Fullstack Development

Database Design

Content

- Database ranking
- SQL database
- NoSQL database
- Schema patterns
- Some useful information

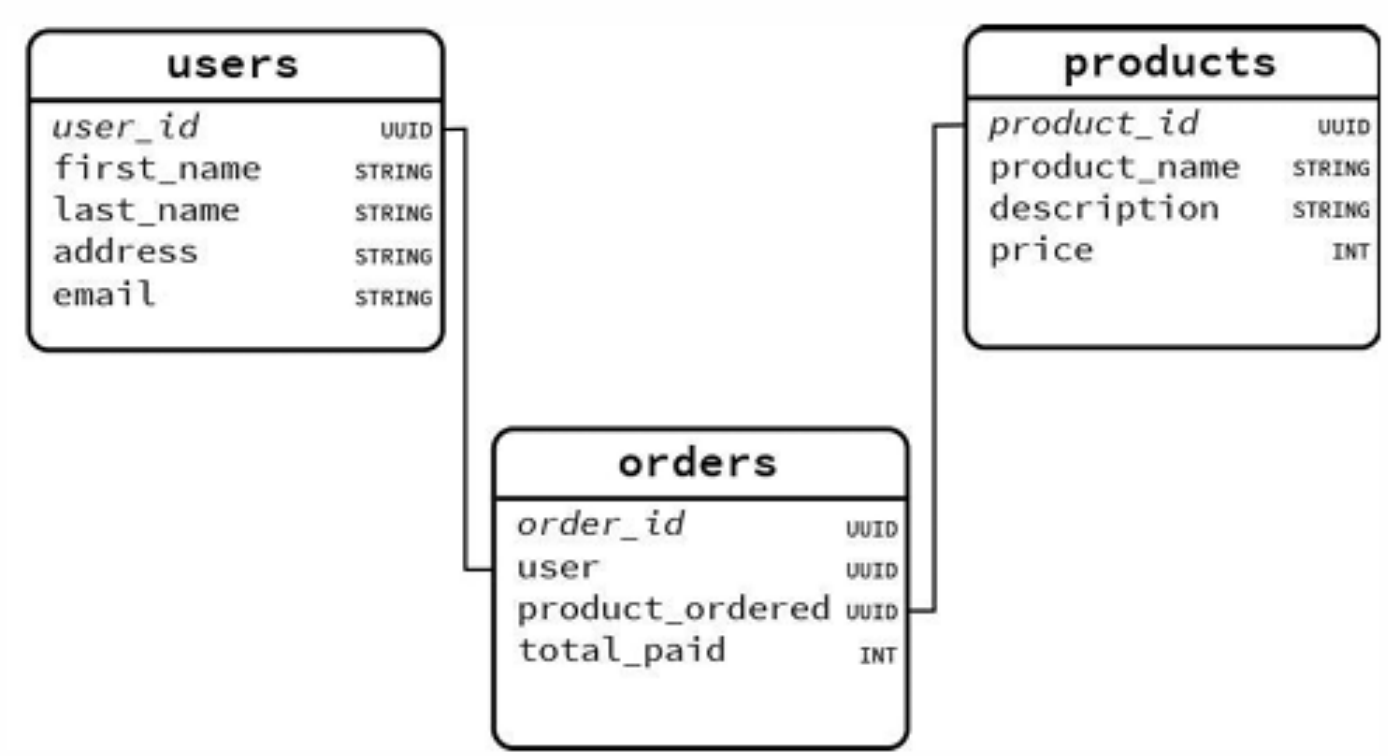
Database Engine Ranking

- Database engine
  - DBMS (Database Management System)
- A brief history of databases
- DB-Engines Ranking

SQL Database

- Relational database
- Organize data into `tables` of related information
- Utilize `Structured Query Language (SQL)` for managing/manipulating data

SQL Database



Popular RDBMS

- Open source: MySQL, PostgreSQL
- Commercial: Oracle Database, Microsoft SQL Server, IBM DB2
- RDBMS Ranking

SQL

The standard language used to interact with SQL databases

- Data Definition Language (DDL)
  - e.g., `CREATE TABLE`, `ALTER TABLE`, `DROP TABLE`
- Data Manipulation Language (DML)
  - e.g., `INSERT`, `UPDATE`, `DELETE`, `SELECT`
- Data Control Language (DCL)
  - e.g., `GRANT`, `REVOKE`

ACID Properties

- An acronym that stands for ...
  - `Atomicity`
  - `Consistency`
  - `Isolation`
  - `Durability`
- Ensure reliable transaction processing and data integrity
- What does ACID Means?

NoSQL

- `non SQL` or `not only SQL`
- Store data in a format other than relational tables
- Mostly designed for high `scalability` and `availability`

Types of NoSQL Database

- Document-oriented
- Column-oriented
- Graph-based
- Key-Value pair
- Time series

Document Database

- The data is stored in `document`
- Each `document` is typically a `nested structure` of `keys` and `values`
- **Possible to retrieve only parts of a document**
- The most commonly used data format are `JSON`, `BSON`, and `XML`
- e.g., MongoDB, Apache CouchDB

Document Database

(a) Embedded Data Model

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

Embedded sub-document

Embedded sub-document

(b) Normalized Data Model

user document

```
{
  _id: <ObjectId1>,
  username: "123xyz"
}
```

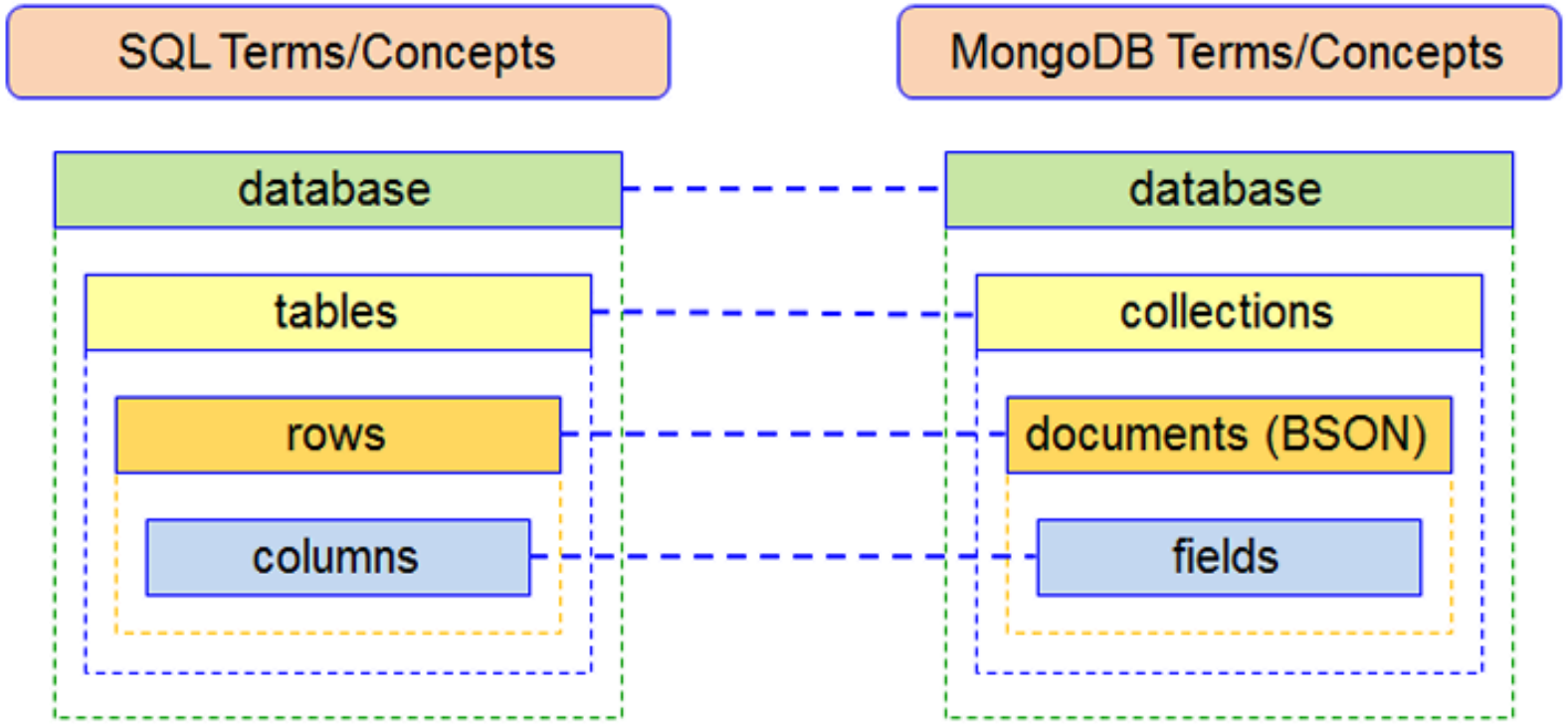
contact document

```
{
  _id: <ObjectId2>,
  user_id: <ObjectId1>,
  phone: "123-456-7890",
  email: "xyz@example.com"
}
```

access document

```
{
  _id: <ObjectId3>,
  user_id: <ObjectId1>,
  level: 5,
  group: "dev"
}
```

