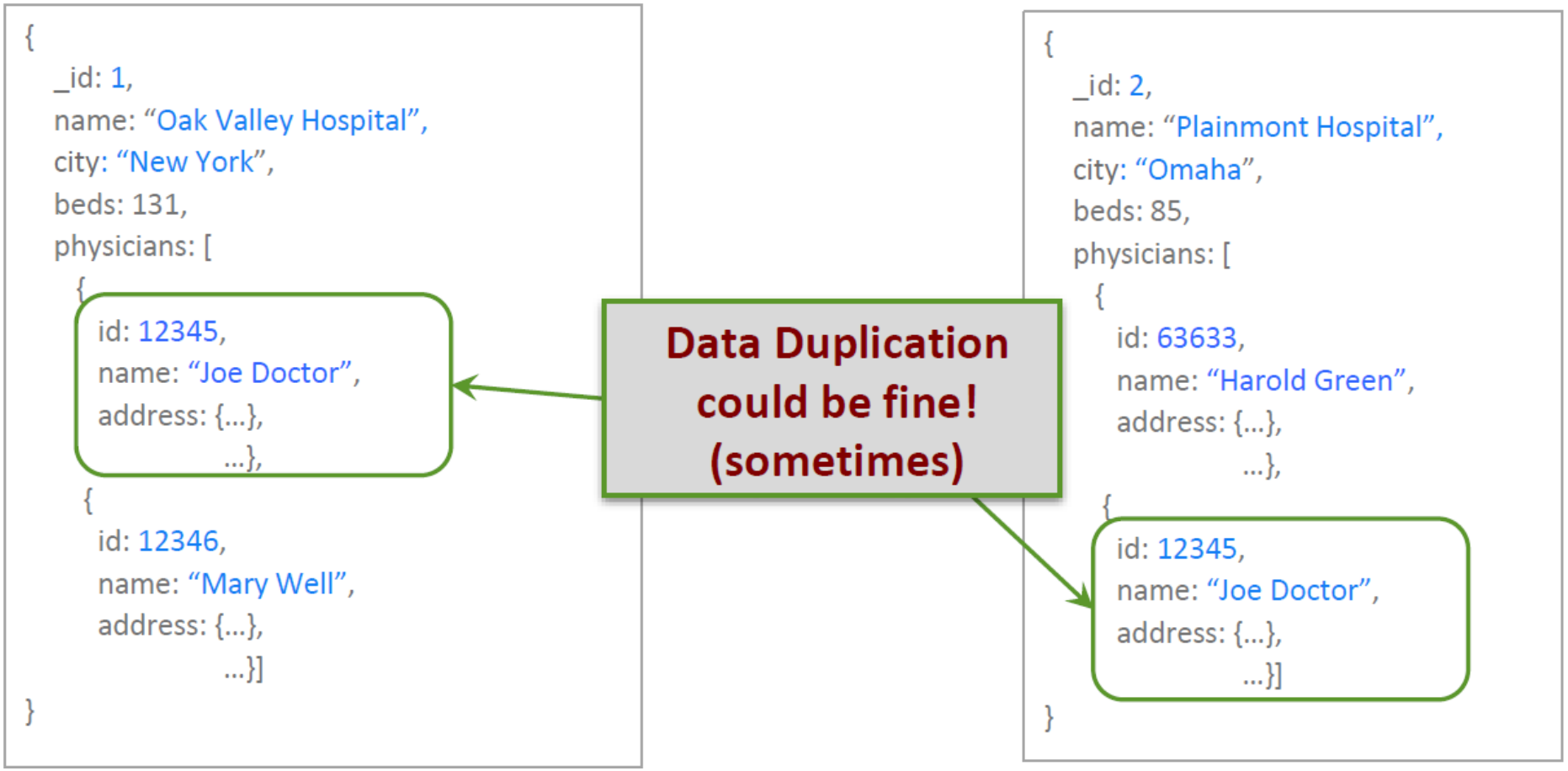
- Like a One-to-Many relationship, you can embed sub-documents or reference them.
- Which approach you take depends on data access patterns and document sizes.

The relational way:



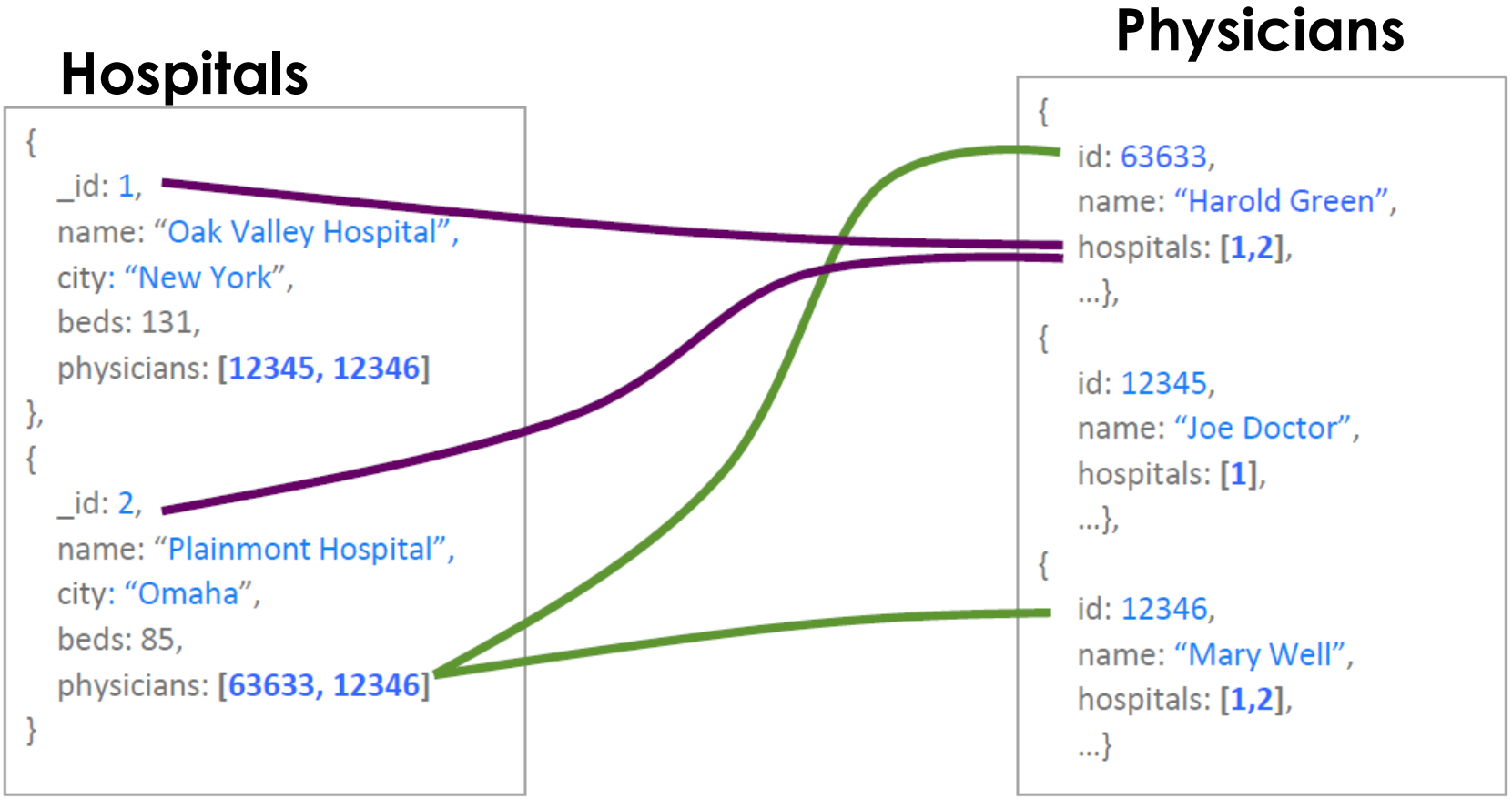
Many to Many Relationship using Embedding

Embedding **Physicians** in **Hospitals** collection



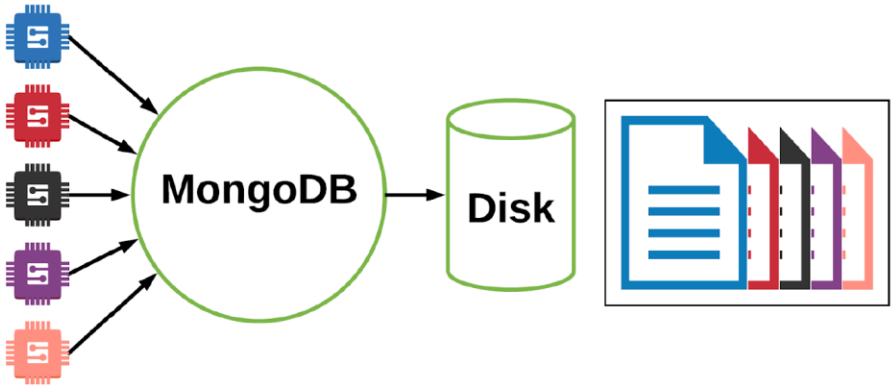
Many to Many Relationship using References

