



UMD DATA605: Big Data Systems

Lesson 1.4: Data Models

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Data Models

- **Data modeling**
 - Represents and captures structure and properties of real-world entities
 - Abstraction: real-world → **representation**
- **Data model**
 - Describes how data is *represented* (e.g., relational, key-value) and *accessed* (e.g., insert operations, query)
 - Schema in a DB describes a specific data collection using a data model
- **Why need data model?**
 - Know data structure to write general-purpose code
 - Share data across programs, organizations, systems
 - Integrate information from multiple sources
 - Preprocess data for efficient access (e.g., building an index)

Multiple Layers of Data Modeling

- **Physical layer**

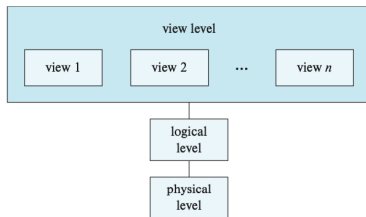
- How is the data physically stored
- How to represent complex data structures (e.g., B-trees for indexing)

- **Logical layer**

- Entities
- Attributes
- Type of information stored
- Relationships among the above

- **Views**

- Restrict information flow
- Security and/or ease-of-use



Data Models: Logical Layer

- **Modeling constructs**

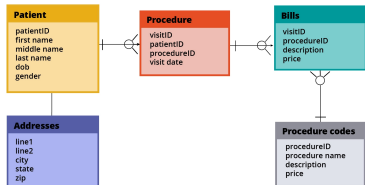
- Concepts to represent data structure
- E.g.,
 - Entity types
 - Entity attributes
 - Relationships between entities
 - Relationships between attributes

- **Integrity constraints**

- Ensure data integrity
 - Avoid errors and inconsistencies
 - E.g., field can't be empty, must be an integer

- **Manipulation constructs**

- E.g., insert, update, delete data



Data Independence

- **Logical data independence**
 - Change data representation without altering programs
 - E.g., API abstracting backend
- **Physical data independence**
 - Change data layout on disk without altering programs
 - Index data
 - Partition/distribute/replicate data
 - Compress data
 - Sort data

Examples of Data Models

- **Some examples of data models**
 - Relational model (SQL)
 - Entity-relationship (ER) model
 - XML
 - Object-oriented (OO)
 - Object-relational
 - RDF
 - Property graph
- **Serialization formats** as data models
 - CSV
 - Parquet
 - JSON
 - Protocol Buffer
 - Avro/Thrift
 - Python Pickle

Good Data Models

- **Good data model** should be:
 - Expressive
 - Capture real-world data
 - Easy to use
 - Perform well
- **Trade-off between characteristics**
 - E.g., more powerful models
 - Represent more datasets
 - Harder to use/query
 - Less efficient (e.g., more memory, time)
- **Evolution of data models** captures data structure
 - Structured data → Relational DBs
 - Semi-structured web data → XML, JSON
 - Unstructured data → NoSQL DBs

A Brief History of Databases (Early 1960s)

- **1960s: Early beginning**
 - Computers become attractive technology
 - Enterprises adopt computers
 - Applications use own data stores
 - Each application has its own format
 - Data unavailable to other programs
- **Database:** term for “shared data banks” by multiple applications
 - Define data format
 - Store as “data dictionary” (schema)
 - Implement “database management” software to access data
- **Issues**
 - How to write data dictionaries?
 - How to access data?
 - Who controls the data?
 - E.g., integrity, security, privacy concerns

A Brief History of Databases (1960s)

- **1960s, Hierarchical and Network Model**
 - Connect records of different types
 - Example: connect accounts with customers
 - Network model aimed for generality and flexibility
- IBM's IMS Hierarchical Database (1966)
 - Designed for Apollo space program
 - Predates hard disks
 - Used by over 95% of top Fortune 1000 companies
 - Processes 50 billion transactions daily, manages 15 million GBs of data
- **Cons**
 - Exposed too much internal data (structures/pointers)
 - Leaky abstraction

Relational, Hierarchical, Network Model

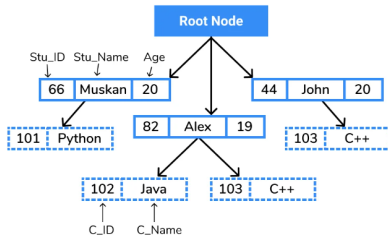
- **Relational model**

- Data as tuples in relations
- SQL

Customer ID	Tax ID	Name	Address	[More fields...]
1234567890	555-5512222	Ramesh	323 Southern Avenue	...
2223344556	555-5523232	Adam	1200 Main Street	...
3334445563	555-5533323	Shweta	871 Rani Jhansi Road	...
4232342432	555-5325523	Sarfaraz	123 Maulana Azad Sarani	...

