JSON & MongoDB

Introduction to Databases

CompSci 316 Fall 2019

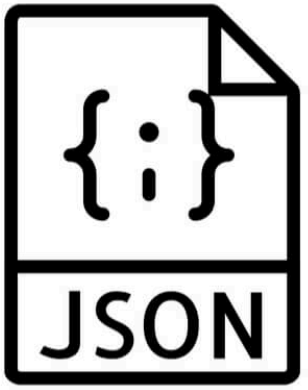
DUKE
COMPUTER SCIENCE

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

```
[
  { "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`)

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`

```
[
  {
    "_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" : "Ranking Member"
      },
      {
        "id" : "T000467"
      }, … …
    ],
    "subcommittees" : [
      {
        "code" : "15",
        "displayname" : "Conservation and Forestry",
        "members" : [
          {
            "id" : "S001209",
            "role" : "Chair"
          },
          {
            "id" : "F000455"
          }, … …
        ]
      }, … …
    ]
  },
  … …
]
```

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 a lightweight version of XML
  - But perhaps not as good for mixed contents
- Writing queries in JSON format 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