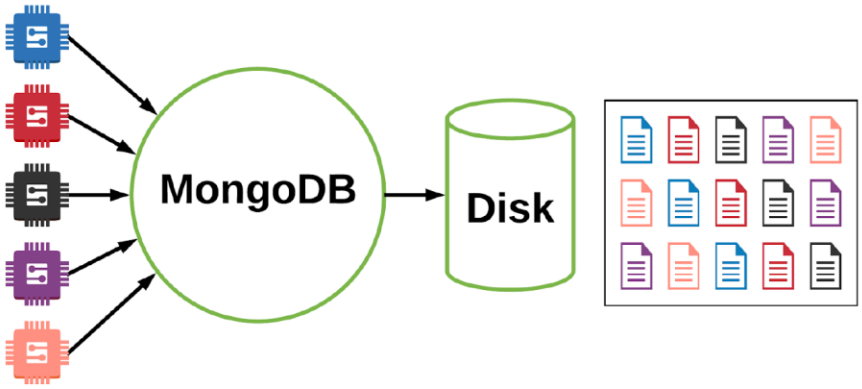
No data duplication. Hence this design is often **recommended**



Note that references can go either direction. There is no primary key/foreign key concept in MongoDB

Bucket Pattern





Bucket per Day

Bucket per Hour

```
{
 "device_id": 000123456,
 "type": "2A",
 "date": ISODate("2018-03-02"),
 "temp": [ [ 20.0, 20.1, 20.2, ... ],
           [ 22.1, 22.1, 22.0, ... ],
           ...
         ]
}

{
 "device_id": 000123456,
 "type": "2A",
 "date": ISODate("2018-03-03"),
 "temp": [ [ 20.1, 20.2, 20.3, ... ],
           [ 22.4, 22.4, 22.3, ... ],
           ...
         ]
```

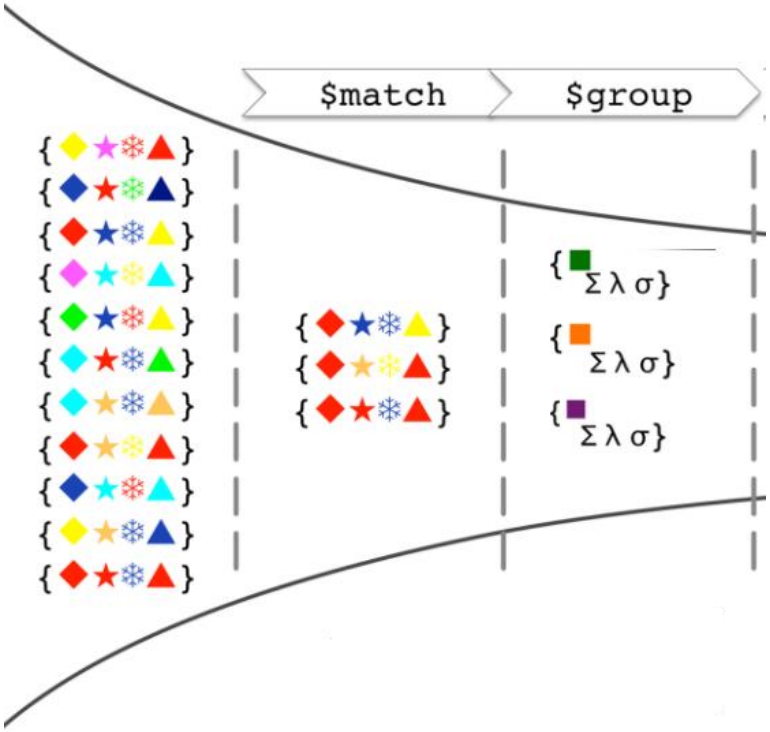
```
{
 "device_id": 000123456,
 "type": "2A",
 "date": ISODate("2018-03-02T13"),
 "temp": { 1: 20.0, 2: 20.1, 3: 20.2, ... }
}

{
 "device_id": 000123456,
 "type": "2A",
 "date": ISODate("2018-03-02T14"),
 "temp": { 1: 22.1, 2: 22.1, 3: 22.0, ... }
}
```

Summary

Type of Relation ->	one-to-one/1-1	one-to-many/1-N	many-to-many/N-N
Document embedded in the parent document	• one read • no joins	• one read • no joins	• one read • no joins • duplication of information
Document referenced in the parent document	• smaller reads • many reads	• smaller reads • many reads	• smaller reads • many reads

Aggregation Queries



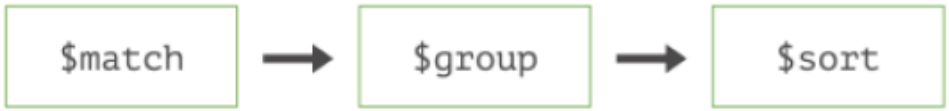
Aggregation Queries

- Summarize data typically for reports
- How would we solve this in SQL?

```
SELECT GROUP BY HAVING
```

- What About MongoDB?

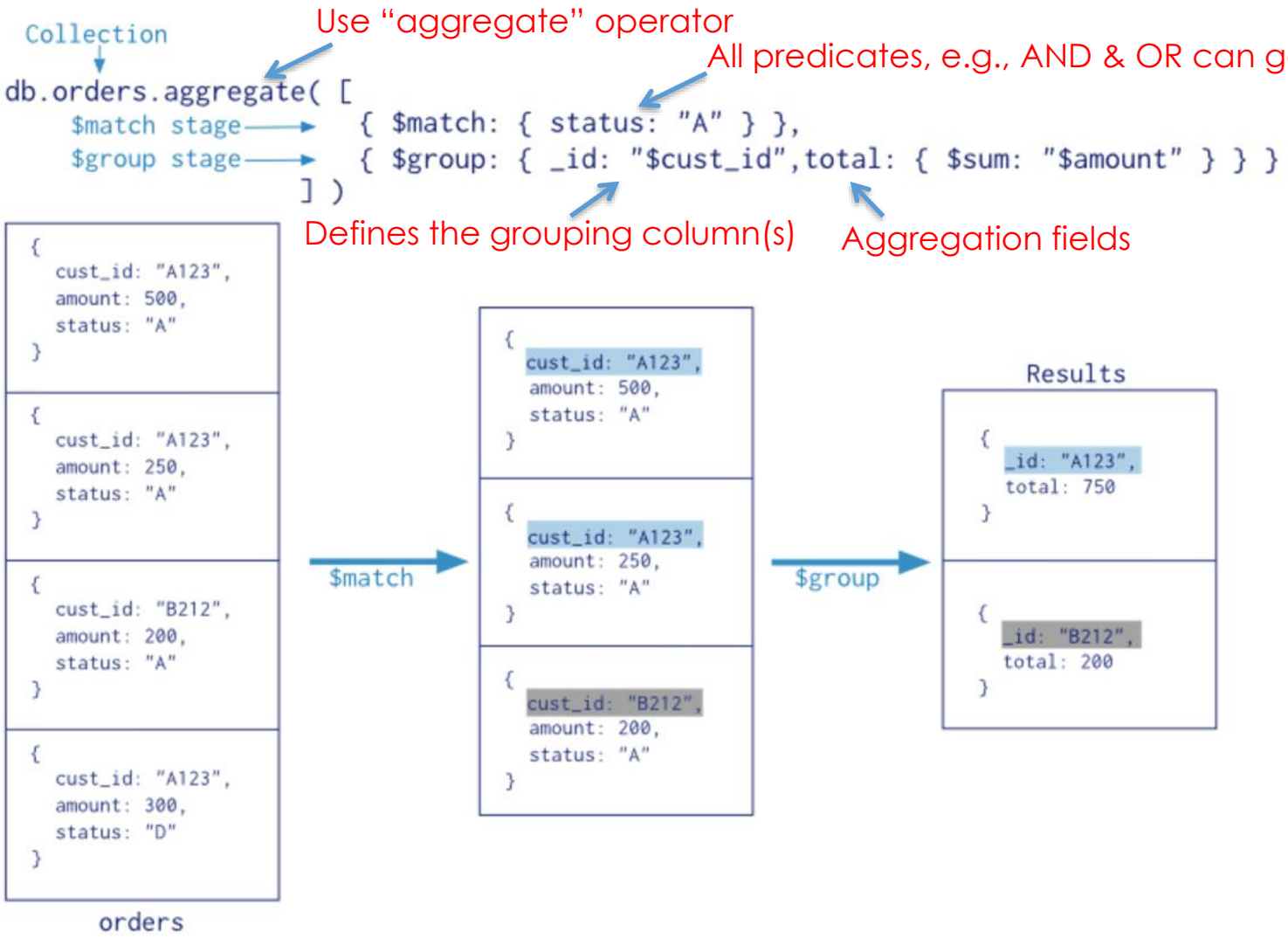
  => **Aggregation Pipeline**



  - Pipeline of functions to filter, group, and sort documents
  - Operations executed in sequential order
  - Output of one stage is used as an input of next

Aggregation Pipeline

- Allows filtering then grouping documents by specific fields



Pipeline Operators

- $match Filter documents
- $group Summarize documents
- $sort Order documents
- $limit Limit returned results

- **$group** specifies:

