NoSQL and MongoDB

CS 4417B

The University of Western Ontario

- MapReduce
  - Shuffle and Sort
  - Examples: PageRank
- MongoDB
  - Aggregation pipeline
- Assignment 3
- Under the hood
  - How data is distributed
  - Consistency
  - Fault tolerance

Introduction

- Motivating "NoSQL" by considering relational databases and modern big data applications.

- We will highlight the limitations of relational databases:
  - Data models
  - Assumptions of the execution environment

Relational Databases (SQL)

- Data stored in tables (columns and rows)
- Requires predefined data models prior to use i.e., static schemas
  - A “schema” tells you what data are stored about each entity in the database, e.g.
  - Person:
    - Name, Address, Phone, E-mail
- Focus on integrity, atomicity
- Distributed implementations an afterthought

Application: Personalization

- Personalization is a means of meeting a customer’s needs more effectively and efficiently
- Personalization engines create customized online experiences for customers in real time based on analysis of behavioral and demographic profiles, historical interactions, and preferences.
- Examples:
  - Netflix/spotify, amazon shopping, YouTube recommendations, …

https://www.mongodb.com/use-cases/personalization

Application: Personalization Data Modelling

- Customer data is more than names and addresses
- Example: For online stores it includes browsing habits to determine ads to display
  - The ads vary based on the product
  - The data model needed for a diverse set of product information typically does not fit well in the rows and columns of a relational database
  - Why? A fixed schema for diverse products is going to be either 1) insufficient and fast or 2) enormous and slow

Application: Personalization – Data Modeling

- Common information about a product includes product name, type
- However, other details may depend on the product:
  - Example:
    - A book has author, title, isbn
    - A song has artist, title, length
- A single schema for all products would be huge
- What happens if you get a new type of product?
  - Do you want to come up with a new schema?
  - Changing the schema of an enormous pre-existing table is a huge computational burden
- Compositional structure of products is challenging to capture

Application: Blogs (e.g. Twitter)

- A blog consists of a collection of text entries or posts
- A tag is a word or two that reflects the content of the post
- Main data entity is a post

Application: Blogs

- A blog post has an author, some text and many comments
- The comments are unique per post, but one author has many posts
- A comment is associated with a post
- A post may have multiple comments
- An author may have many comments spread out over multiple posts

Relational Data Model for Blogs

comments
comment_id
post_id
by_author
message
date_time
likes

posts
post_id
title
description
url
likes
post_by

tags
tag_id
post_id
tag

author
author_id
name
create_date

- What if I want all the posts by a particular author?
- What if I want all the tags used by a particular author?
- Using the SQL operations of join, select is non-trivial

Relational structure may be hard to manage at scale.

Problems With Relational Databases

- Overhead for complex select, update, delete operations
  - Select: Joining too many tables to create a huge size intermediate table.
  - Update: Each update can affect many other tables
  - Delete: Must guarantee the consistency of data
- Schemas may be difficult to define and may evolve over time.

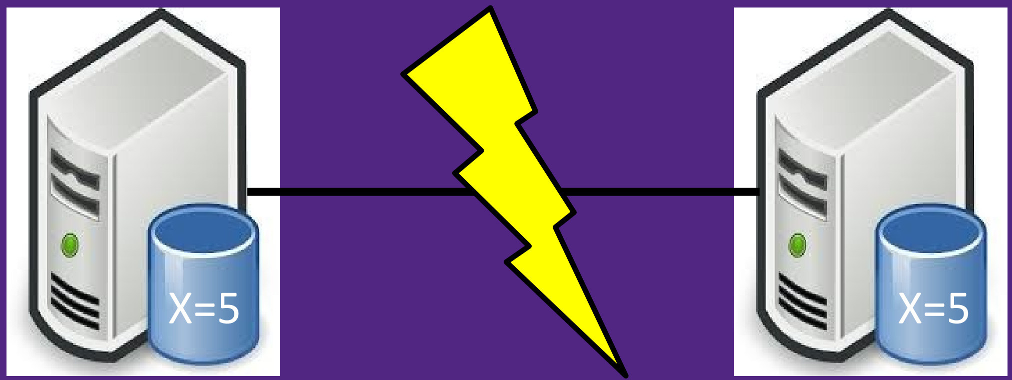
Relational Databases

- Relational databases are expected to have these properties:
  - Atomicity: Each transaction must be "all or nothing" i.e. if one part fails then the transaction fails
    - Example: Let's say that you are updating two tables that have fields in common. We expect this update to be atomic.
  - Consistency: A write to a table means that any read of the table after the write will see the most recent value i.e.,
    - Every read receives the most recent write or an error

