B4M36DS2, BE4M36DS2: **Database Systems 2**

https://cw.fel.cvut.cz/b231/courses/b4m36ds2/

Lecture 8

Document Databases: MongoDB

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Lecture Outline

Document databases

- Introduction

MongoDB

- Data model
- CRUD operations
    - **Insert**
    - **Update**
    - **Remove**
    - **Find**: projection, selection, modifiers

Document Stores

Data model

- **Documents**
  - Self-describing
  - **Hierarchical tree structures** (JSON, XML, …)
    - Scalar values, maps, lists, sets, nested documents, …
  - Identified by a **unique identifier** (key, …)
- Documents are **organized into collections**

Query patterns

- Create, update or remove a document
- **Retrieve documents according to complex query conditions**

Observation

- Extended key-value stores where the value part is examinable

MongoDB Document Database

MongoDB

JSON document database

- https://www.mongodb.com/
- Features
  - Open source, high availability, eventual consistency, automatic sharding, master-slave replication, automatic failover, secondary indices, …
- Developed by **MongoDB**
- Implemented in C++, C, and JavaScript
- Operating systems: **Windows**, **Linux**, Mac OS X, …
- Initial release in 2009

Query Example

Collection of movies

```
{
  _id: ObjectId("1"),
  title: "Vratné lahve",
  year: 2006
}
```

```
{
  _id: ObjectId("2"),
  title: "Samotáři",
  year: 2000
}
```

```
{
  _id: ObjectId("3"),
  title: "Medvídek",
  year: 2007
}
```

Query statement

Titles of movies filmed in *2005* and later, sorted by these titles in descending order

```
db.movies.find(
  { year: { $gt: 2005 } },
  { _id: false, title: true }
).sort({ title: -1 })
```

Query result

```
{ title: "Vratné lahve" }
```

```
{ title: "Medvídek" }
```

Data Model

Database system structure

$\boxed{\text{Instance} \rightarrow \textbf{databases} \rightarrow \textbf{collections} \rightarrow \textbf{documents}}$

- Database
- Collection
  - Collection of documents, usually of a similar structure
- Document
  - MongoDB **document** = **one** JSON **object**
    - I.e. even a complex JSON object with other recursively nested objects, arrays or values
  - Each document has a **unique identifier** (primary key)
    - Technically realized using a **top-level `_id` field**

Data Model

MongoDB **document**

- Internally stored in BSON format (*Binary JSON*)
    - Maximal allowed size 16 MB
    - GridFS can be used to split larger files into smaller chunks

Restrictions on fields

- **Top-level** `_id` is reserved for a **primary key**
- Field names **cannot start with** $ and **cannot contain .**
    - $ is reserved for query operators
    - . is used when accessing nested fields
- The order of fields is preserved
    - Except for `_id` fields that are always moved to the beginning
- **Names of fields must be unique**

Primary Keys

Features of identifiers

- **Unique** within a collection
- **Immutable** (cannot be changed once assigned)

- Can be of **any type** other than a JSON array

Key management

- Natural identifier
- Auto-incrementing number – not recommended
- UUID (*Universally Unique Identifier*)

- ObjectId – **special 12-byte BSON type** (the default option)
  Small, likely unique, fast to generate, ordered, based on a timestamp, machine id, process id, and a process-local counter

Design Questions

Data modeling (in terms of **collections and documents**)

- No explicit schema is provided, nor expected or enforced
  - However…
    - documents within a collection are similar in practice
    - **implicit schema** is required nevertheless
- Challenge
  - Balancing application requirements, performance aspects, data structure, mutual relationships, query patterns, …