– Properties to group by

– Computed output properties using $max, $min, $avg, $sum …

```
{ "_id" : 1, "item" : "abc", "price" : 10, "quantity" : 2, "date" : ISODate("2014-03-01T08:00:00Z") }
{ "_id" : 2, "item" : "jkl", "price" : 20, "quantity" : 1, "date" : ISODate("2014-03-01T09:00:00Z") }
{ "_id" : 3, "item" : "xyz", "price" : 5, "quantity" : 10, "date" : ISODate("2014-03-15T09:00:00Z") }
{ "_id" : 4, "item" : "xyz", "price" : 5, "quantity" : 20, "date" : ISODate("2014-04-04T11:21:39.736Z") }
{ "_id" : 5, "item" : "abc", "price" : 10, "quantity" : 10, "date" : ISODate("2014-04-04T21:23:13.331Z") }
```

For each day, get the:
- TotalPrice ← Sum (Price * Quantity)
- average quantity
- Count

```
db.sales.aggregate([
    {$group : {_id : {  month: { $month: "$date" },
                        day: { $dayOfMonth: "$date" },
                        year: { $year: "$date" } } ,
       totalPrice: { $sum: { $multiply: [ "$price", "$quantity" ] } },
       averageQuantity: { $avg: "$quantity" },
       count: { $sum: 1 }
     }}])
```

Group By…Having

- In MongoDB ➔ $match operator after the $group

```
{ "_id": "10280",
  "country": "USA",
  "city": "NEW YORK",
  "state": "NY",
  "pop": 5574,
  "loc": [ -74.016323, 40.710537]
}
```

```
Select state, sum(pop)
From collection
Where country = "USA"
Group By state
Having sum(pop) > 10,000,000;
```

Group By…Having

- In MongoDB ➔ $match operator after the $group

```
{ "_id": "10280",
  "country": "USA",
  "city": "NEW YORK",
  "state": "NY",
  "pop": 5574,
  "loc": [ -74.016323, 40.710537]
}
```

```
Select state, sum(pop)
From collection
Where country = "USA"
Group By state
Having sum(pop) > 10,000,000;
```

Get USA states having total population > 10,000,000

```
db.zipcodes.aggregate( [
    { $match: { country: "USA" }},
    { $group: { _id: "$state", totalPop: { $sum: "$pop" }
    } },
    { $match: { totalPop: { $gt: 10*1000*1000 } } }
] )
```

$group Examples

- Return average GPA for all students

```
Student.aggregate([
    {
        "$group" : {"_id" : null,
        "avgGPA" : {$avg : "$gpa"}
    }}])
```

- Return total completed Credit Hours per student

```
StudentCourse.aggregate([
    {
        "$group" : {"_id" : studentId,
            "completedCHs" : {$sum : "$CourseCH"}
        }}])
```

https://jongo.org/

Database Scalability Solutions

Back

What is scalability?

A service is said to be scalable if when we increase the resources in a system, it results in increased performance in a manner proportional to resources added.

Werner Vogels *CTO - Amazon.com*

Scale up

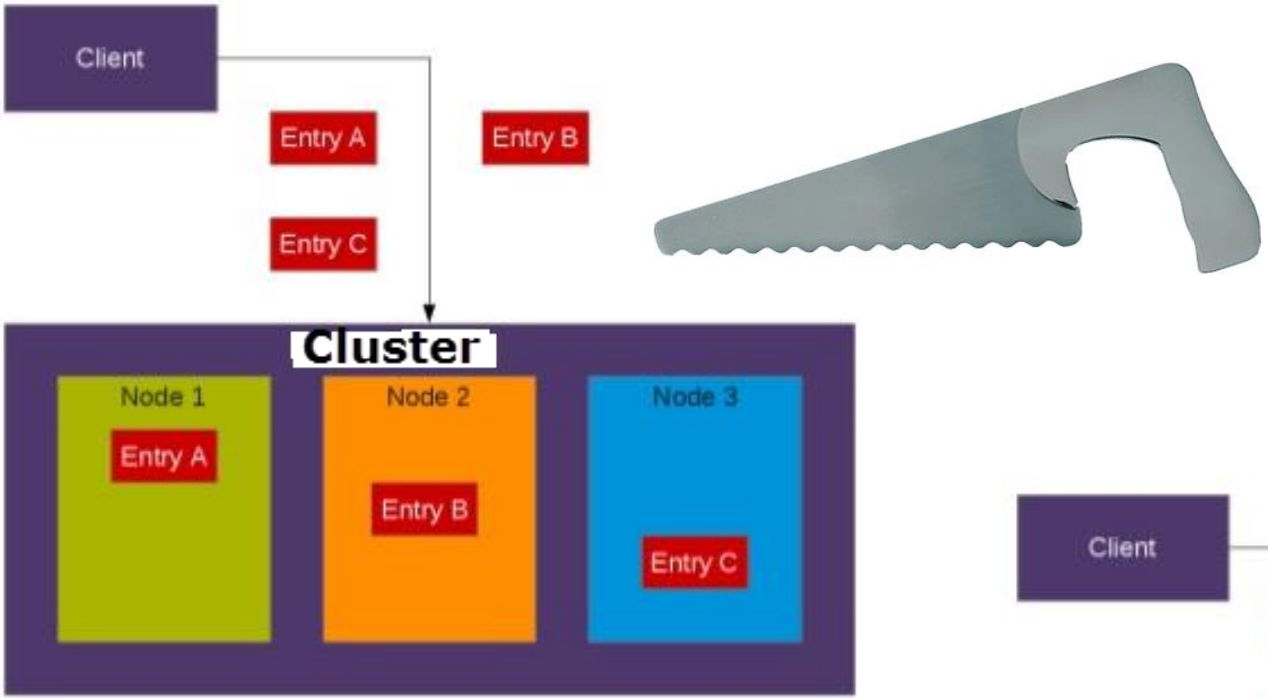
Scale out

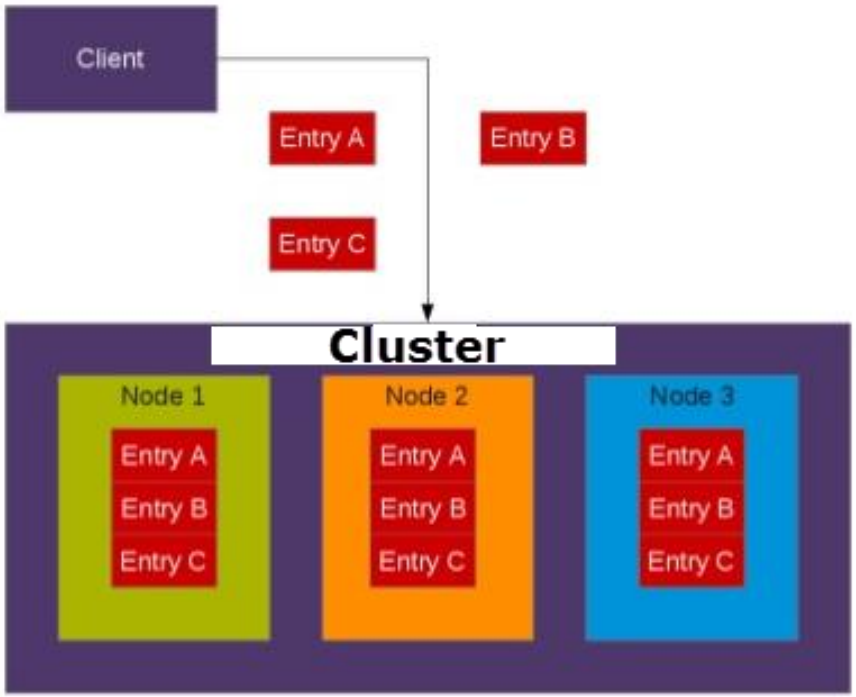
Solutions to address scalability

Two styles of **distributing data** to enhance scalability:

- **Sharding** (aka Data Partitioning) distributes different data across multiple servers
  - each server acts as the single source for a subset of data
- **Replication** copies data across multiple servers
  - each bit of data can be found in multiple places
  - Replication is good for performance & reliability
    - Key challenge = keeping replicas up-to-date

