

## Week 1 Lecture 1

Class	BSCCS2001
Created	@August 19, 2021 1:46 PM
Materials	<a href="https://drive.google.com/drive/folders/19FhdYYKeH3ZshWhoZIJIP_MC1nVnUUmU?usp=sharing">https://drive.google.com/drive/folders/19FhdYYKeH3ZshWhoZIJIP_MC1nVnUUmU?usp=sharing</a>
Module #	1
Type	Lecture
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## Database Management Systems (DBMS)



**DBMS:** A database management system (or DBMS) is essentially nothing more than a computerized data-keeping system. (via IBM)

### DBMS contains info about a particular enterprise

- Collection of interrelated data
- Set of programs to access the data
- An environment that is both *convenient* and *efficient* to use

### Database Applications:

- Banking: transactions
- Airlines: reservations, schedules
- Universities: registration, grades
- Sales: customers, products, purchases
- Online retailers: order tracking, customized recommendations
- Manufacturing: production, inventory, orders, supply chain
- HR: employee records, salaries, tax deductions

### Databases can be very large

Databases touch various aspects of our lives

# University Database Example

## Application program examples

- Add new students, instructors and courses
- Register students for courses and generate class rosters
- Assign grades to students, compute Grade Point Average (GPA) and generate transcripts

In early days, database applications were built directly on top of file systems

## Drawbacks of using file systems to store data

- Data redundancy and inconsistency
  - Multiple file formats, duplication of information in different files
- Difficulty in accessing data
  - Need to write a new program to carry out each new task
- Data isolation
  - Multiple files and formats
- Integrity problems
  - Integrity constraints (eg: account balance > 0) become "buried" in program code rather than being stated explicitly
  - Hard to add new constraints or change existing ones
- Atomicity of updates
  - Failures may leave databases in an inconsistent state with partial updates carried out
  - **Example:** Transfer of funds from one account to another should either complete or not happen at all
- Concurrent access by multiple users
  - Concurrent access needed for performance
  - Uncontrolled concurrent accesses can lead to inconsistencies
    - **Example:** Two people reading a balance (say 100) and updating it by withdrawing money (say 50 each) at the same time
- Security problems
  - Hard to provide user access to some, but not all, data

Database systems offer solutions to the above problems

## Course pre-requisites:

### Set Theory

- Definition of a set
  - Intensional definition
  - Extensional definition
  - Set-builder notation
- Membership, Subset, Superset, Power set, Universal set
- Operations on sets:
  - Unions, Intersections, Complement, Difference, Cartesian product
- De-Morgan's Law

### Relations and Functions

- Definition of Relations
- Ordered pairs and Binary relations
  - Domain and Range

- Image, Pre-image, Inverse
- Properties: Reflexive, Symmetric, Anti-symmetric, Transitive, Total
- Definition of functions
- Properties of functions: Injective, Surjective, Bijective
- Composition of functions
- Inverse of functions

## Propositional Logic

- Truth values and Truth tables
- Operators: conjunction (and), disjunction (or), negation (not), implication, equivalence
- Closure under Operations

## Predicate Logic

- Predicates
- Quantification
  - Existential
  - Universal

## Python

## Algorithms and Programming in C

- Sorting
  - Merge sort
  - Quick sort
- Search
  - Linear search
  - Binary search
  - Interpolation search

