MI-PDB, MIE-PDB: **Advanced Database Systems**

http://www.ksi.mff.cuni.cz/~svoboda/courses/2015-2-MIE-PDB/

Lecture 13:

Document Databases, JSON, MongoDB

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Document Databases

Basic Characteristics

- Documents are the main concept
  - Stored and retrieved
  - XML, JSON, …
- Documents are
  - Self-describing
  - Hierarchical tree data structures
  - Can consist of maps, collections, scalar values, nested documents, …
- Documents in a collection are expected to be similar
  - Their schema can differ
- Document databases store documents in the value part of the key-value store
  - Key-value stores where the value is examinable

Document Databases

Suitable Use Cases

Event Logging

- Many different applications want to log events
  - Type of data being captured keeps changing
- Events can be sharded by the name of the application or type of event

Content Management Systems, Blogging Platforms

- Managing user comments, user registrations, profiles, web-facing documents, …

Web Analytics or Real-Time Analytics

- Parts of the document can be updated
- New metrics can be easily added without schema changes

E-Commerce Applications

- Flexible schema for products and orders
- Evolving data models without expensive data migration

Document Databases

When Not to Use

Complex Transactions Spanning Different Operations

- Atomic cross-document operations
  - Some document databases do support (e.g., RavenDB)

Queries against Varying Aggregate Structure

- Design of aggregate is constantly changing → we need to save the aggregates at the lowest level of granularity
  - i.e., to normalize the data

Document Databases

Representatives

mongoDB ✓

Apache CouchDB

terrastore

OrientDB

RAVENDB

Lotus Notes
Storage Facility

JSON

JavaScript Object Notation

Introduction

- **JSON** = JavaScript Object Notation
  - **Text-based easy-to-read-and-write open standard for data interchange**
    - Serializing and transmitting structured data
    - Design goals: **simplicity and universality**
  - Derived from JavaScript, but language independent
    - Uses conventions of the C-family of languages (C, C++, C#, Java, JavaScript, Perl, Python, …)
  - Filename: ***.json**
  - Media type: **application/json**
  - http://www.json.org/

Example

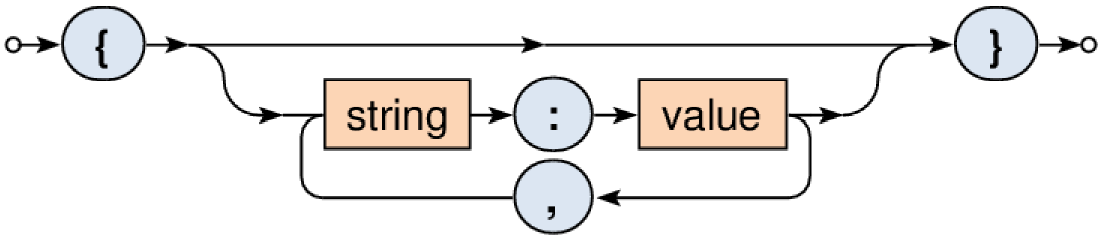
```
{
    "firstName" : "John",
    "lastName" : "Smith",
    "age" : 25,
    "address" : {
        "street" : "21 2nd Street",
        "city" : "New York",
        "state" : "NY",
        "postalCode" : 10021
    },
    "phoneNumbers" : [
        { "type" : "home", "number" : "212 555-1234" },
        { "type" : "fax", "number" : "646 555-4567" }
    ]
}
```

Data Structures

- Built on two general structures
  - **Object**
    - Collection of name-value pairs
      - Realized as an object, record, struct, dictionary, hash table, keyed list, associative array, …
  - **Array**
    - List of values
      - Realized as an array, vector, list, sequence, …
  - All modern programming languages support them

Data Structures

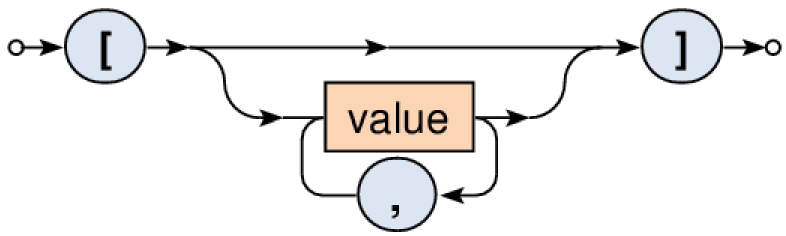
- **Object**
  - Unordered set of name-value pairs
    - Called properties of an object



  - Examples
    - `{ "name" : "Peter", "age" : 30 }`
    - `{ }`

Data Structures

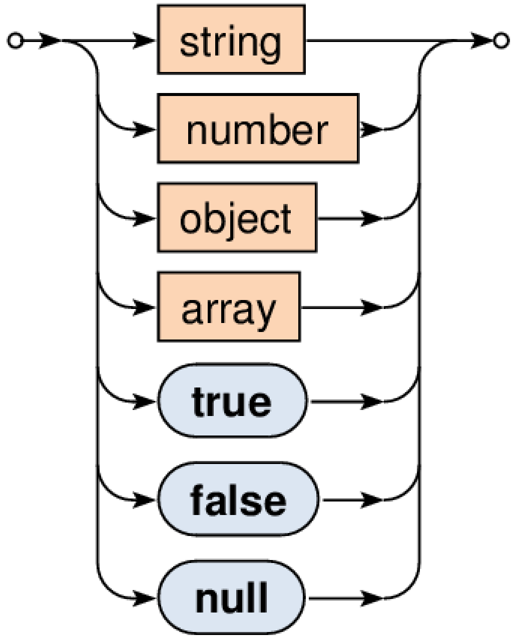
- **Array**
  - <u>Ordered</u> collection of values
    - Called items or elements of an array