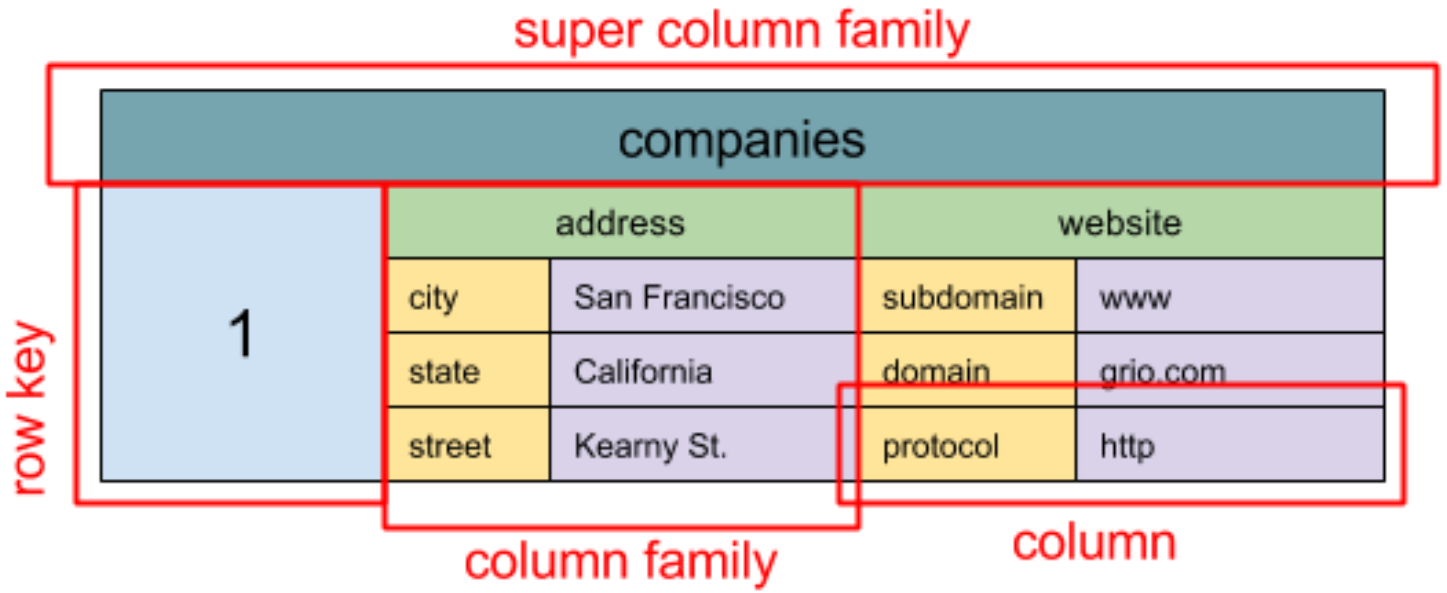
Document Database: Terminology



Wide Column Data Store

- Store data in columns rather than rows
- Able to store large amounts of data in a single column
- Allows to reduce disk resources and the time to retrieve information
- Highly scalable and flexible
- e.g., Apache Cassandra

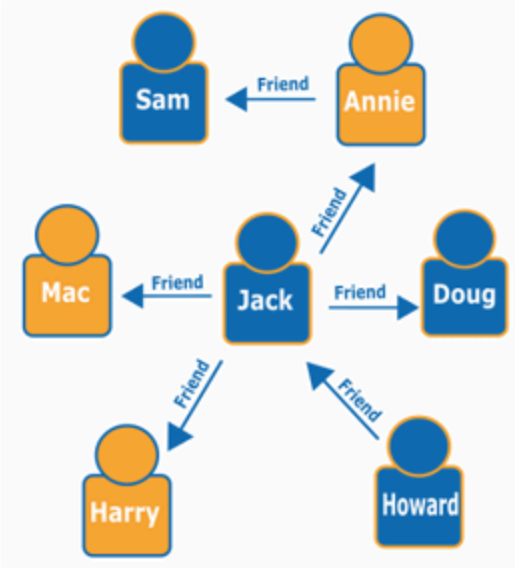
Wide Column Data Store

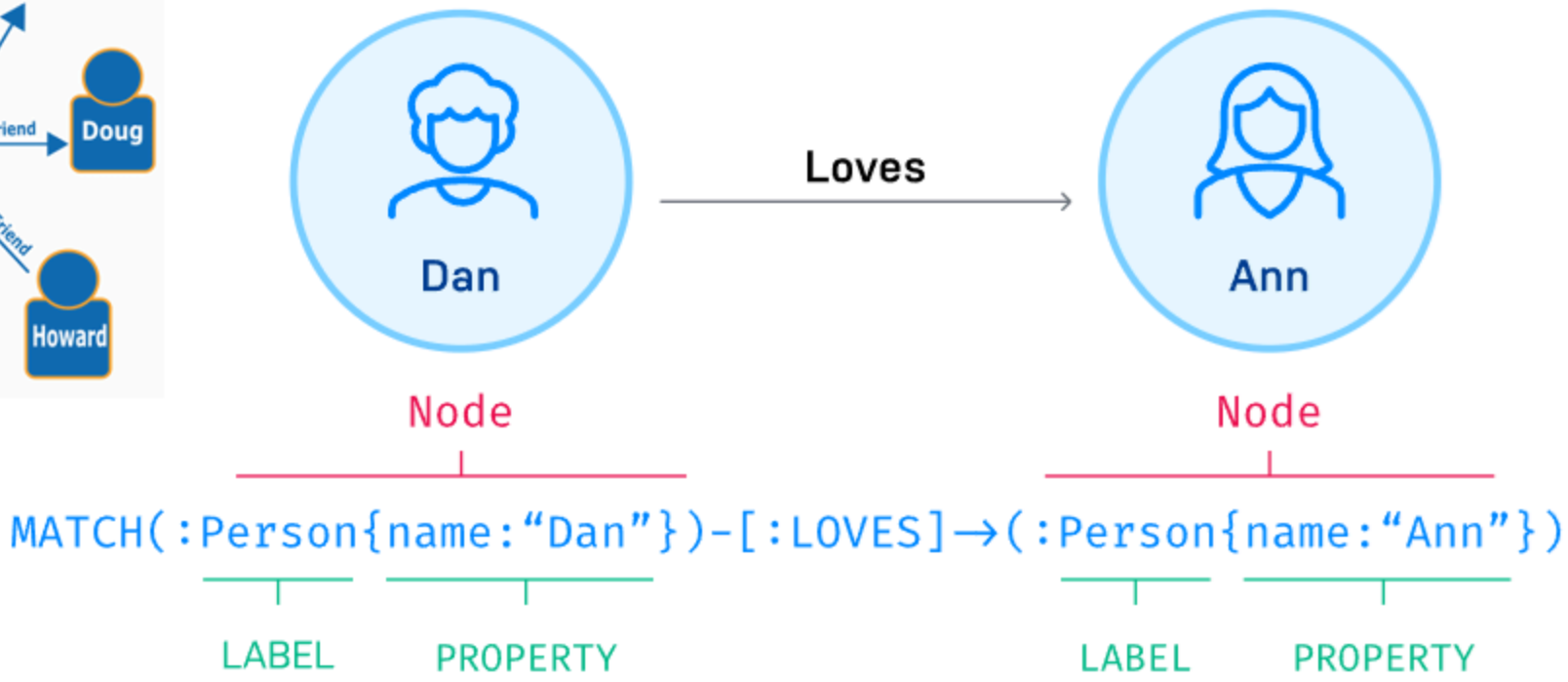


Graph Database

- Store and query highly connected data
- Data are modeled in the form of **entities** (`nodes`) and **relationships** (`edges`) between them
- Able to traverse from `nodes` or `edges` along defined relationship types until reaching some `defined condition`
  - Results : `lists` , `maps` , or graph `traversal path`
- e.g., Neo4j

Graph Database

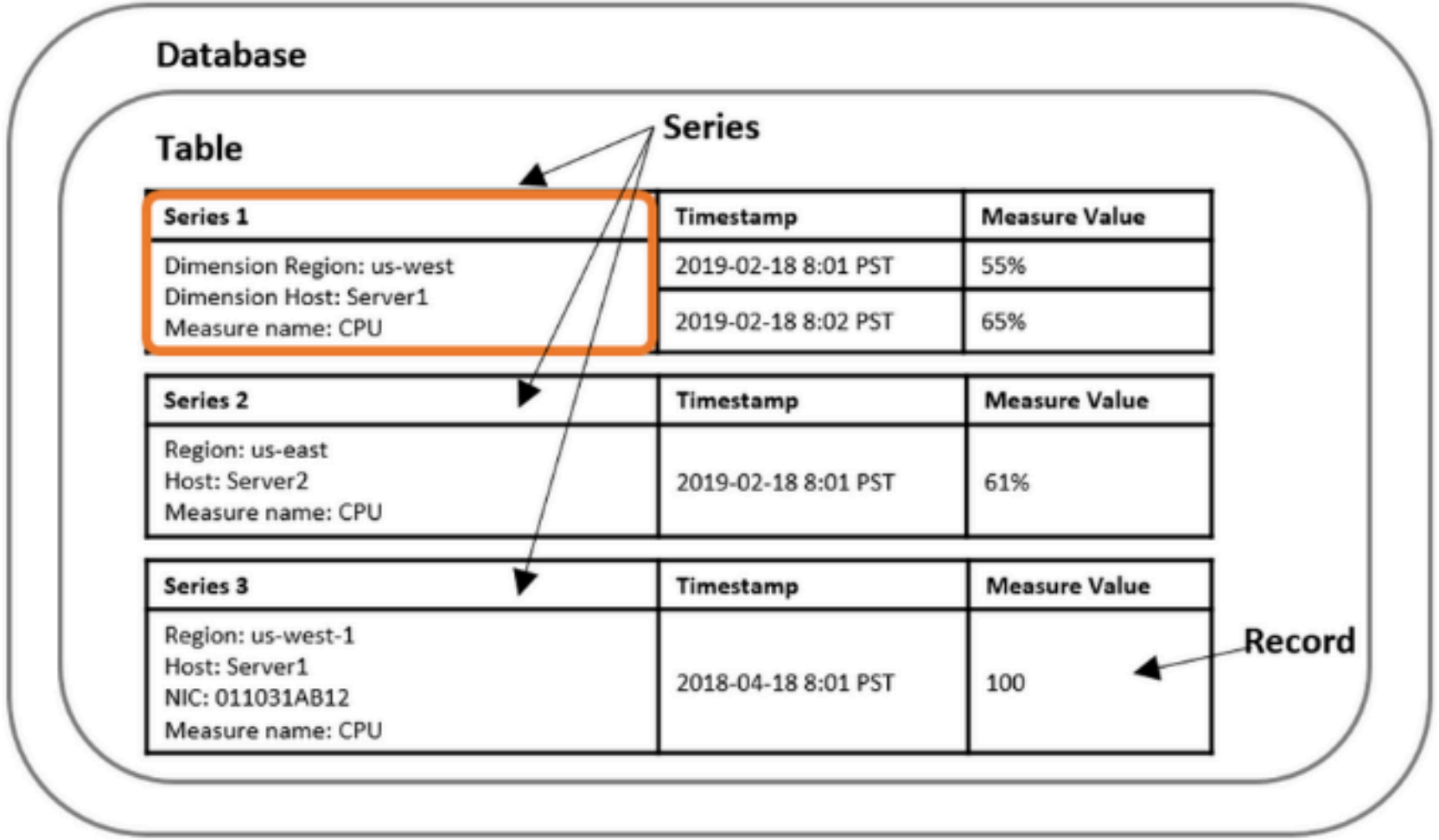




Time Series Database

- Store and retrieve data records that are **sequenced by** `time`
  - Sets of data points associated with `timestamps` and stored in time sequence order
- Easy to measure how data change over time (e.g., IoT application)
- e.g., InfluxDB, Prometheus

