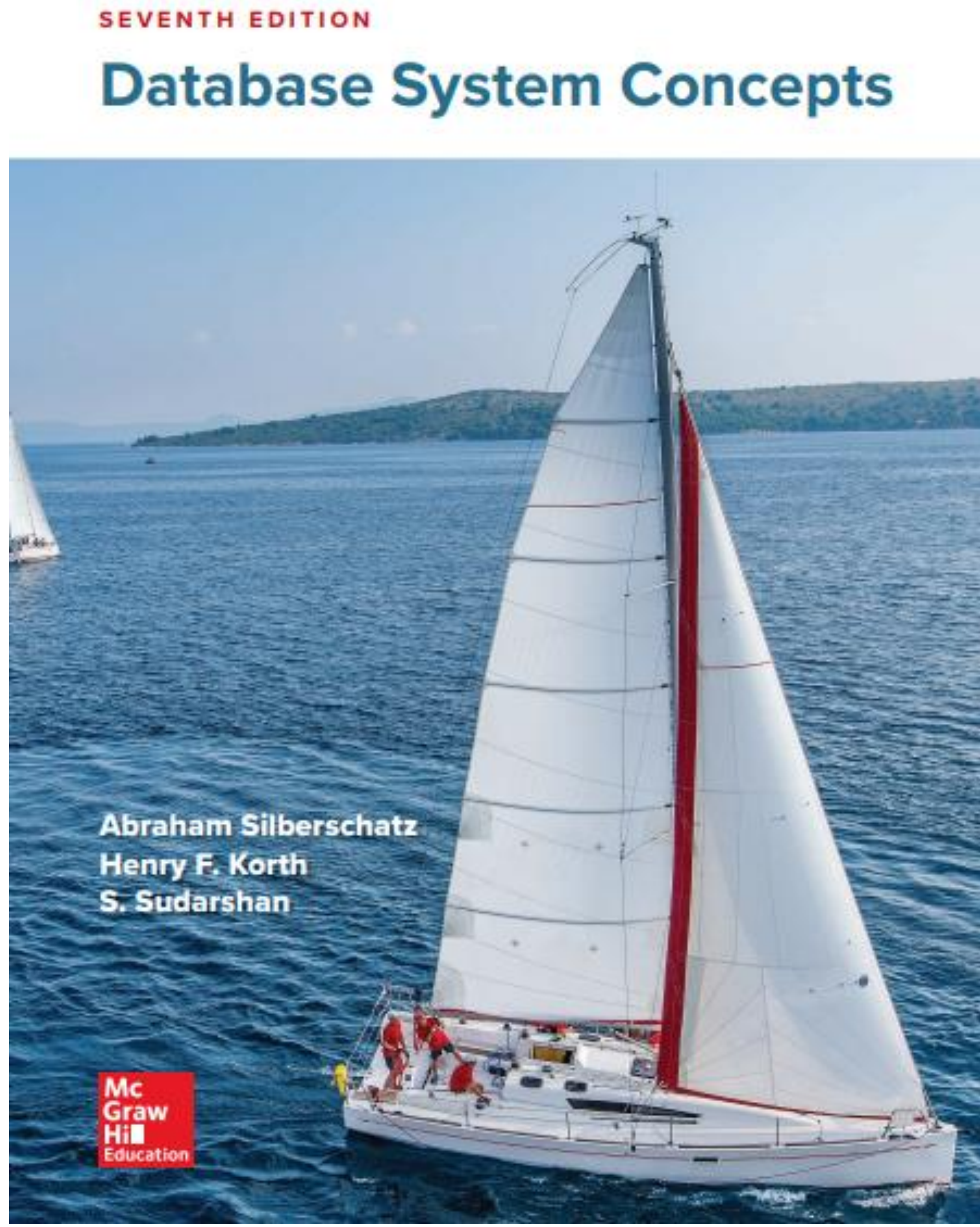
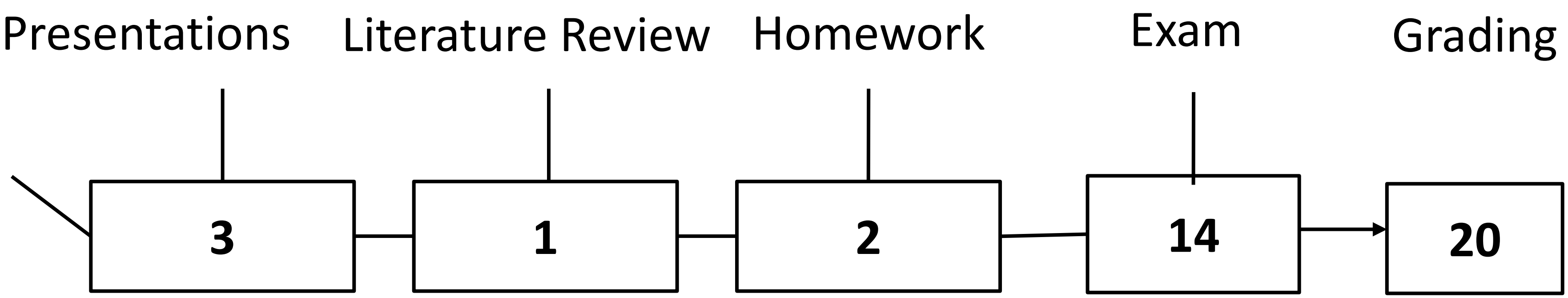
Advance Database -Lecture 1

By Dr. Taghinezhad

Mail: a0taghinezhad@gmail.com



About This Course



Projects include:

Each student needs to **review at least three papers** and write a **literature review** on these subjects. The subjects are as follows, but not limited to them:

1. **immutable databases, decentralized databases, and smart contracts1.**

2. **Real-time Data Processing with In-memory Databases**: This is a hot topic as it offers a glimpse into the exciting future of database research[1].

3. **Cloud-Inspired Operating Models: Cloud-inspired operating models, cybersecurity, and data insights are among the top enterprise storage trends of 2023-4.**

4. **Artificial Intelligence and Database Technology**

5. **Object Storage as Primary Storage**

Outlines of this course

- Complex Data Types
  - Semi-structured data
  - Textual data
  - Spatial Data
- Transaction
- Concurrency
- Recovery
- Parallel and Distributed Database

Chapter 8: Complex Data Types

Database System Concepts, 7th Ed.

Outline

- Semi-Structured Data
- Object Orientation
- Textual Data
- Spatial Data

Relational Model and Non-Atomic Data Types

- The relational model is widely used for data representation across various application domains.
- A key requirement of **the relational model is atomic data** values**, disallowing multivalued, composite, and other complex data types.**
- the **relational model's constraints** on data types can **cause more problems than they solve in certain applications**.
- **Non-atomic data types include semi-structured data, object-based data, textual data, and spatial data.**
- PostgreSQL, for example, allows columns to contain sub-values, such as arrays of base types and multi-dimensional arrays.

limitations of the relational model

1. **Performance Issues**: Dealing with **large datasets or complex joins** between tables can lead **to slow performance**. Optimizing indexing strategies can also be challenging
2. **Scalability Challenges**: While generally scalable, managing the relational model as the database grows in size can become difficult. **Adding new tables or indexes can be time-consuming**, and **managing relationships between tables can become complex**
3. **Cost**: Relational databases can be **expensive to license and maintain**, particularly for large-scale deployments. They often require dedicated hardware and specialized software, adding to the cost
4. **Limited Flexibility:** The relational model is designed to **work with tables** that have predefined structures, making it difficult to work with unstructured or semi-structured data
5. **Data Redundancy**: In some cases (Denormalization, Poor Design), the relational model can lead to data redundancy, which can impact data integrity and efficiency

Semi-Structured Data

- Many applications require storage of complex data, whose schema changes often
- The relational model's requirement of atomic data types may be an overkill
  - E.g., storing set of interests as a set-valued attribute of a user profile may be simpler than normalizing it

Structured data example

- The mathematical term *"relation"* specifies a formed set of data held as a table.
- In structured data. all row in a table has the same set of columns.

id	name	age
1	Jim	28
2	Pam	26
3	Michael	42

id	subject	Teacher
1	Languages	John Jones
2	Track	Wally West
3	Swimming	Arthur Curry
4	Computers	Victor Stone

student_id	subject_id	grade
2	1	98
1	2	100
1	4	75
3	3	60
2	4	76
3	2	88

Semi-structured data

- **Semi-structured** data is information that doesn't consist of Structured data (relational database) but still has some structure to it.
- In ***JavaScript Object Notation* (JSON) format**. It also includes ***key-value*** stores and ***graph*** databases.

```
## Document 1 ##
{
  "customerID": "103248",
  "name":
  {
    "first": "AAA",
    "last": "BBB"
  },
  "address":
  {
    "street": "Main Street",
    "number": "101",
    "city": "Acity",
    "state": "NY"
  },
  "ccOnFile": "yes",
  "firstOrder": "02/28/2003"
}
```

Semi-Structured Data

- **Data exchange** can benefit greatly from semi-structured data
  - Exchange can be between applications, or between back-end and front-end of an application
  - Web-services are widely used today, with complex data fetched to the front-end and displayed using a mobile app or JavaScript
- JSON and XML are widely used semi-structured data models

Features of Semi-Structured Data Models

- **Flexible schema**
  - **Wide column** representation: allow **each tuple to have a different set of attributes,** can add new attributes at any time
    - user1 = {"username": "user1", "email": "user1@email.com", "bio": "Hello, world!", "website": "www.user1.com", "phone number": "+1234567890"}
    - user2 = {"username": "user2", "email": "user2@email.com"}
  - **Sparse column** representation: schema has a fixed but large set of attributes, by each tuple may store only a subset
    - user1_preferences = {"likes_sports": True, "likes_cooking": False}
    - user2_preferences = {"likes_travel": True}

Features of Semi-Structured Data Models

- **Multivalued data types:** allow attributes to contain non-atomic values.
  - **Sets**, **multisets**
    - E.g.,: User 1, set of interests {‘Sport, ‘Cooking’, ‘Travel’, ‘anime’, ‘jazz’}

UserID	UserName	Email
1	User1	user1@email.com
2	User2	user2@email.com

InterestID	Interest
1	Sports
2	Cooking
3	Travel

UserID	InterestID
1	1
1	3

(Cont.)Features of Semi-Structured Data Models

- **Multivalued data types:**allow attributes to contain non-atomic values.
  - **Key-value map** (or just **map** for short)
    - Store a set of key-value pairs
    - E.g., {(brand, Apple), (ID, MacBook Air), (size, 13), (color, silver)}
    - Operations on maps: *put*(key, value), *get*(key), *delete*(key)
  - In a relational database, you need to have a table for each of which due to normalization
    - **e-commerce sites** often list specifications or details for **each product** that they sell, such **as brand, model, size, color, and numerous** other product-specific details.
    - **specifications form the key**, and the **associated value is stored with the key**.