Sharding vs. Replication

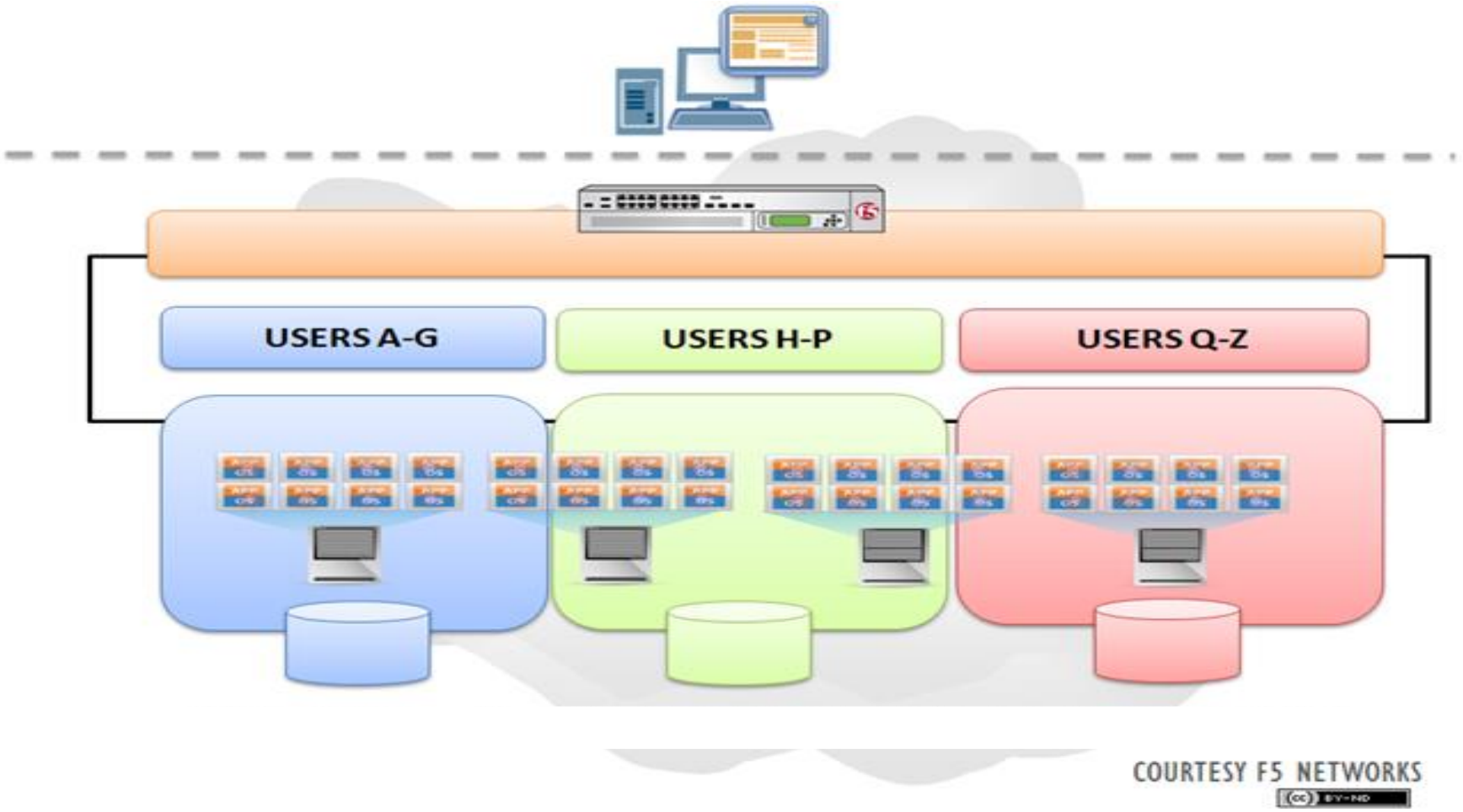




What is Sharding?

- **Problem:** one database can't handle all the data
  - Too big, poor performance, needs geo distribution, …
- **Solution:** split data across multiple databases
  - One **Logical Database**, multiple **Physical Databases**
  - *Scales well for both reads and writes*
- Each Physical Database Node is a **Shard**

Database Sharding



All shards have same schema

Horizontal Partitioning

- Horizontal or Range Based Sharding: the data is split based on the value ranges of a particular attribute such as the last name.

First Name	Last Name	Email	Thumbnail	Photo
David	Alexander	davida@contoso.com	3kb	3MB
Jarred	Carlson	jaredc@contosco.com	3kb	3MB
Sue	Charles	suec@contosco.com	3kb	3MB
Simon	Mitchel	simonm@contoso.com	3kb	3MB
Richard	Zeng	richard@contosco.com	3kb	3MB

Vertical Partitioning

First Name	Last Name	Email	Thumbnail	Photo
David	Alexander	davida@contoso.com	3kb	3MB
Jarred	Carlson	jaredc@contosco.com	3kb	3MB
Sue	Charles	suec@contosco.com	3kb	3MB
Simon	Mitchel	simonm@contoso.com	3kb	3MB
Richard	Zeng	richard@contosco.com	3kb	3MB

RDMS Server

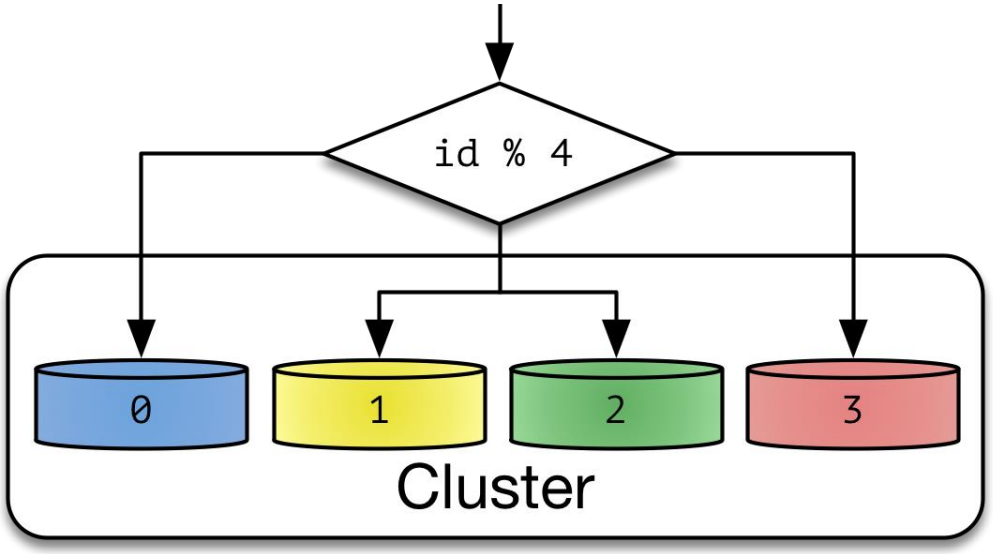
BLOBS

BLOBs

Hybrid Portioning

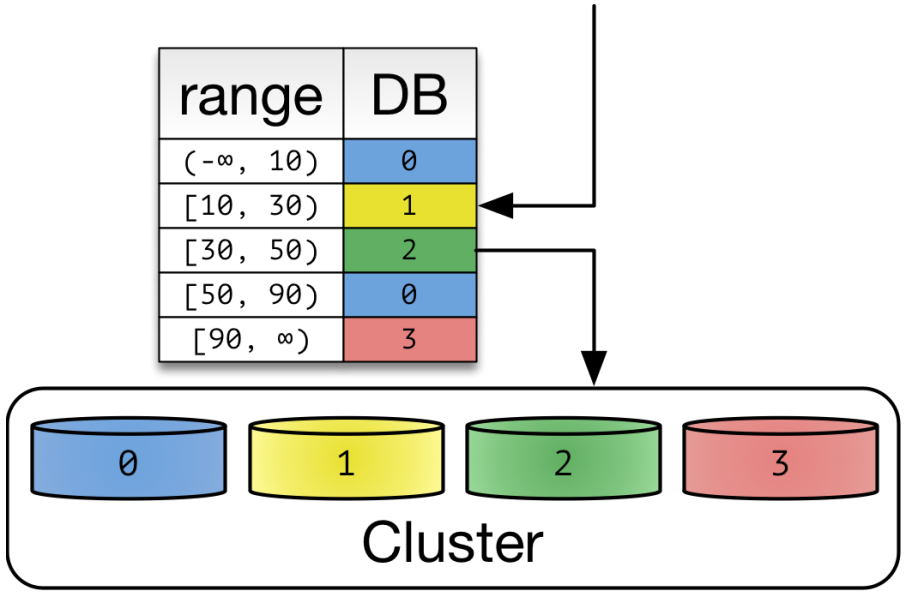
First Name	Last Name	Email	Thumbnail	Photo
David	Alexander	davida@contoso.com	3kb	3MB
Jarred	Carlson	jaredc@contosco.com	3kb	3MB
Sue	Charles	suec@contosco.com	3kb	3MB
Simon	Mitchel	simonm@contoso.com	3kb	3MB
Richard	Zeng	richard@contosco.com	3kb	3MB

Algorithmic versus Dynamic.



hashValue = hashFunction(key)
serverIndex = hashValue % numberOfServers

- Algorithmic sharding: **hash(key) -> Node$_{id}$**



- Dynamic sharding: uses a **locator service** to map key ranges to nodes

Sharding Challenges

- For most RDBMS, sharding is NOT transparent, the application needs to be partition-aware