  - Examples
    - `[ 3, 5, 7, 9 ]`
    - `[ 15, "word", -5.6 ]`
    - `[ ]`

Values

- **Strings**
- **Numbers**
- Nested **objects** or **arrays**
- **Boolean** values
  - `true` and `false`
- **Null** value
  - Missing information



Values

- **String**
  - Sequence of Unicode characters
    - Wrapped in double quotes
    - Backslash escaping sequences for special characters
  - Example: `"ab \n cd \" ef \\ gh"`
- **Number**
  - Integers or floating point numbers
    - Decimal system only
    - Scientific notation allowed
  - Examples: `10`, `-0.5`, `1.5e3`

Example

```
{
    "firstName" : "John",
    "lastName" : "Smith",
    "age" : 25,
    "address" : {
        "street" : "21 2nd Street",
        "city" : "New York",
        "state" : "NY",
        "postalCode" : 10021
    },
    "phoneNumbers" : [
        { "type" : "home", "number" : "212 555-1234" },
        { "type" : "fax", "number" : "646 555-4567" }
    ]
}
```

BSON

Binary JSON

Introduction

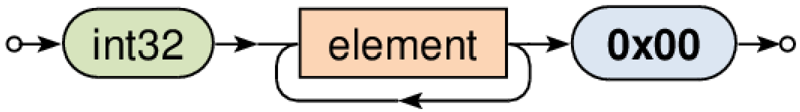
- **BSON**
  - **Binary-encoded serialization of JSON documents**
    - Allows embedding of JSON objects, arrays and standard simple data types together with a few new ones
  - MongoDB database
    - NoSQL database built on JSON documents
      - http://www.mongodb.com/
    - Primary data representation = BSON
      - Data storage and network transfer format
  - Filename: ***.bson**
  - http://bsonspec.org/

Example

- **JSON**
  - `{ "hello" : "world" }`
- **BSON**
  - `\x16\x00\x00\x00` Document size
    `\x02` String data type
    `hello\x00` Field name
    `\x06\x00\x00\x00world\x00` Field value
    `\x00` End of object

Grammar

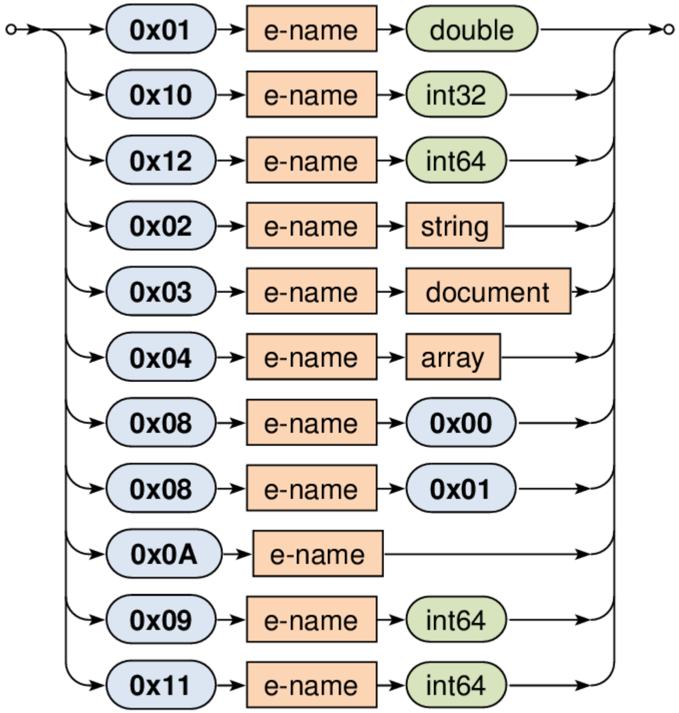
- **Document**
  - Encodes one JSON object (or array or value)
    - There can be more documents in one *.bson file
  - – JSON array is first transformed into an object
    - E.g.: `[ "red", "blue" ]` → `{ "0": "red", "1": "blue" }`



  - Structure
    - – **Total document size** in a number of bytes
    - – Sequence of **elements**
    - – Terminating 0x00

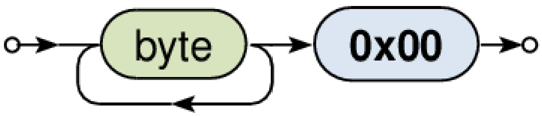
Grammar

- **Element**
  - Encodes one object property (name-value pair)
  - Structure
    - **Type** selector
      - 0x01 = double
      - 0x10 = 4B integer
      - 0x12 = 8B integer
      - 0x08 = boolean
      - 0x0A = null
      - 0x09 = datetime
      - 0x11 = timestamp
      - …
    - Field **name**
    - Field **value**

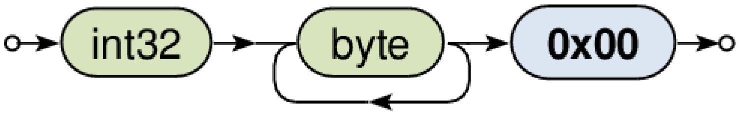


Grammar

- **Element name**
  - Unicode **string**
    - 0x00 not allowed inside
  - Terminating 0x00



- **String**
  - Total string **length**
  - Unicode **string**
  - Terminating 0x00



Grammar

- **Basic types**
  - `byte` – 1 byte (8-bits)
  - `int32` – 4 bytes (32-bit signed integer)
  - `int64` – 8 bytes (64-bit signed integer)
  - `double` – 8 bytes (64-bit IEEE 754 floating point)