## Data Structures

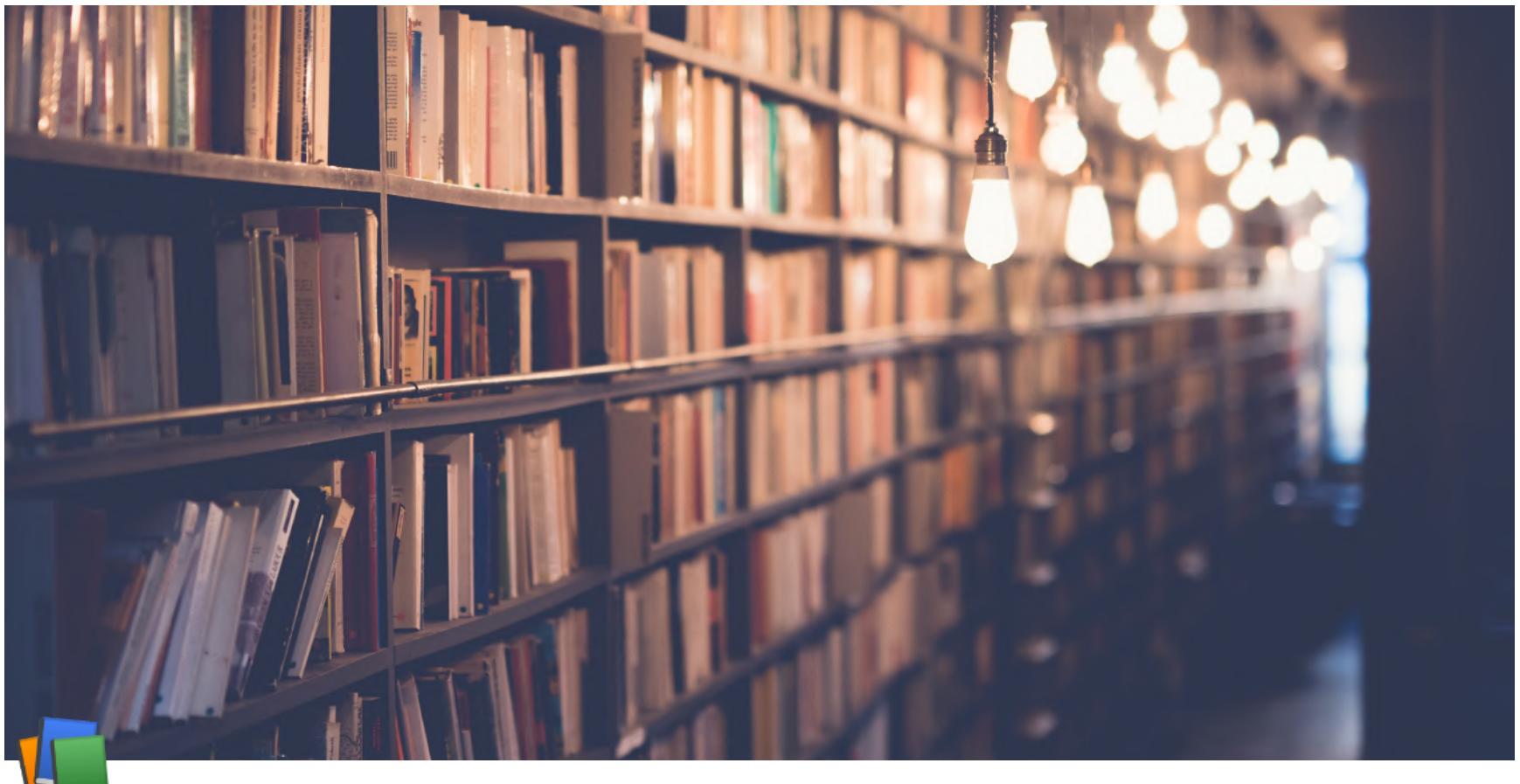
- Arrays
- List
- Binary Search Tree
  - Balanced Tree
- B - Tree
- Hash table/map

## Object-Oriented analysis and design

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- **Refresher material**
  - Discrete Mathematics by Brilliant: <https://brilliant.org/wiki/discrete-mathematics>
  - Python
    - IITM online book: <https://pypod.github.io>
    - Cheatsheet: <https://www.pythoncheatsheet.org>
  - DataCamp Cheatsheet: <https://www.datacamp.com/community/tutorials/python-data-science-cheat-sheet-basics>

- C Language: [https://www.youtube.com/watch?v=zYierUhIFNQ&list=PLhQjrBD2T382\\_R182iC2gNZI9HzWFMC\\_8&index=2](https://www.youtube.com/watch?v=zYierUhIFNQ&list=PLhQjrBD2T382_R182iC2gNZI9HzWFMC_8&index=2) (part of CS50 2020 Lectures)



## Week 1 Lecture 2

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## Why DBMS?

### Data Management

- Storage
- Retrieval
- Transaction
- Audit
- Archival

For

- Individuals
- Small / Big Enterprises
- Global

There has been 2 major approaches in this practice:

#### 1. Physical:

Physical Data or Records Management, more formally known as **Book Keeping**, has been using physical ledgers and journals for centuries

The most significant development happened when Henry Brown patented a "receptacle for storing and preserving papers" on November 2, 1886

Herman Hollerith adapted the punch cards used for weaving looms to act as the memory for a mechanical tabulating machine in 1890

## 2. Electronic:

Electronic Data or Records management moves with the advances in technology, especially of memory, storage, computing and networking

- 1950s: Computer programming started
- 1960s: Data Management with punch cards / tapes and magnetic tapes
- 1970s:
  - COBOL and CODASYL approach was introduced in 1971
  - On October 14, 1979, Apple II platform shipped VisiCalc, marking the birth of spreadsheets
  - Magnetic disks became prevalent
  - 1980s: RDBMS changed the face of data management
  - 1990s: With internet, data management started becoming global
  - 2000s: e-Commerce boomed, NoSQL was introduced for unstructured data management
  - 2010s: Data Science started riding high

## Electronic Data Management Params

Electronic Data or Records management depends on various params including ...