  – Sharding is largely managed outside RDBMS

  – Recent version of RDBMS may provide limited support for sharding

- Joins become too expensive

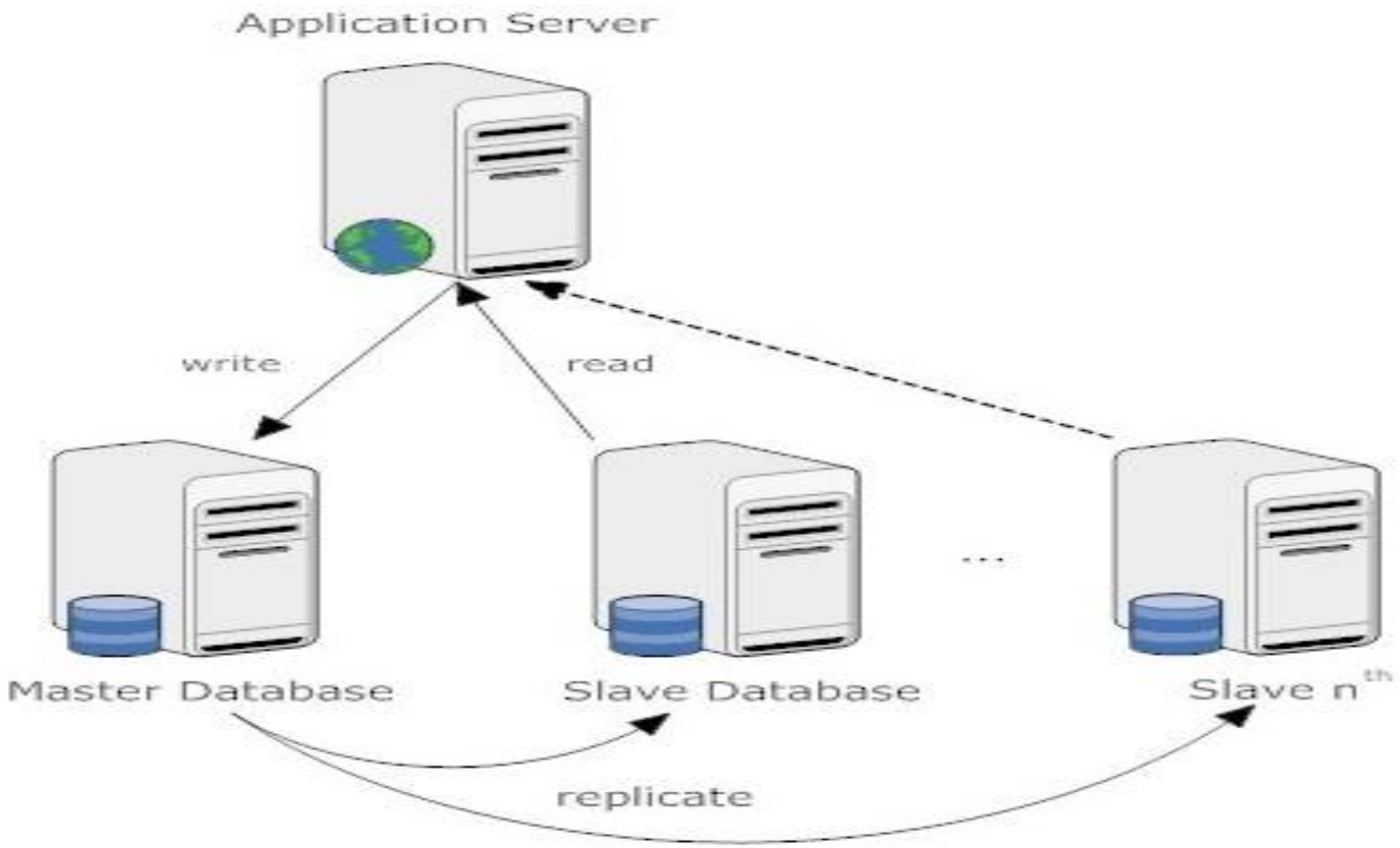
- Loss of referential integrity across shards. So the constraints are moved away from database and are part of the application

- Re-balancing or Re-Sharding is hard
  – What to do when data do not fit in one shard
- Deciding on a partition key/plan is hard
  – May generate hotspots

Sharding is Difficult

- What defines a shard? (Where to put stuff?)
  - Example – use country of origin: customer_us, customer_fr, customer_cn, customer_ie, …
  - Use same approach to find records
  - May generate hotspots
- What happens if a shard gets too big?
  - Rebalancing shards can get complex
- Query / join / transact **across** shards

Master-Slave Replication



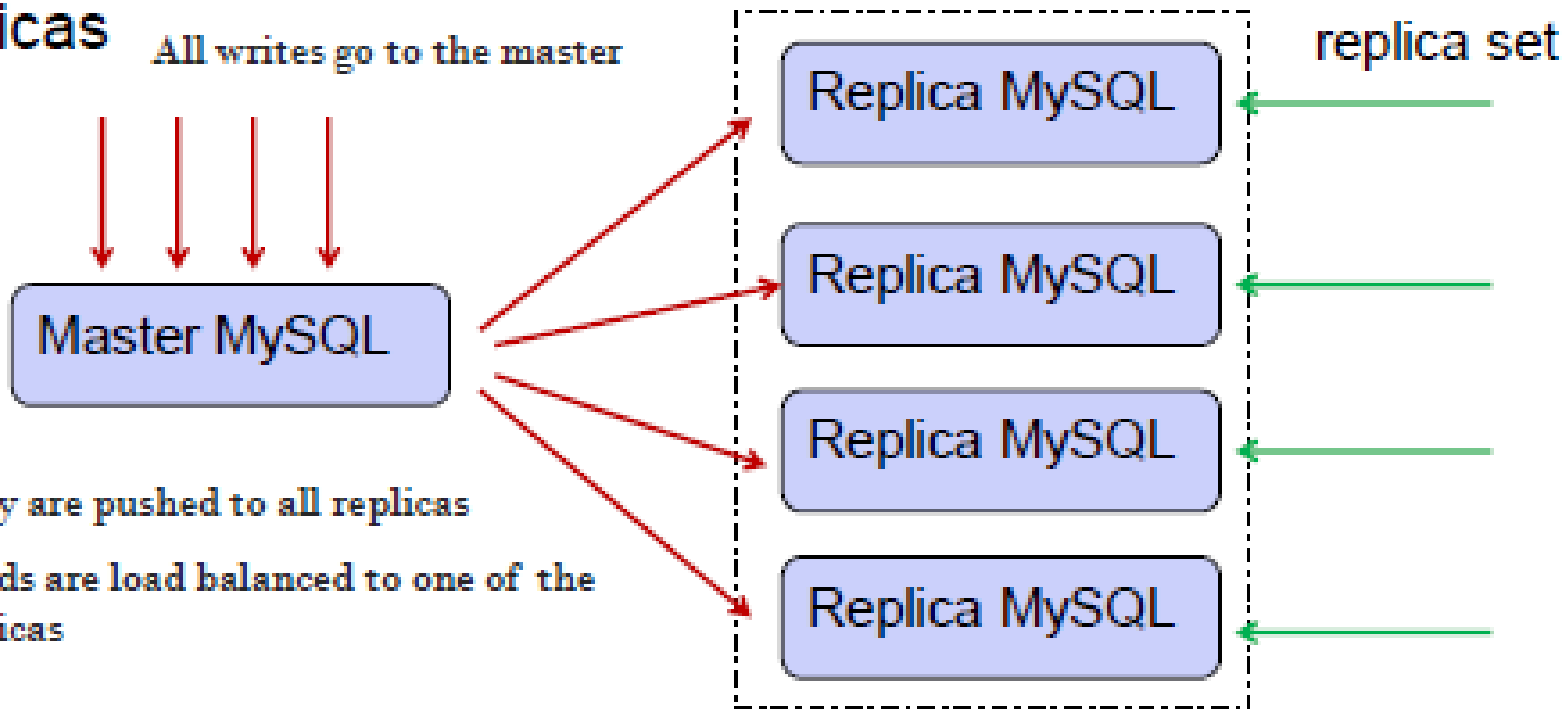
- Replication increases resilience and availability but introduces new class of **consistency** problems

Master-Slave Replication

- Makes one node the authoritative copy that handles writes while slaves synchronize with the master and may handle reads
  - Reads may be inconsistent as writes may not have been propagated to slaves
  - Large data sets can pose problems as master needs to duplicate data to slaves

Master-Slave Replication Example

- Example: Wikipedia has one Master database and many replicas



http://www.nedworks.org/~mark/presentations/san/Wikimedia%20architecture.pdf

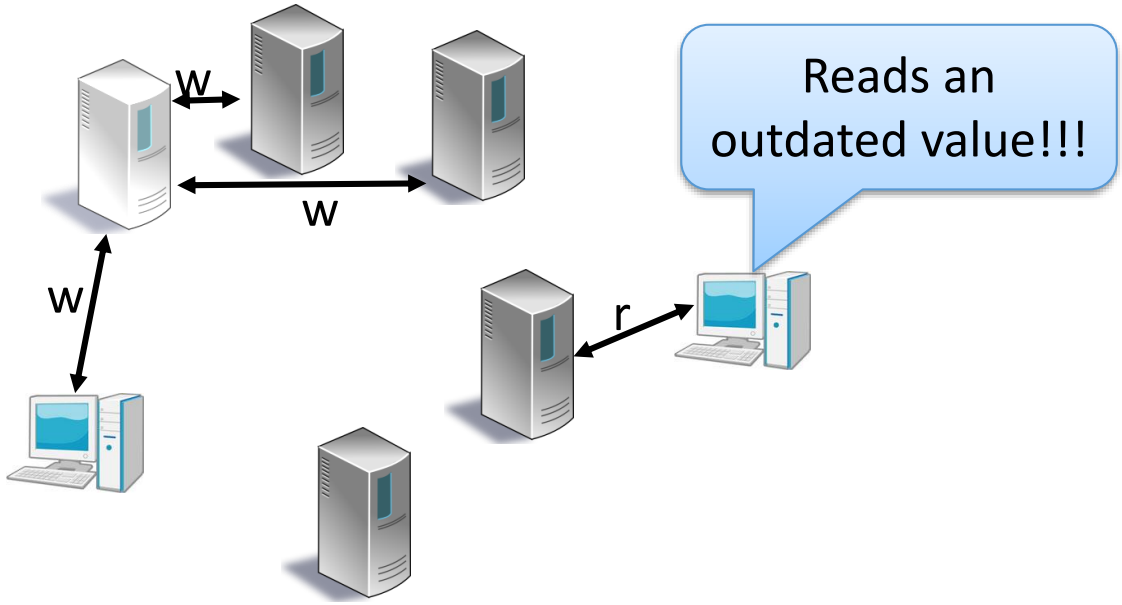
Master-Slave Replication Implications

- When the master dies
  - One of the replica can be elected as the new master
- Some read may return old data if the latest value has not been pushed from the master
- It is possible to let Master handle read request for data requiring strong consistency
- Relatively easy to setup in most RDBMS