(Cont.)Features of Semi-Structured Data Models

- **Key-value map:** Example: a social media application where **users can post status updates**

```
RELATIONAL DATABASE:
SELECT *
FROM Posts
   LEFT JOIN Images ON Posts.post_id = Images.post_id
   LEFT JOIN Locations ON Posts.post_id = Locations.post_id
   LEFT JOIN Tags ON Posts.post_id = Tags.post_id
   LEFT JOIN Reactions ON Posts.post_id = Reactions.post_id
   LEFT JOIN Comments ON Posts.post_id = Comments.post_id
WHERE Posts.post_id = 123;
```

```
JSON:{
  "post_id": 123,
  "text": "Hello, world!",
  "images": ["img1.jpg", "img2.jpg"],
  "location": "Paris, France",
  "tags": ["friend1", "friend2"],
  "reactions": {"likes": 100, "loves": 50, "wows": 10},
  "comments": [
    {"user": "friend1", "text": "Great post!", "time": "2022-01-
01T10:00:00Z"},
    {"user": "friend2", "text": "Thanks for sharing!", "time": "2022-01-
01T11:00:00Z"}
  ]
}
```

(Cont.) Features of Semi-Structured Data Models

- **Arrays**
  - Widely used for **scientific** and **monitoring** applications
  - E.g., readings taken at regular intervals can be represented as array of values instead of (time, value) pairs
    - [5, 8, 9, 11] instead of {(1,5), (2, 8), (3, 9), (4, 11)}
    - scientific applications may need to store images, which are two-dimensional arrays of pixel values
- Multi-valued attribute types
  - Modeled using ***non first-normal-form*** (*NFNF*) data model
  - Supported by most database systems today: **Oracle, PostgreSQL**
- **Array database**: a database that provides specialized support for arrays
  - E.g., compressed storage, query language extensions etc
  - Oracle **GeoRaster**, **PostGIS** extension to **PostgreSQL**, the **SciQL** extension of **MonetDB**, and **SciDB**

Nested Data Types

- Hierarchical data is common in many applications
  - Many databases support such types as part of their support for object-oriented data
- JSON: (JavaScript Object Notation)
  - Widely used today
- XML: (Extensible Markup Language)
  - Earlier generation notation, still used extensively

JSON

- **Textual representation** widely used for data exchange & store complex data
- Example of JSON data

```
{
    "ID": "22222",
    "name": {
          "firstname: "Albert",
          "lastname: "Einstein"
    },
    "deptname": "Physics",
    "children": [
          {"firstname": "Hans", "lastname": "Einstein"
},
          {"firstname": "Eduard", "lastname": "Einstein"
}
    ]
}
```

- **Types: integer, real, string, and**
  - ***Objects**: are* key-value maps, i.e. sets of (attribute name, value) pairs
  - **Arrays** are also key-value maps (from offset to value)

JSON

- JSON is **ubiquitous** in data exchange today
  - Widely used for **web services**
  - Most **modern applications** are architected around on web services
- SQL extensions for
  - JSON types for storing JSON data
  - Extracting data from JSON objects using path expressions
    - E.g. *V-> ID*, or *v.ID*
  - **Generating** JSON from **relational** data
    - E.g. json.build_object('ID', 12345, 'name', 'Einstein')
  - Creation of JSON collections using aggregation
    - E.g. json_agg **aggregate function** in PostgreSQL
  - **Syntax varies greatly across databases**

XML

- XML uses tags to mark up text
- E.g.

  <**course**>

  <**course id**> CS-101 </**course id**>

  <**title**> Intro. to Computer Science </**title**>

  <**dept name**> Comp. Sci. </**dept name**>

  <**credits**> 4 </credits>

  </**course**>

- Tags make the **data self-documenting**
- Tags can be hierarchical

Example of Data in XML

```
<purchase order>
      <identifier> P-101 </identifier>
      <purchaser>
            <name> Cray Z. Coyote </name>
            <address> Route 66, Mesa Flats, Arizona 86047, USA </address>
      </purchaser>
      <supplier>
            <name> Acme Supplies </name>
            <address> 1 Broadway, New York, NY, USA </address>
      </supplier>
      <itemlist>
         <item>
            <identifier> RS1 </identifier>
            <description> Atom powered rocket sled </description>
            <quantity> 2 </quantity>
            <price> 199.95 </price>
         </item>
         <item>…</item>
      </itemlist>
      <total cost> 429.85 </total cost>
      ….
</purchase order>
```

XML Cont.

- **XQuery language developed to query nested XML structures**
  - Not widely used currently
- SQL extensions to support XML
  - Store XML data
  - Generate XML data from relational data
  - Extract data from XML data types
    - Path expressions
- See Chapter 30 (online) for more information

Knowledge Representation

- **RDF: Resource Description Format**
  - is a standard way to make statements about resources. An RDF statement consists of three components, referred to as a *triple*:

1. **Subject** is a resource being described by the triple.
2. **Predicate** describes the **relationship** between the subject and the object.
3. **Object** is a **resource** that is related to the **subject**.

Knowledge Representation

- **RDF: Resource Description Format**
- RDF is a data representation standard based on the entity-relationship mode: **Subject(Entity), Predicate(Attribute), Object(Value)**
  - (*ID, attribute-name, value*)
  - (*ID1, relationship-name, ID2*)
  - where ID, ID1 and ID2 are identifiers of entities; entities are also referred to as resources in RDF
  - **Unlike**, **the E-R model,** the RDF model only **supports binary relationships**, and it does not support more general **n-ary relationships**;
  - Each triple has a unique identifier which is International Resource Identifier (IRI)

An example of a triple

Subject	Predicate	Object
Alireza	hasSpouse	Fatima
Alireza	hasAge	25

Triple View of RDF Data

a small part of the University database

10101	instance-of	instructor .
10101	name	"Srinivasan" .
10101	salary	"6500" .
00128	instance-of	student .
00128	name	"Zhang" .
00128	tot_cred	"102" .
comp_sci	instance-of	department .
comp_sci	dept_name	"Comp. Sci." .
biology	instance-of	department .
CS-101	instance-of	course .
CS-101	title	"Intro. to Computer Science" .
CS-101	course_dept	comp_sci .
sec1	instance-of	section .
sec1	sec_course	CS-101 .
sec1	sec_id	"1" .
sec1	semester	"Fall" .
sec1	year	"2017" .
sec1	classroom	packard-101 .
sec1	time_slot_id	"H" .
10101	inst_dept	comp_sci .
00128	stud_dept	comp_sci .
00128	takes	sec1 .
10101	teaches	sec1 .

Graph View of RDF Data

- **Knowledge graph**

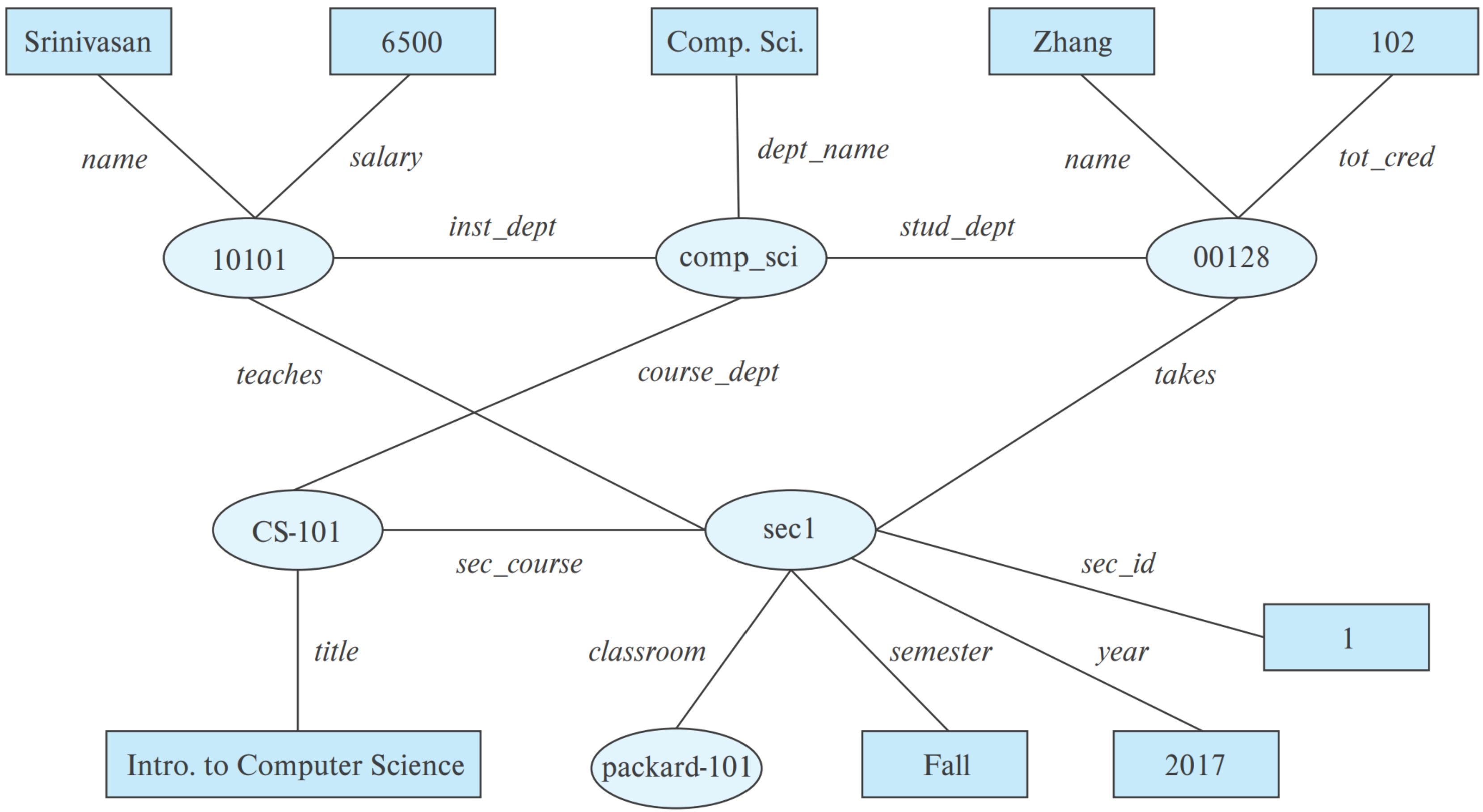


Figure 8.4 Graph representation of RDF data.