- Durability
- Scalability
- Security
- Retrieval
- Ease of Use
- Consistency
- Efficiency
- Cost

## Book Keeping

A book register was maintained on which the shop owner wrote the amount received from customers, the amount due for any customer, inventory details and so on ...

Problems with such an approach of book keeping:

- **Durability:** Physical damage to these registers is a possibility due to rodents, humidity, wear and tear
- **Scalability:** Very difficult to maintain over the years, some shops have numerous registers spanning over the years
- **Security:** Susceptible to tampering by the outsiders
- **Retrieval:** Time consuming process to search for previous entry
- **Consistency:** Prone to human errors

Not only small shops but large orgs also used to maintain their transactions in book registers

## Spreadsheet files - A better solution

### Mostly useful for single user or small enterprise applications

Spreadsheet software like Google Sheets: Due to disadvantages of maintaining ledger registers, organizations dealing with huge amount of data shifted to using spreadsheets for maintaining records in files

- **Durability:** These are computer applications and hence data is less prone to physical damage
- **Scalability:** Easier to search, insert and modify records as compared to book ledgers
- **Security:** Can be password protected
- **Easy to Use:** Computer applications are used to search and manipulate records in the spreadsheets leading to reduction in manpower needed to perform routing computations

- **Consistency:** Not guaranteed but spreadsheets are less prone to mistakes registers

## Why leave filesystems?

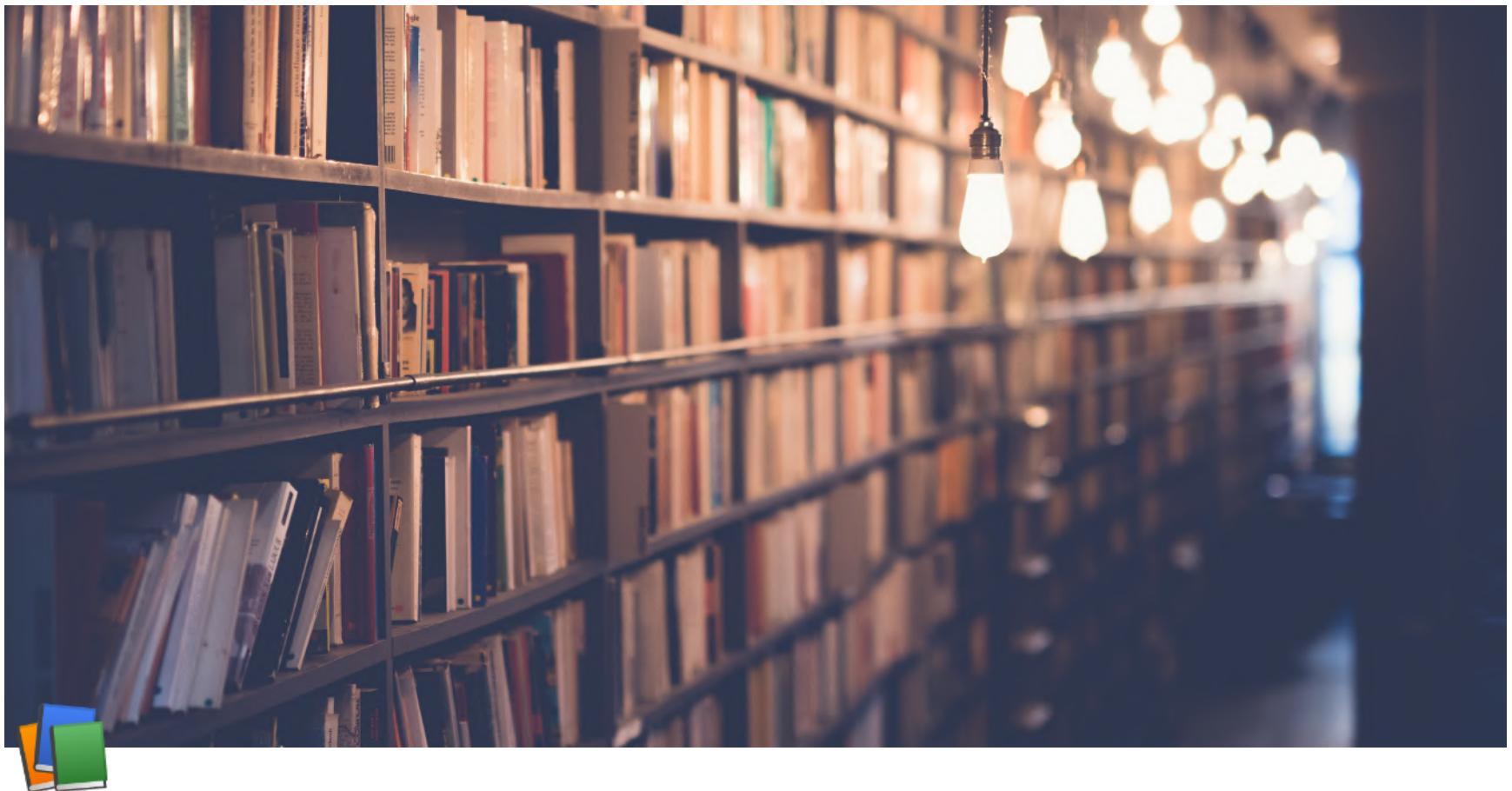
Lack of efficiency in meeting growing needs