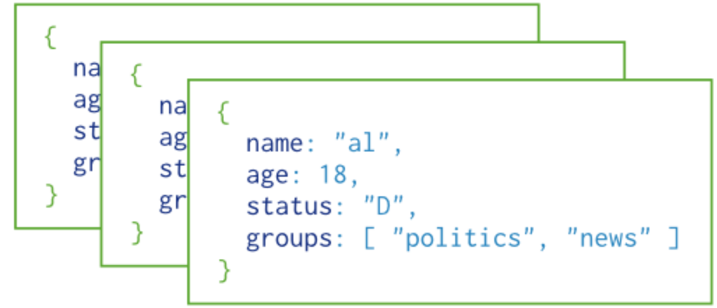
MongoDB

MongoDB

- Initial release: 2009
- Written in C++
  - Open-source
- Cross-platform
- JSON documents
  - Dynamic schemas
- Features:
  - High performance – indexes
  - High availability – replication + eventual consistency + automatic failover
  - Automatic scaling – automatic sharding across the cluster
  - MapReduce support

http://www.mongodb.org/

MongoDB
Terminology



Collection

Oracle	MongoDB
database instance	MongoDB instance
schema	database
table	collection
row	document
rowid	_id
join	DBRef

Terminology in Oracle and MongoDB

- Each MongoDB instance has multiple databases
- Each database can have multiple collections
- When we store a document, we have to choose database and collection

MongoDB

Documents

- Use JSON
- Stored as BSON
  - Binary representation of JSON
- Have maximum size: 16MB (in BSON)
  - Not to use too much RAM
  - GridFS tool divides larger files into fragments
- Restrictions on field names:
  - `_id` is reserved for use as a primary key
    - Unique in the collection
    - Immutable
    - Any type other than an array
  - The field names cannot start with the `$` character
    - Reserved for operators
  - The field names cannot contain the `.` character
    - Reserved for accessing fields

MongoDB

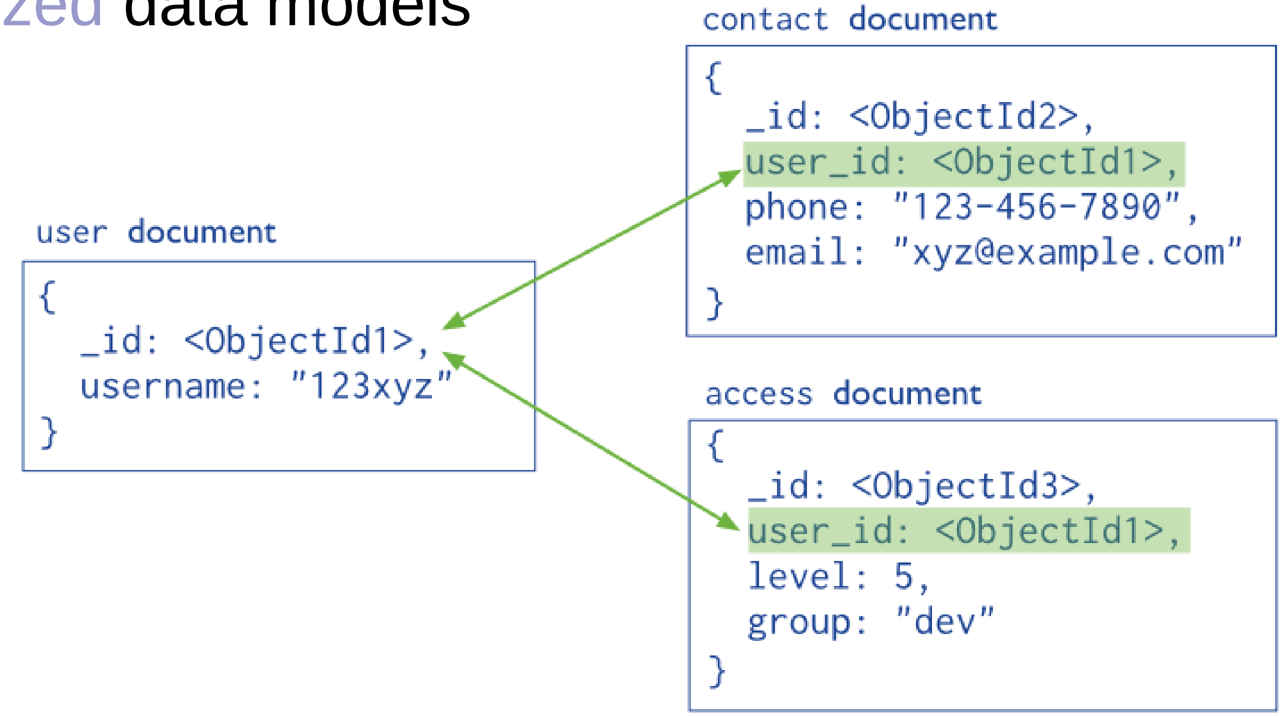
Data Model

- Documents have flexible schema
  - Collections do not enforce structure of data
  - In practice the documents are similar
- Challenge: Balancing
  - the needs of the application
  - the performance characteristics of database engine
  - the data retrieval patterns
- Key decision: references vs. embedded documents
  - Structure of data
  - Relationships between data

MongoDB

Data Model – References

- Including links / references from one document to another
- Normalized data models



MongoDB
Data Model – References

- References provides more flexibility than embedding
- Use normalized data models:
  - When embedding would result in duplication of data not outweighted by read performance
  - To represent more complex many-to-many relationships
  - To model large hierarchical data sets
- Disadvantages:
  - Can require more roundtrips to the server (follow up queries)