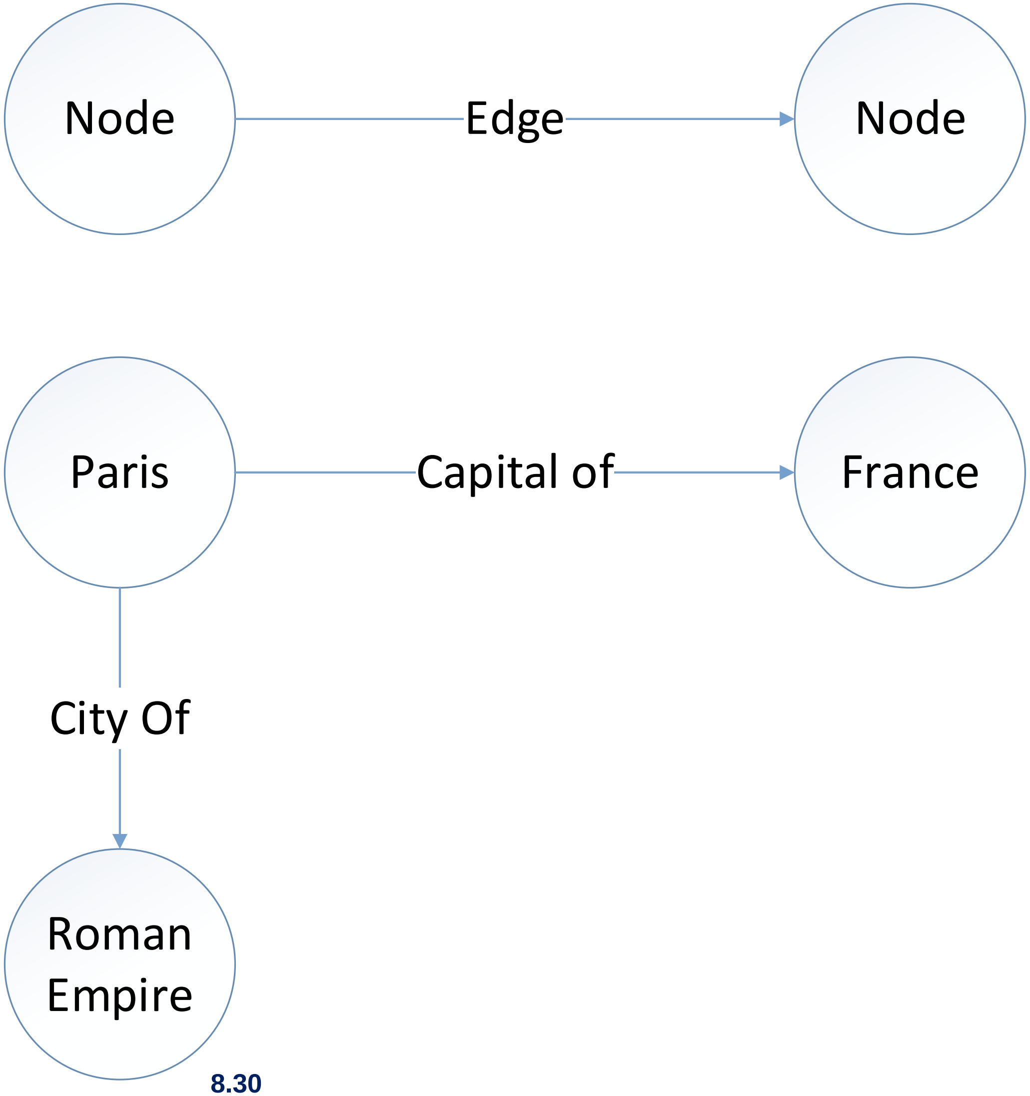
Knowledge Representation

- Representation of **human knowledge** is a long-standing **goal of AI**
- A representation of **information using the RDF graph model** (or its variants and extensions) is referred to as a knowledge graph.
- **Knowledge graphs** are used for **a variety of purposes**. One such application is to store facts that are harvested from a variety of data sources, such as Wikipedia, Wikidata, and other sources on the web.

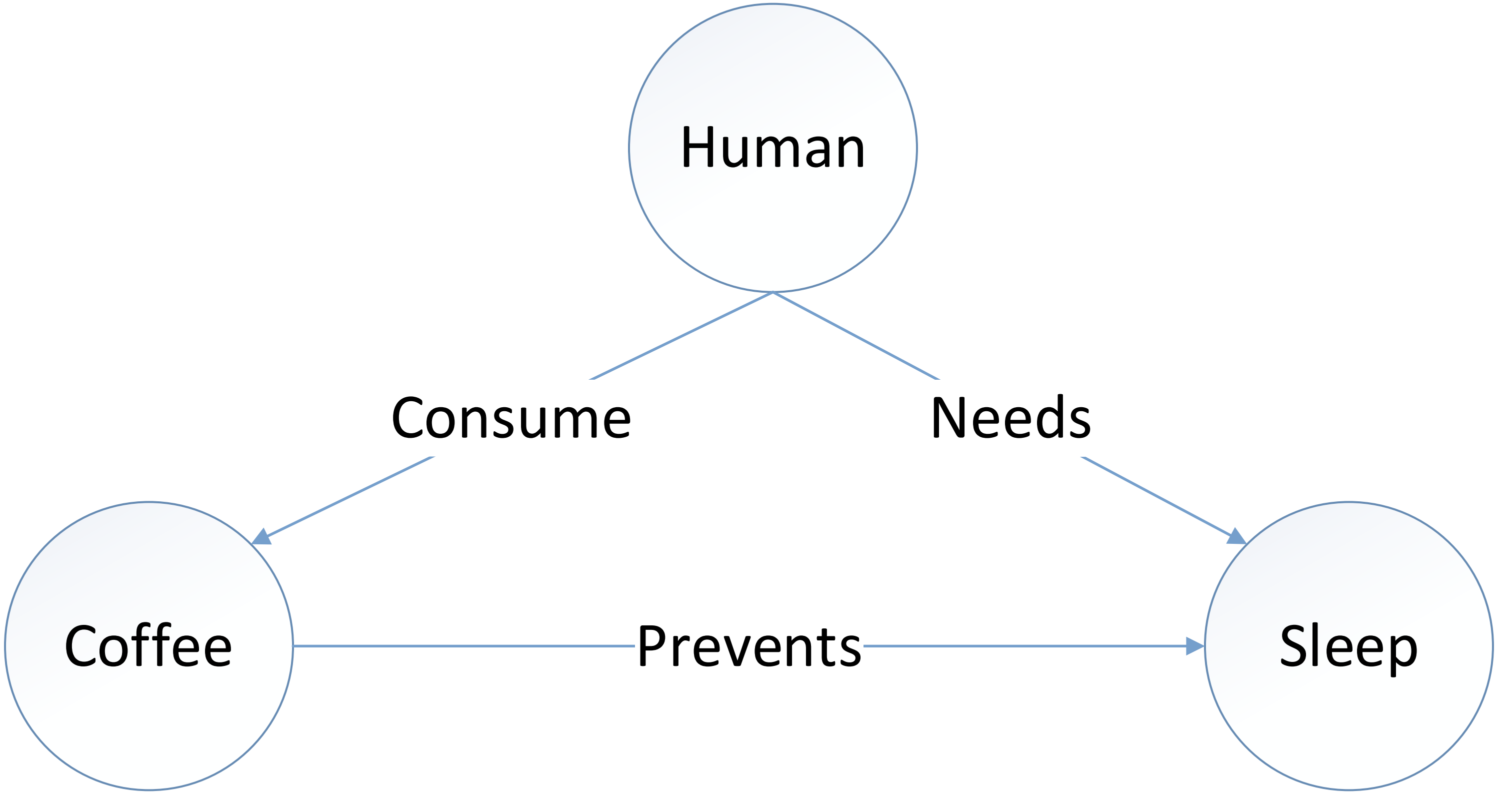
- **RDF: Resource Description Format**
  - Simplified representation for facts, represented as triples (*subject, predicate, object*)
    - E.g., (NBA-2019, *winner*, Raptors)
      (Washington-DC, *capital-of*, USA)
      (Washington-DC, *population*, 6,200,000)

Knowledge graph

- ·Resurgence of interest in Knowledge Graphs·
  - Search engines
  - Data integration
  - Artificial Intelligence



[(580) CS520: 2021 Knowledge Graphs Seminar Session 1 - YouTube]



Human
Consume
Needs
Coffee
Prevents
Sleep

Data Integration

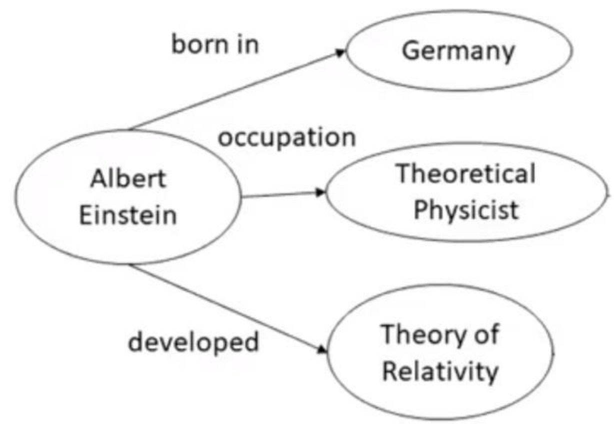
- For example Data reside in multiple sources·
  - Company directory, product catalog, government database, weather report,
- Answering queries requires combining data from multiple sources.
  - We need to provide translations of data between multiple sources·
    - Direct mappings
    - Shared schema