Problems with Master-Slave Replication

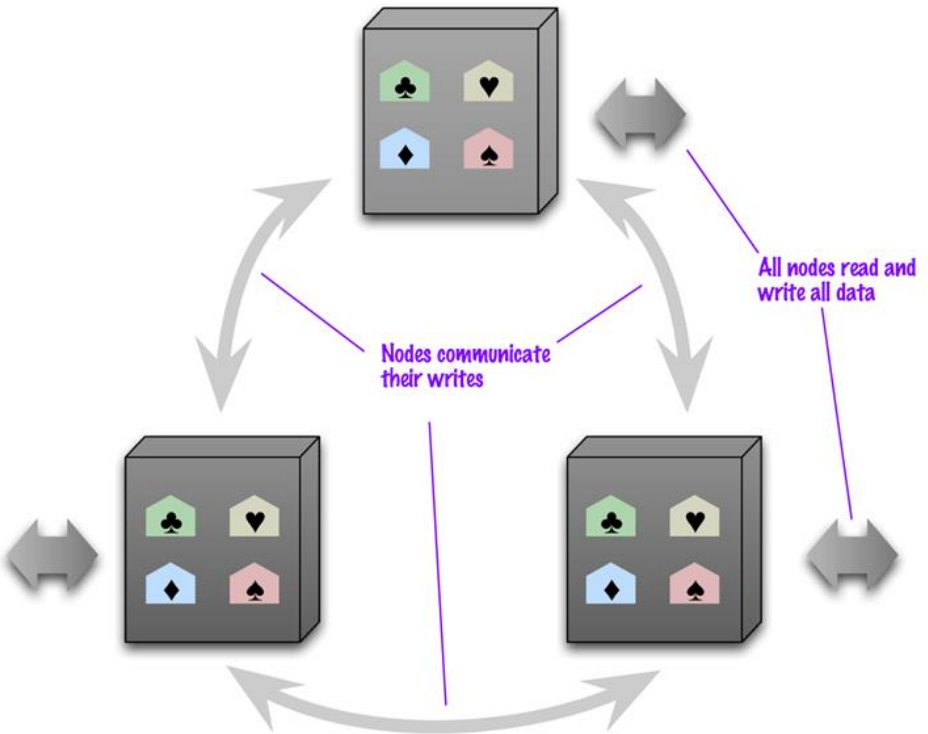
- If the clients can only send read requests to the Master, the system stalls if the Master fails
- However, if the clients can also send read requests to the other servers, the clients may not have a consistent view

- Master-slave replication helps with read scalability but doesn't help with scalability of writes



Peer-to-Peer Replication

- ***Peer-to-peer replication*** allows writes to any node; the nodes coordinate to synchronize their copies of the data.



Replication: consistency of copies

- Synchronous: All copies of a modified data item must be updated before the modifying transaction commits
  - copies are consistent
- Asynchronous: Copies of a modified data item are asynchronously updated
  - copies may be inconsistent over periods of time.

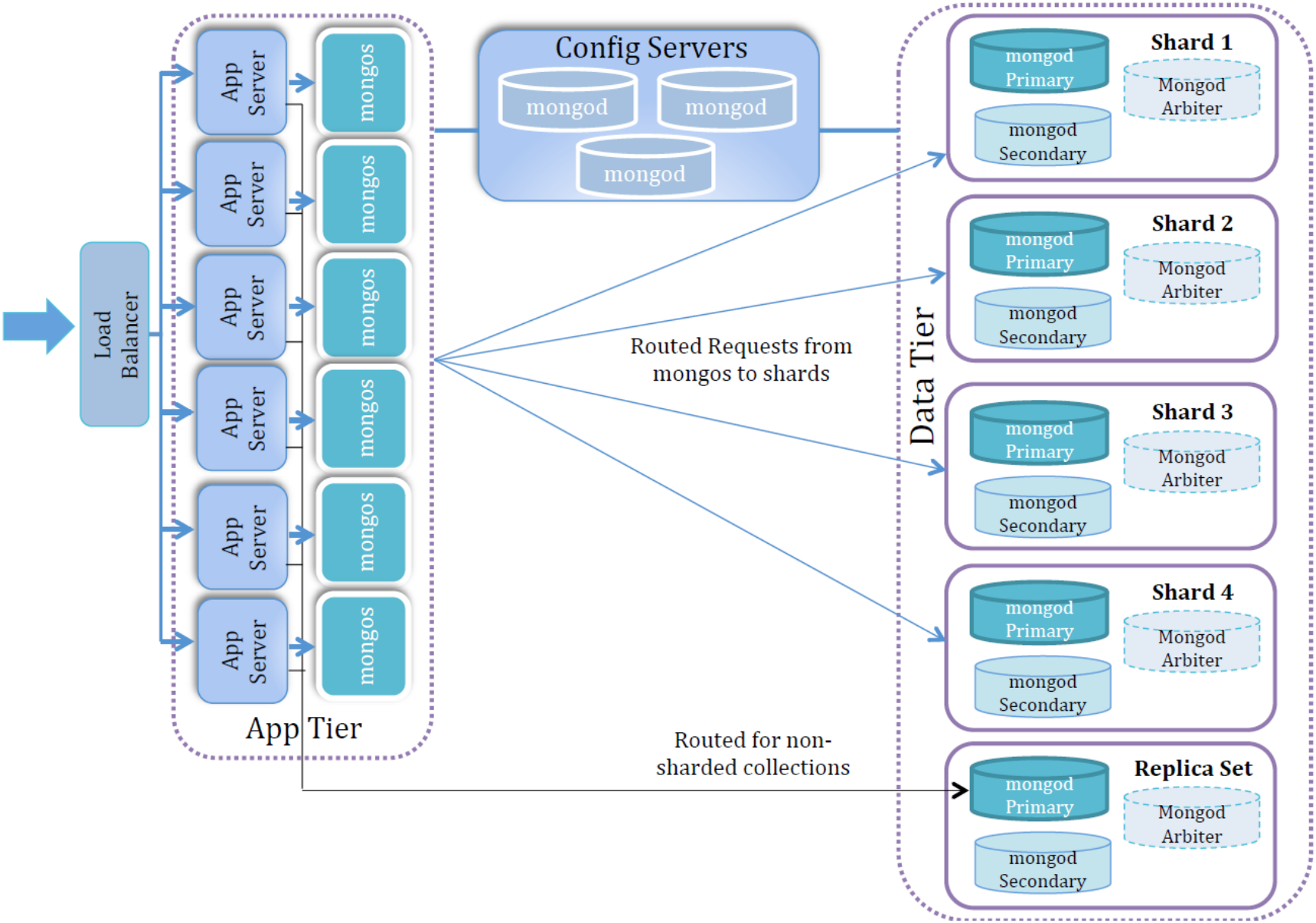
Summary

- Master-slave replication reduces the chance of update conflicts but peer-to-peer replication avoids loading all writes onto a single point of failure.

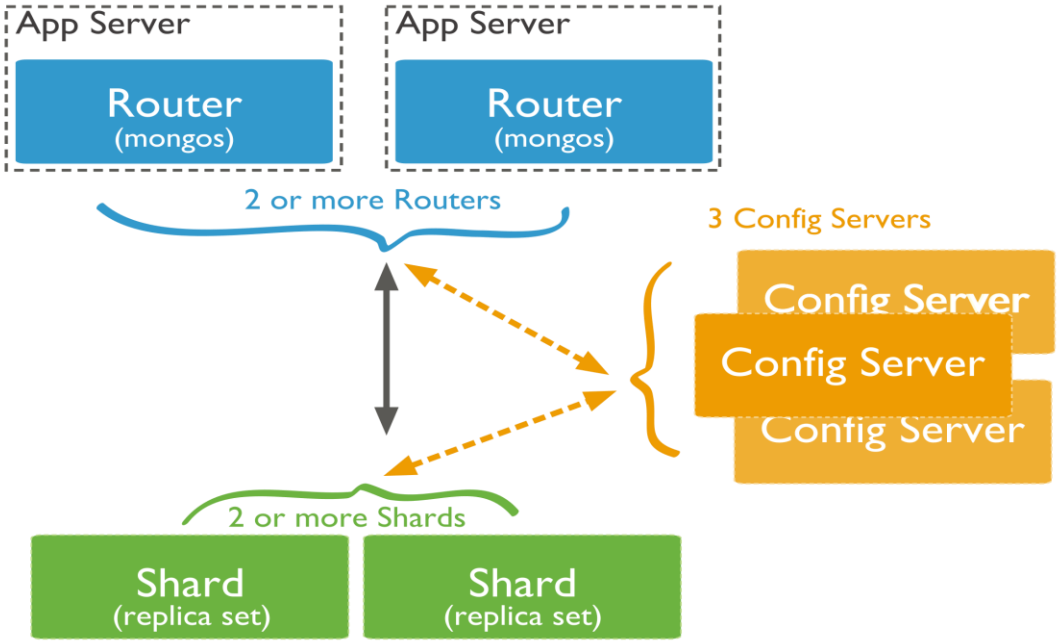
- Replication and sharding are strategies that are often combined.

