JSON & MongoDB

Introduction to Databases
CompSci 316 Fall 2019
Announcements (Wed. Oct. 23)

• Homework 3 due in 1½ weeks
• Project milestone 2 due in 2 weeks
• See email about weekly project progress updates
  • Check Sakai email archive if you missed it
  • First one is due tonight!
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

```json
[
  {
    "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"
      }
    ]
  }, ... ...
]
```

```xml
<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

• 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
[  
  {  
    "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" }
        ]
      }
    ]
  }, ...
]
```
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",
    },
    "price": {
      "type": "number",
      "description": "The book's price."
    },
    "exclusiveMinimum": 0
  }
}
```
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 \texttt{find}()

- All books
  \texttt{db.bib.find()}

- Books with title “Foundations of Databases"
  \texttt{db.bib.find(\{ title: "Foundations of Databases" \})}

- Books whose title contains “Database” or “database” and whose price is lower than $50
  \texttt{db.bib.find(\{ title:/[dD]atabase/, price:{\$lt:50} \})}

- Books with price between $70 and $100
  \texttt{db.bib.find(\{$and:[[\{price:{\$gte:70}\}, \{price:{\$lte:100}\}\}]}\})}
  - By the way, why wouldn’t the following work?
    \texttt{db.bib.find(\{ price:{\$gte:70}, price:{\$lte:100} \})}

- Books authored by Widom
  \texttt{db.bib.find(\{ authors: "Widom" \})}
  - Note the implicit existential quantification

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

```javascript
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
  
  ```javascript
  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
  
  ```javascript
  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)
The congress MongoDB database

• As in your Homework 3
• 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
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 notation
- 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

```javascript
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

- `$filter` filters input array according to cond and produces and output array

```plaintext
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]
            }
        }
    }
])
```

- 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 a 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 a pipeline: less declarative, but arguably easier to implement (especially to parallelize)

• Nested structures require more query constructs
  • $\text{unwind}$ stage, $\text{elemMatch} / \text{map} / \text{filter} / \text{push} / \text{arrayElemAt}$ operators, etc.
  • Distinction between the top-level and nested arrays is annoying
    • E.g., $\text{match}$ stage and $\text{filter}$ 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