MongoDB

Data Model – Embedded Data

- Related data in a single document structure
  - Documents can have subdocuments (in a field of array)
  - Applications may need to issue less queries
- Denormalized data models
- Allow applications to retrieve and manipulate related data in a single database operation

```
{
  _id: <ObjectId1>,
  username: "123xyz",
  contact: {
              phone: "123-456-7890",
              email: "xyz@example.com"
           },
  access: {
             level: 5,
             group: "dev"
          }
}
```

Embedded sub-document (contact)

Embedded sub-document (access)

MongoDB

Data Model – Embedded Data

- Use embedded data models when:
  - When we have “contains” relationships between entities
    - One-to-one relationships
  - In one-to-many relationships, where child documents always appear with one parent document
- Provides:
  - Better performance for read operations
  - Ability to retrieve/update related data in a single database operation
- Disadvantages:
  - Documents may significantly grow after creation
    - Impacts write performance
      - The document must be relocated on disk if the size exceeds allocated space
      - May lead to data fragmentation

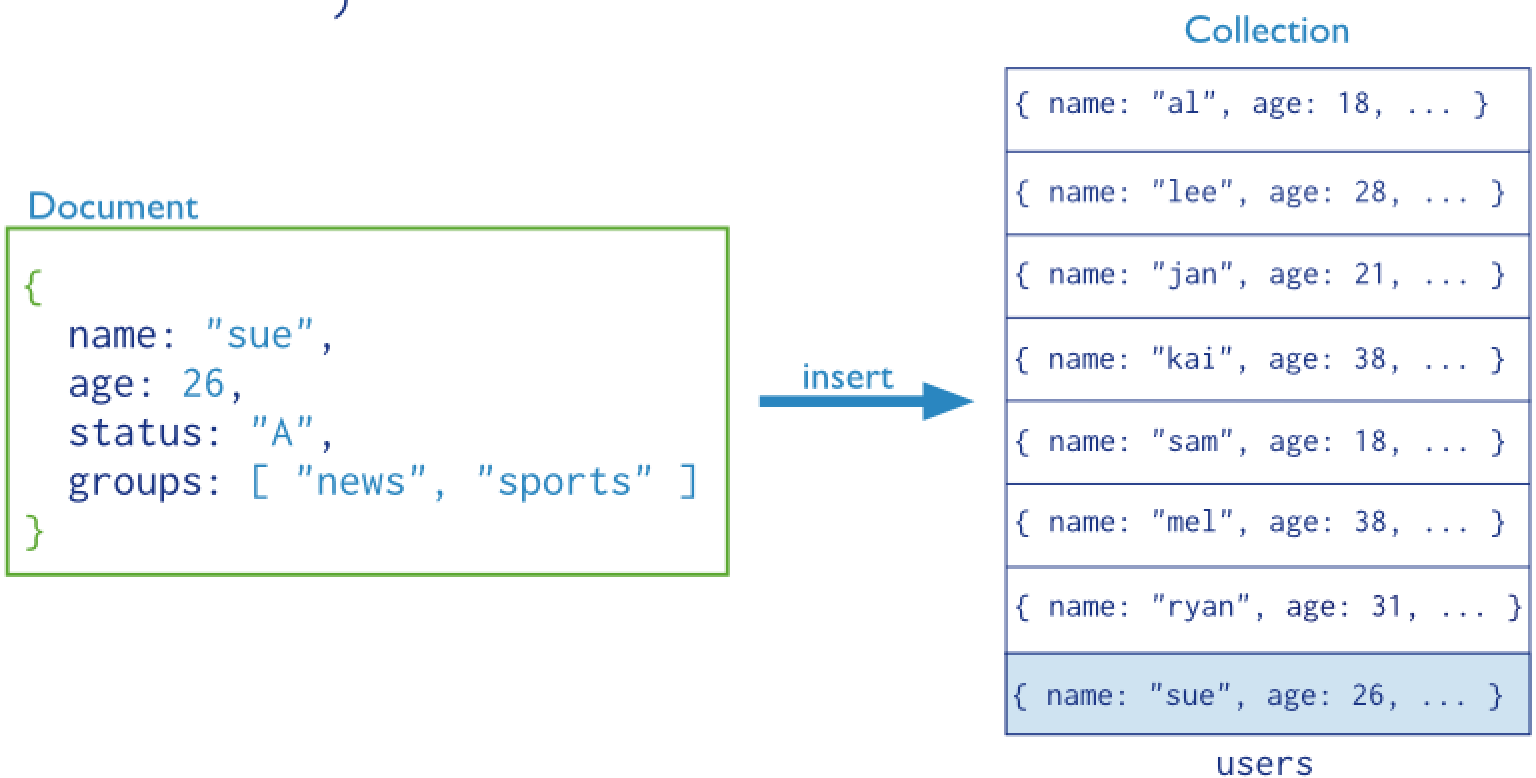
MongoDB

Data Modification

- Operations: create, update, delete
  - Modify the data of a single collection of documents
- For update / delete: criteria to select the documents to update / remove

Collection — Document

```
db.users.insert(
                {
                   name: "sue",
                    age: 26,
                 status: "A",
                 groups: [ "news", "sports" ]
                }
               )
```



MongoDB

Data Insertion

```
db.inventory.insert( { _id: 10, type: "misc", item:
   "card", qty: 15 } )
```

- Inserts a document with three fields into collection `inventory`
  - User-specified `_id` field

```
db.inventory.update(
                   { type: "book", item : "journal" },
                   { $set : { qty: 10 } },
                   { upsert : true }
                     )
```