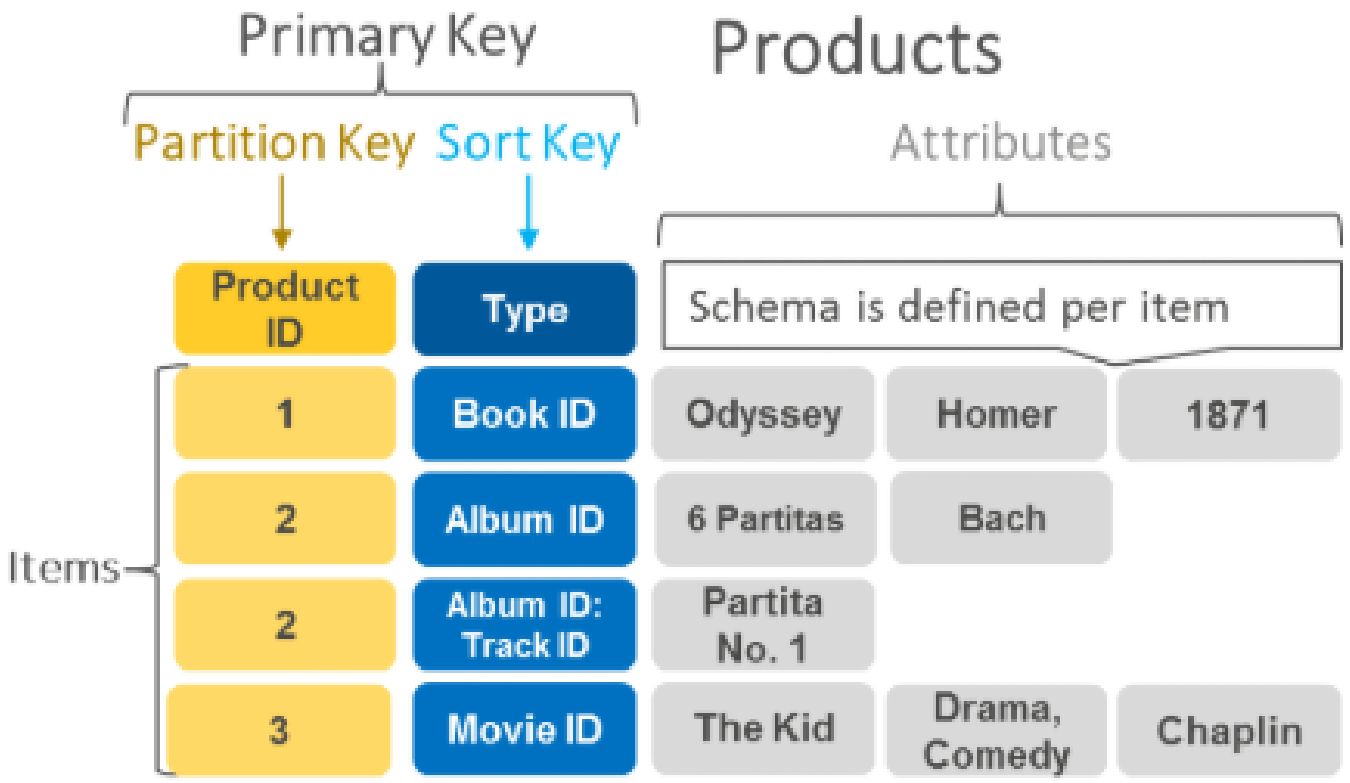
Time Series Database



Key-value Data Store

- Stores data as a collection of `key-value pairs`
- Each data item is identified by a `unique key`
- The `value` can be anything (string, number, object, ...)
- e.g., Redis, Memcached

Key-value Data Store



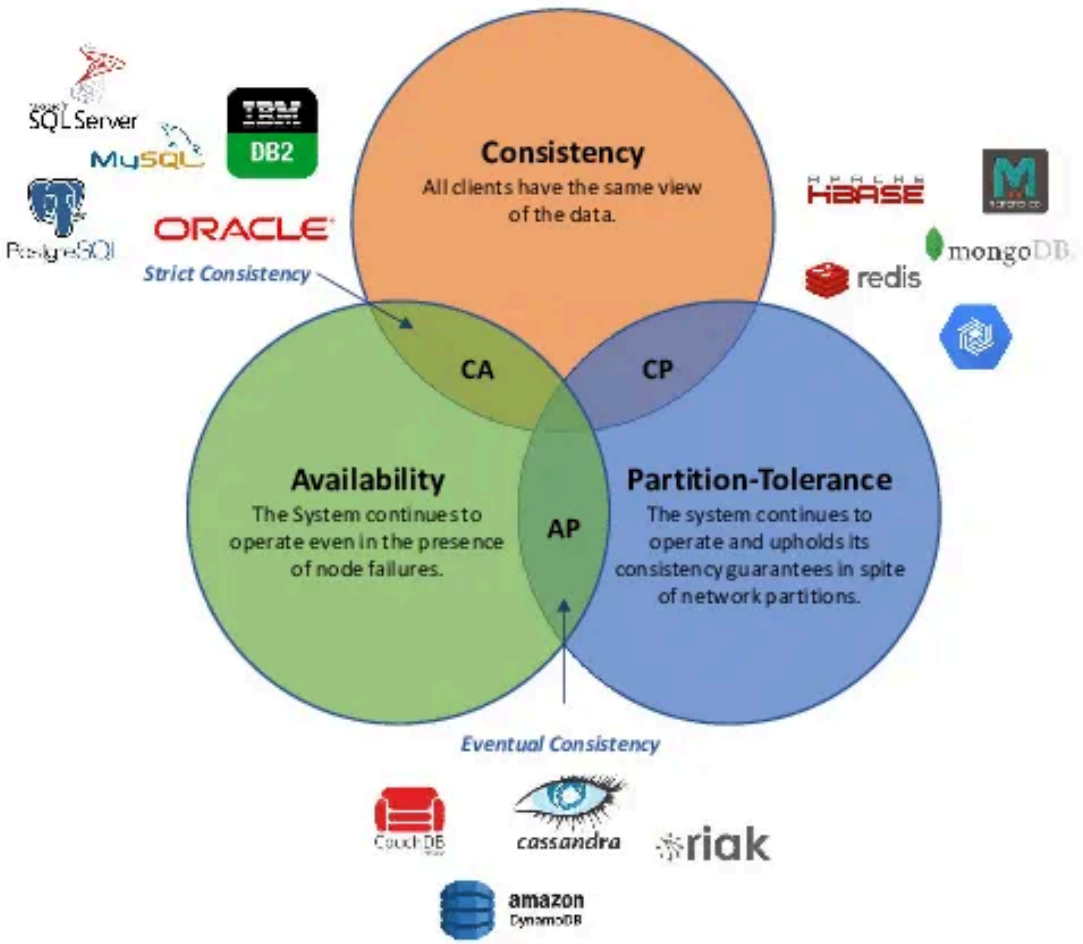
CAP Theorem

In a distributed data system, it is impossible to simultaneously guarantee all of these properties:

- **C** : `Consistency`
- **A** : `Availability`
- **P** : `Partition Tolerance`

Many NoSQL databases are **AP** systems

CAP Theorem


SQL Server
MySQL
DB2
PostgreSQL
ORACLE
Strict Consistency
Consistency
All clients have the same view of the data.
HBASE
redis
mongoDB
CA
CP
Availability
The System continues to operate even in the presence of node failures.
AP
Partition-Tolerance
The system continues to operate and upholds its consistency guarantees in spite of network partitions.
Eventual Consistency
CouchDB
cassandra
riak
amazon
DynamoDB

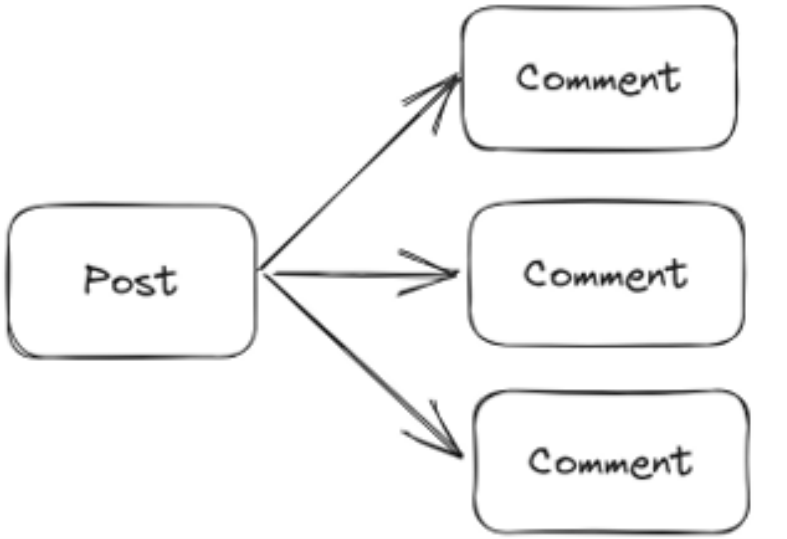
Database Schema

What is Database Schema?