Data Integration

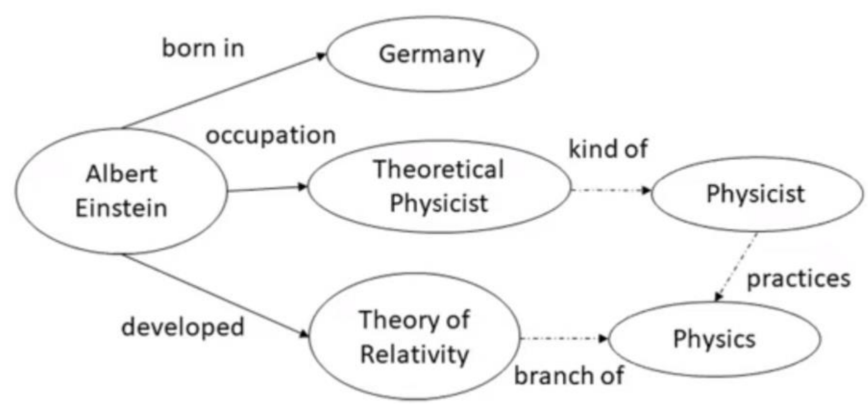
- Schema-free approach to data integration.
  - Convert the relational data from multiple sources into triples·
    - Stored in a graph database·
      - Referred to as a knowledge graph.
    - Deal with schema mappings/translations on "pay as you go" basis·
      I. Visualization
      II. Optimized for graph traversals

Knowledge graph: Natural Language Processing

- Entity Extraction:
  - **Albert Einstein** was a **German-born theoretical physicist** who developed the **theory of relativity**.
  - Relation Extraction->

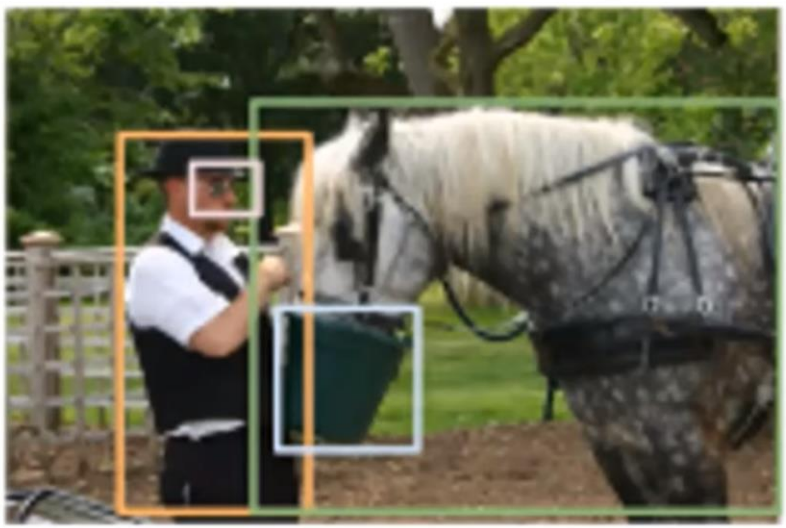


  - New relations
    - Questions answering
    - Common reasoning

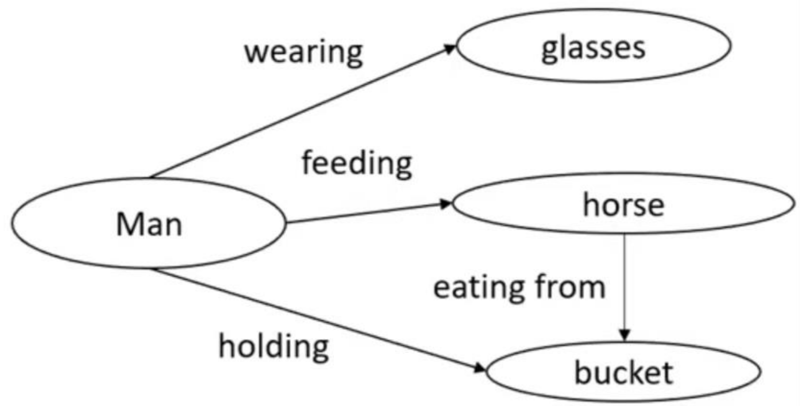


Knowledge graph in Object detection

Object Detection

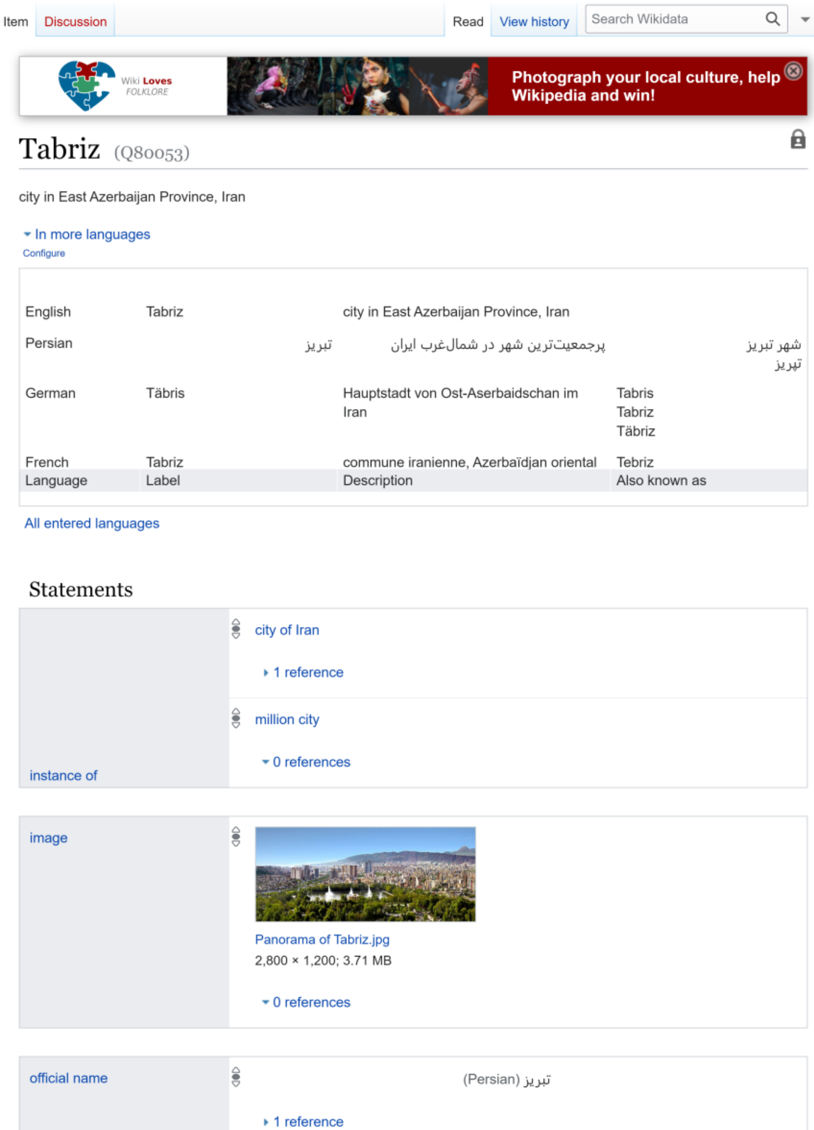


- Edge Detection



WIKIDATA.
KNOWLEDGE

https://www.wikidata.org/wiki/Q80053



Querying RDF: SPARQL

- **SPARQL** is a query language **designed to query RDF data**.
  - is based on triple patterns, which look like RDF triples but may contain variables. For example,
- Triple patterns
  - **?cid *title* "Intro. to Computer Science"**
    - match all triples whose predicate is “title” and object is “Intro. to Computer Science”

University Database

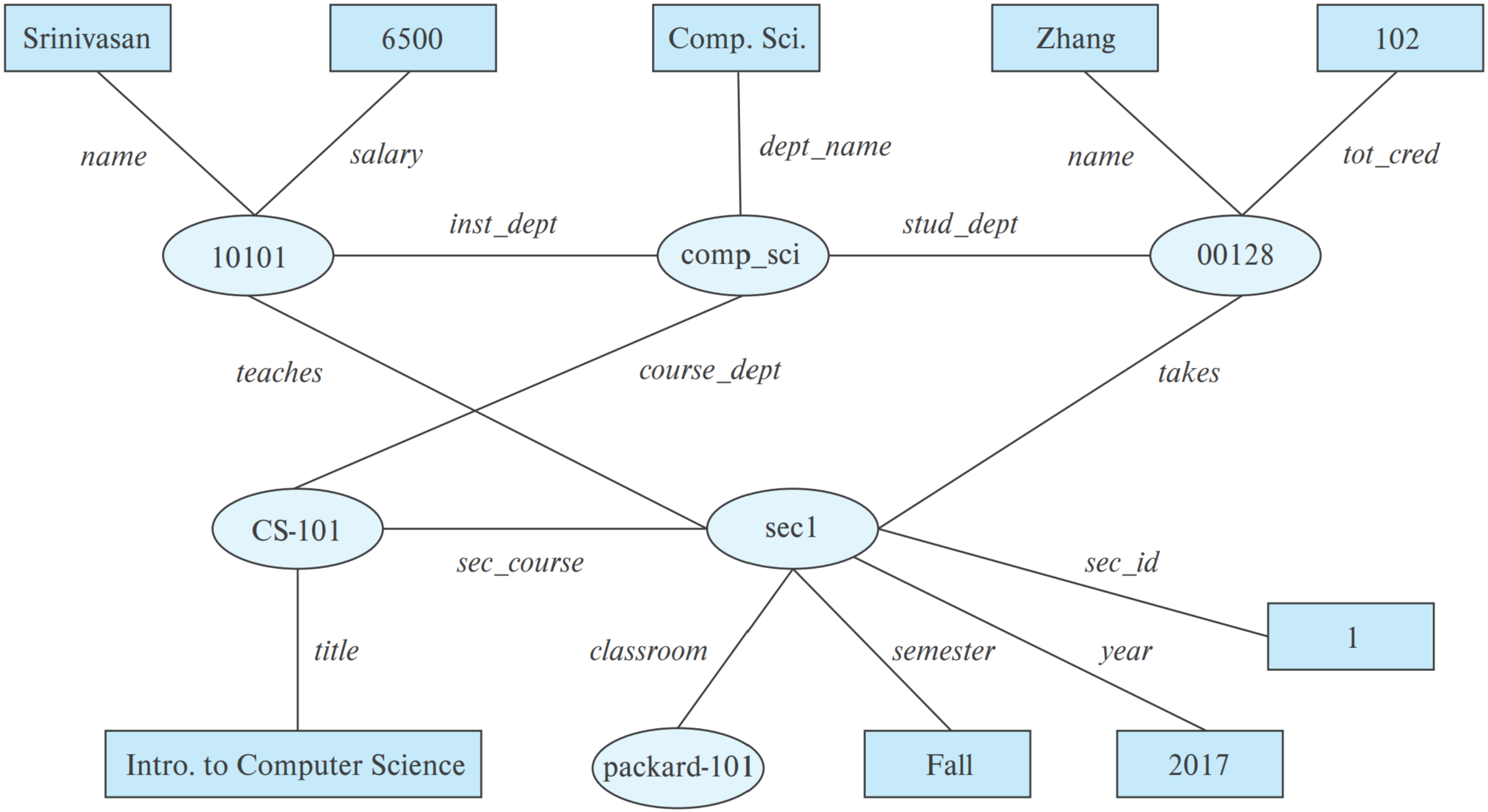


Figure 8.4 Graph representation of RDF data.