- Creates a new document if no document in the inventory collection contains `{ type: "books", item : "journal" }`
  - MongoDB adds the `_id` field and assigns as its value a unique `ObjectId`
  - The result contains fields `type`, `item`, `qty` with the specified values

MongoDB

Data Insertion and Removal

```
db.inventory.save( { type: "book", item:
  "notebook", qty: 40 } )
```

- Creates a new document in collection `inventory` if `_id` is not specified or does not exist in the collection

```
db.inventory.remove( { type : "food" } )
```

- Removes all documents that have `type` equal to `food` from the `inventory` collection

```
db.inventory.remove( { type : "food" }, 1 )
```

- Removes <u>one</u> document that have `type` equal to `food` from the `inventory` collection

MongoDB

Data Updates

```
db.inventory.update(
                    { type : "book" },
                    { $inc : { qty : -1 } },
                    { multi: true }
                   )
```

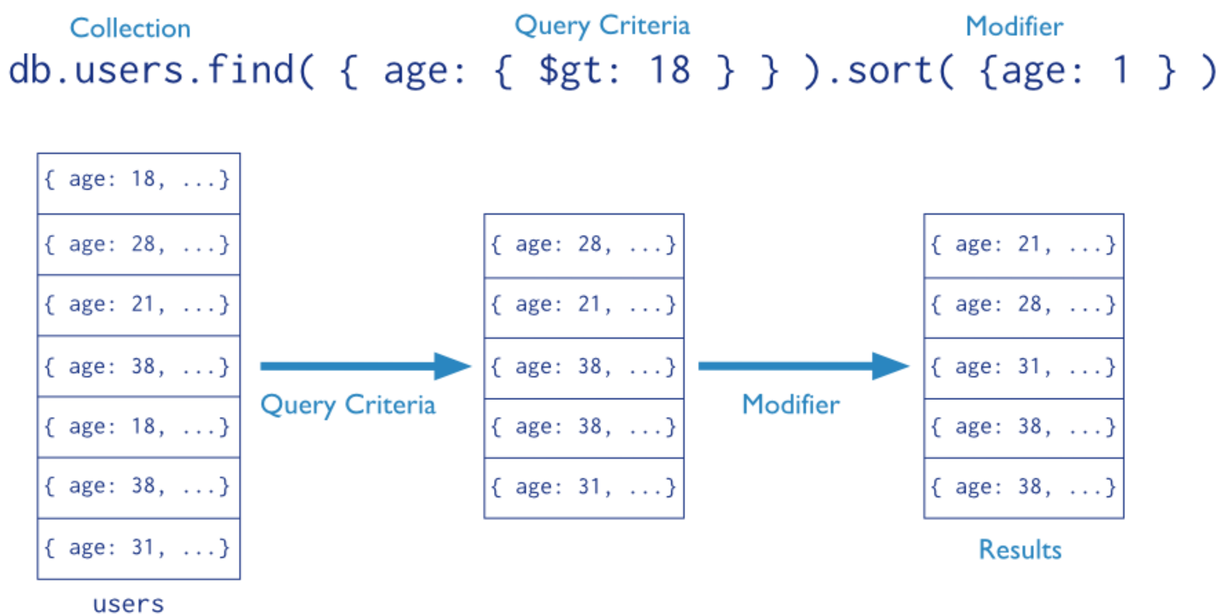
- Finds all documents with `type` equal to `book` and modifies their `qty` field by -1

```
db.inventory.save(
   {
     _id: 10,
     type: "misc",
     item: "placard"
   } )
```

- Replaces document with `_id` equal to 10

MongoDB
Query

- Targets a specific collection of documents
- Specifies criteria that identify the returned documents
- May include a projection that specifies the fields from the matching documents to return
- May impose limits, sort orders, …



MongoDB

Query – Basic Queries, Logical Operators

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

- All documents in the collection

```
db.inventory.find( { type: "snacks" } )
```

- All documents where the `type` field has the value `snacks`

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

- All documents where value of the `type` field is either `food` or `snacks`

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

- All documents where the `type` field has the value `food` **and** the `value` of the `price` field is less than `9.95`

MongoDB

Query – Logical Operators

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

- All documents where the field `qty` has a value greater than (`$gt`) `100` **or** the value of the `price` field is less than (`$lt`) `9.95`

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

- All documents where the value of the `type` field is `food` **and** either the `qty` has a value greater than (`$gt`) `100` **or** the value of the `price` field is less than (`$lt`) `9.95`

MongoDB

Query – Subdocuments

```
db.inventory.find( {
                     producer: {
                                 company: 'ABC123',
                                 address: '123 Street'
                               }
                   } )
```

- All documents where the value of the field `producer` is a subdocument that contains only the field `company` with the value `ABC123` and the field `address` with the value `123 Street`, in the exact order

```
db.inventory.find( { 'producer.company': 'ABC123' } )
```

- All documents where the value of the field `producer` is a subdocument that contains a field `company` with the value `ABC123` and may contain other fields

dot notation

MongoDB

Query – Arrays

exact match

```
db.inventory.find( { tags: [ 'fruit', 'food',
   'citrus' ] } )
```

- All documents where the value of the field `tags` is an array that holds exactly three elements, `fruit`, `food`, and `citrus`, in this order

```
db.inventory.find( { tags: 'fruit' } )
```

- All documents where value of the field `tags` is an array that contains `fruit` as <u>one of</u> its elements

```
db.inventory.find( { 'tags.0' : 'fruit' } )
```

- All documents where the value of the `tags` field is an array whose <u>first element</u> equals `fruit`