- DB Schema defines how data is organized within the databasae
- Outlining how data is logically stored
- **Key components**:
  - Tables, Columns, Data types, Constraints
  - Primary / Foreign keys
  - Relationships (`one-to-one`, `one-to-many`, `many-to-many`)

Relationship : One-to-Many

e.g., **"Social media status post"**



- A `Post` may have many `comments`
- A `comment` belongs to only one `Post`

SQL Schema : One-to-Many

Post Table

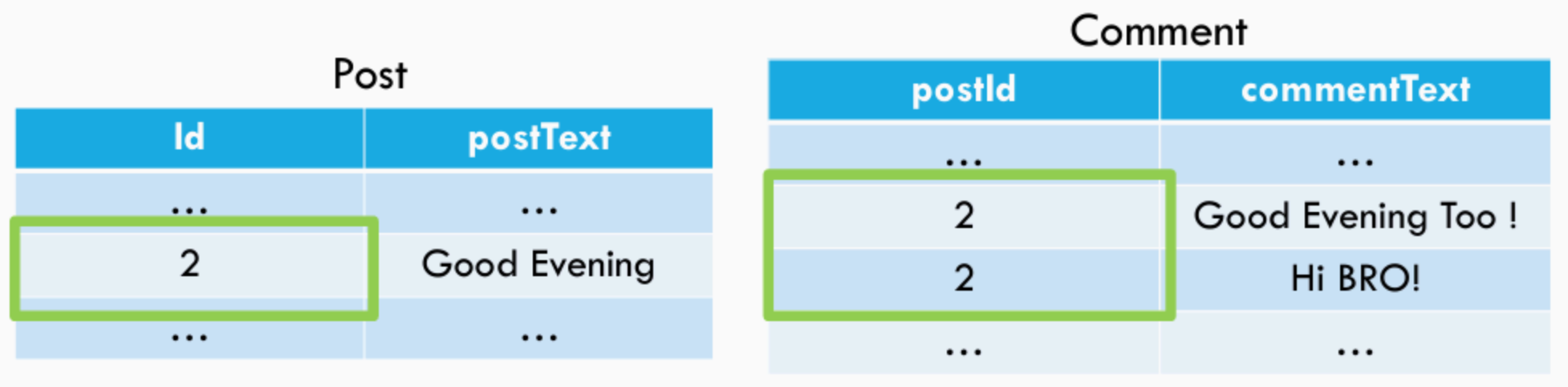
#	Name	Datatype
1	id	INTEGER
2	ownerId	INTEGER
3	postText	TEXT
4	createdAt	TIMESTAMP
5	updatedAt	TIMESTAMP

Comment Table

#	Name	Datatype
1	id	INTEGER
2	postId	INTEGER
3	createdAt	TIMESTAMP
4	updatedAt	TIMESTAMP
5	commentText	TEXT

SQL Query : One-to-Many

e.g., **"Get a `Post` together with its `Comments`"**



SELECT * FROM `Post` JOIN `Comment` ON `Post.Id` = `Comment.postId`;

NoSQL Schema #1 : One-to-Many

Option 1 - Embedding `Comments` as array in `Post` document

- Assuming that a `Post` has less than a hundred `Comments`


```
{
  "_id": {…},
  "postId": 2,
  "postText": "Good evening!",
  "comments": [
    {
      "commentText": "Good evening Too!",
      "username": "bob"
    },
    {
      "commentText": "Good evening Bro!",
      "username": "Alice"
    }
  ]
}
```

NoSQL Schema #2 : One-to-Many

Option 2 - Reference to other collections, avoiding massive array

- Reference each `Comment` to a single `Post`
- What if a `Post` may have thousands of `Comments`

Summary : One-to-Many

SQL

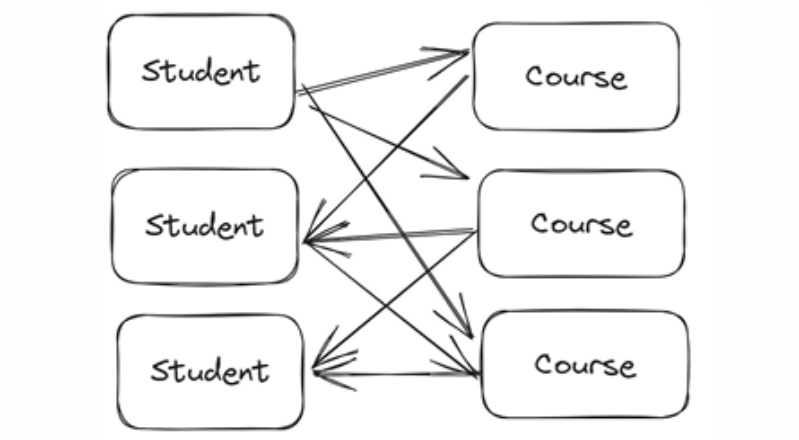
- Create two tables with a `foreign key` (representing a relationship)

NoSQL

- Embedding an `array of objects` in `another type of object`
- References multiple `objects` to `another type of object`

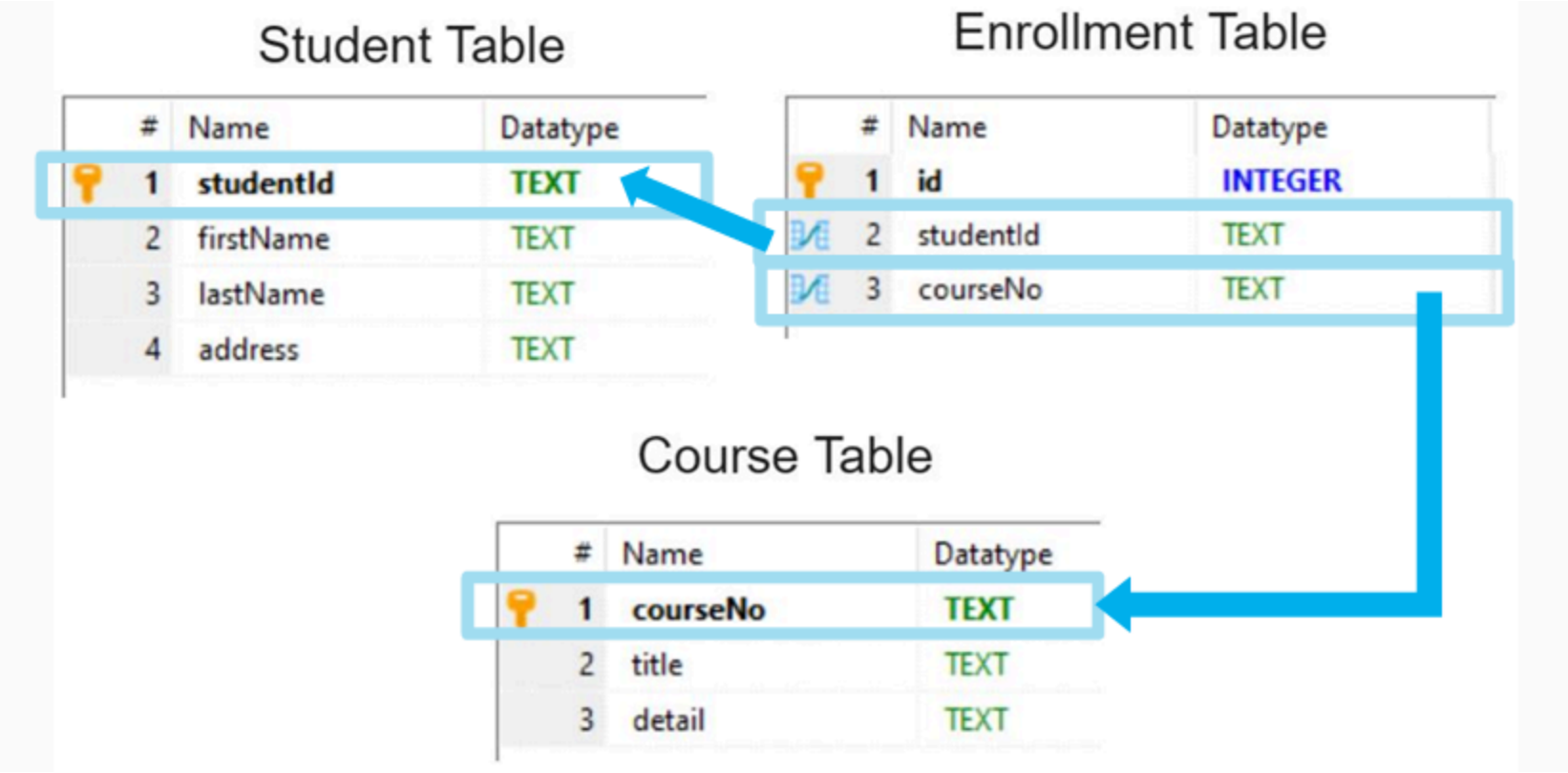
Relationship : Many-to-Many

e.g., **"Students Enrollment"**



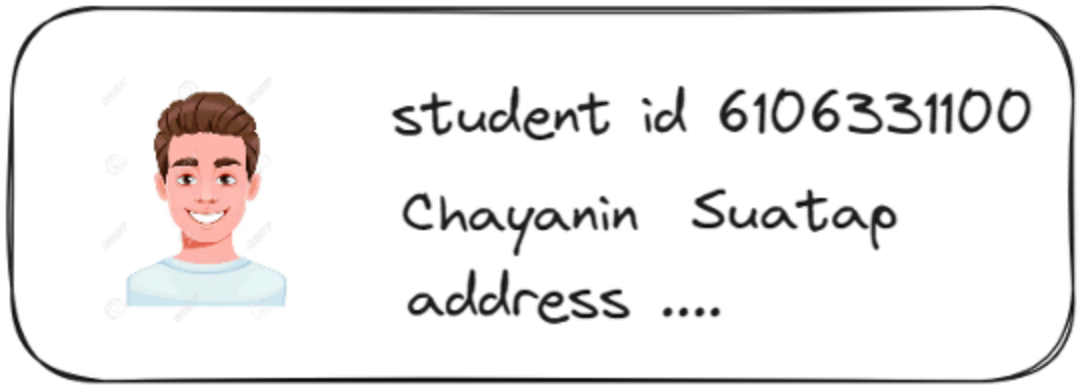
- A `Student` may enroll in multiple `Courses`
- A `Course` is enrolled by many `Students`