Two main concepts

- References
- Embedded documents

Denormalized Data Models

Embedded documents

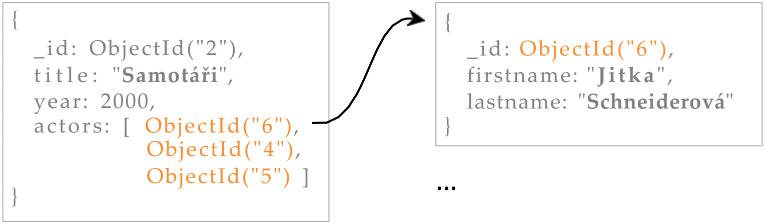
- Related data in a single document
  - with embedded JSON objects, so called subdocuments
- Pros: data manipulation (fewer queries need to be issued)
- Cons: possible data redundancies
- Suitable for **one-to-one** or **one-to-many** relationships

```
{
  _id: ObjectId("2"), title: "Samotáři", year: 2000,
  actors: [
    { firstname: "Jitka", lastname: "Schneiderová" },
    { firstname: "Ivan", lastname: "Trojan" },
    { firstname: "Jiří", lastname: "Macháček" }
  ]
}
```

Normalized Data Models

References

- Related data in separate documents
  - These are interconnected via directed links (references)
  - Technically expressed using **ordinary values with identifiers of target documents** (i.e. no special construct is provided)
- Features: higher flexibility, follow up queries might be needed
- Suitable for **many-to-many** relationships



```
{
  _id: ObjectId("2"),
  title: "Samotáři",
  year: 2000,
  actors: [ ObjectId("6"),
            ObjectId("4"),
            ObjectId("5") ]
}
```

```
{
  _id: ObjectId("6"),
  firstname: "Jitka",
  lastname: "Schneiderová"
}
```

…

Sample Data

Collection of **movies**

```
{
  _id: ObjectId("1"),
  title: "Vratné lahve", year: 2006,
  actors: [ ObjectId("7"), ObjectId("5") ]
}
```

```
{
  _id: ObjectId("2"),
  title: "Samotáři", year: 2000,
  actors: [ ObjectId("6"), ObjectId("4"),
            ObjectId("5") ]
}
```

```
{
  _id: ObjectId("3"),
  title: "Medvídek", year: 2007,
  actors: [ ObjectId("5"), ObjectId("4") ]
}
```

Collection of **actors**

```
{ _id: ObjectId("4"),
  firstname: "Ivan",
  lastname: "Trojan" }
```

```
{ _id: ObjectId("5"),
  firstname: "Jiří",
  lastname: "Macháček" }
```

```
{ _id: ObjectId("6"),
  firstname: "Jitka",
  lastname: "Schneiderová" }
```

```
{ _id: ObjectId("7"),
  firstname: "Zdeněk",
  lastname: "Svěrák" }
```

Application Interfaces

mongo shell

- **Interactive interface to MongoDB**

mongosh "mongodb://localhost:42222" -u login -p password

Drivers

- Java, C, C++, C#, Perl, PHP, Python, Ruby, Scala, ...

Query Language

MongoDB query language is based on **JavaScript**

- **Single command** / **entire script**
- Read queries return a cursor
  - Allows us to iterate over all the selected documents
- Each command is always evaluated over a <u>single collection</u>

Query patterns

- Basic **CRUD** operations
  - Accessing documents via identifiers or **conditions on fields**
- Aggregations: **MapReduce**, pipelines, grouping

CRUD Operations

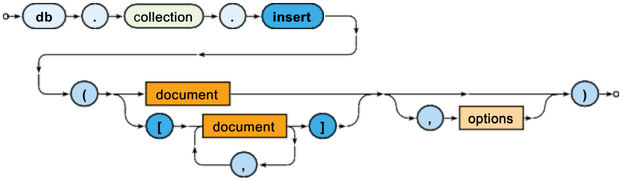
Overview

- **Create**
  - db.collection.**insertOne**(), **insertMany()**
    - Insert a new document (or documents) into a collection
- **Update**
  - db.collection.**replaceOne**()
  - db.collection.**updateOne**(), **updateMany()**
    - Modifiy an existing document / documents or insert a new one
- **Delete**
  - db.collection.**deleteOne**(), **deleteMany()**
    - Delete an existing document / documents
- **Read**
  - db.collection.**find**(), **findOne()**

Insert Operation

Insert Operation: insertOne, insertMany

Inserts a new document / documents into a given collection



- Parameters
  - **Document**: one or more documents to be inserted
    - Provided document identifiers (_id fields) must be unique
    - When missing, they are generated automatically (ObjectId)
  - **Options**
- Collections are created automatically when not yet exist