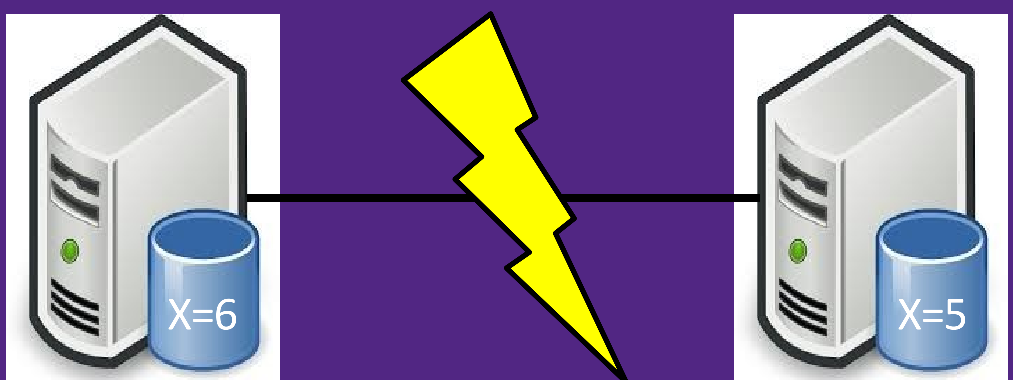
Relational Databases

- These were designed to run on a single server to maintain the integrity of the tables
  - The reason for this is that distributing data and ensuring atomicity and consistency is hard

Relational Databases



- X is to become 6
- What if the network fails after one of the updates is done?



- Possible to handle by e.g. deciding no write is valid unless all replicas have been updated, but this negatively impacts performance

Large-Scale Databases

- When companies such as Google and Amazon were designing large-scale databases, 24/7 availability was a key requirement
  - A few minutes of downtime means lost revenue
- When horizontally scaling databases to 1000s of machines, the likelihood of at least one node or network failure increases tremendously
- Difficult to have strict consistency

Problems With Relational Databases

- Relational databases were defined for certain types of applications
  - Examples: Banking, finance
  - These were the primary applications 40+ years ago
  - “Truth” and consistency are necessary requirements
- Scaling these kinds of databases is hard

How to store, query and process these data efficiently?

NoSQL

- NoSQL = Non SQL or Not only SQL
- NoSQL is a better solution for many types of data where
  - Strict schema won’t work
  - Relational structures are complicated
  - Atomicity and consistency maybe not crucial
  - Distribution/efficiency is crucial
  - Fault-tolerance
- Definition (Wikipedia)
  - "…storage and retrieval of data that is modeled in means other than the tabular relations used in relational databases."

NoSQL

- A form of database management system that is non-relational
- Systems are often schema-less, avoid joins and are easy to scale, by
  - Adding computers
  - Sharding and replication
- The term NoSQL was coined in 1998 by Carlo Strouzi

Why NoSQL?

- The data we store is more complex and dynamic than 20-40 years ago
- Data can’t fit on a single server
- Easy Distribution
  - With all this data there is a need to make use of multiple servers
  - Should be able to add servers in response to demand
  - No disruption of service in the presence of failures

Different Types of NoSQL Systems

- Document Store
- Key-value store
- Graph
- BigTable

Examples of NoSQL Systems

Document Database	Graph Databases
Couchbase MarkLogic mongoDB	Neo4j InfiniteGraph The Distributed Graph Database
Wide Column Stores	**Key-Value Databases**
redis amazon DynamoDB AEROSPIKE riak	accumulo HYPERTABLE INC Cassandra APACHE HBASE Amazon SimpleDB

What will we focus on?

- This week’s lectures focus on the following:
  - MongoDB – This is an example of NoSQL database that supports document store
  - Example related to challenges with NoSQL
  - Relational vs NoSQL
  - Other models of NoSQL

References

[1] Mikayel Vardanyan, Picking the right NoSQL Database Tool:
http://blog.monitis.com/index.php/2011/05/22/picking-the-right-nosql-database-tool/

MongoDB – Part 1

A Document Store

Who Uses MongoDB?