MongoDB

Query – Arrays of Subdocuments

```
db.inventory.find( { 'memos.0.by': 'shipping' } )
```

- All documents where the `memos` field contains an array whose first element is a subdocument with the field `by` with the value `shipping`

```
db.inventory.find( { 'memos.by': 'shipping' } )
```

- All documents where the `memos` field contains an array that contains at least one subdocument with the field `by` with the value `shipping`

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

- All documents where the value of the `memos` field is an array that has at least one subdocument that contains the field `memo` equal to `on time` and the field `by` equal to `shipping`

MongoDB

Query – Limit Fields of the Result

or true

```
db.inventory.find( { type: 'food' }, { item: 1, qty:
  1 } )
```

- Only the `item` and `qty` fields (and by default the `_id` field) return in the matching documents

```
db.inventory.find( { type: 'food' }, { item: 1, qty:
  1, _id: 0 } )
```

- Only the `item` and `qty` fields return in the matching documents

```
db.inventory.find( { type: 'food' }, { type : 0 } )
```

- The `type` field does not return in the matching documents

or false

- Note: With the exception of the `_id` field we cannot combine inclusion and exclusion statements in projection documents.

MongoDB

Query – Sorting

```
db.collection.find().sort( { age: -1 } )
```

- Returns all documents in `collection` sorted by the `age` field in <u>descending</u> order

```
db.bios.find().sort( { 'name.last': 1,
  'name.first': 1 } )
```

- Specifies the sort order using the fields from a sub-document `name`
- Sorts first by the `last` field and then by the `first` field in <u>ascending</u> order

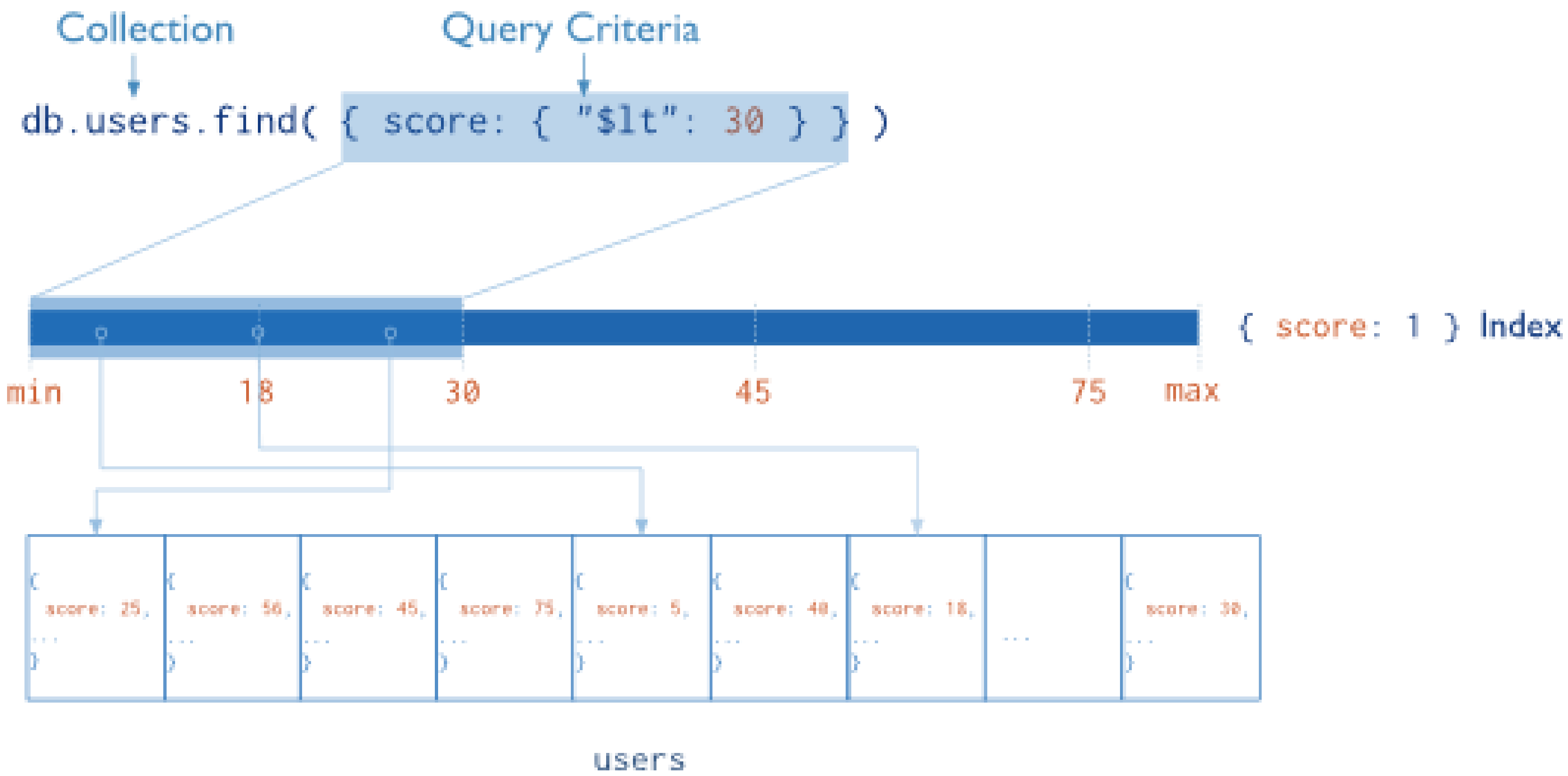
MongoDB

Indexes

- Without indexes:
  - MongoDB must scan every document in a collection to select those documents that match the query statement
- Indexes store a portion of the collection's data set in an easy to traverse form
  - Stores the value of a specific field or set of fields ordered by the value of the field
  - B-tree like structures
- Defined at collection level
- Purpose:
  - To speed up common queries
  - To optimize the performance of other operations in specific situations