Insert Operation: Examples

Insert a new actor document

```
db.actors.insertOne(
  {
    firstname: "Anna",
    lastname: "Geislerová"
  }
)
```

```
{
  _id: ObjectId("8"),
  firstname: "Anna",
  lastname: "Geislerová"
}
```

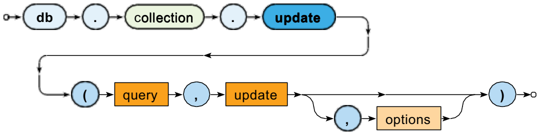
Insert two new movies

```
db.movies.insertMany(
 [
    {
       _id: ObjectId("9"), title: "Želary", year: 2003,
       actors: [ ObjectId("4"), ObjectId("8") ]
    },
    { title: "Anthropoid", year: 2016, actors: [ ObjectId("8") ] },
 ]
)
```

Update Operation

Update Operation: replaceOne, updateOne

Modifies / replaces an existing document / documents



- Parameters
  - **Query**: description of documents to be updated
    - The same behavior as in find operations
  - **Update**: modification actions to be applied
  - **Options**
- Use **replaceOne** or **updateOne** to update **one document**
  - Use **updateMany** to update two or more documents

Update Operation: Examples

Replace the whole document of at most one specified actor

```
db.actors.replaceOne(
  { _id: ObjectId("8") },
  { firstname: "Aňa",
    lastname: "Geislerová" }
)
```

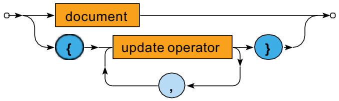
```
{
  _id: ObjectId("8"),
  firstname: "Aňa",
  lastname: "Geislerová"
}
```

Update all movies filmed in 2015 or later

```
db.movies.updateMany(
  { year: { $gt: 2015 } },
  {
    $set: { new: true },
    $inc: { rating: 3 }
  }
)
```

Update Operation

Update / replace modes

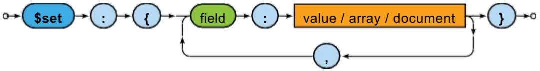


- **Replace (replaceOne** method**)**
  - **The whole document is replaced** (_id is preserved)
- **Update (updateOne, updateMany** methods**)**
  the `update` parameter contains only **update operators**
  - **The current document is updated** using these operators
    - $set, $unset, $inc, $mul, …
    - Each operator can be used at most once

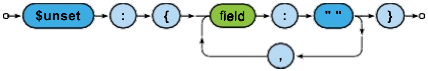
Update Operators

Field operators

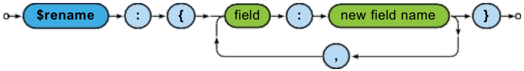
- **$set** – sets the value of a given field / fields



- **$unset** – removes a given field / fields



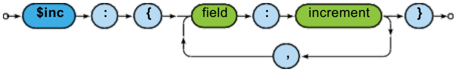
- **$rename** – renames a given field / fields



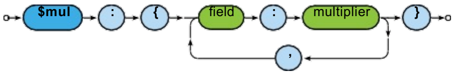
Update Operators

Field operators

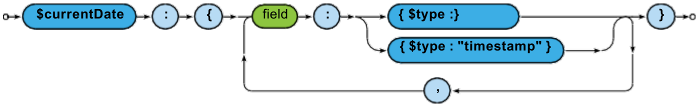
- **$inc** – increments the value of a given field / fields



- **$mul** – multiplies the value of a given field / fields



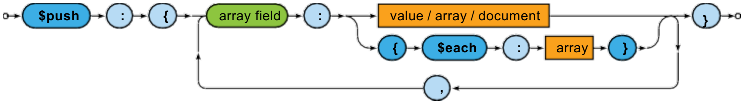
- **$currentDate** – stores the current date time / timestamp to a given field / fields



