CompSci 516
Database Systems

Lecture 20
(Additional/Optional Slides)
NoSQL/MongoDB

Instructor: Sudeepa Roy

Additional and Optional Slides on MongoDB

(May be useful for HW3)
https://docs.mongodb.com
https://docs.mongodb.com/manual/reference/sql-comparison/

Optional slide: Read yourself

MongoDB

- MongoDB is an open source document store written in C++
- provides indexes on collections
- lockless
- provides a document query mechanism
- supports automatic sharding
- Replication is mostly used for failover
- does not provide the global consistency of a traditional DBMS
  - but you can get local consistency on the up-to-date primary copy of a document
- supports dynamic queries with automatic use of indices, like RDBMSs
- also supports map-reduce – helps complex aggregations across docs
- provides atomic operations on fields

Optional slide: Read yourself

MongoDB: Atomic Ops on Fields

- The update command supports "modifiers" that facilitate atomic changes to individual values
  - $set sets a value
  - $inc increments a value
  - $push appends a value to an array
  - $pushAll appends several values to an array
  - $pull removes a value from an array, and $pullAll removes several values from an array
- Since these updates normally occur "in place", they avoid the overhead of a return trip to the server
- There is an "update if current" convention for changing a document only if field values match a given previous value
- MongoDB supports a findAndModify command to perform an atomic update and immediately return the updated document
  - useful for implementing queues and other data structures requiring atomicity

Optional slide: Read yourself

MongoDB: Index

- MongoDB indices are explicitly defined using an ensureIndex call
  - any existing indices are automatically used for query processing
- To find all products released last year (2015) or later costing under $100 you could write:
- db.products.find(
  {released: {$gte: new Date(2015, 1, 1,)}, price
  {'$lte': 100},})

Optional slide: Read yourself

MongoDB: Data

- MongoDB stores data in a binary JSON-like format called BSON
  - BSON supports boolean, integer, float, date, string and binary types
  - MongoDB can also support large binary objects, eg. images and videos
  - These are stored in chunks that can be streamed back to the client for efficient delivery

Optional slide: Read yourself

MongoDB: Replication

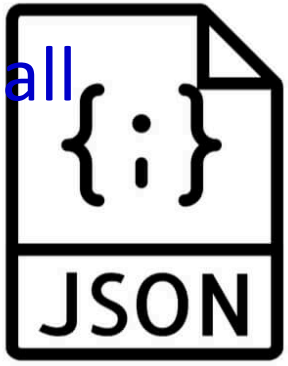
- MongoDB supports master-slave replication with automatic failover and recovery
  - Replication (and recovery) is done at the level of shards
  - Replication is asynchronous for higher performance, so some updates may be lost on a crash

Additional Slides on MongoDB and JSON

ACK: Slides by Prof. Jun Yang

JSON (JavaScript Object Notation)

- Very lightweight data exchange format
  - Much less verbose and easier to parse than XML
  - Increasingly used for data exchange over Web: many Web APIs use JSON to return responses/results
- Based on JavaScript
  - Conforms to JavaScript object/array syntax—you can directly manipulate JSON representations in JavaScript
- But it has gained widespread support by all programming languages



Example JSON vs. XML

```
[
  { "ISBN": "ISBN-10",
    "price": 80.00,
    "title": "Foundations of Databases",
    "authors": [ "Abiteboul",  "Hull", "Vianu" ],
    "publisher": "Addison Wesley",
    "year": 1995,
    "sections": [
      { "title": "Section 1",
        "sections": [
          { "title": "Section 1.1" },
          { "title": "Section 1.2" }
        ]
      },
      { "title": "Section 2" }
    ]
  }, … …
]
```

```
<bibliography>
  <book ISBN="ISBN-10" price="80.00">
    <title>Foundations of Databases</title>
    <author>Abiteboul</author>
    <author>Hull</author>
    <author>Vianu</author>
    <publisher>Addison Wesley</publisher>
    <year>1995</year>
    <section>
      <title>Section 1</title>
      <section><title>Section 1.1</title></section>
      <section><title>Section 1.2</title></section>
    </section>
    <section>
      <title>Section 2</title>
    </section>
  </book>
</bibliography>
```