In Good Company

MongoDB

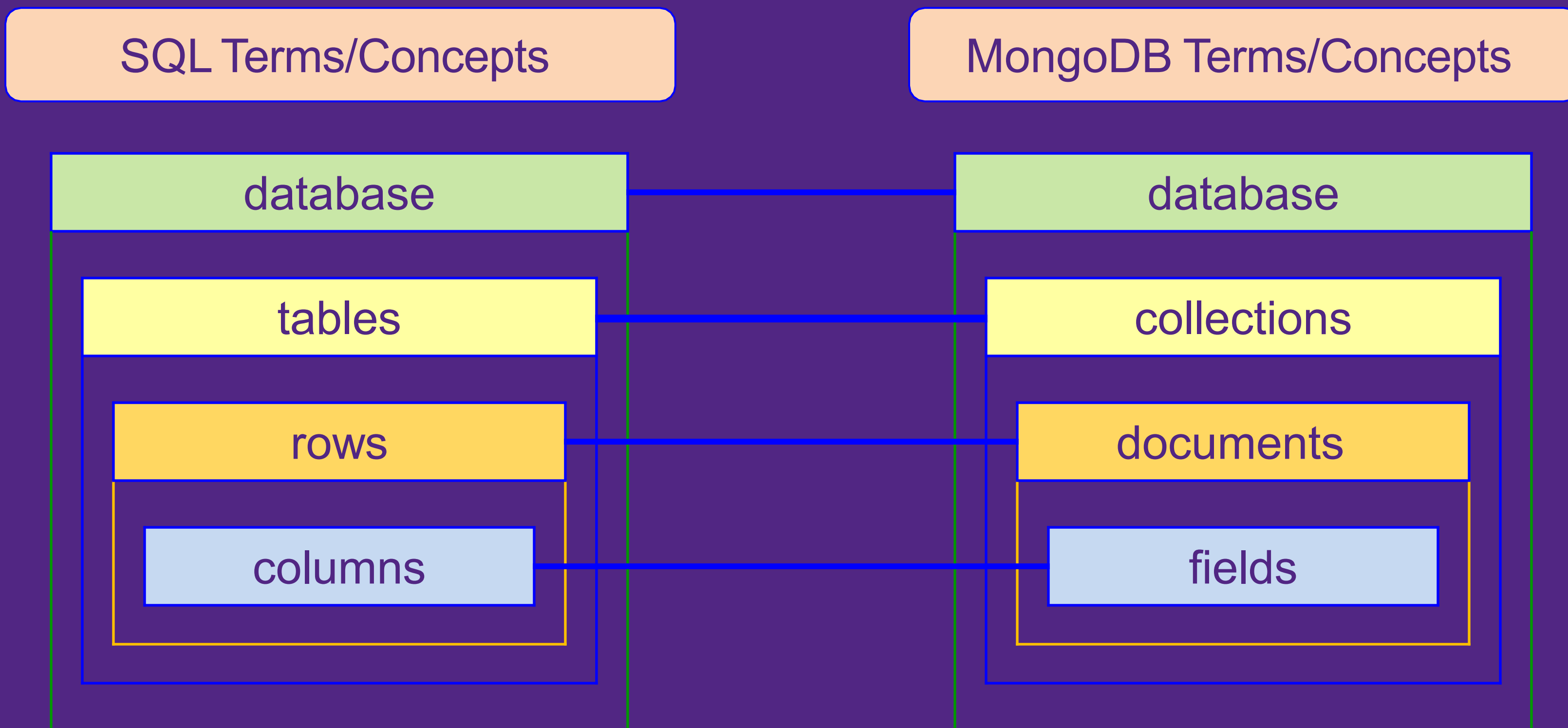
- An open source and document-oriented database.
- Documents are in BSON format, consisting of field-value pairs
  - Binary JSON; like JSON but less space
- Designed for scalability and developer agility
- Dynamic schemas (more like no schema at all.)