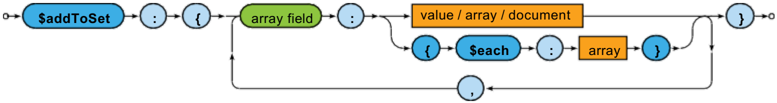
Update Operators

Array operators

- **$push** – adds one item / all items to the end of an array



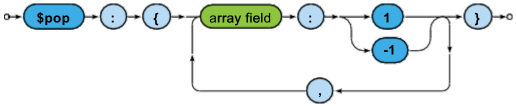
- **$addToSet** – adds one item / all items to the end of an array, but duplicate values are ignored



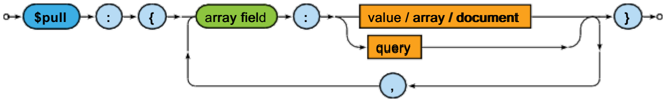
Update Operators

Array operators

- **$pop** – removes the first / last item of an array



- **$pull** – removes all array items that match a specified query



Upsert Mode

Upsert behavior of update operation

- When `{ upsert: true }` option is specified,
  and, at the same time, **no document was updated**
  $\Rightarrow$ **new document is inserted**

What this document will contain?

- In case of the **replace** mode…
  - All the fields (i.e. value fields) from the update parameter
- In case of the **update** mode…
  - All the value fields from the query parameter,
  - and the outcome of all the update operators from the update parameter
- `_id` field is preserved, or newly generated if necessary

Upsert Mode: Example

Unsuccessful update of a movie resulting to an insertion

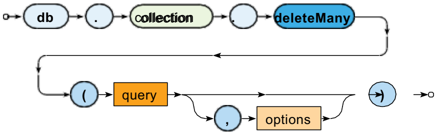
```
db.movies.updateOne(
  { title: "Tmavomodrý svět", year: { $gt: 2000 } },
  {
    $set: {
      director: { firstname: "Jan", lastname: "Svěrák" },
      year: 2001
    },
    $inc: { rating: 2 }
  },
  { upsert: true }
)
```

```
{ _id: ObjectId("11"),
  title: "Tmavomodrý svět",
  director: { firstname: "Jan", lastname: "Svěrák" },
  year: 2001,
  rating: 2 }
```

Remove Operation

Delete Operation: deleteOne, deleteMany

Removes a document / documents from a given collection



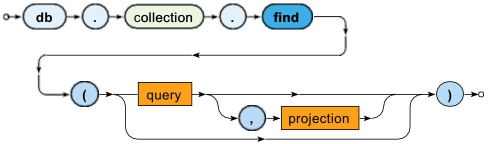
- Parameters
  - **Query**: description of documents to be removed
    - The same behavior as in find operations
  - **Options**: allows users to specify language-specific rules for string comparison, such as rules for lettercase and accent marks

db.collection.deleteOne() deletes the first document that matches the query

Find Operation

Find Operation

Selects documents from a given collection



- Parameters
  - **Query**: description of documents to be selected
  - **Projection**: fields to be included / excluded in the result
- Matching documents are returned via an iterable cursor
  - This allows us to chain further sort, skip or limit operations

Find Operation: Examples

Select all movies from our collection

```
db.movies.find()
```

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

Select a particular movie based on its document identifier

```
db.movies.findOne( { _id: ObjectId("2") } )
```

Select movies filmed in *2000* with a rating greater than *1*

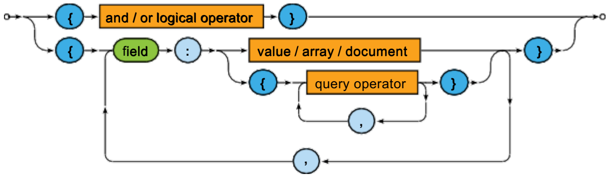
```
db.movies.find( { year: 2000, rating: { $gt: 1 } } )
```

Select movies filmed between *2005* and *2015*

```
db.movies.find( { year: { $gte: 2005, $lte: 2015 } } )
```

Selection

Query parameter describes the documents we are interested in



Boolean expression with <u>one</u> top-level logical operator: `$and`, `$or`

Conditions on individual <u>distinct</u> fields

- **Value equality**
  - The actual field value must be identical to the specified value
- **Query operators**
  - The actual field value must satisfy all the provided operators