Querying RDF: SPARQL

- **Another Example of SPARQL:**
  - **?cid title "Intro. to Computer Science"**

    ?sid course ?cid
    - On the university-triple dataset, the first triple pattern matches the triple:
      - (CS-101, title, "Intro. to Computer Science"),
    - the second triple pattern matches
      - (sec1, course, CS-101).
    - The **shared variable ?cid enforces** a **join condition** between the two triple patterns.

What is SPARQL?

SPARQL is a SQL-like query language for RDF graph data with the following query types:

- SELECT returns tabular results
- CONSTRUCT creates a new RDF graph based on query results
- ASK returns ‘yes’ if the query has a solution, otherwise ‘no’
- DESCRIBE returns RDF graph data about a resource; useful when the query client does not know the structure of the RDF data in the data source
- INSERT inserts triples into a graph
- DELETE deletes triples from a graph

Graph View of RDF Data

- **Knowledge graph**

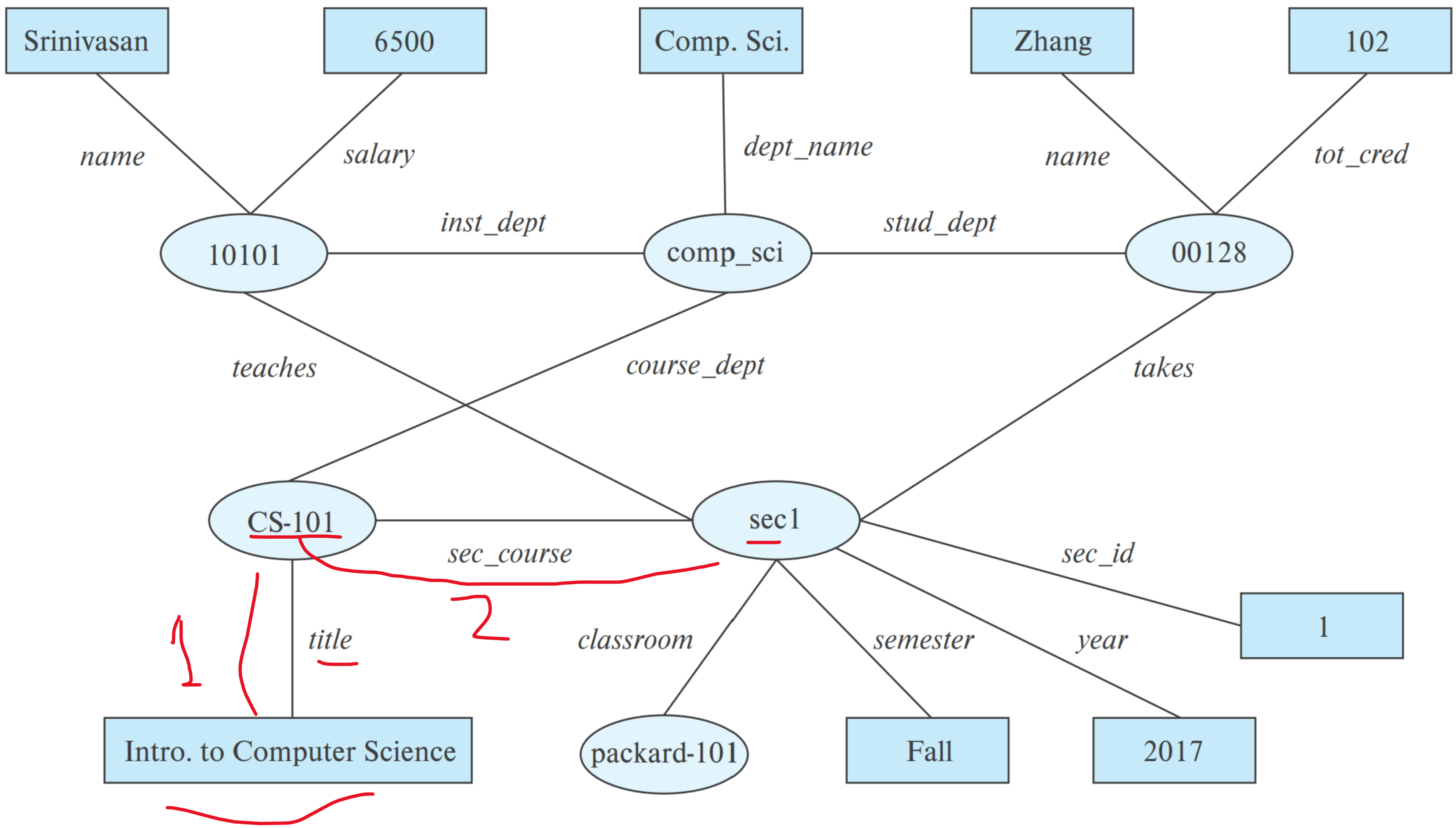


Figure 8.4 Graph representation of RDF data.

Querying RDF: SPARQL

- SPARQL queries
  - **select** ?name
    where {
        ?cid *title* "Intro. to Computer Science" .
        ?sid *course* ?cid .
        ?id *takes* ?sid .
        ?id *name* ?name .
    }
  - Also supports
    - Aggregation, Optional joins (similar to outerjoins), Subqueries, etc.
    - Transitive closure on paths

The following query retrieves **names of all students** who have **taken a section** whose **course is titled “Intro. to Computer Science”.**