SQL Schema : Many-to-Many



SQL Query : Many-to-Many

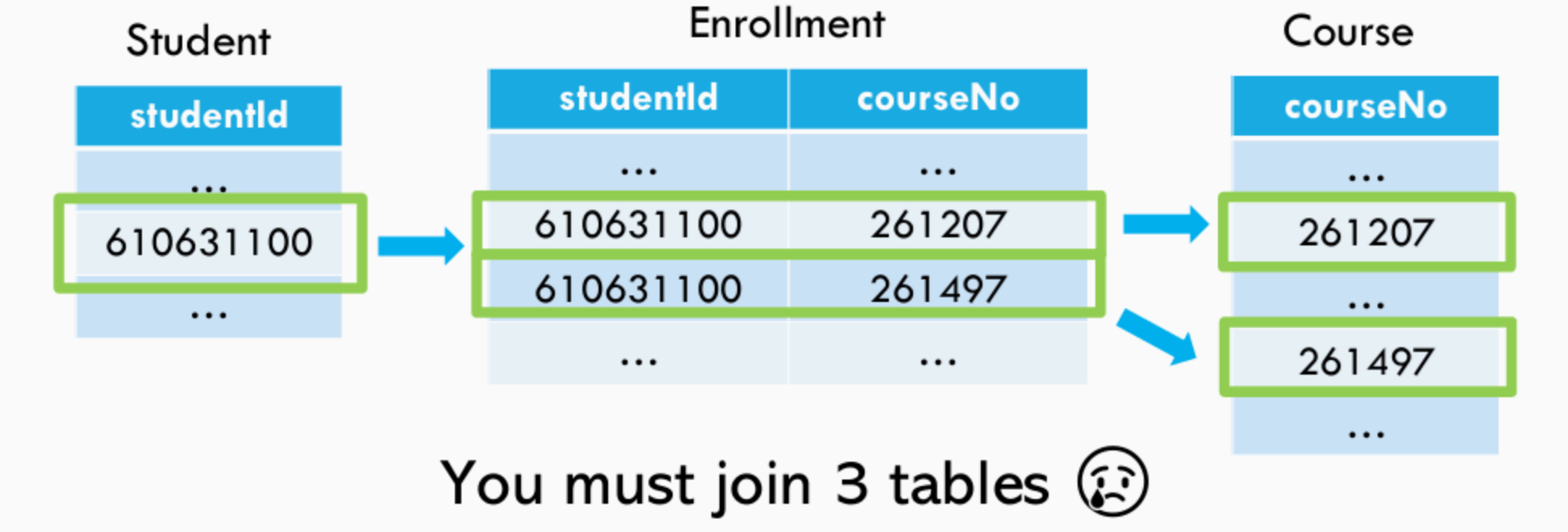
e.g., **"Get all `Courses` title enrolled by a `Student` with specified `studentId`"**



course no	course title
261207	BASIC COMP LAB
261497	FULL STACK DEV

SQL Query : Many-to-Many

e.g., **"Get all `Courses` title enrolled by a `Student` with specified `studentId`"**



NoSQL Schema #1 : Many-to-Many

Option 1 - Embedding a list of `Courses` in a `Student` document

Student

```
_id: ObjectId('649bfc8916b194f723bae07e')
studentId: "610631100"
firstName: "Chayanin"
lastName: "Suatap"
address: "Some place on earth"
▼ coursesEnrolled: Array
    0: "261207"
    1: "261497"
```

Course

```
_id: ObjectId('649bfd7e16b194f723bae07f')
courseNo: "261207"
title: "BASIC COMPUTER ENGINEERING LAB"
detail: "Teaching web development using React and JavaScript"
```

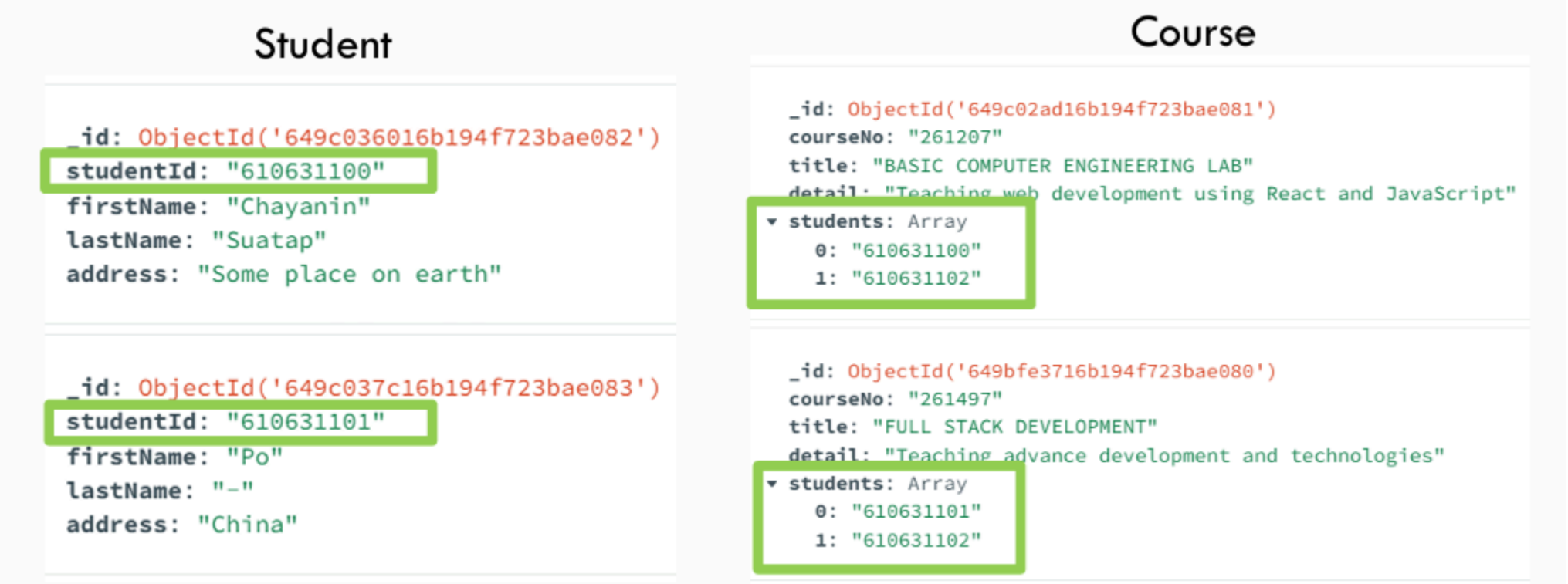
```
_id: ObjectId('649bfe3716b194f723bae080')
courseNo: "261497"
title: "FULL STACK DEVELOPMENT"
detail: "Teaching advance development and technologies"
```

NoSQL Query #1 : Many-to-Many

e.g., **"Which `Students` enroll in my `Course`"**

NoSQL Schema #2 : Many-to-Many

Option 2 - Embedding a list of `Students` in a `Course` document



What if we want both?

NoSQL Schema #3 : Many-to-Many

Option 3 - Embedding a list of `References` in both documents

Student

```
_id: ObjectId('649c5446b325ea1ba80bc21a')
studentId: "610631100"
firstName: "Chayanin"
lastName: "Suatap"
address: "Some place on earth"
▾ coursesEnrolled: Array
    0: "261207"
    1: "261497"
```

Course

```
_id: ObjectId('649c02ad16b194f723bae081')
courseNo: "261207"
title: "BASIC COMPUTER ENGINEERING LAB"
detail: "Teaching web development using React and JavaScript"
▾ students: Array
    0: "610631100"
    1: "610631102"
```

- `Pros` : query efficiently from both sides
- `Cons` : duplicate data, need to update on both side