JSON data model

```
[
 { "ISBN": "ISBN-10",
  "price": 80.00,
  "title": "Foundations of Databases",
  "authors": [ "Abiteboul",  "Hull", "Vianu" ],
  "publisher": "Addison Wesley",
  "year": 1995,
  "sections": [
    { "title": "Section 1",
      "sections": [
        { "title": "Section 1.1" },
        { "title": "Section 1.2" }
      ]
    },
    { "title": "Section 2" }
  ]
 }, … …
]
```

- Two basic constructs
  - Array: comma-separated list of “things” enclosed by brackets
    - Order is important
  - Object: comma-separated set of pairs enclosed by braces; each pair consists of an attribute name (string) and a value (any “thing”)
    - Order is unimportant
    - Attribute names “should” be unique within an object
- Simple types: numbers, strings (in double quotes), and special values “true”, “false”, and “null”
- Thing = a simple value or an array or an object

JSON Schema

- Recall the advantages of having a schema
  - Defines a structure, helps catch errors, facilitates exchange/automation, informs optimization…
- Just like relational data and XML, JSON is getting a schema standard too!
  - Up and coming, but still a draft at this stage

```
{
 "definitions": {
  "sections": {
   "type": "array",
   "description": "Sections.",
   "sections": {"$ref":"#definitions/sections"},
   "minItems": 0
  }
 },
 "title": "Book",
 "type": "object",
 "properties": {
  "ISBN": {
   "type": "string",
   "description": "The book's ISBN number."
  },
  "price": {
   "type": "number",
   "description": "The book's price.",
   "exclusiveMinimum": 0
  },
  ... ...
  "sections": {"$ref":"#definitions/sections"},
  }
 }
 ... ...
}
```

MongoDB

- One of the “NoSQL” poster children
- Started in 2007
- Targeting semi-structured data in JSON
- Designed to be easy to “scale out”
- Good support for indexing, partitioning, replication
- Nice integration in Web development stacks
- Not-so-great support for joins (or complex queries) or transactions

Inside a MongoDB database

- Database = a number of “collections”
- Collection = a list of “documents”
- Document = a JSON object
  - Must have an _id attribute whose value can uniquely identify a document within the collection

☞In other words, a database has collections of similarly structured “documents”

  - Much like tables of records, as opposed to one big XML document that contains all data

Querying MongoDB

- find() and sort()
  - Analogous to single-table selection/projection/sort
- "Aggregation" pipeline
  - With "stages" analogous to relational operators
  - Join, group-by, restructuring, etc.
- MapReduce:
  - Supports user-defined functions
  - We will save this topic until later in this course

☞ We won't cover syntax for creating/updating MongoDB databases in lecture

  - See "Help" of the course website and read the manuals!

Key features to look out for

- Queries written as JSON objects themselves!
  - Natural in some cases (e.g., for specifying conditions on subsets of attributes), but awkward/misleading in others
- Simple path expressions using the "dot notation"
  - Analogous to XPath "/"
- Arrays within objects
  - Work on nested array directly using constructs like dot-index notation, $elemMatch, $map, and $filter
  - Or "unnest" an array so its elements get paired with the owner object in turn for pipeline processing
    - A fundamental concept in working with nested data

Basic MongoDB find()

- Assume db refers to the database and db.bib refers to the collection of books
- Add .toArray() at end to get pretty output
  - You need to do this for Homework 3!

- All books

  db.bib.find()

- Books with title “Foundations of Databases”

  db.bib.find({ title: "Foundations of Databases" })

- Books whose title contains “Database” or “database” and whose price is lower than $50

  db.bib.find({ title:/[dD]atabase/, price:{$lt:50} })

- Books with price between $70 and $100

  db.bib.find({$and:[{price:{$gte:70}}, {price:{$lte:100}}]})

  – By the way, why wouldn’t the following work?

  db.bib.find({ price:{$gte:70}, price:{$lte:100} })

- Books authored by Widom

  db.bib.find({ authors: "Widom" })

  – Note the implicit existential quantification

No general “twig” matching!

