UMD DATA605: Big Data Systems

Lesson 1.3: Data Models

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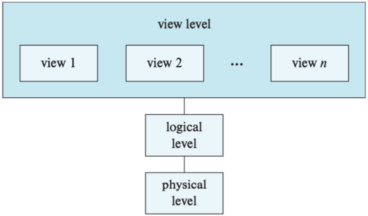
Data Models

- **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)

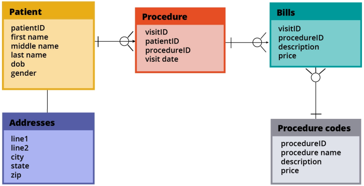
Multiple Layers of Data Modeling

- **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



Patient
patientID
first name
middle name
last name
dob
gender

Procedure
visitID
patientID
procedureID
visit date

Bills
visitID
procedureID
description
price

Addresses
line1
line2
city
state
zip

Procedure codes
procedureID
procedure name
description
price

Examples of Data Models

- We will cover:
  - 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

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

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

Databases: A Brief History

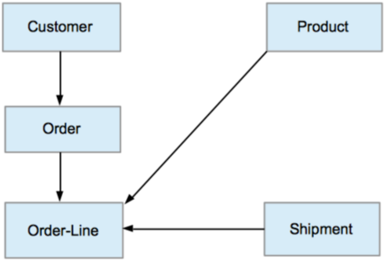
- **1960s: Early beginning**
  - Computers become attractive technology
  - Enterprises adopt computers
  - Applications use own data stores
    - Each application has its own format
    - Data unavailable to other programs
  - **Database**: term for “shared data banks” by multiple applications
    - 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

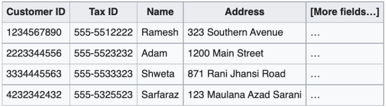
Databases: A Brief History

- **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 gigabytes of data
- Cons:
  - Exposed too much internal data (structures/pointers)
  - Leaky abstraction

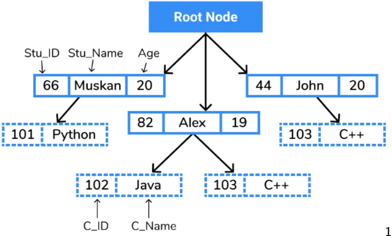
Relational, Hierarchical, Network Model

- **Relational model**
  - Data as tuples in relations
  - SQL
- **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





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	...

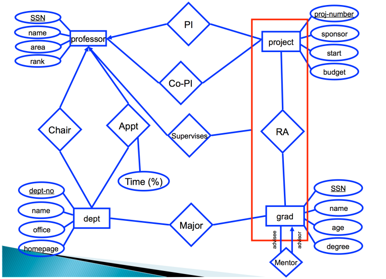


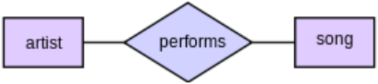
Databases: A Brief History

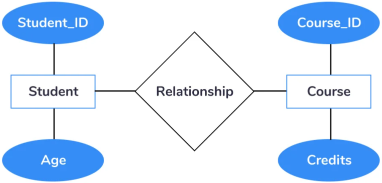
- **1970s: Relational model**
  - Set theory, first-order predicate logic
    - Ted Codd developed the Relational Model
  - Elegant, formal model
    - Provided data independence
    - Users didn't worry about data storage, processing
  - High-level query language
    - SQL based on relational algebra
  - 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

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







Databases: A Brief History

- **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**
  - Aka `has-a` relationships
  - E.g., `Employee` class has an `Address` class
- **Inheritance**
  - Aka `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

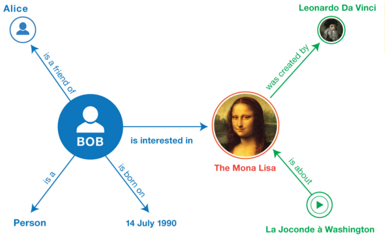
Databases: A Brief History

- **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>
```

Resource Description Framework

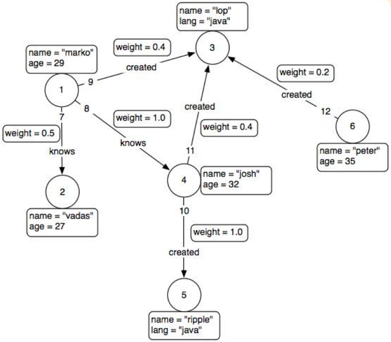
- Aka RDF
- Key construct: “subject-predicate-object” triple
  - Subject=sky
  - Predicate=has-the-color
  - Object=blue
- Maps to a labeled, directed multi-graph
  - More general than a tree
- Stored in:
  - Relational DBs
  - Dedicated “triple-stores” DBs



```
<http://example.org/bob#me
<http://example.org/bob#me
<http://example.org/bob#me
<http://example.org/bob#me
<http://www.wikidata.org/
<http://www.wikidata.org/
<http://data.europeana.eu/
```

Property Graph Model

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


name = "lop"
lang = "java"
3
weight = 0.4
created
9
name = "marko"
age = 29
1
weight = 0.2
created
12
6
name = "peter"
age = 35
8
weight = 1.0
knows
created
weight = 0.4
11
7
weight = 0.5
knows
2
name = "vadas"
age = 27
4
name = "josh"
age = 32
10
weight = 1.0
created
5
name = "ripple"
lang = "java"