Summary : Many-to-Many

SQL

- Create **three** tables with `foreign keys` and `JOIN` them together

NoSQL

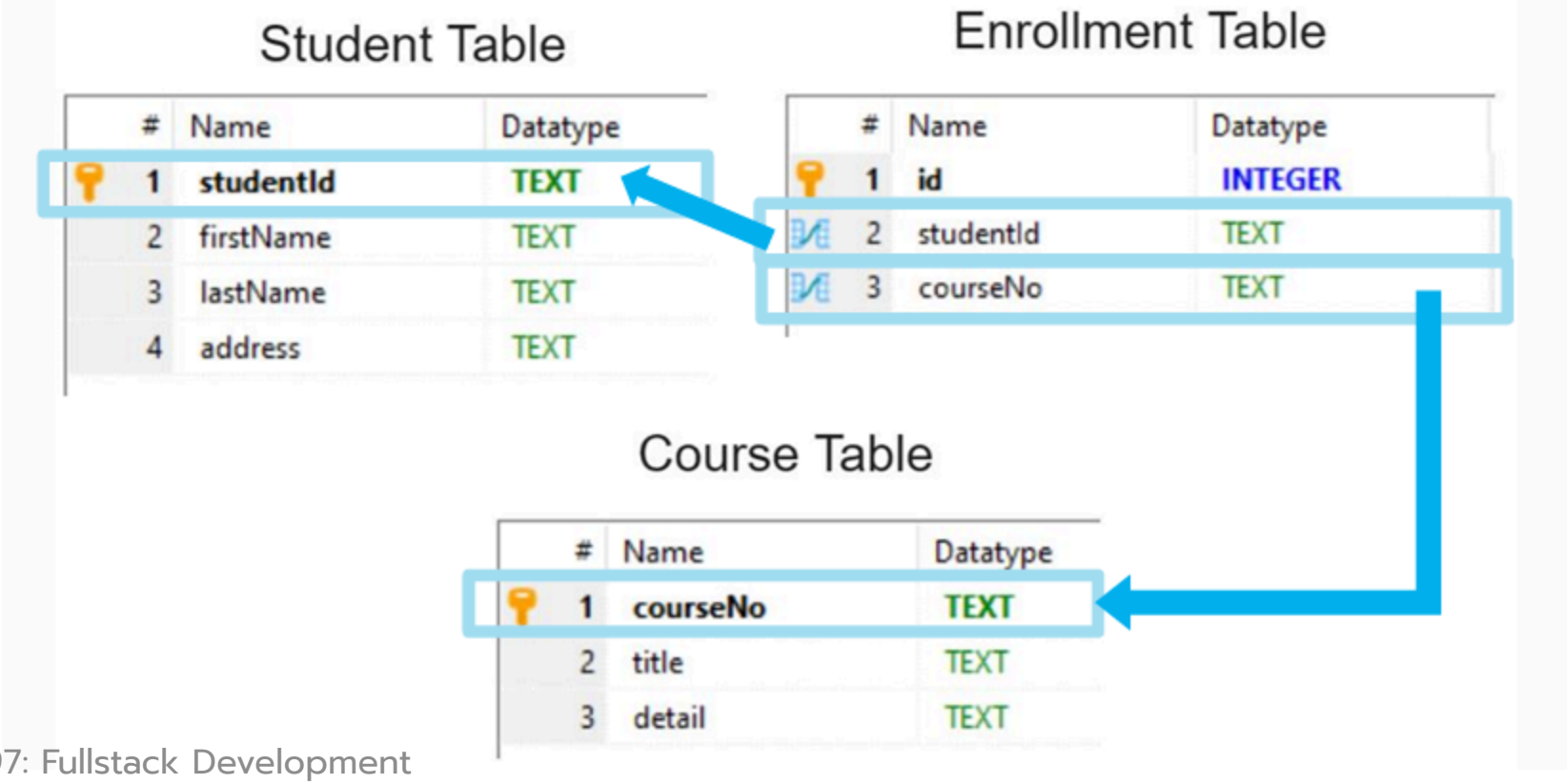
- Choose which side of document to be embedded by determining which side has more queries
- Embedded on both sides and apply `data mutation` very carefully

Data Integrity

SQL Data Integrity

Foreign Key

- Keeps data consistent across related tables



SQL Data Integrity

Data Normalization

- The process of restructuring a relational database
- Helps reducing `data redundancy` (multiple copies of the same data)
- Improves `data integrity` by avoiding updating data in multiple locations

Data Normalization

EmpID	Employee	Age	Dept
1001	ABC	30	Sales,Finance
1002	CDE	30	Sales,Finance,DevOps

DeptID	DeptName
1	Sales
2	Finance
3	DevOps

EmpId	Employee	Age	DepID
1001	ABC	30	1
1001	ABC	30	2
1002	CDE	40	1
1002	CDE	40	2
1002	CDE	40	3

Data Normalization

Compsite Keys

Name	Date	Title	...
AWS_101	9/17/2018	Amazon Web Services	
Azure_101	9/18/2018	SQL Azure Essentials	
DynamoDB_102	9/20/2018	DyanamoDB Advanced Concepts	
SQL_101	11/26/2018	T-SQL Essentials	
SQL_102	11/26/2018	SQL Server for DBA	
AWS_101	11/26/2018	Amazon Web Services	

The column Title is functionally dependent on Name column

Name	Date	...
AWS_101	9/17/2018	
Azure_101	9/18/2018	
DynamoDB_102	9/20/2018	
SQL_101	11/26/2018	
SQL_102	11/26/2018	
AWS_101	11/26/2018	

CourseID	Title
AWS_101	Amazon Web Services
Azure_101	SQL Azure Essentials
DynamoDB_102	DyanamoDB Advanced Concepts
SQL_101	T-SQL Essentials
SQL_102	SQL Server for DBA
AWS_101	Amazon Web Services

How far to take normalization in SQL database?

- This question is **opinion-based**
- Query **more tables* is typically slower (due to more `JOIN` operations)
- Normalize as far as necessary to **remove data integrity issues**
    - Potential data duplication or missing data

Data normalization in NoSQL database

- NoSQL prefers `denormalization`
  - Accept data duplication to improve querying speed
  - `Insert` / `Update` / `Delete` must be performed carefully
- No `foreign key` mechanism built-in

Schema and Data Type Safety

Schema validation

- **SQL** has built-in schema and data type validation (duhh!!!)
- **NoSQL** database usually allows you to annotate and validate JSON documents
  - `MongoDB` uses `JSON schema` to specify validation rules when creating a collection
- Some `ORMs` can be used to defines a schema for **NoSQL**
  - This ORM helps validating data during coding
  - `Prisma ORM` defines a schema for `MongoDB`, providing type safety
  - Unfortunately, `Drizzle` does not natively support MongoDB

MongoDB JSON Schema

```
db.createCollection("students", {
   validator: {
      $jsonSchema: {
         bsonType: "object",
         title: "Student Object Validation",
         required: [ "address", "major", "name", "year" ],
         properties: {
            name: {
               bsonType: "string",
               description: "'name' must be a string and is required"
            },
            year: {
               bsonType: "int",
               minimum: 2017,
               maximum: 3017,
               description: "'year' must be an integer in [ 2017, 3017 ] and is required"
            },
            gpa: {
               bsonType: [ "double" ],
               description: "'gpa' must be a double if the field exists"
            }
         }
      }
   }
} )
```

Prisma ORM Schema

```
model Post {
  id       String    @id @default(auto()) @map("_id") @db.ObjectId
  slug     String    @unique
  title    String
  body     String
  author   User      @relation(fields: [authorId], references: [id])
  authorId String    @db.ObjectId
  comments Comment[]
}

model User {
  id      String   @id @default(auto()) @map("_id") @db.ObjectId
  email   String   @unique
  name    String?
  address Address?
  posts   Post[]
}
```

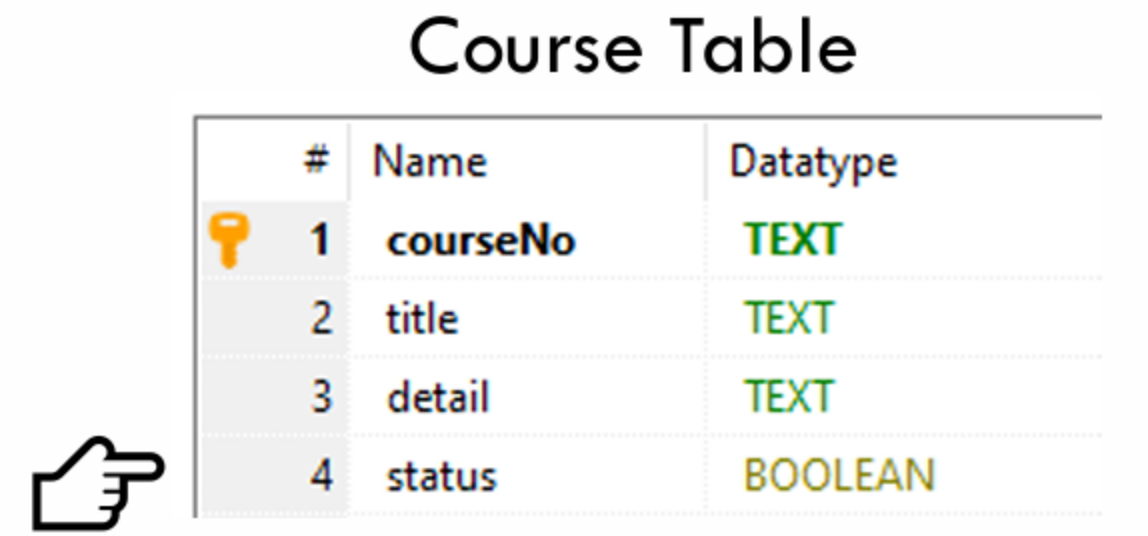
```
model Comment {
  id      String @id @default(auto()) @map("_id") @db.ObjectId
  comment String
  post    Post   @relation(fields: [postId], references: [id])
  postId  String @db.ObjectId
}

// Address is an embedded document
type Address {
  street String
  city   String
  state  String
  zip    String
}
```

Common Database Patterns

Soft DELETE

To delete a row, marks the `status` field as `false`.