JSON and BSON

- JSON: JavaScript Object Notation
  - Built on
    - Name and value pairs
  - Objects can be nested
- BSON – Binary JSON
  - Binary encoded serialization of JSON-like documents

- Embedded structure reduces the need for joins

SQL vs MongoDB



JSON vs Normalization

E.g. keeping track of business cell phones

JSON-format

```
{
  _id : "Key123",
  name: "Jane",
  phones: [123, 456],
  …
}
```

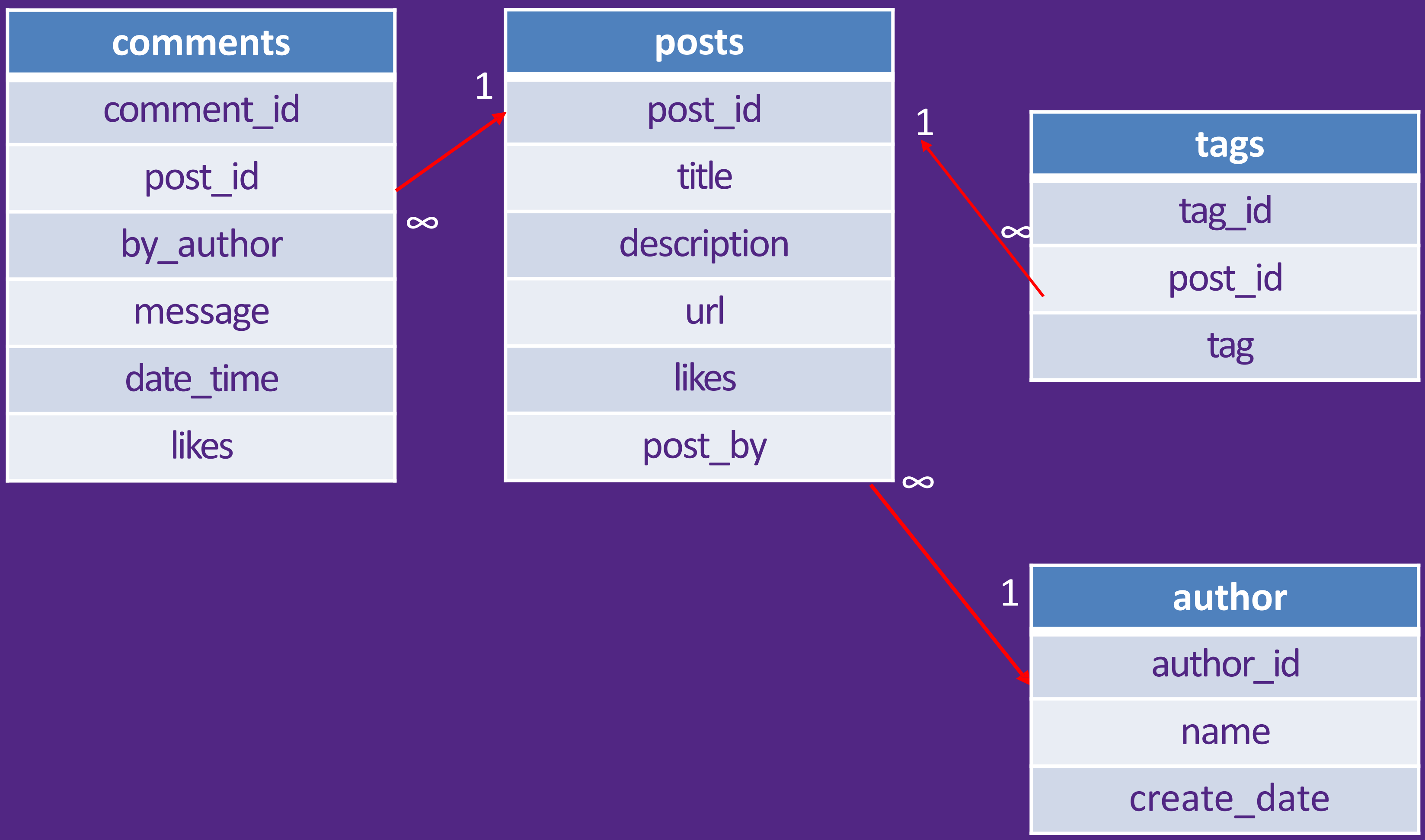
No Normalization

Id	name
Key123	Jane

PersonId	PhoneId
Key123	1
Key123	2

Id	Phone
1	123
2	456

Relational Data Model for Blogs



MongoDB "Data Model" for Blogs

```
{
    _id: POST_ID,
    title: TITLE_OF_POST,
    description: POST_DESCRIPTION,
    by: NAME,
    url: URL_OF_POST,
    tags: [TAG1,TAG2,TAG3],
    likes: TOTAL_LIKES,
```