- With rapid scale up of data, there has been considerable increase in the time required to perform most operations
- A typical spreadsheet file may have an upper limit on the number of rows
- Ensuring consistency of data is a big challenge
- No means to check violations of constraints in the face of concurrent processing
- Unable to give different permissions to different people in a centralized manner
- A system crash could be catastrophic

The above mentioned limitations of filesystems paved the way for a comprehensive platform dedicated to management of data - the **Database Management System**

## History of Database Systems

- 1950s and early 1960s
  - Data processing using magnetic tapes for storage
    - Tapes provided only sequential access
  - Punched cards for input
- Late 1960s and 1970s
  - Hard disks allowed direct access to data
  - Network and hierarchical data model in widespread use
  - Ted Codd defines the relational data model
    - Would win the ACM Turin Award for his work
    - IBM Research begins in System R prototype
    - UC Berkeley begins Ingres prototype
  - High-performance (for the era) transaction processing
- 1980s
  - Research relational prototypes evolve into commercial systems - SQL becomes industrial standard
  - Parallel and distributed database systems
  - Object oriented database systems
- 1990s
  - Large decision support and data mining applications
  - Large multi-terabyte data warehouses
  - Emergence of Web commerce
- Early 2000s
  - XML and XQuery standards
  - Automated database administration
- Later 2000s
  - Giant data storage systems - Google BigTable, Yahoo PNuts, Amazon, ...



## Week 1 Lecture 3

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## Why DBMS? (part 2)

### Case study of a Bank Transaction

Consider a simple banking system where a person can open a bank account, transfer funds to an existing account and check the history of all her transactions till date

The application performs the following checks

- If the account balance is not enough, it will now allow the fund transfer
- If the account numbers are not correct, it will flash a message and terminate the transaction
- If a transaction is successful, it prints a confirmation message

We will use this banking transaction system to compare various features of a file-based (.csv file) implementation viz-a-viz a DBMS-based implementation

- Account details are stored in
  - Accounts.csv for file-based implementation
  - Accounts table for DBMS implementation
- The transaction details are stored in
  - Ledger.csv for file-based implementation
  - Ledger table for DBMS implementation

Source: <https://github.com/bhaskariitm/transition-from-files-to-db>

### Initiating a transaction

Python

```

def begin_Transaction(credit_account, debit_account, amount):
    temp = []
    success = 0

    # Open file handles to retrieve and store transaction data
    f_obj_Account1 = open('Accounts.csv', 'r')
    f_reader1 = csv.DictReader(f_obj_Account1)
    f_obj_Account2 = open('Accounts.csv', 'r')
    f_reader2 = csv.DictReader(f_obj_Account2)
    f_obj_Ledger = open('Ledger.csv', 'a+')
    f_writer = csv.DictWriter(f_obj_Ledger, fieldnames=col_name_Ledger)