Selection: Field Conditions

Value equality

- The actual field value must be identical to the specified value
- I.e. identical…
  - including the number, order and names of recursively identical values of all nested **object fields**
  - including the number and order of recursively identical **array items**

Query operators

- The actual field value must satisfy all the provided operators
  - Each operator can be used at most once

Value Equality: Examples

Select movies having a specific director

```
db.movies.find(
  { director: { firstname: "Jan", lastname: "Svěrák" } }
)
```

```
db.movies.find(
  { director: { lastname: "Svěrák", firstname: "Jan" } }
)
```

Select movies having specific actors

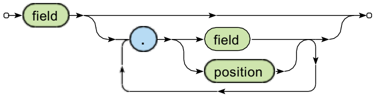
```
db.movies.find( { actors: [ ObjectId("7"), ObjectId("5") ] } )
```

```
db.movies.find( { actors: [ ObjectId("5"), ObjectId("7") ] } )
```

Queries in both the pairs are <u>not equivalent</u>!

Dot Notation

The **dot notation** for field names



- Accessing **fields of embedded documents**
  - "field.**subfield**"
    - E.g.: "director.firstname"
- Accessing **items of arrays**
  - "field.**index**"
    - E.g.: "actors.2"
    - Positions start at 0

Value Equality

Example (revisited)

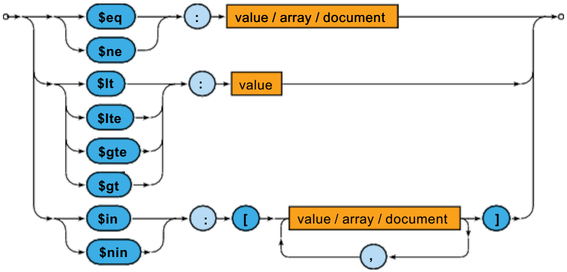
Select movies having a specific director

```
db.movies.find(
  { director: { firstname: "Jan", lastname: "Svěrák" } }
)
```

```
db.movies.find(
  { "director.firstname": "Jan", "director.lastname": "Svěrák" }
)
```

Query Operators

Comparison operators



- Comparisons take particular BSON data types into account
  - Certain numeric conversions are automatically applied

Query Operators

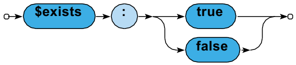
Comparison operators

- **$eq, $ne**
  - Tests the actual field value for **equality** / **inequality**
    - The same behavior as in case of value equality conditions
- **$lt, $lte, $gte, $gt**
  - Tests whether the actual field value is **less than** / **less than or equal** / **greater than or equal** / **greater than** the provided value
- **$in**
  - Tests whether the actual field value is equal to **at least one** of the provided values
- **$nin**
  - Negation of $in

Query Operators

Element operators

- **$exists** – tests whether a given field **exists** / **not exists**



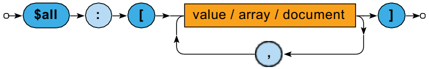
Evaluation operators

- **$regex** – tests whether a given field value matches a specified **regular expression** (PCRE)
- **$text** – performs **text search** (text index must exists)

Query Operators

Array operators

- $all – tests whether a given array **contains all the specified items** (in any order)



Example (revisited)

Select movies having specific actors

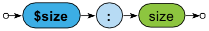
```
db.movies.find(
  { actors: [ ObjectId("5"), ObjectId("7") ] }
)
```

```
db.movies.find(
  { actors: { $all: [ ObjectId("5"), ObjectId("7") ] } }
)
```

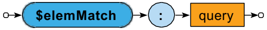
Query Operators

Array operators

- **$size** – tests the size of a given array against a fixed number (and not, e.g., a range, unfortunately)



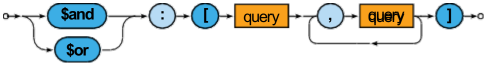
- **$elemMatch** – tests whether a given array **contains at least one item** that satisfies <u>all</u> the involved query operations



Query Operators

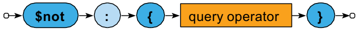
Logical operators

- $and, $or



  - Logical connectives for **conjunction** / **disjunction**
  - At least 2 involved query expressions must be provided
  - **Only allowed at the top level** of a query

- $not



  - Logical **negation** of exactly one involved query operator
  - I.e. **cannot be used at the top level** of a query

Querying Arrays

Condition based on **value equality** is satisfied when...