- Suppose for a moment publisher is an object itself, with attributes name, state, and country
- The following query won’t get you database books by US publishers:

```
db.bib.find( { title: /[dD]atabase/,
               publisher: { country: "US" } } )
```

  - Instead, the condition on publisher is satisfied only if it is an object with exactly one attribute, and this attribute must be named country and has value "US"
  - What happens is that MongoDB checks the equality against {country: "US"} *as an object*, not as a pattern!

More on nested structures

- Dot notation for XPath-like path expressions
  - Books where some subsection title contains “1.1”

```
db.bib.find({ "sections.sections.title": /1\.1/ })
```

    - Note we that need to quote the expression
    - Again, if the expression returns multiple things, the condition only needs to hold for at least one of them
- Use $elemMatch to ensure that the same array element satisfies multiple conditions, e.g.:

```
db.bib.find({ sections: { $elemMatch: {
            title: /Section/,
            "sections.title": /1\.1/
        }}})
```

- Dot notation for specifying array elements
  - Books whose first author is Abiteboul

```
db.bib.find({ "authors.0": "Abiteboul" })
```

    - Note 0-based indexing; again, need to quote the expression

find() with projection and sorting

- List just the book prices and nothing else

```
db.bib.find( { price: { $exists: true } },
             { _id: 0, price: 1 } )
```

  - The (optional) second argument to find() specifies what to project: 1 means to return, 0 means to omit
    - _id is returned by default unless otherwise specified
- List books but not subsections, ordered by ISBN

```
db.bib.find( {}, {"sections.sections":0} ).sort( {ISBN:1} )
```

  - Output from find() is further sorted by sort() , where 1/-1 mean ascending/descending order

☞"Aggregation pipelines" (next) are better suited for constructing more complex output

MongoDB aggregation pipeline

- Idea: think of a query as performing a sequence of "stages," each transforming an input sequence of JSON objects to an output sequence of JSON objects
- "Aggregation" is a misnomer: there are all kinds of stages
  - Selection ($match), projection ($project), sorting ($sort)
    - Much of which find() and sort() already do
  - Computing/adding attributes with generalized projection ($project/$addFields), unnesting embedded arrays ($unwind), and restructuring output ($replaceRoot)
    - Operators to transform/filter arrays ($map/$filter)
  - Join ($lookup)
  - Grouping and aggregation ($group)
    - Operators to aggregate (e.g., $sum) or collect into an array ($push)

Example: The congress MongoDB database

- Two collections, people and committees
  - Each object in people is a legislator
    - roles = array of objects
  - Each object in committees is a committee
    - members = array of objects
    - subcommittees = an array of subcommittee objects, each with its own members array
    - Each member object's id field references a legislator _id

```
[
  {
   "_id" : "B000944",
   "birthday" : ISODate("1952-11-09T00:00:00Z"),
   "gender" : "M",
   "name" : "Sherrod Brown",
   "roles" : [
     {
      "district" : 13,
      "enddate" : ISODate("1995-01-03T00:00:00Z"),
      "party" : "Democrat",
      "startdate" : ISODate("1993-01-05T00:00:00Z"),
      "state" : "OH",
      "type" : "rep"
     },
     {
      "district" : 13,
      "enddate" : ISODate("1997-01-03T00:00:00Z"),
      "party" : "Democrat",
      "startdate" : ISODate("1995-01-04T00:00:00Z"),
      "state" : "OH",
      "type" : "rep"
     }, … …
   ]
  },
 … …
]
```

```
[
  {
   "_id" : "HSAG",
   "displayname" : "House Committee on Agriculture",
   "type" : "house",
   "members" : [
     {
      "id" : "C001062",
      "role" : "Chair"
     },
     {
      "id" : "G000289"
     }, … …
   ],
   "subcommittees" : [
     {
      "code" : "15",
      "displayname" : "Conservation and Forestry",
      "members" : [
        {
         "id" : "L000491",
         "role" : "Chair"
        },
        {
         "id" : "T000467"
        }, … …
      ]
     }, … …
   ]
  },
 … …
]
```