```

## SQL

```
-- Handled implicitly by the DBMS
```

## Transaction

### Python

```

try:
    for sRec in f_reader1:
        # CONDITION CHECK FOR ENOUGH BALANCE
        if sRec['AcctNo'] == debitAcc and int(sRec['Balance']) > int(amt):
            for rRec in f_reader2:
                if rRec['AcctNo'] == creditAcc:
                    sRec['Balance'] = str(int(sRec['Balance']) - int(amt))      # DEBIT
                    temp.append(sRec)
                    # CRITICAL POINT
                    f_writer.writerow({
                        'Acct1':sRec['AcctNo'],
                        'Acct2':rRec['AcctNo'],
                        'Amount':amt,
                        'D/C':'D'
                    })
                    rRec['Balance'] = str(int(rRec['Balance']) + int(amt))      # CREDIT
                    temp.append(rRec)
                    f_writer.writerow({'Account1': r_record['Account_no'], 'Account2': s_record['Account_no'], 'Amount': amount, 'D/C': 'C'})
                    success = success + 1
                break
            f_obj_Account1.seek(0)
            next(f_obj_Account1)
            for record in f_reader1:
                if record['Account_no'] != temp[0]['Account_no'] and record['Account_no'] != temp[1]['Account_no']:
                    temp.append(record)
except:
    print('\nWrong input entered !!!!')

```

## SQL

```

do $$ 
begin
amt = 5000
sendVal = '1800090';
recVal = '1800100';
select balance from accounts
into sbalance
where account_no = sendVal;
if sbalance < amt then
raise notice "Insufficient balance";
else
update accounts
set balance = balance - amt
where account_no = sendVal;
insert into ledger(sendAc, recAc, amnt, ttype)
values(sendVal, recVal, amt, 'D')
update accounts
set balance = balance + amt
where account_no = recVal;
insert into ledger(sendAc, recAc, amnt, ttype)
values(sendVal, recVal, amt, 'C')
commit;
raise notice "Successful";
end if;
end; $$
```

## Closing a transaction

### Python

```
f_obj_Account1.close()
f_obj_Account2.close()
f_obj_Ledger.close()
if success == 1:
    f_obj_Account = open('Accounts.csv', 'w+', newline='')
    f_writer = csv.DictWriter(f_obj_Account, fieldnames=col_name_Account)
    f_writer.writeheader()
    for data in temp:
        f_writer.writerow(data)
    f_obj_Account.close()
    print("\nTransaction is successful !!")
else:
    print('\nTransaction failed : Confirm Account details')
```

### SQL

```
-- Handled implicitly by the DBMS
```

### Comparison

Aa Parameter	File handling via Python	DBMS
<u>Scalability with respect to amount of data</u>	Very difficult to handle insert, update and querying of records	In-built features to provide high scalability for a large number of records
<u>Scalability with respect to changes in structure</u>	Extremely difficult to change the structure of records as in the case of adding or removing attributes	Adding or removing attributes can be done seamlessly using simple SQL queries
<u>Time of execution</u>	in seconds	in milliseconds
<u>Persistence</u>	Data processed using temporary data structures have to be manually updated to the file	Data persistence is ensured via automatic, system induced mechanisms
<u>Robustness</u>	Ensuring robustness of data has to be done manually	Backup, recovery and restore need minimum manual intervention
<u>Security</u>	Difficult to implement in Python (Security at OS level)	User-specific access at database level
<u>Programmer's productivity</u>	Most file access operations involve extensive coding to ensure persistence, robustness and security of data	Standard and simple built-in queries reduce the effort involved in coding thereby increasing a programmer's throughput
<u>Arithmetic operations</u>	Easy to do arithmetic computations	Limited set of arithmetic operations are available
<u>Costs</u>	Low costs for hardware, software and human resources	High costs of hardware, software and human resources

## Parameterized Comparison

### Scalability

#### File Handling in Python

- **Number of records:** As the # of records increases, the efficiency of flat files reduces:
  - the time spent in searching for the right records
  - the limitations of the OS in handling huge files
- **Structural Change:** To add an attribute, initializing the new attribute of each record with a default value has to be done by program. It is very difficult to detect and maintain relationships between entities if and when an attribute has to be removed

#### DBMS

- **Number of records:** Databases are built to efficiently scale up when the # of records increase drastically.
  - In-built mechanisms, like indexing, for quick access of right data

- **Structural Changes:** During adding an attribute, a default value can be defined that holds for all existing records - the new attribute gets initialized with default value. During deletion, constraints are used either not to allow the removal or ensure its safe removal

## Time and Efficiency

- If the number of records is very small, the overhead in installing and configuring a database will be much more than the time advantage obtained from executing the queries
- However, if the number of records is really large, then the time required in the initialization process of a database will be negligible as compared to that of using SQL queries