MongoDb Sharding & Replication

MongoDB Scalability Architecture



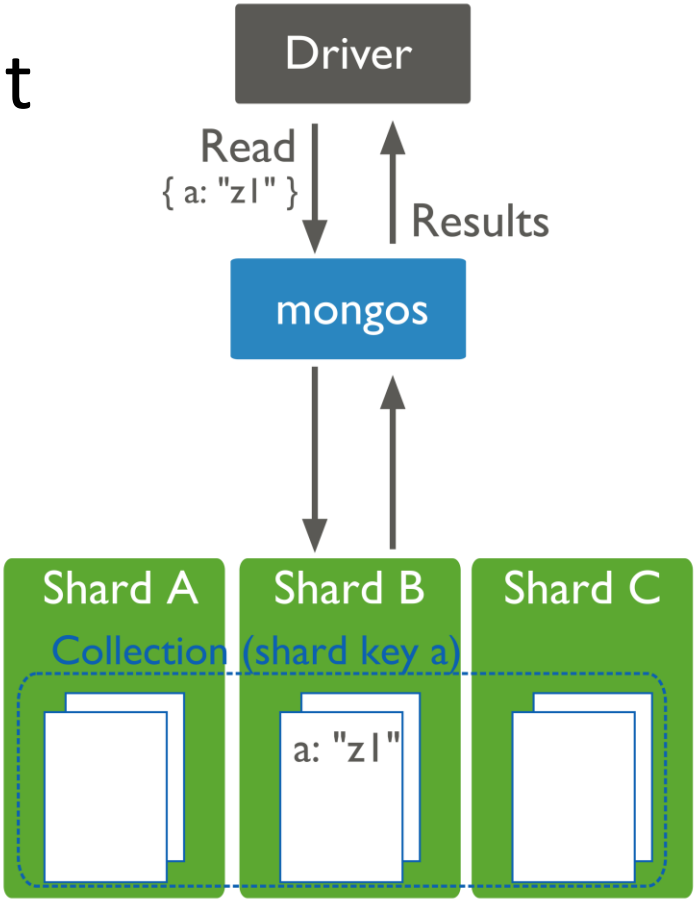
MongoDB Sharded Cluster



- Shard: managed data, can be replicated (replica set)
- Config Server: managed metadata info (e.g., list of chunks on every shard and the ranges that define the chunks)
- Router (mongos): accepts and routes client's queries & update operations

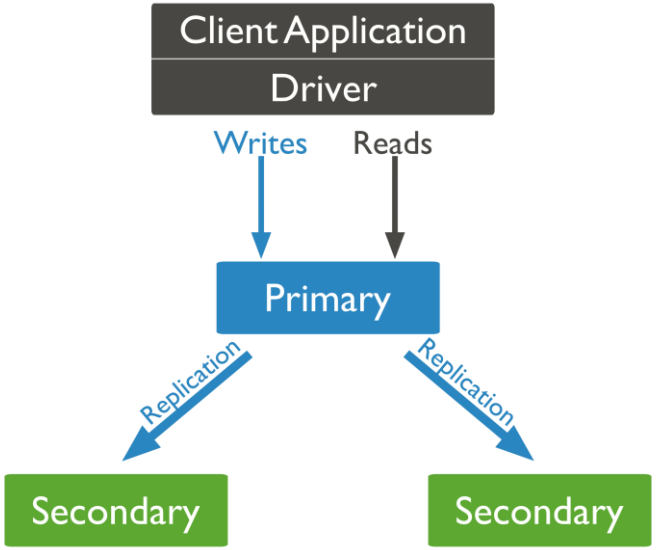
Router (mongos) = routing Operations to Shards

- Read/write operations are sent from client to mongos
- Mongos routes them to the appropriate shards(s)



Replication using Replica Set

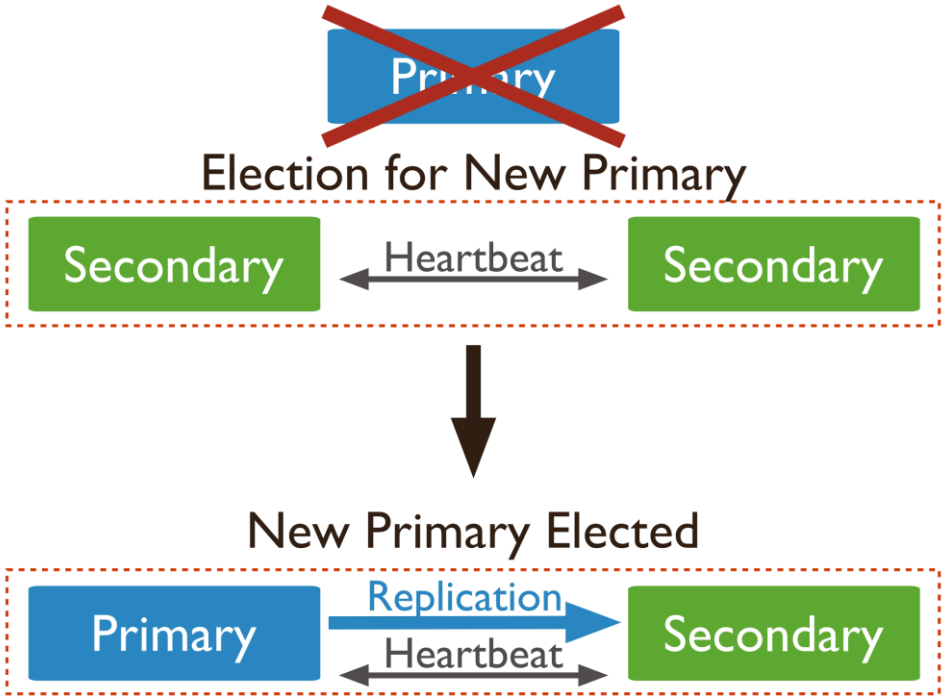
- Goal: Improved Availability, Fault Tolerance, Load Balancing
- Uses Master-Slave architecture: consists of one "***Primary***" and multiple "***Secondary***"
- All write ops must go to the primary
- Primary maintains a log "OpLog"
- Secondary sites periodically read & apply the log from the primary node



Eventual Consistency

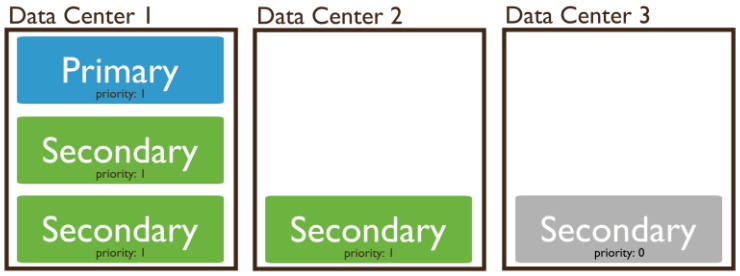
Election when Primary Fails

- Based on majority voting
- Number of members should be odd
- During election, no writes are accepted



Configuring Secondary Nodes

- **Priority = 0**
  - Cannot be primary
  - Cannot accept write only reads
  - May want some data centers not to accept write ops

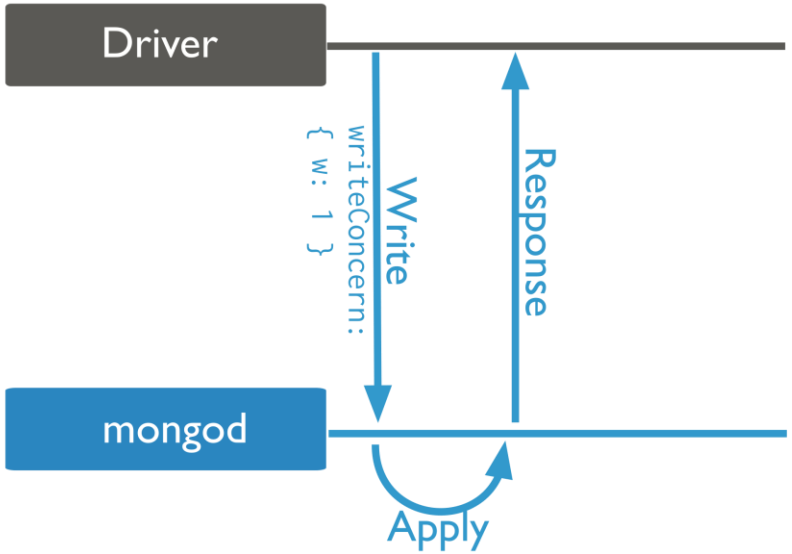


- **Hidden = True**
  - Imply Priority = 0
  - But also cannot accept reads from clients
  - Good for dedicated offline tasks, e.g., reporting
- **SlaveDelay = m**
  - Should be Hidden = True
  - Good to recover from bad transactions

- **Read Modes**
  - Primary
  - PrimaryPreferred
  - Secondary
  - SecondayPreferred
  - Nearest