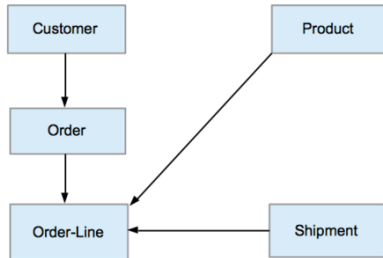
- **Hierarchical model**

- Tree-like structure
 - One parent, many children
 - Connected through links
- XML DBs resurgence in 1990s



- **Network model**

- Graph organization
 - Multiple parents and children
- Graph DBs resurgence in 2010s



A Brief History of Databases (1970s)

- **1970s: Relational model**

- Set theory, first-order predicate logic
 - Ted Codd developed the Relational Model
- Elegant, formal model
 - Provided data independence
 - Users didn't worry about data storage, processing
- High-level query language
 - SQL based on relational algebra
- Notion of normal forms
 - Reason about data and relations
 - Remove redundancies

- **Influential projects**

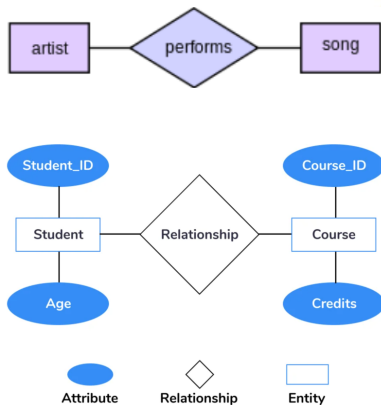
- INGRES (UC Berkeley), System R (IBM)
- Ignored IMS compatibility

- **Debates:**

- Relational Model vs Network Model proponents

Entity-Relationship Model

- **Entity-Relationship Model**
 - Proposed in 1976 by Peter Chen
- Describes knowledge as:
 - **Entities**: Physical or logical objects, “Nouns”
 - **Relationships**: Connections between entities, “Verbs”
- Map ER model to relational DB
 - Entities, relationships → tables



A Brief History of Databases (1980s)

- **1980s: Relational model acceptance**
 - SQL standard due to IBM's backing
 - Enhanced relational model
 - Set-valued attributes, aggregation
- **Late 80's**
 - Object-oriented DBs
 - Store objects, not tables
 - Overcome *impedance mismatch* between languages and databases
 - Object-relational DBs
 - User-defined types
 - Combine object-oriented benefits with relational model
 - No expressive difference from pure relational model

Object-Oriented

- OOP is a data model
 - Object behavior described through data (fields) and code (methods)
- **Composition**
 - has-a relationships
 - E.g., Employee class has an Address class
- **Inheritance**
 - is-a relationships
 - E.g., Employee class derives from Person class
- **Polymorphism**
 - Code executed depends on the class of the object
 - One interface, many implementations
 - E.g., draw() method on a Circle vs Square object, both descending from Shape class
- **Encapsulation**
 - E.g., private vs public fields/members
 - Prevents external code from accessing inner workings of an object

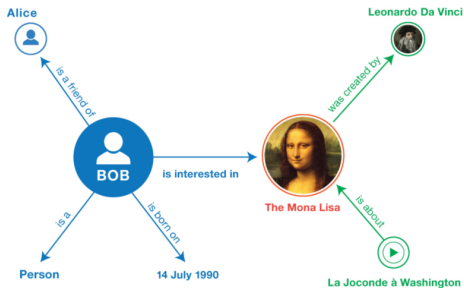
A Brief History of Databases (1990s)

- **Late 90's-today**
- Web/Internet emerges
- XML: eXtensible Markup Language
 - For *semi-structured* data
 - Tree-like structure
 - Flexible schema

```
<?xml version="1.0" encoding="UTF-8"?>
<CATALOG>
  <CD>
    <TITLE>Empire Burlesque</TITLE>
    <ARTIST>Bob Dylan</ARTIST>
    <COUNTRY>USA</COUNTRY>
    <COMPANY>Columbia</COMPANY>
    <PRICE>10.90</PRICE>
    <YEAR>1985</YEAR>
  </CD>
  <CD>
    <TITLE>Hide your heart</TITLE>
    <ARTIST>Bonnie Tyler</ARTIST>
    <COUNTRY>UK</COUNTRY>
    <COMPANY>CBS Records</COMPANY>
    <PRICE>9.90</PRICE>
    <YEAR>1988</YEAR>
  </CD>
  ...
```

Resource Description Framework

- Aka RDF
- **(subject, predicate, object) triple**
- Example of RDF triple
 - Subject=smy
 - Predicate=has-the-color
 - Object=blue
- Maps to a labeled, directed multi-graph
 - More general than a tree
- **Stored in:**
 - Relational DBs
 - Dedicated “triple-stores” DBs



Property Graph Model

- **Graph:**
 - Vertices and edges
 - Properties for each edge and vertex
- **Stored in:**
 - Relational DBs
 - Graph DBs