### File Handling in Python

- The effort needed to implement a file handler is quite less in Python
- In order to process a 1GB file, a program in Python would typically take a few seconds

### DBMS

- The effort to install and configure a DB in a DB server is expensive and time consuming
- In order to process a 1GB file, an SQL query would typically take a few milliseconds

## Programmer's Productivity

### File Handling in Python

- **Building a file handler:** Since the constraints within and across entities have to be enforced manually, the effort involved in building a file handling application is huge
- **Maintenance:** To maintain the consistency of data, one must regularly check for sanity of data and the relationships between entities during inserts, updates and deletes
- **Handling huge data:** As the data grows beyond the capacity of the file handler, more efforts are needed

### DBMS

- **Configuring the database:** The installation and configuration of a database is a specialized job of a DBA. A programmer, on the other hand, is saved the trouble
- **Maintenance:** DBMS has built-in mechanisms to ensure consistency and sanity of data being inserted, updated or deleted. The programmer does not need to do such checks
- **Handling huge data:** DBMS can handle even terabytes of data - Programmer does not have to worry

## Arithmetic Operations

### File Handling in Python

- Extensive support for arithmetic and logical operations on data using Python. These include complex numerical calculations and recursive computations

### DBMS

- SQL provides limited support for arithmetic and logical operations. Any complex computation has to be done outside of SQL