…continued top of next column…

```
comments: [
    {
        user: COMMENT_BY,
        message: TEXT,
        dateCreated: DATE_TIME,
        likes: TOTAL_LIKES
    },
    {
        user: COMMENT_BY,
        message: TEXT,
        dateCreated: DATE_TIME,
        likes: TOTAL_LIKES
    }
    ]
}
```

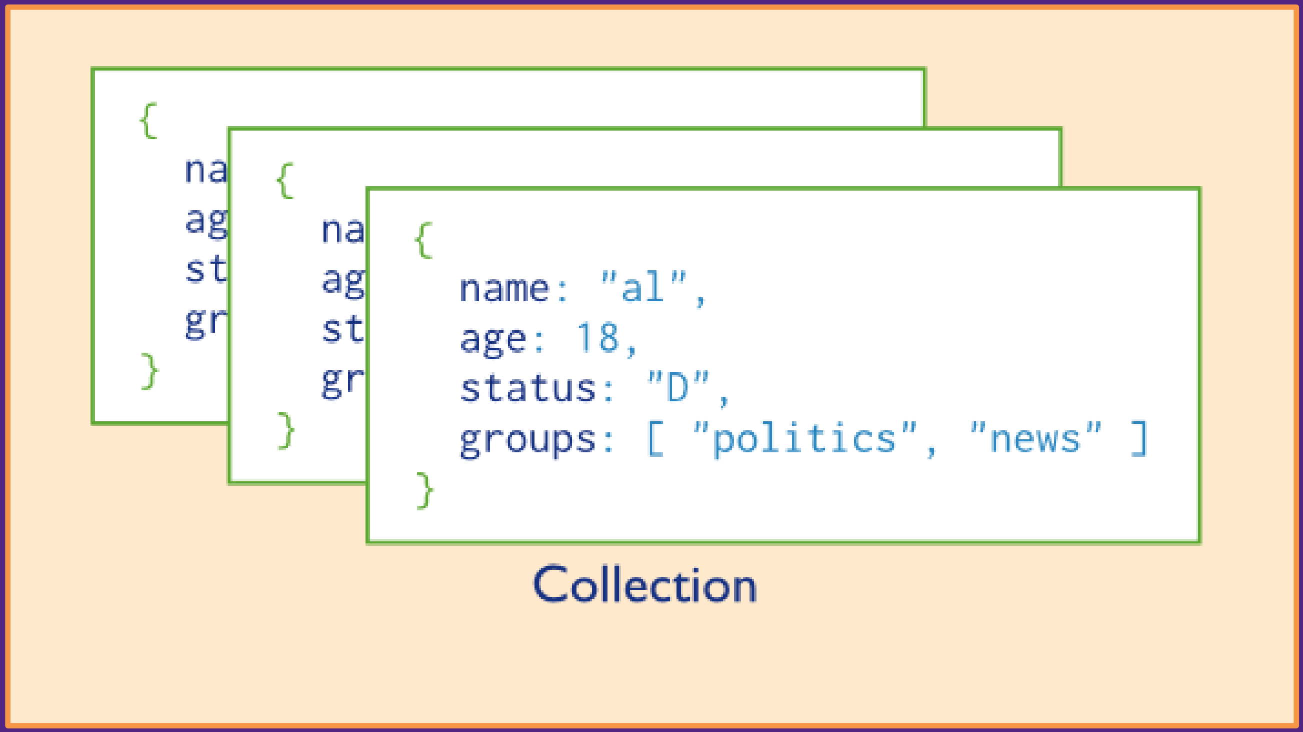
Note that this isn't a "real" data model – you don't need to give this to MongoDB to import documents

Benefits

- When doing a query: Embedded objects/documents retrieved in the same query as parent object/document
  - Only 1 trip to the DB server required
- Objects in the same collection are generally stored contiguously on disk
  - Faster access
- Easier than specifying joins