Graph View of RDF Data

- **Knowledge graph**

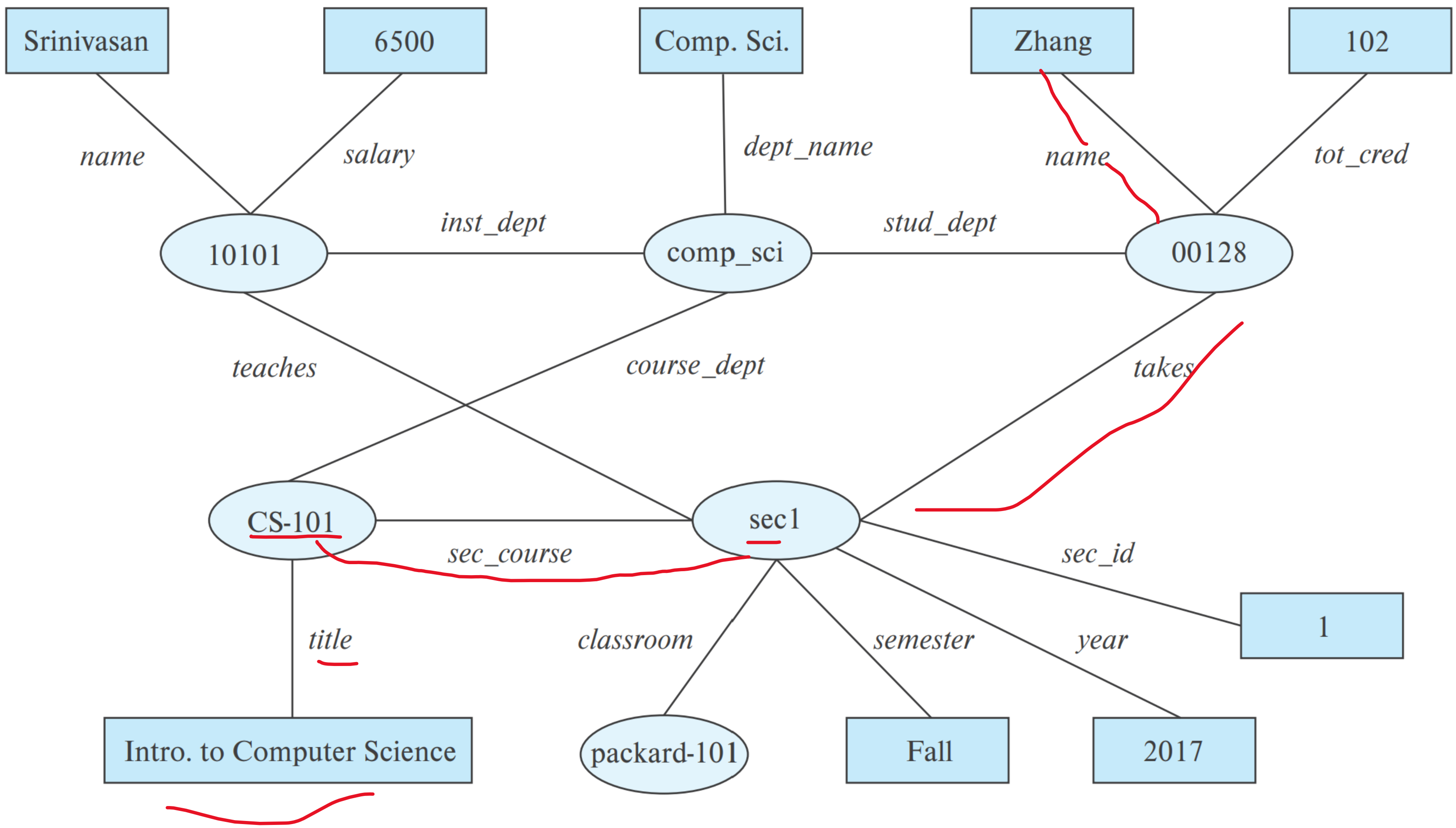


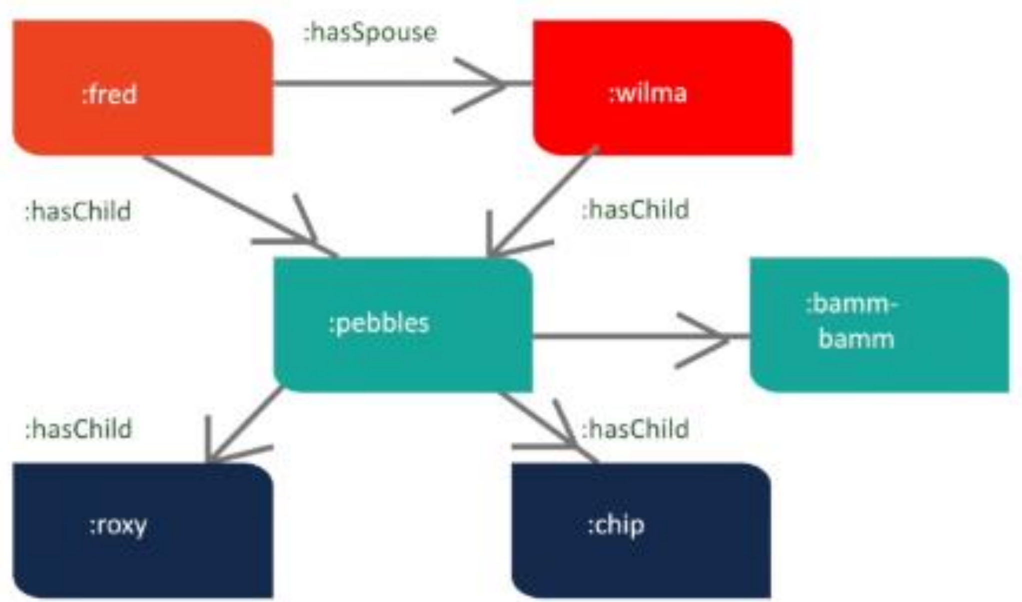
Figure 8.4 Graph representation of RDF data.

Using SPARQL to Insert Triples

To create an RDF graph, perform these steps:

- Define prefixes to IRIs with the PREFIX keyword
- Use INSERT DATA to signify you want to insert statements. Write the subject-predicate-object statements (triples).
- Execute this query.

```
PREFIX br: <http://bedrock/>
INSERT DATA {
  br:fred      br:hasSpouse  br:wilma .
  br:fred      br:hasChild   br:pebbles .
  br:wilma     br:hasChild   br:pebbles .
  br:pebbles  br:hasSpouse br:bamm-bamm ;
               br:hasChild   br:roxy, br:chip .
}
```



Using SPARQL to Select Triples

To access the RDF graph you just created, perform these steps:

- Define prefixes to IRIs with the PREFIX keyword.
- Use SELECT to signify you want to select certain information, and WHERE to signify your conditions, restrictions and filters.
- Execute this query.

```
PREFIX br: <http://bedrock/>
SELECT ?subject ?predicate ?object
WHERE {?subject ?predicate ?object}
```

Subject	Predicate	Object
br:fred	br:hasChild	br:pebbles
br:pebbles	br:hasChild	br:roxy
br:pebbles	br:hasChild	br:chip
br:wilma	br:hasChild	br:pebbles

Using SPARQL to Find Fred’s Grandchildren

To find Fred’s grandchildren, first find out if Fred has any grandchildren:

- Define prefixes to IRIs with the PREFIX keyword
- Use ASK to discover whether Fred has a grandchild, and WHERE to signify your conditions.

```
PREFIX br: <http://bedrock/>
ASK
WHERE {
  br:fred    br:hasChild    ?child .
  ?child     br:hasChild    ?grandChild .
}
```

→ YES

Using SPARQL to Find Fred's Grandchildren

Now that we know he has at least one grandchild, perform these steps to find the grandchild(ren):

- Define prefixes to IRIs with the PREFIX keyword
- Use SELECT to signify you want to select a grandchild, and WHERE to signify your conditions.

```
PREFIX br: <http://bedrock/>
SELECT ?grandChild
WHERE {
  br:fred    br:hasChild      ?child .
  ?child     br:hasChild      ?grandChild .
}
```

grandChild

1. br:roxy
2. br:chip

RDF Representation (Cont.)

- RDF triples represent binary relationships
- How to **represent n-ary relationships**?
  - Approach 1 (from Section 6.9.4): Create **artificial entity**, and link to each of the n entity's
    - E.g., (Barack Obama, *president-of*, USA, 2008-2016) can be represented as
      (*e1*, *person*, Barack Obama), (*e1*, *country*, USA),
      (*e1*, *president-from*, 2008) (*e1*, *president-till*, 2016)
  - Approach 2: use **quads** instead of triples, with **context entity**
    - E.g., (Barack Obama, *president-of*, USA, *c1*)
      (*c1*, *president-from*, 2008) (*c1*, *president-till*, 2016)

RDF Representation (Cont.)

- RDF widely used as knowledge base representation
  - **DBPedia**, **Yago**, **Freebase**, **WikiData**, ..
- **Linked open data** project aims to connect different knowledge graphs to allow queries to span databases

RDF DATA STORES:

Object Orientation

- **Object-relational data model** provides richer type system
  - with complex data types and object orientation
- Applications are often written in **object-oriented programming languages**
  - Type system does not match relational type system
  - Switching between imperative language and SQL is troublesome

Object Orientation

- Approaches for integrating object-orientation with databases
  - Build an **object-relational database**, adding object-oriented features to a relational database
  - Automatically convert data between programming language model and relational model; data conversion specified by **object-relational mapping**
  - Build an **object-oriented database** that natively supports object-oriented data and direct access from programming language

Object-Oriented Programming and Databases

- **Point 1**: Many database **applications are written using an object-oriented** programming language.
  - Examples: Java, Python, C++
- **Point 2**: These **applications need to store and fetch data** from databases.
- **Point 3**: There is a type difference between the native type system of the object-oriented programming language and the relational model supported by databases.
- **Point 4**: Data need to be translated between the two models whenever they are fetched or stored.

Object-Relational Database Systems

- SQL allow creation of structured user-defined types:
  - **create type** *Person*
    (*ID* **varchar**(20) **primary key**,
    name **varchar**(20),
    address **varchar**(20)) **ref from**(*ID*);
  - **create table** *people* **of** *Person*;
- Then we create a new person as follows:
  - **insert into** people (ID, name, address) **values** ('12345', 'Srinivasan', '23 Coyote Run')

Object-Relational Database Systems

- Table user types
  - **create type** <u>*interest*</u> **as table** (
    topic **varchar**(20),
    degree_of_interest **int**);
  - SQL Server allows table-valued types(e.g., <u>interest</u> type) to be declared as shown in the following example:
    create table *users* (
    ID **varchar**(20),
    name **varchar**(20),
    interests <u>***interest***</u>);
- Array, multiset data types also supported by many databases

Type and Table Inheritance

- Type **inheritance**
  - **create type** *Person*
    (*ID* **varchar**(20) **primary key**,
    name **varchar**(20),
    address **varchar**(20)) **ref from**(*ID*);
    We want to store extra information in the database about people who are students
  - **create type** *Student* **under** *Person*
    (*degree* **varchar**(20)) ;
    create type *Teacher* **under** *Person*
    (*salary* **integer**);
  - Both Student and Teacher inherit the attributes of Person

Type and Table Inheritance

- Table inheritance syntax in PostgreSQL and oracle
  - **create table** *students*
    (*degree* **varchar**(20))
    inherits *people*;
create table *teachers*
    (*salary* **integer**)
    inherits *people*;
  - **create table** *people* **of** *Person*;
create table *students* **of** *Student*
    under *people*;
create table *teachers* **of** *Teacher*
    under *people*;
- As a result, every attribute present in the table people is also present in the subtables students and teachers.

Reference Types

- For example, we could define the Person type as follows, with a reference-type declaration:
- Creating reference types
  - **create type** *Person*
    (*ID* **varchar**(20) **primary key**,
    name **varchar**(20),
    address **varchar**(20))
    ref from(*ID*);
    create table *people* **of** *Person*;

Reference Types

- a type Department with a field name and a field head that is a reference to the type Person.
- **create type** *Department* (
  dept_name **varchar(20)**,
  head **ref**(*Person*) **scope** *people*);
  create table *departments* **of** *Department*

  insert into *departments* **values** ('CS', '12345')

- scope clause above completes **the definition of the foreign** key from departments.head to the people relation.

Object-Relational Mapping

- **Object-relational mapping** (ORM) systems allow
  - Specification of **mapping** between **programming language objects** and **database tuples**
  - **Automatic creation** of **database** tuples **upon creation** of **objects**
  - Automatic **update/delete** of database tuples when objects are update/deleted
  - **Interface** to **retrieve objects** satisfying specified conditions
- Details in Section 9.6.2
  - Hibernate ORM for Java
  - Django ORM for Python

ORM benefits

- **Simplify** the **job** of **developers** by providing an **object model,** while still leveraging the power of a robust relational database.

- ORM systems can offer significant **performance improvements** when **operating on objects cached in memory**, compared **to direct access** to the underlying database.

- ORM can **use any number of databases** to store data, **all with the same high-level code.**

- ORM systems **abstract away minor SQL differences** between databases. This makes migration from one database to another relatively straightforward when using an ORM, as opposed to the significant challenges posed by SQL differences.

ORM EXAMPLE

Imagine you're building an online store. You need to manage data like products, customers, and orders.

Without ORM:

- You'd **write complex SQL queries** to interact with the database: **add new products**, **update order** details, etc.
- You'd need to **understand** the **specific syntax for your chosen database** (MySQL, PostgreSQL, etc.).
- **Switching databases would require rewriting most or all of your SQL** code, due to different syntax and functionalities.

With ORM:

- You'd **define your data structures as objects (Product, Customer, Order).**
- You'd use simple, object-oriented methods to interact with your data:
  - product.save(), order.update_status().
- The ORM system translates these object operations into the appropriate SQL queries
- Switching databases might involve some configuration changes within the ORM, but most of your code would remain the same.