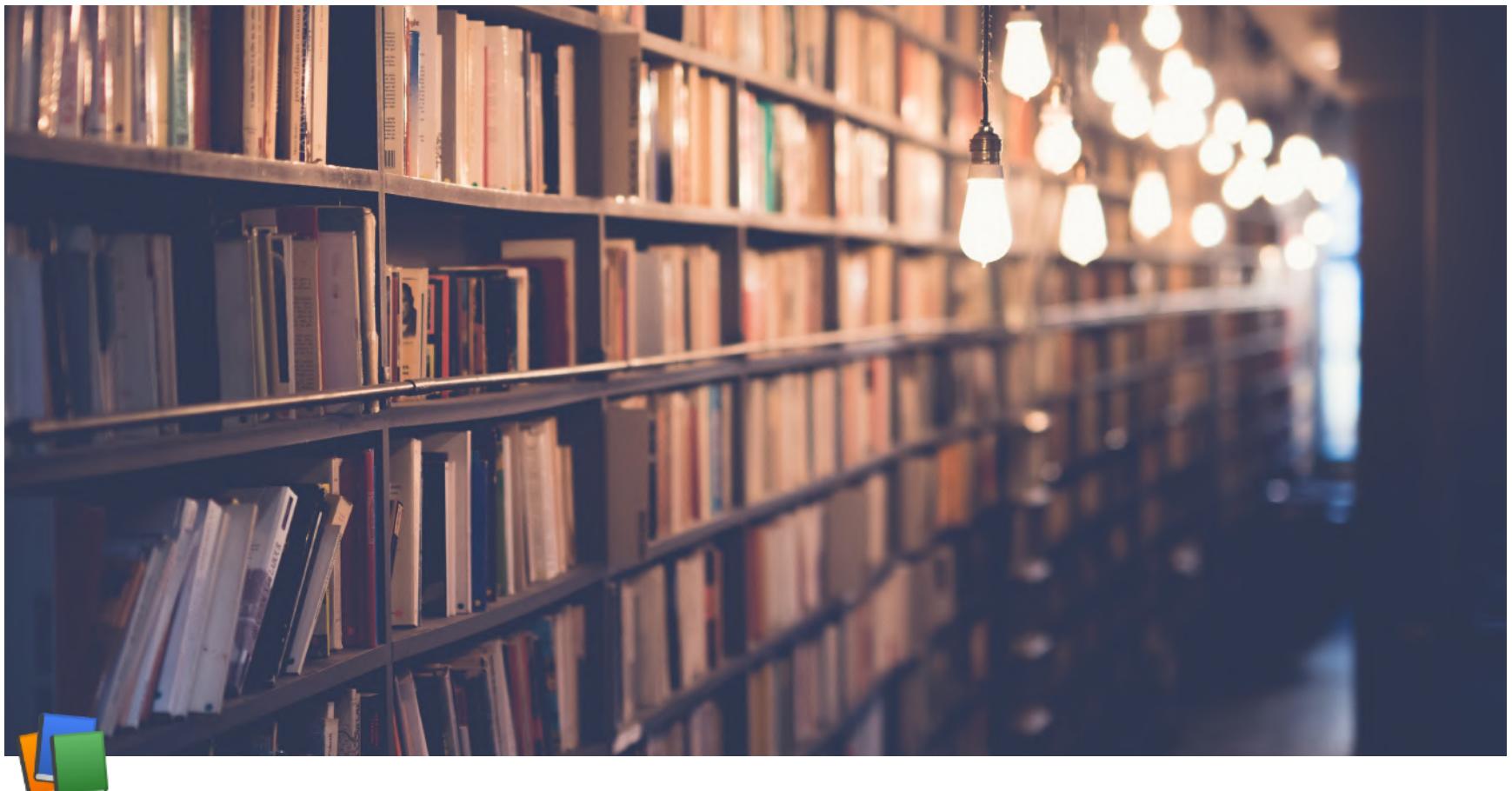
## Costs and Complexity

### File Handling in Python

- File systems are cheaper to install and use. No specialized hardware, software or personnel are required to maintain filesystems

### DBMS

- Large databases are served by dedicated database servers which need large storage and processing power
- DBMSs are expensive software that have to be installed and regularly updated
- Databases are inherently complex and need specialized people to work on it - like DBA (Database System Administrator)
- The above factors lead to huge costs in implementing and maintaining database management systems