MongoDB Data Model

A collection contains documents



MongoDB Data Model

Structure of a JSON document:

```
{
  name: "sue",                          ← field: value
  age: 26,                              ← field: value
  status: "A",                          ← field: value
  groups: [ "news", "sports" ]          ← field: value
}
```

The value of **field**

- Native data types
- Arrays
- Other documents

MongoDB Data Model

Embedded documents:

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

The "primary key"

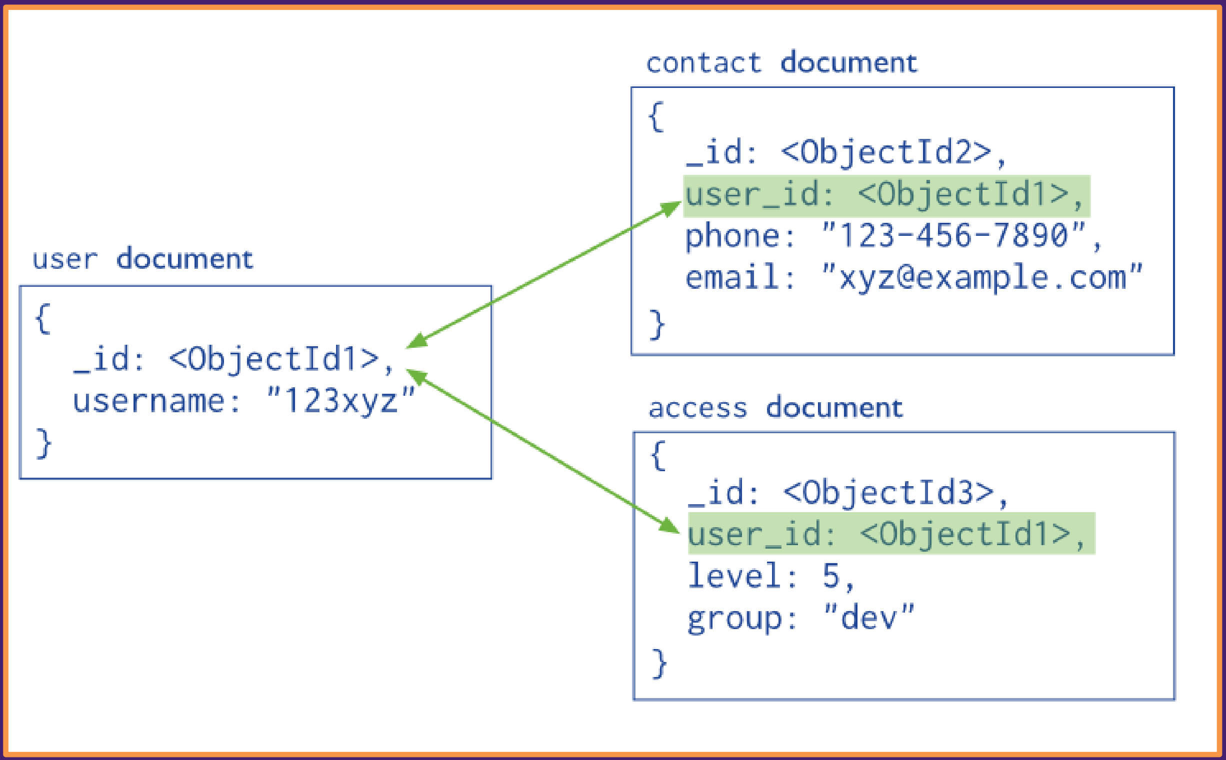
Embedded sub-document

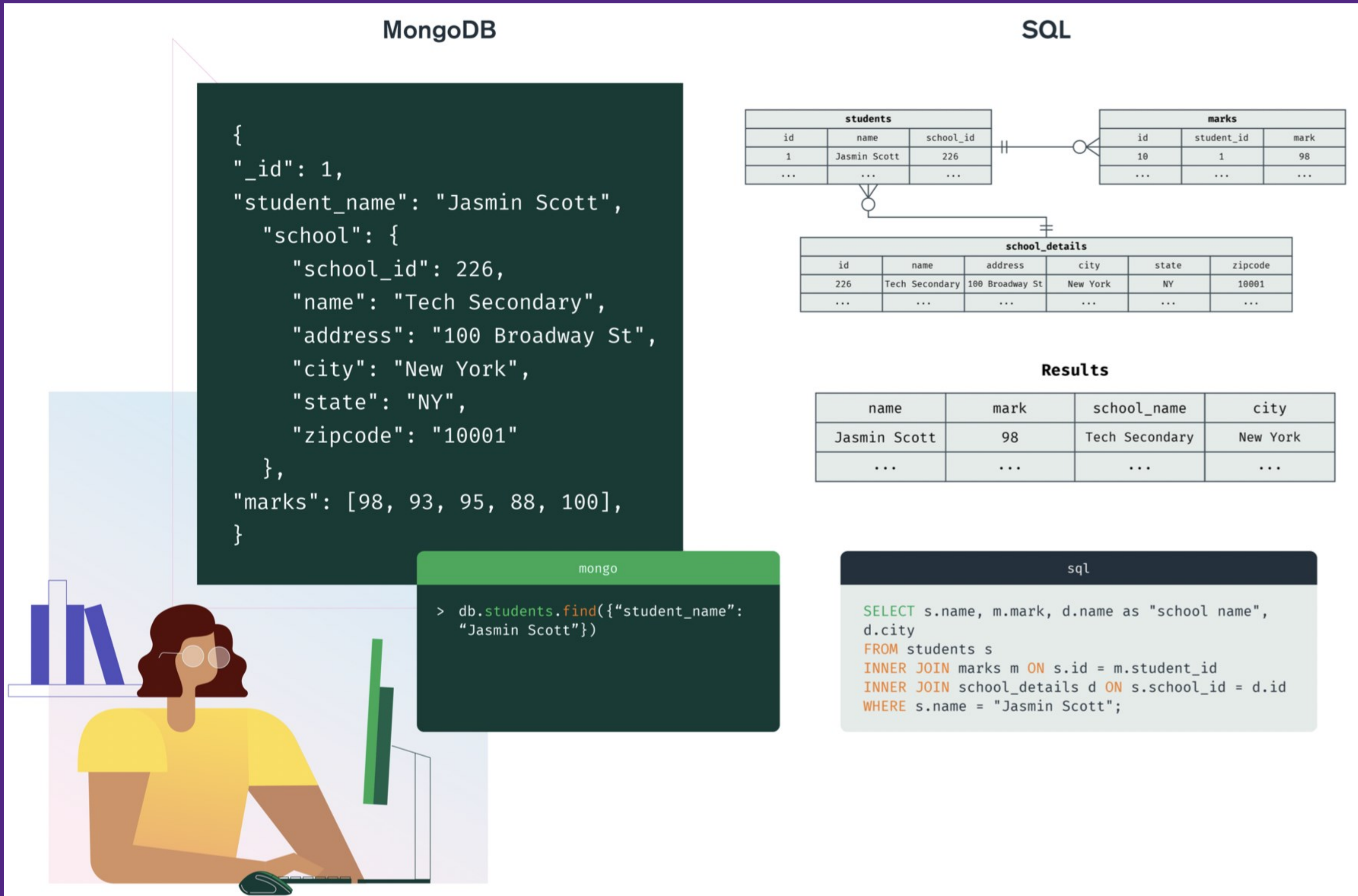
Embedded sub-document

- Example of specification of access to a field in an embedded document
  - Contact: phone, email
- Embedded documents means we do not need complicated join tables

MongoDB Data Model

Referencing or linking documents





https://www.mongodb.com/docs/

References

1 Mikayel Vardanyan, Picking the right NoSQL Database Tool: http://blog.monitis.com/index.php/2011/05/22/picking-the-right-nosql-database-tool/

2 BSON Specification: http://bsonspec.org/

3 MongoDB CRUD operations: http://docs.mongodb.org/manual/crud/

4 MongoDB Write operations: http://docs.mongodb.org/manual/core/write-operations/

5 MongoDB Investors: http://www.mongodb.com/investors

6 MongoDB Closes $150 Million in Funding: http://www.mongodb.com/press/mongodb-closes-150-million-funding

7 MongoDB Aggregation introduction: http://docs.mongodb.org/manual/core/aggregation-introduction/