Writing/Reading: Default Behavior

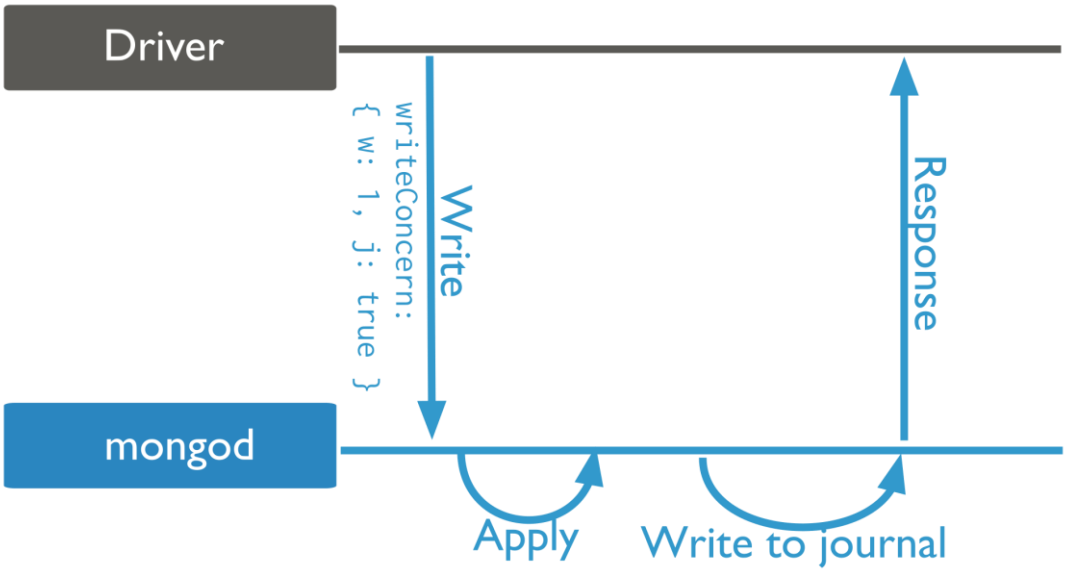
- **Write**
  - All writes go to the primary
  - A write is accepted once the primary accept op. (in memory)
  - Secondaries are not updated yet
- **Read**
  - All reads go to the primary
  - Ensures ***Strict Consistency***



Accepted data can be lost

In this case Secondaries are mostly for Availability & Fault Tolerance

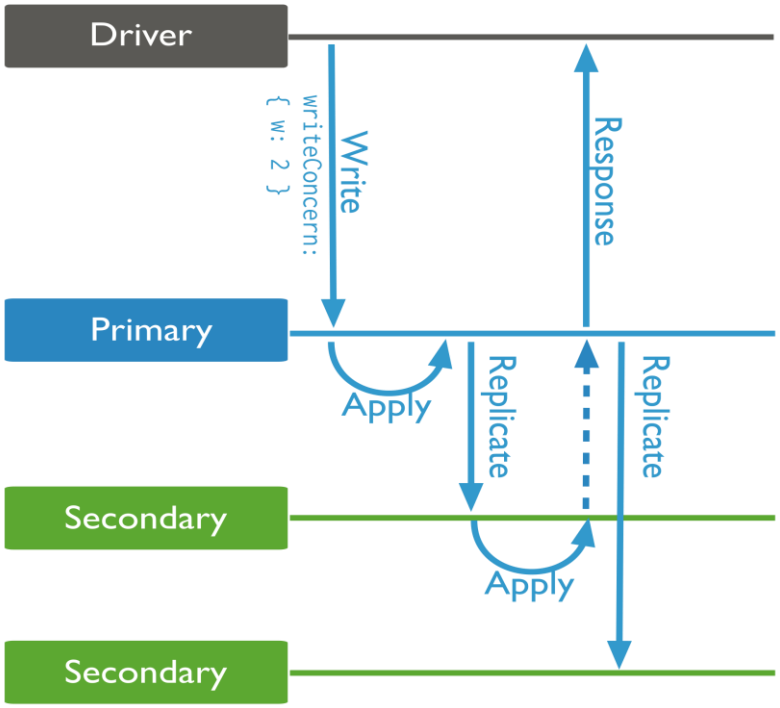
Journaling: Persistent Data



- As before, but a write is accepted only after written to a log on disk
- Still on the primary site
- Accepted data become persistent

Higher Consistency For Reads

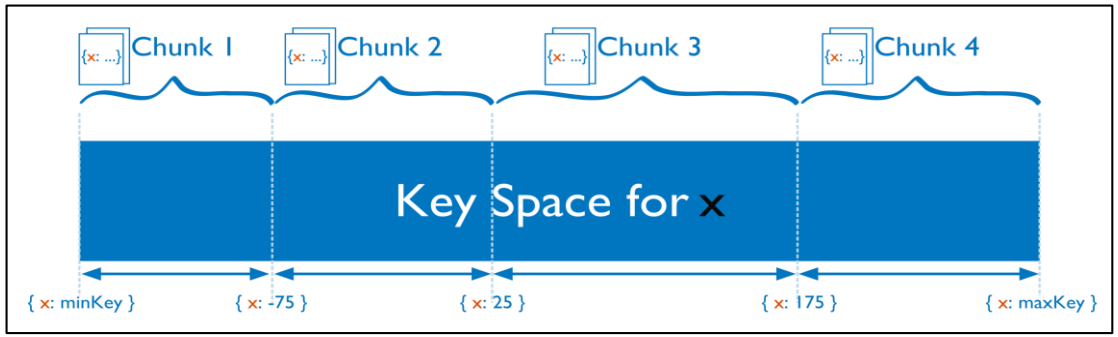
- **Option 1: Read From Primary**
  - Keep writing as is
  - Enforce the read from Primary
  - ➔ Strict Consistency
- **Option 2: Expensive Write**
  - Write is not accepted until **m** secondaries are also updated




```
db.products.insert(
     { item: "envelopes", qty : 100, type: "Clasp" },
     { writeConcern: { w: 2, wtimeout: 5000 } }
)
```

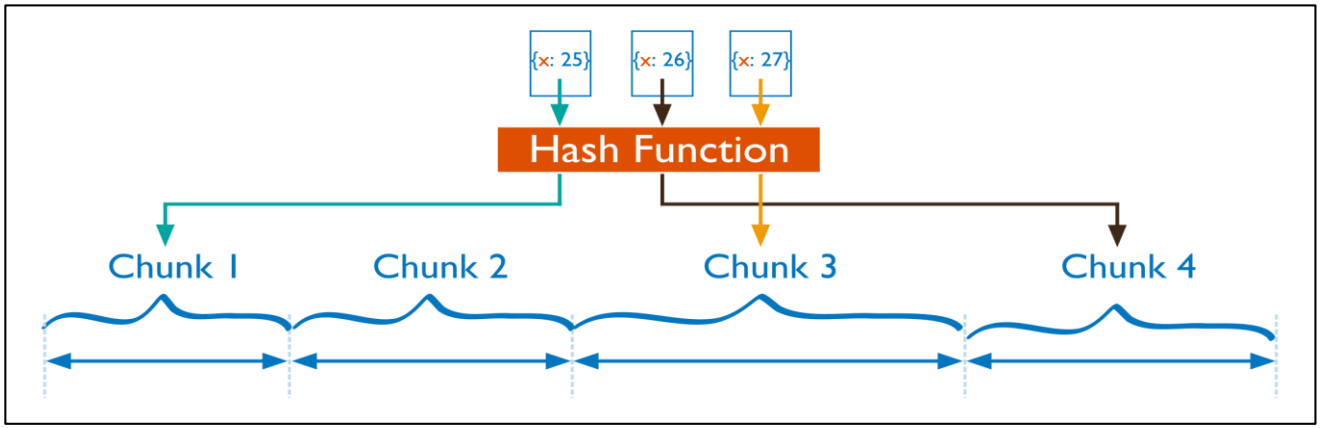
Sharding

- Partitioning the data across many nodes
- A collection is sharded based on a ***key*** into chunks
- ***Key:*** must be present in each document (and indexed)



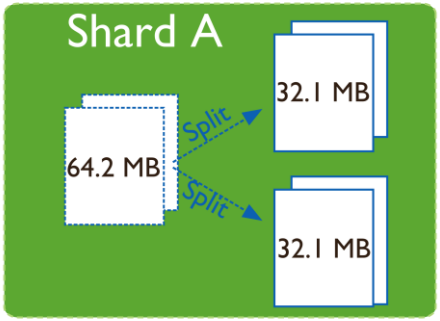
Range-Based

Hash-Based

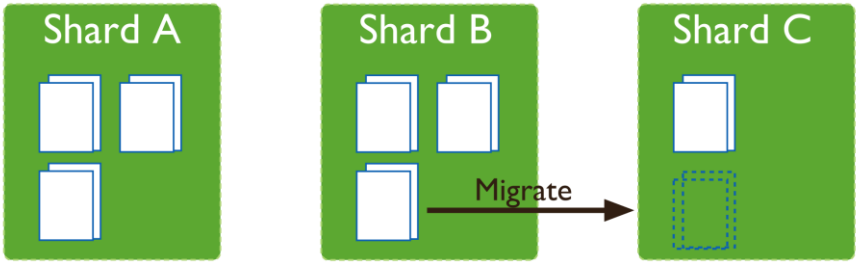


Keeping Balanced Shards

- **Splitter**
  - Splits a big chunk into two
  - Triggered by inserts/updates



- **Balancer**
  - Migrates chunks from one shard to another (least occupied)



Resources

- MongoDB University

https://university.mongodb.com/

- Queries Cheat Sheet

http://s3.amazonaws.com/info-mongodb-com/mongodb_qrc_queries.pdf

- Aggregation Queries

https://docs.mongodb.com/manual/reference/operator/aggregation-pipeline/