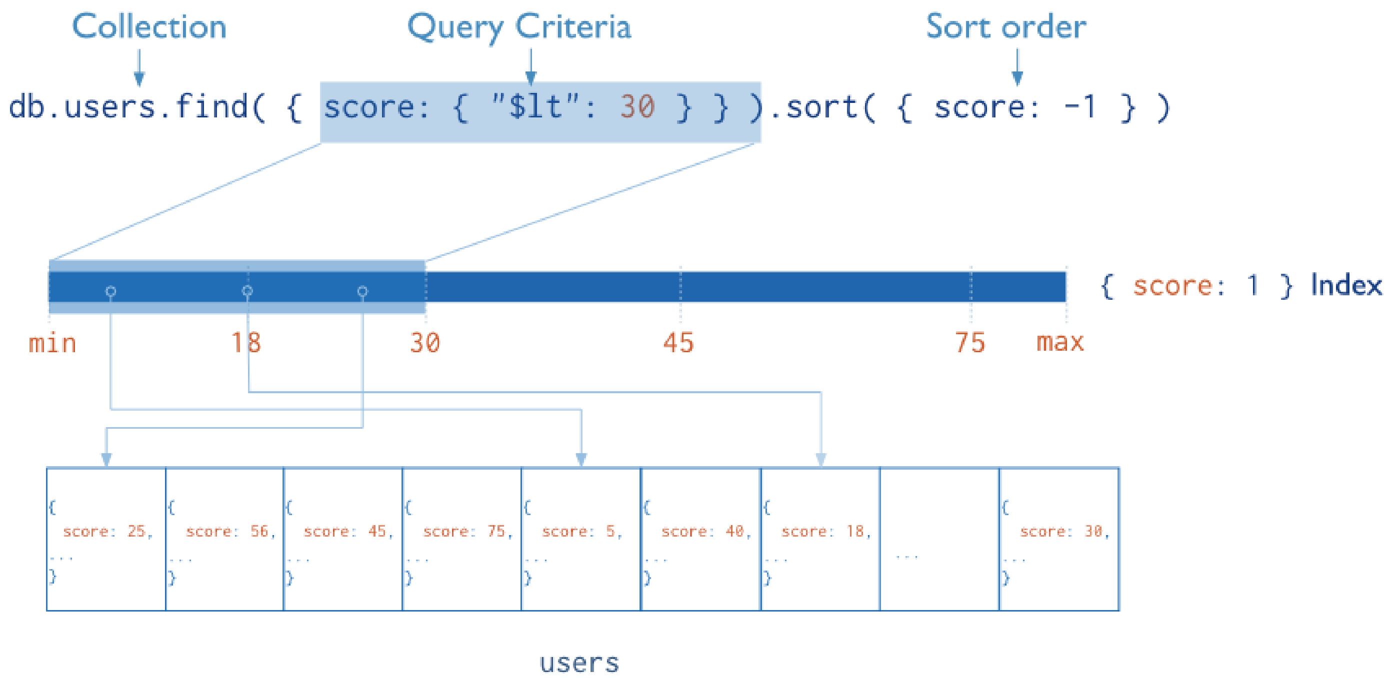
MongoDB

Indexes – Example



MongoDB

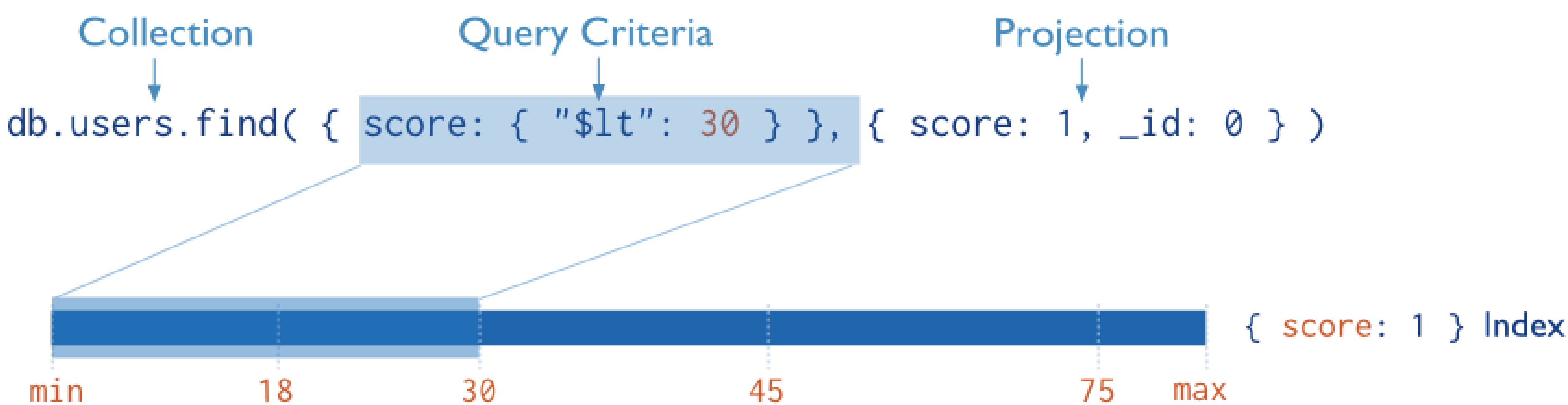
Indexes – Usage for Sorted Results



- The index stores `score` values in ascending order
- MongoDB can traverse the index in either ascending or descending order to return sorted results (without sorting)