Performance issue of ORM

- We have a User table in a database and we are using an ORM system in our application.
- we want to update the status of all users to inactive.

```
users = session.query(User).all()
for user in users:
    user.status = 'inactive'
    session.commit()
```

  - This result in a **separate UPDATE statement for each user**, which could be very inefficient if there are a large number of users.
- Alternative where we bypass the ORM and write the update directly in SQL

```
session.execute("UPDATE users SET status='inactive'")
session.commit()
```

  - Executing a single UPDATE statement for all users is significantly more efficient than issuing individual statements for each user.

Textual Data

- **Information Retrieval Definition**:
  - Information retrieval is the process of querying unstructured textual data. Which is used in
  - **Traditional Model**: Textual information is organized into documents.
  - **Database Context**: A text-valued attribute can be considered a document.
  - **Web Context**: Each web page can be considered a document.

Textual Data (Cont.)

- **Keyword Description**: Desired **documents** are typically **described** by **a set of keywords.**
- **Examples**: **Keywords** such as “**database system**” can **locate documents** on **database** systems. “**Stock**” and “**scandal**” can locate **articles** about **stock-market scandals.**
- **Document Keywords**: Documents have a set of keywords associated with them. Typically, all **words in the documents are considered keywords.**
- **Keyword Query**: A keyword **query retrieves documents** whose **set of keywords contains all the keywords** in the query.

Textual Data

- **Information retrieval**: querying of unstructured data
  - **Simple model of keyword queries**: given query keywords, retrieve documents containing all the keywords
  - More advanced models **rank relevance of documents**
  - Today, keyword queries return many types of information as answers
    - E.g., a query “cricket” typically returns information about ongoing cricket matches like scores, league table
- Relevance ranking
  - Essential since there are usually many documents matching keywords

Keyword Search and Information Retrieval

- **Keyword Search**
  - Initially **targeted at document repositories** within **organizations** or **domain-specific document** repositories such as research publications.
  - Now, also important for **documents stored** in a database.
- **Keyword-based Information Retrieval**
  - Used for **retrieving not only textual data**, but also **other types of data.**
  - **Video and audio data that have descriptive keywords** associated with them can be retrieved.
  - Example: A **video movie may have keywords** such as its **title**, **director**, **actors**, and **genre**. An image or **video** clip may have **tags**, which are **keywords** describing the image or video clip.

Keyword Search and Information Retrieval

- **Web Search Engines**
  - At the core, they are information retrieval systems.
  - They **retrieve** and **store web pages by crawling the web**.

Relevance Ranking

- **Document Set Size**
  - The set of all documents that contain the keywords in a query may be very large.
  - There are billions of documents on the web, and most keyword queries on a web search engine find hundreds of thousands of documents containing some or all of the keywords.
- **Relevance of Documents**
  - Not all the documents are equally relevant to a keyword query.
  - Information-retrieval systems estimate the relevance of documents to a query and return only highly ranked documents as answers.

Ranking using TF-IDF

- Term: **keyword occurring** in a document/query
- **Term Frequency:** TF(d, t), **the relevance of a term *t* to a document *d***
  - One definition:

$$TF(d,t) = \log\left(1 + \frac{n(d,t)}{n(d)}\right)$$

  - where
    - n(d,t) = number of **occurrences** of **term *t*** in document ***d***
    - n(d) = **number of terms** in **document *d***
    - takes the length of the document into account.
    - The relevance grows with **more occurrences of a term in the document.**

Query and Keyword Relevance

- **Multiple Keywords**
  - A query Q may contain multiple keywords.
  - The relevance of a document to a query with two or more keywords is estimated by combining the **relevance measures of the document for each keyword.**
- **Combining Measures**
  - A **simple way** of combining the measures is to **add them up.**

Query and Keyword Relevance

- **Keyword Frequency**
  - **Not** all terms used as **keywords** are **equal**.
  - Suppose a query uses two terms, one of which occurs frequently, such as “**database**”, and another that is less frequent, such as “**Silberschatz**”.
  - A document containing “**Silberschatz**” but not “database” should be ranked higher than a document containing the term “database” but not “Silberschatz”.

Ranking using TF-IDF

- **Inverse document frequency**: IDF(t)
  - One definition:
  - $\mathrm{IDF(t)} = \frac{1}{n(t)}$
  - n(t) denotes the number of documents (among those indexed by the system) that contain the term t
- **Relevance** of a document ***d*** to a set of terms ***Q***
  - *One definition:* $r(d,Q) = \sum_{t \in Q} TF(d,t) * IDF(t)$
  - Other definitions
    - take **proximity** of words into account
    - **Stop words** are often ignored

Example for Inverse Document Frequency (IDF)

- Imagine a **collection** with **three documents** (A, B, C) and two keywords ("mushroom" and "poisonous mushroom"):
- * Document A: "**Mushrooms** are living organisms that..."
- * Document B: "There are many types of **mushrooms**, some edible and others **poisonous**."
- * Document C: "**Poisonous mushrooms** can be very dangerous."
- **Calculating IDF:**
- * Keyword "mushroom": ?
- * Keyword "poisonous mushroom": ?

Example for IDF (Cont.)

- **Calculating IDF:**
- * Keyword "mushroom":
-     * Number of documents containing "mushroom" (n(mushroom)) = 3
-     * **IDF**(mushroom) = 1 / 3 ≈ 0.33
- * Keyword "poisonous mushroom":
-     * Number of documents containing "poisonous mushroom" (n("poisonous mushroom")) = 2
-     * **IDF**("poisonous mushroom") = 1 / 2 ≈ 0.50

Example of document relevance calculation

Scenario:

Imagine a collection with three documents (A, B, C) and two keywords ("music" and "concert"):

- **Document A:** "I enjoy listening to music." (Mentions "music" once)
- **Document B:** "Last weekend, I went to a music concert." (Mentions both "music" and "concert" once)
- **Document C:** "Did you know the speed of sound varies depending on the medium?" (Mentions neither "music" nor "concert")

Example of document relevance calculation (Cont.)

Calculating Relevance (r(d, Q)) for the query "music concert":

1. Document A:

- **TF(A, "music") = 1:** Document A mentions "music" once.
- **TF(A, "concert") = 0:** Document A doesn't mention "concert".
- **IDF("music") = 0.2 (assumed value):** Let's assume "music" is a common term with a lower IDF.
- **IDF("concert") = 0.8 (assumed value):** Let's assume "concert" is a less common term with a higher IDF.
- **r(A, "music concert") = TF(A, "music") * IDF("music") + TF(A, "concert") * IDF("concert") = 1 * 0.2 + 0 * 0.8 = 0.2**

Example of document relevance calculation (Cont.)

Calculating Relevance (r(d, Q)) for the query "music concert":

2. Document B:

- **TF(B, "music") = 1:** Document B mentions "music" once.
- **TF(B, "concert") = 1:** Document B mentions "concert" once.
- **IDF("music") = 0.2 (assumed value):** Consistent with Document A.
- **IDF("concert") = 0.8 (assumed value):** Consistent with Document A.
- **r(B, "music concert") = TF(B, "music") * IDF("music") + TF(B, "concert") * IDF("concert") = 1 * 0.2 + 1 * 0.8 = 1.0**

Example of document relevance calculation (Cont.)

3. Document C:

- **TF(C, "music") = 0:** Document C doesn't mention "music".
- **TF(C, "concert") = 0:** Document C doesn't mention "concert".
- **IDF("music") = 0.2 (assumed value):** Consistent with Documents A and B.
- **IDF("concert") = 0.8 (assumed value):** Consistent with Documents A and B.
- **r(C, "music concert") = TF(C, "music") * IDF("music") + TF(C, "concert") * IDF("concert") = 0 * 0.2 + 0 * 0.8 = 0**

Stop Words in Information Retrieval

- **Information-retrieval** systems define a **set** of **words**, called **stop words**, **containing 100** or so of the most common words, and ignore these words when indexing a document.
  - **Such** words are **not used** as **keywords**, and **they are discarded** if present in the keywords supplied by the user.
    - and," "or," "a," and so on.
  - **Including them** in the indexing process and user queries can **increase processing** time and **potentially distract** the system from identifying more informative keywords.

Proximity of Terms

- **Proximity of Terms**
  - Another factor taken into account when a query contains multiple terms is the proximity of the terms in the document.
  - If the **terms occur close to each other** in the document, the **document** will be **ranked higher than if they occur far apart.**
  - The formula for **r(d, Q)** can be modified to take **proximity** of the terms into account.

Ranking Using Hyperlinks

- **Hyperlinks** provide very important **clues** to **importance**
- **Google** introduced **PageRank**, a measure of **popularity/importance** based on hyperlinks to pages
  - **Pages hyperlinked from many pages** should have **higher PageRank**
  - **Pages** hyperlinked **from pages with higher PageRank** should have **higher** PageRank
    - Formalized by **random walk** model

Ranking Using Hyperlinks

- Let **T[i, j]** be the **probability** that a **random walker** who is on **page *i* will click on the link to page *j***
  - Assuming all links from i has an equal **probability of being** followed: $\boldsymbol{T}[\boldsymbol{i}, \boldsymbol{j}] = \frac{1}{N_i}$
  - $\boldsymbol{N_i}$: number of **outgoing** links **from Page i**
- Then **PageRank**[j] as **P[j]** for each page j can be defined as $P[j] = \frac{\delta}{N} + (1 - \delta) * \sum_{i=1}^{N} (T[i, j]. P[i])$
  - ***N*** = total number of pages
  - **δ=** a constant usually set to **0.15**

Ranking Using Hyperlinks

- Definition of PageRank is circular, but can be solved as a set of **linear equations**
  - Simple iterative technique works well
  - Initialize all P[i] = 1/N
  - In each iteration use equation
  - $P[j] = \frac{\delta}{N} + (1 - \delta) * \sum_{i=1}^{N} (T[i,j] . P[i])$ to update *P*
  - Stop iteration when changes are small, or some limit (say 30 iterations) is reached.