Soft DELETE

`Pros`

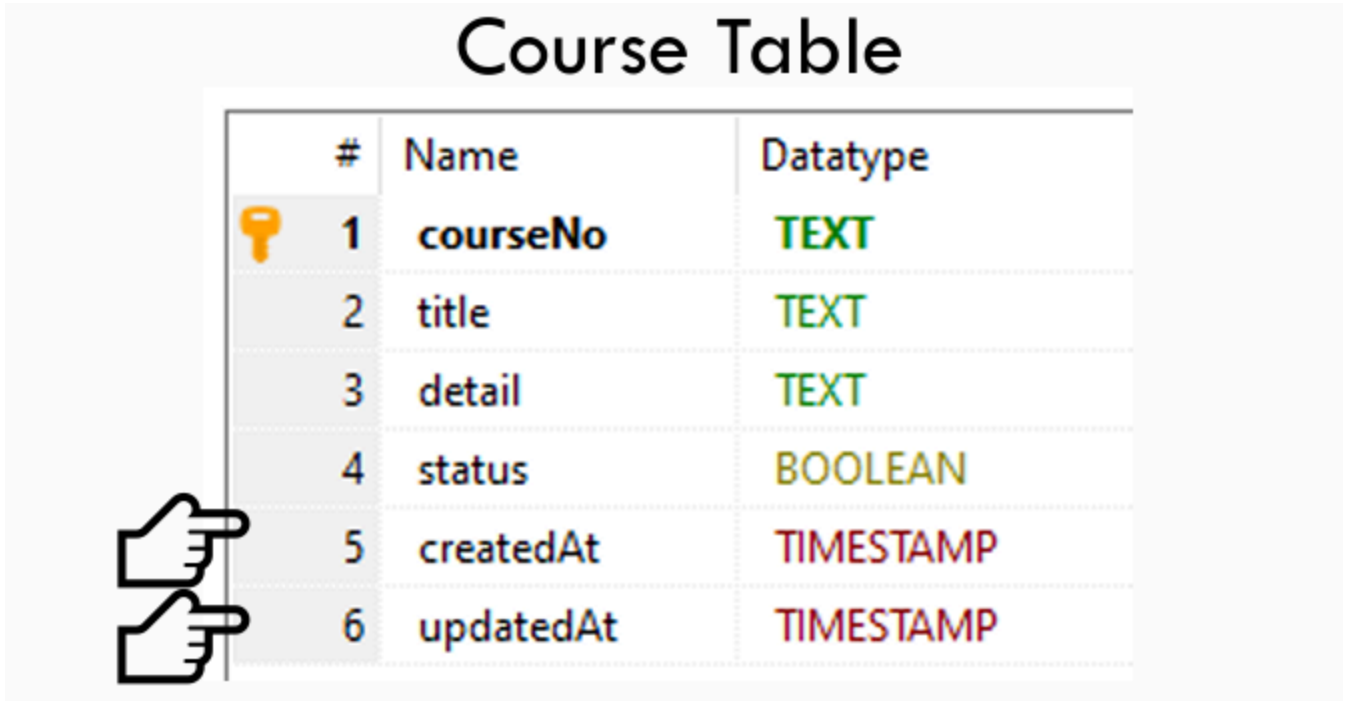
- Able to view history of data
- Sensitive data remains in the database
- Undeletion is possible

`Cons`

- Every query must has `where status = true` condition
- `Size` of **table / collection** is larger

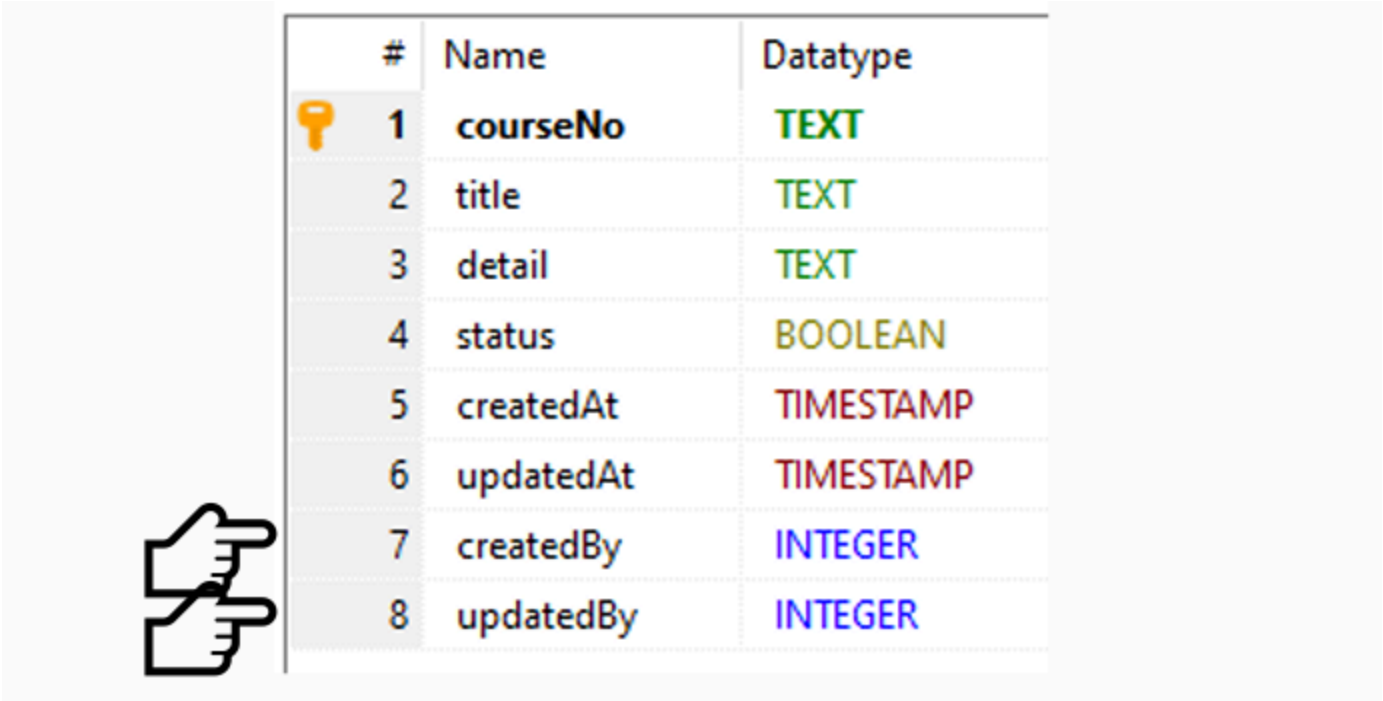
Created-At and Updated-At

"Tracking `when` a row was **created** or **updated**"



Created-By and Updated-By

"Tracking `who` has interacted with the data"



#	Name	Datatype
1	courseNo	TEXT
2	title	TEXT
3	detail	TEXT
4	status	BOOLEAN
5	createdAt	TIMESTAMP
6	updatedAt	TIMESTAMP
7	createdBy	INTEGER
8	updatedBy	INTEGER

NoSQL Pattern

Example: Social media latest [#] posts

"Get the latest [#] Posts of specified User in one query"

Example: Social media latest [#] posts

User Collection

```
username: "Arm",
password: "xxxx",
birthDate: "xxx",
latest5Posts : [{
        postText:" Good Evening",
        likeNum: 400
    },
    {
        postText:" Hi bro",
        likeNum: 500
    }
    ...
]
```

Comment Collection

```
{
    username: "Arm"
    postText:"Good Evening",
    likeNum: 400
}
{
    username: "Arm"
    postText:"Good Morning",
    likeNum: 500
}
...
```

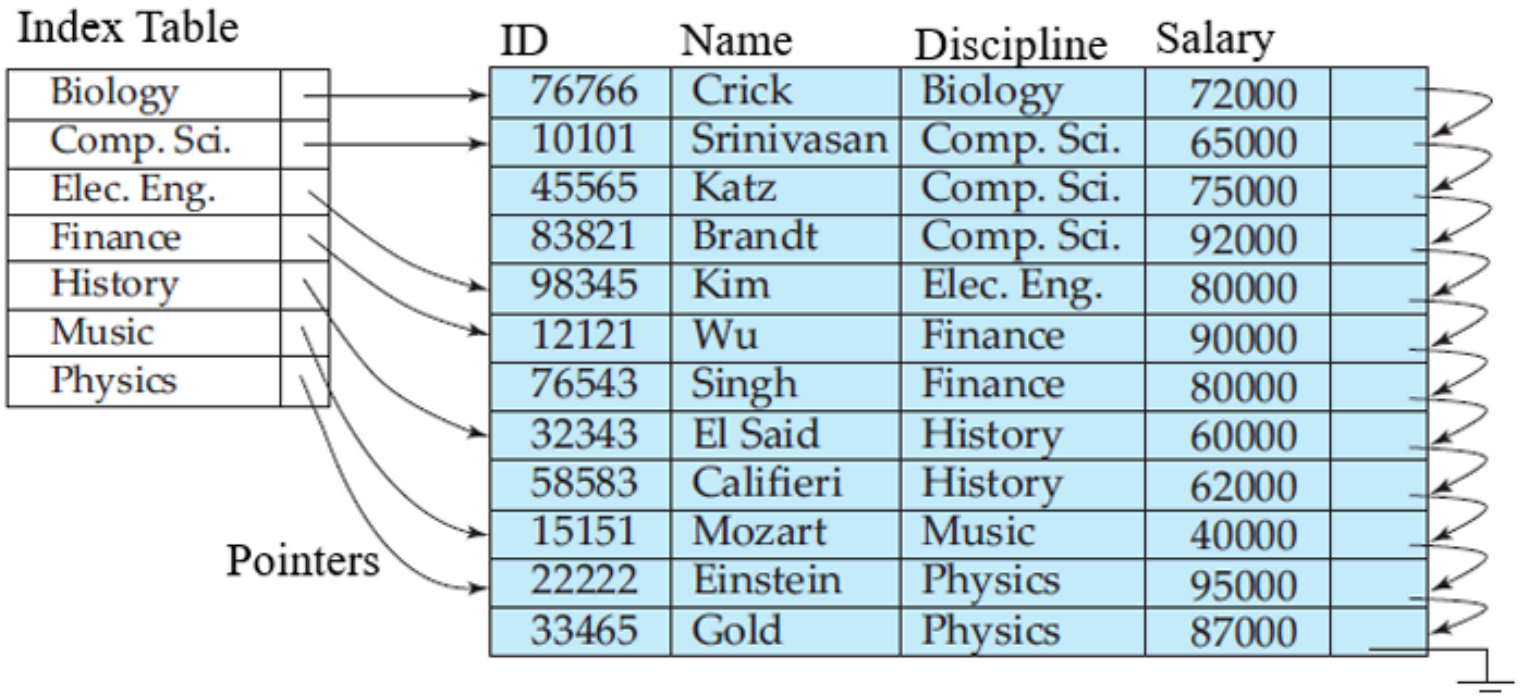
Database Index

What is Index?