- the given field as a whole is identical to the provided value, or
- at least one item of the array is identical to the provided value

```
db.movies.find( { actors: ObjectId("5") } )
```

```
{ actors: ObjectId("5") }
```

```
{ actors: [ ObjectId("5"), ObjectId("7") ] }
```

Querying Arrays

Condition based on **query operators** is satisfied when...

- the given field as a whole satisfies all the involved operators, or
- each of the involved operators is satisfied by at least one item of the given array
  - note, however, that this item **may not be the same** for all the individual operators

```
db.movies.find( { ratings: { $gte: 2, $lte: 3 } } )
```

```
{ ratings: 3 }
```

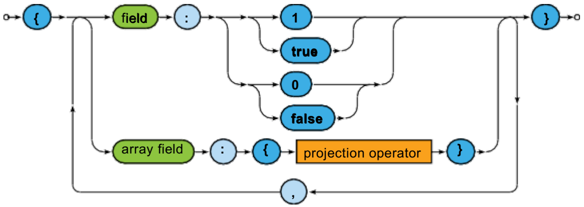
```
{ ratings: [ 3, 7, 5 ] }
```

```
{ ratings: [ 1, 4 ] }
```

Use `$elemMatch` when just a single array item should be found for all the operators

Projection

Projection allows us to determine the fields returned in the result

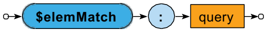


- `true` or `1` for fields to be **included**
- `false` or `0` for fields to be **excluded**
- Positive and negative enumerations <u>cannot be combined!</u>
    - The only exception is `_id` which is **included by default**
- **Projection operators** – allow to select particular array items

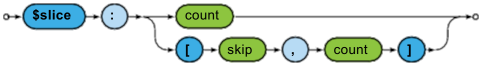
Projection Operators

Array operators

- **$elemMatch** – selects <u>the first</u> matching item of an array
  This item must satisfy <u>all</u> the operators included in `query`
  When there is no such item, the field is not returned at all



- **`$slice`** – selects the first `count` items of an array (when `count` is positive) / the last `count` items (when negative)
  Certain number of items can also be skipped



Projection: Examples

Find a particular movie, select its identifier, title and actors

```
db.movies.find(
  { _id: ObjectId("2") },
  { title: true, actors: true }
)
```

```
{
  _id: ObjectId("2"),
  title: "Samotáři",
  actors: [ ObjectId("6"),
            ObjectId("4"),
            ObjectId("5") ]
}
```

Find movies from *2000*, select their titles and the last two actors

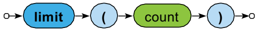
```
db.movies.find(
  { year: 2000 },
  {
    title: 1, _id: 0,
    actors: { $slice: -2 }
  }
)
```

```
{
  title: "Samotáři",
  actors: [ ObjectId("4"),
            ObjectId("5") ]
}
```

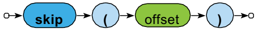
Modifiers

Modifiers change the order and number of returned documents

- **sort** – orders the documents in the result
- **limit** – returns at most a certain number of documents



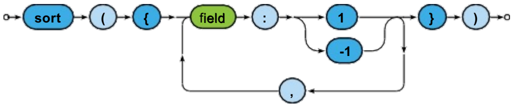
- **skip** – skips a certain number of documents from the beginning



All the modifiers are optional, can be chained in <u>**any order**</u> (without any implications), but **must all be specified before any documents are retrieved** via a given cursor

Modifiers

Sort modifier orders the documents in the result



- 1 for **ascending**, -1 for **descending** order
- The order of documents is undefined unless explicitly sorted
- Sorting of larger datasets should be supported by indices
- **Sorting happens before the projection phase**
    - I.e. not included fields can be used for sorting purposes as well

Lecture Conclusion

MongoDB

- Document database for **JSON documents**
- **Sharding with master-slave replication architecture**

Query functionality

- CRUD operations
  - **Insert**, **find**, **update**, **remove**
  - Complex filtering conditions
- MapReduce
- Index structures