Selection/projection/sorting

Find Republican legislators, output only their name and gender, sort by name

```
db.people.aggregate([
    { $match: {
       "roles.party": "Republican”
    } },
    { $project: {
       _id: false,
       name: true,
       gender: true
    } },
    { $sort: {
       name: 1
    } }
])
```

- *aggregate() takes an array of stages*
- *Note again quoting the dot natation*
- *Note again the semantics of comparing a list of values: i.e., the query finds legislators who have ever served roles as Republicans*

Generalized projection

Find Republican legislators, output their name, gender, and roles as an array of types (sen or rep)

```
db.people.aggregate([
  { $match: {
    "roles.party": "Republican"
  } },
  { $addFields: {
    compact_roles: {
      $map: { input: "$roles",
              as: "role",
              in: "$$role.type" }
    }
  } },
  { $project: {
    _id: false,
    name: true,
    gender: true,
    roles: "$compact_roles"
  } }
])
```

- *Use " : "$xxx" " to tell MongoDB to interpret xxx as a field in the "current" object instead of just a string literal*
- *In $map, as defines a new variable to loop over elements in the input array*
- *For each input element, $map computes the in expression and appends its value to the output array*
  - *Use " : "$$xxx" " to tell MongoDB that xxx is a new variable created during execution (as opposed to a field in the current object)*

Unnesting and restructuring

Create a list of subcommittees: for each, simply display its name and the name of the committee it belongs to

```
db.committees.aggregate([
    { $unwind: "$subcommittees" },
    { $replaceRoot: { newRoot: {
       committee: "$displayname",
       subcommittee: "$subcommittees.displayname"
    } } }
])
```

For each input committee, $unwind loops over its subcommittees array, one element at a time, and outputs a copy of the committee object, with its subcommittees value replaced with this single element

Join

For each committee (ignore its subcommittees), display its name and the name of its chair

```
db.committees.aggregate([
  { $addFields: {
      chair_member: { $filter: {
        input: "$members",
        as: "member",
        cond: { $eq: ["$$member.role",
                      "Chairman"] }
      } }
  } },
  { $lookup: {
      from: "people",
      localField: "chair_member.id",
      foreignField: "_id",
      as: "chair_person"
  } },
  { $project: {
      _id: false,
      name: "$displayname",
      chair: { $arrayElemAt:["$chair_person.name",0] }
  } },
])
```

- *$filter filters input array according to cond and produces and output array*
  - *In $lookup, localField specifies the attribute in the current object whose value will be used for lookup*
  - *from specifies the collection in which to look for joining objects; foreignField specifies the attribute therein to be joined*
  - *$lookup creates an attribute in the current object with the name specified by as, and sets it value to an array holding all joining objects*
  - ☞ *Non-equality joins are also possible, with more complex syntax*

$arrayElemAt extracts an array element by its index ("chair_person.0.name" doesn't work here)

Grouping and aggregation

- Count legislators by gender, and list the names of legislators for each gender

```
db.people.aggregate([
    { $group: {
        _id: "$gender",
        count: { $sum: 1 },
        list: { $push: "$name" }
    } }
])
```

- *The required _id specifies the grouping expression, whose value becomes the identifying attribute of output objects (one per group)*
- *Other attributes hold aggregate values, computed using aggregation operators*
  - *$sum compute a total by adding each input*
  - *$push creates an array by appending each input*

Summary and discussion

- JSON is like much more lightweight version of XML
  - But perhaps not as good for mixed contents
- Writing queries JSON is sometimes convenient, but confusing in many situations
- Query as as pipeline: less declarative, but arguably easier to implement (especially to parallelize)
- Nested structures requires more query constructs
  - $unwind stage, $elemMatch/$map/$filter/$push/$arrayElemAt operators, etc.
  - Distinction between the top-level and nested arrays is annoying
    - E.g., $match stage and $filter operator basically do the same thing
    - XQuery is much nicer in this regard (with ability to nest queries in return)

☞ There is actually XQuery-like language for JSON called "JSONiq," but it remains less known