- A **data structure** that improves the speed of data retrieval operations on `database table`
- `Index` costs **additional writes** and **storage space** to maintain the index data structure

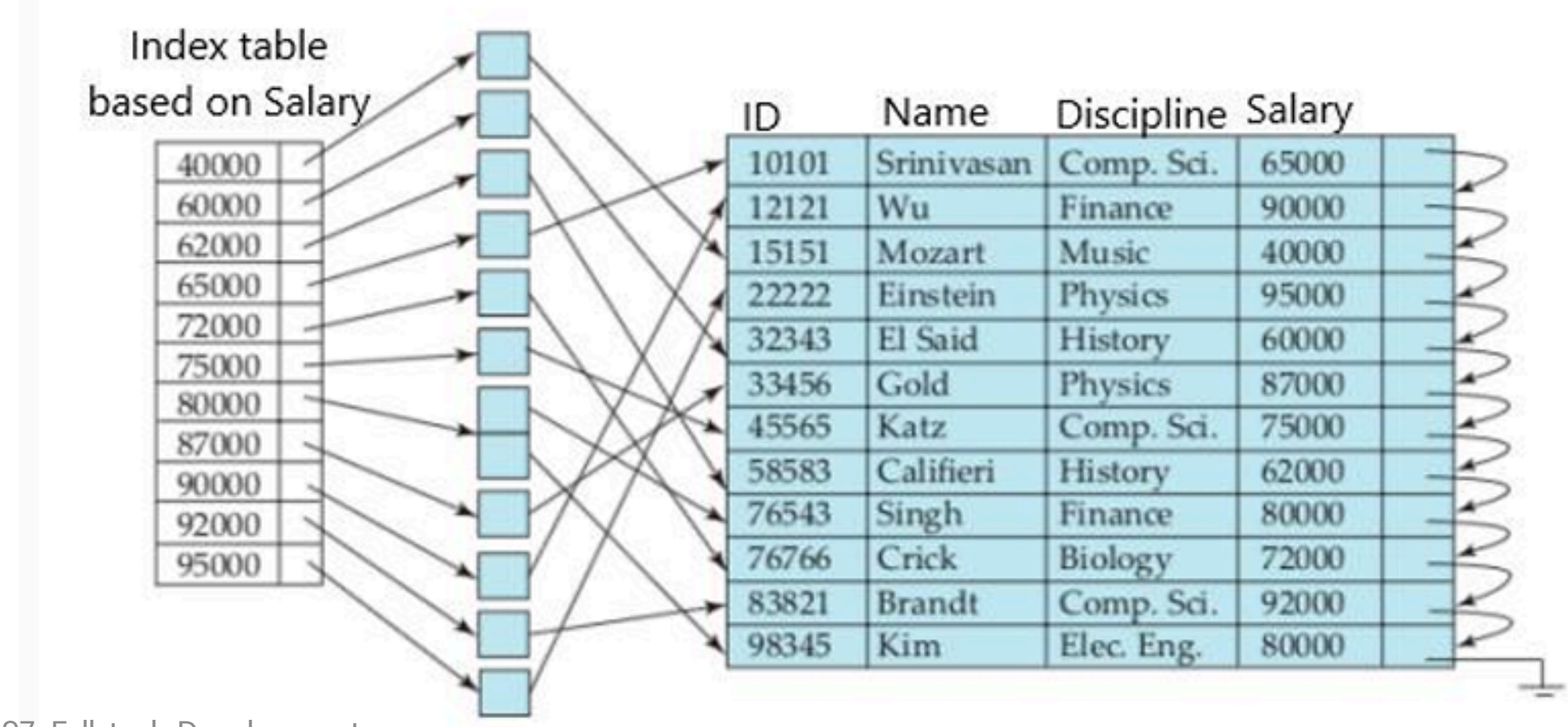
Index Example

"Get `instructors` with `Finance` discipline"



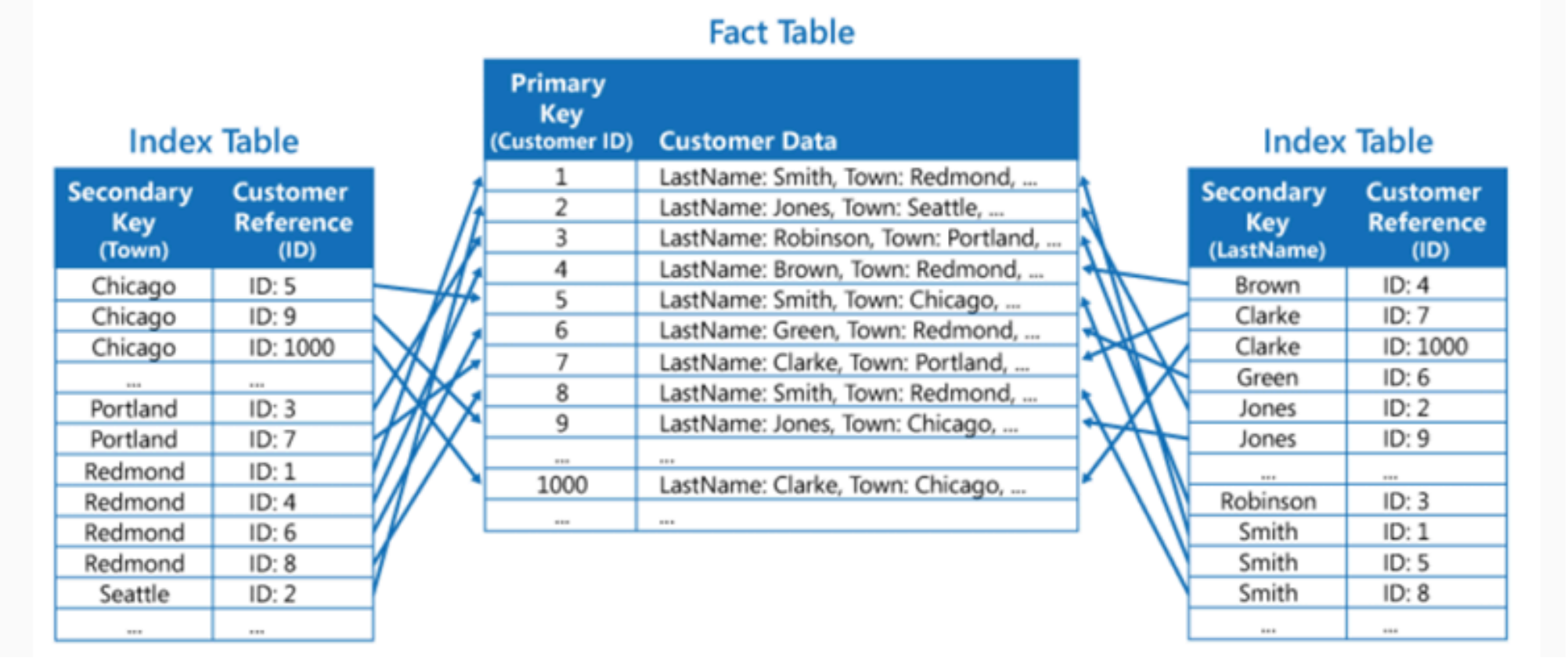
Index Example

"Get `instructors` ordered by `Salary`"



Composite Index

"Get `Customers` ordered by `Name` and `Town`"



Unique Index

- Unique index is used to ensure data uniqueness
- e.g., To ensure that a `Student` cannot enroll the same `Course` twice
  - Create a **`compound unique index`** containing `studentId` and `courseNo`

Enrollment Table

#	Name	Datatype
1	id	INTEGER
2	studentId	TEXT
3	courseNo	TEXT

Index Summary

Pros

- Query data more efficiently, speed up `SELECT` operation

Cons

- Index must be rebuilt when `INSERT` / `UPDATE` / `DELETE`, hence slower
- Index requires addtional storage space on database

Unique Identifier

- A value that distinquishes a **specific record** (row, document) from others within the table
- Prevent ambiguity and enabling efficient data retrieval and management

Auto Increment ID

SQL database only

- MySQL uses the `AUTO_INCREMENT` keyword

```
CREATE TABLE table_name (
    id INT AUTO_INCREMENT PRIMARY KEY,
    column2 VARCHAR(255),
    column3 INT,
    -- Add other columns as needed
);
```

Auto Increment ID

- PostgreSQL uses the `SERIAL` or `SEQUENCE` keywords

```
CREATE TABLE my_table (
    id SERIAL PRIMARY KEY,
    name VARCHAR(255)
);
```

```
CREATE SEQUENCE my_sequence START 100 INCREMENT 5;

CREATE TABLE another_table (
    id INTEGER NOT NULL DEFAULT nextval('my_sequence'),
    description TEXT
);

ALTER SEQUENCE my_sequence OWNED BY another_table.id;
```

UUID

Universally Unique ID

- Not able to find the same `UUID` in the same Universe
- The term **Globally Unique Identifier** (`GUID`) is also used
  - Used mostly in Microsoft systems
- `UUID 4` is widely used

UUID v4

- The most commonly used and recommended for general-purpose applications
  - Due to its **simplicity** and reliance on **pseudo-random number generator**
- 128-bit value (32-Hexadecimal)
- Formated as 5-group of characters (8-4-4-4-12)

c9b135f6-f163-40d6-8483-0a57780e3f17

What to use as Primary Keys?

Auto-increment IDs vs. UUIDs ?

ID	Value		ID	Value
1	Apple		C87FC84A-EE47-47EE-842C-29E969AC5131	Apple
2	Orange	**vs.**	2A734AE4-E0EF-4D77-9F84-51A8365AC5A0	Orange
3	Pear		70E2E8DE-500E-4630-B3CB-166131D35C21	Pear
4	Mango		15ED815C-921C-4011-8667-7158982951EA	Mango

UUID Pros and Cons

Pros

- Unique across every table, database, every server
- Easy merging of records form different databases
- Easy distribution of databases across multiple servers, aka. **sharding**

Cons

- Larger than tradition typically ID
- This can have serious performance and storage implications
- May be difficult to debug

```
... where userid = ‘{BAE7DF4-DDF-3RG-5TY3E3RF456AS10}’
```

MongoDB Object ID

- Insert automatically in every document
- Embedded `timestamp` inside the ID > Can be used to sort as `create date`

```
[
  {
    _id: ObjectId("62bb413014b92d148400f7a5"),
    name: "Alice",
    year: 2019,
    major: "History",
    gpa: 3,
    address: { city: "NYC", street: "33rd Street" },
  },
];
```