MongoDB

Indexes – Usage for Covered Results

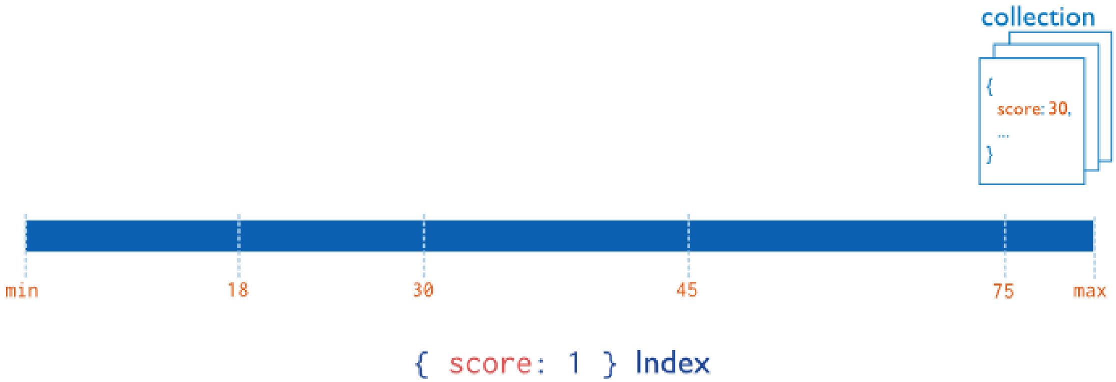


- MongoDB does not need to inspect data outside of the index to fulfil the query

MongoDB

Index Types

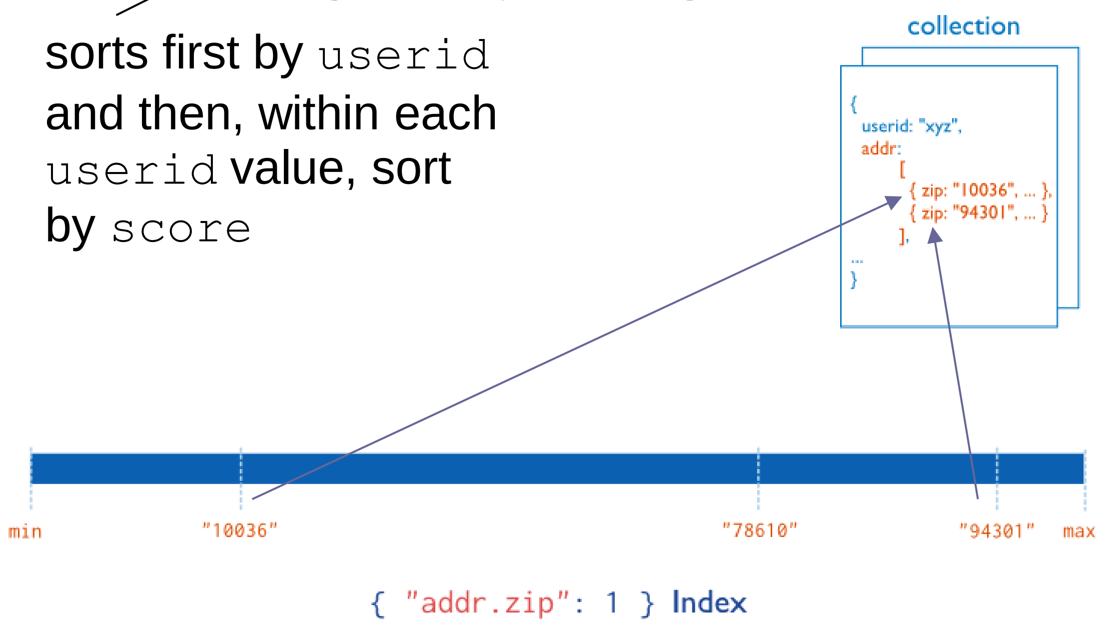
- **Default `_id`**
  - Exists by default
    - If applications do not specify `_id`, it is created automatically
  - Unique by default
- **Single Field**
  - User-defined indexes on a single field of a document
- **Compound**
  - User-defined indexes on multiple fields
- **Multikey index**
  - To index the content stored in arrays
  - Creates separate index entry for every element of the array



Single field index on the `score` field (ascending).

Compound index on the `userid` field (ascending) and the `score` field (descending).

sorts first by `userid` and then, within each `userid` value, sort by `score`



Multikey index on the `addr.zip` field

MongoDB

Indexes

```
db.people.createIndex( { "phone-number": 1 } )
```

- Creates a single-field index on the `phone-number` field of the `people` collection

```
db.products.createIndex( { item: 1, category: 1, price: 1 } )
```

- Creates a compound index on the `item`, `category`, and `price` fields

```
db.accounts.createIndex( { "tax-id": 1 }, { unique: true } )
```

- Creates a unique index
  - Prevents applications from inserting documents that have duplicate values for the inserted fields

```
db.collection.createIndex( { _id: "hashed" } )
```

- Creates a hashed index on `_id`

MongoDB

Index Types

- **Geospatial Field**
  - 2d indexes = use planar geometry when returning results
    - For data representing points on a two-dimensional plane
  - 2sphere indexes = use spherical (Earth-like) geometry to return results
    - For data representing longitude, latitude
- **Text Indexes**
  - Searching for string content in a collection
- **Hash Indexes**
  - Indexes the hash of the value of a field
  - Only support equality matches (not range queries)