Example

a simple web network with four web pages: A, B, C, D

$$T = \begin{pmatrix} 0 & 0.5 & 0.5 & 0.5 \\ 0.5 & 0 & 0.5 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

- an initial PageRank vector P where each page has an initial score of 0.25= 1/N=1/4, so:

$$P[j] = \frac{\delta}{N} + (1 - \delta) * \sum_{i=1}^{N} (T[i,j].\, P[i])$$

$$P = \begin{pmatrix} 0.25 \\ 0.25 \\ 0.25 \\ 0.25 \end{pmatrix}$$

- Let's calculate P[j] for each page:
  - **P[A]=**0.15/4+(1−0.15)×[(0×0.25)+(0.5×0.25)+(0.5×0.25)+(0.5×0.25)]= 0.35625
  - After one iteration of the PageRank algorithm, the PageRank scores are approximately.

Retrieval Effectiveness

- Measures of effectiveness
  - **Precision**: what **percentage** of **returned results** are **relevant**
  - **Recall**: what **percentage** of **relevant results** were returned
    - since search engines find a very large number of answers, **precision and recall numbers are usually measured by** "@K", where K is the number of answers viewed

Spatial Data

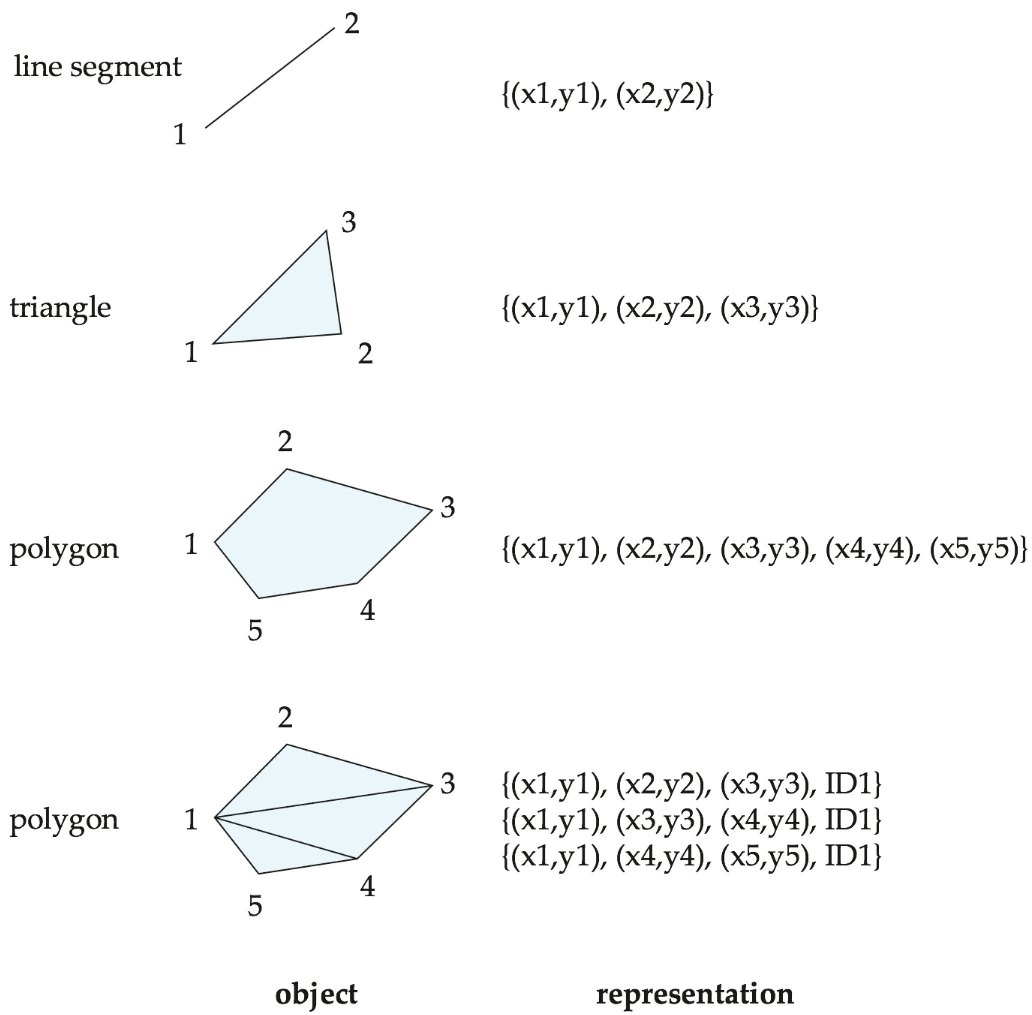
Spatial Data

- Spatial databases store information related to spatial locations, and support efficient **storage**, **indexing** and **querying** of **spatial** data.
  - **Geographic data** -- **road maps**, **land-usage maps**, **topographic** elevation maps, political maps showing boundaries, land-ownership maps, and so on.
    - **Geographic information systems** are special-purpose databases tailored for storing geographic data.
    - Round-earth coordinate system may be used
      - (Latitude, longitude, elevation)
  - **Geometric data:** design information about **how objects are constructed** . For example**, designs of buildings**, aircraft, layouts of integrated-circuits.
    - 2 or 3 dimensional Euclidean space with (X, Y, Z) coordinates

Represented of Geometric Information

- Various geometric constructs can be represented in a database in a normalized fashion (see next slide)
- A **line segment** can be represented by the coordinates of its endpoints.
- A **polyline** or **linestring** consists of a connected sequence of line segments and can be represented by a list containing the coordinates of the endpoints of the segments, in sequence.
- **Polygons** are represented by a list of vertices in order.
  - The list of vertices specifies the boundary of a polygonal region.
  - Can also be represented as a set of triangles (**triangulation**)

Representation of Geometric Constructs



For example

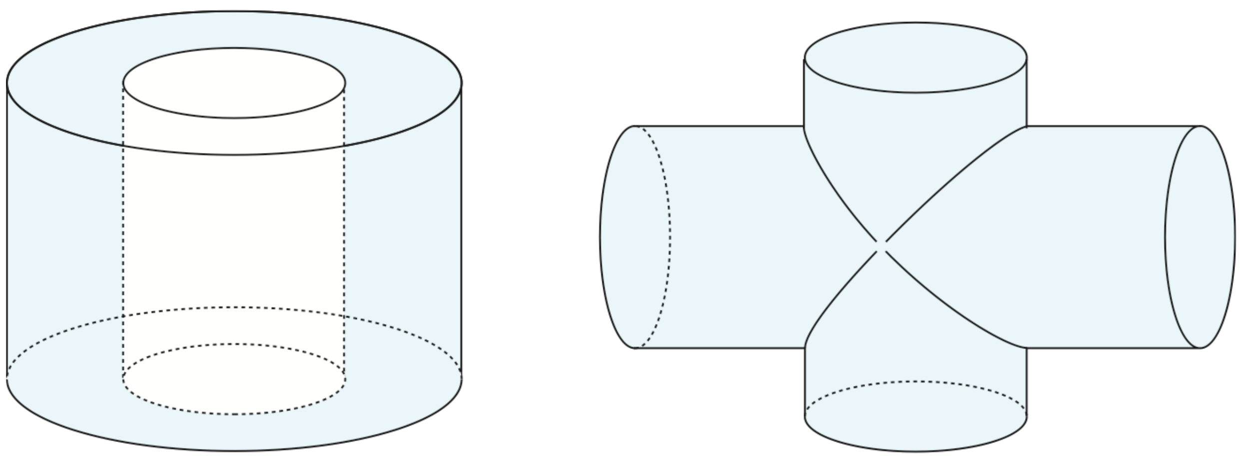
- SQL Server and PostGIS support the geometry and geography types
  - **subtypes** such as **point**, **linestring**, **curve**, **polygon**, as collections of these types called multipoint, multilinestring, multicurve and multipolygon.
- Textual representations of these types are defined by the OGC standards, and can be converted to internal representations using conversion functions.
  - For example,
    - **LINESTRING**(1 1, 2 3, 4 4) defines a line that connects points (1, 1), (2, 3) and (4, 4),
    - **POLYGON**((1 1, 2 3, 4 4, 1 1)) defines a triangle defined by these points.

To Design Databases

- Represent design components as objects (generally geometric objects); the **connections** between the **objects** indicate how **the design is structured**.
- Simple **two-dimensional** objects: **points**, **lines**, **triangles**, **rectangles**, **polygons**.
- **Complex two-dimensional objects**: formed from simple objects via **union**, **intersection**, and **difference operations**.
- Complex **three-dimensiona**l objects: formed from simpler objects such as **spheres**, **cylinders**, and **cuboids**, by **union**, **intersection**, and **difference** operations.

Representation of Geometric Constructs

- Design databases also store **non-spatial** information about objects (e.g., **construction material**, color, etc.)
- **Spatial integrity** constraints are important.
  - E.g., pipes should not intersect, wires should not be too close to each other, etc.



(a) Difference of cylinders (b) Union of cylinders

Geographic Data

- **Raster data** consist of bit maps or **pixel maps**, in two or more dimensions.
  - Example 2-D raster image: **satellite image** of **cloud cover**, where **each** pixel stores the **cloud visibility** in a particular area.
  - Additional dimensions might include the temperature at different altitudes at different regions, or measurements taken at different points in time.
- Design databases generally do not store raster data.

Geographic Data (Cont.)

- **Vector data** are constructed from basic geometric objects: **points**, **line segments**, **triangles**, and **other polygons** in two dimensions, and **cylinders**, **spheres**, **cuboids**, and other **polyhedrons** in three dimensions.
- Vector format often used to represent map data.
  - **Roads** can be considered as **two-dimensional** and represented **by lines and curves.**
  - Some features, **such as rivers, may be represented either as complex curves** or as **complex polygons**, depending on whether their width is relevant.
  - Features such as regions and lakes can be depicted as polygons.

Spatial Queries

- **Region queries** deal with spatial regions. e.g., ask for objects that lie partially or fully inside a specified region
  - E.g., PostGIS *ST_Contains*(), *ST_Overlaps*(), …
- **Nearness queries** request objects that lie near a specified location.
- **Nearest neighbor queries**, given a **point** or an **object**, **find** the **nearest object** that satisfies given conditions.
- **Spatial graph queries** request information based on spatial graphs
  - E.g., **shortest path** between **two points** via a road **network**
- **Spatial join** of two **spatial relations** with the **location** playing the role of join attribute.
  - Queries that **compute intersections** or **unions** of **regions**

End of Lecture 1