## Week 1 Lecture 4

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## Introduction to DBMS

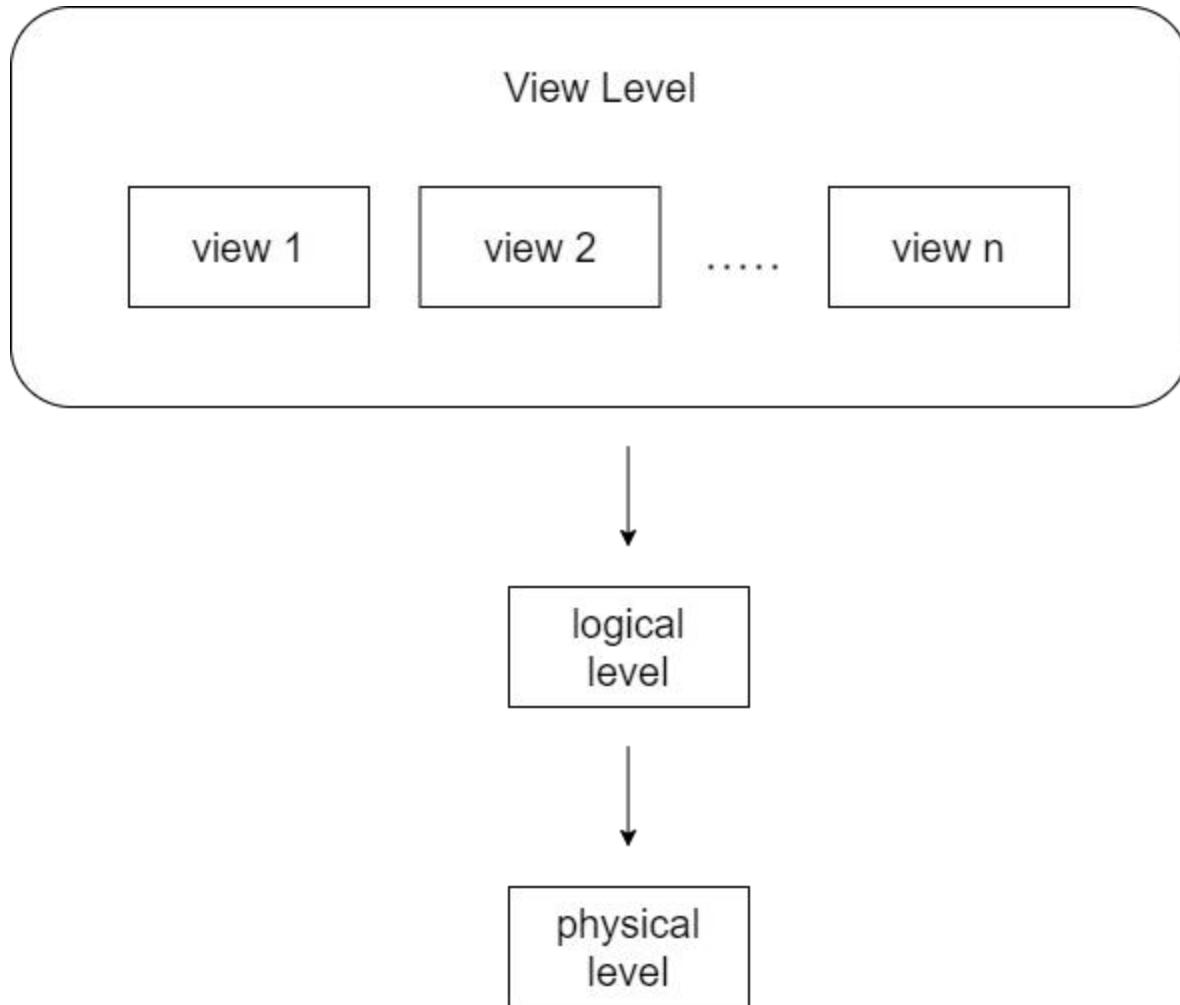
### Levels of Abstraction

- **Physical Level:** describes how a record (eg: instructor) is stored
- **Logical Level:** describes data stored in a database and the relationships among the data fields

```
type instructor = record
  ID: string;
  name: string;
  dept_name: string;
  salary: integer;
end;
```

- **View Level:** application programs hide details of data types
  - Views can also hide information (such as employee's salary) for security purposes

### An architecture for a database system



## Schema and Instances

**TLDR:** *Schema* is the way in which data is organized and *Instance* is the actual value of the data

- **Schema**

- **Logical Schema** - the overall logical structure of the database
  - Analogous to type information of a variable in a program (eg: int x = 5)
  - *Example:* The database consists of information about a set of customers and accounts in a bank and the relationship between them

### Customer Schema

Aa Name	≡ Customer ID	≡ Account #	≡ Aadhaar ID	≡ Mobile #
Untitled				

### Account Schema

Aa Account #	≡ Account Type	≡ Interest Rate	≡ Min. Bal.	≡ Balance
Untitled				

- **Physical Schema** - the overall physical structure of the database

- **Instance**

- The actual content of the database at a particular point in time
- Analogous to the value of a variable

### Customer Instance

Aa Name	≡ Customer ID	≡ Account #	≡ Aadhaar ID	≡ Mobile #
Pavan Lakha	6728	917322	182719289372	9830100291
Lata Kala	8912	827183	918291204829	7189203928
Nand Prabhu	6617	372912	127837291021	8892021892

### Account Instance

Aa Account #	≡ Account Type	≡ Interest Rate	≡ Min. Bal.	≡ Balance

Aa Account #	Account Type	Interest Rate	Min. Bal.	Balance
917322	Savings	4.0%	5000	7812
372912	Current	0.0%	0	291820
827183	Term Deposit	6.75%	10000	100000

- **Physical Data Independence** - the ability to modify the physical schema without changing the logical schema
  - Analogous to independence of *Interface* and *Implementation* in object-oriented systems
  - Applications depend on the logical schema
  - In general, the interfaces between various levels and components should be well defined so that changes in some parts do not seriously influence others.

## Data Models

- A collection of tools that describe the following ...
  - Data
  - Data relationships
  - Data semantics
  - Data constraints
- **Relational model** (our focus in this course)
  - Entity-Relationship data model (mainly for database design)
  - Object-based data models (Object-oriented and Object-relational)
  - Other older models
    - Network model
    - Hierarchical model
  - Recent models for Semi-structured or Unstructured data
    - Converted to easily manageable formats
    - Content Addressable Storage (CAS) with metadata descriptors
    - XML format
    - RDBMS which support BLOBs

## Relational Model

- All the data is stored in various tables
  - Tables are also called Relations
  - Columns are called attributes
  - They have particular names which tells us the schema
  - Rows are records that are the values

## Data Definition Language (DDL)

- Specification notation for defining the database schema
  - Example

```
create table instructor (
    ID char(5),
    name varchar(20),
    dept_name varchar(20),
    salary numeric(8, 2))
```

- DDL compiler generates a set of table templates stored in a data dictionary
- Data dictionary contains metadata (that is, data about the data)
  - Database schema

- Integrity constraints
  - Primary key (ID uniquely identifies instructors)
- Authorization
  - Who can access what

## Data Manipulation Language (DML)

Language for accessing and manipulating the data organized by the appropriate data model

- **DML:** also known as *Query Language*
- Two classes of languages
  - **Pure** - used for proving properties about computational power and for optimization
    - *Relational Algebra* (our focus in this course)
    - Tuple relational calculus
    - Domain relational calculus
  - **Commercial** - used in commercial systems
    - SQL is the most widely used commercial language

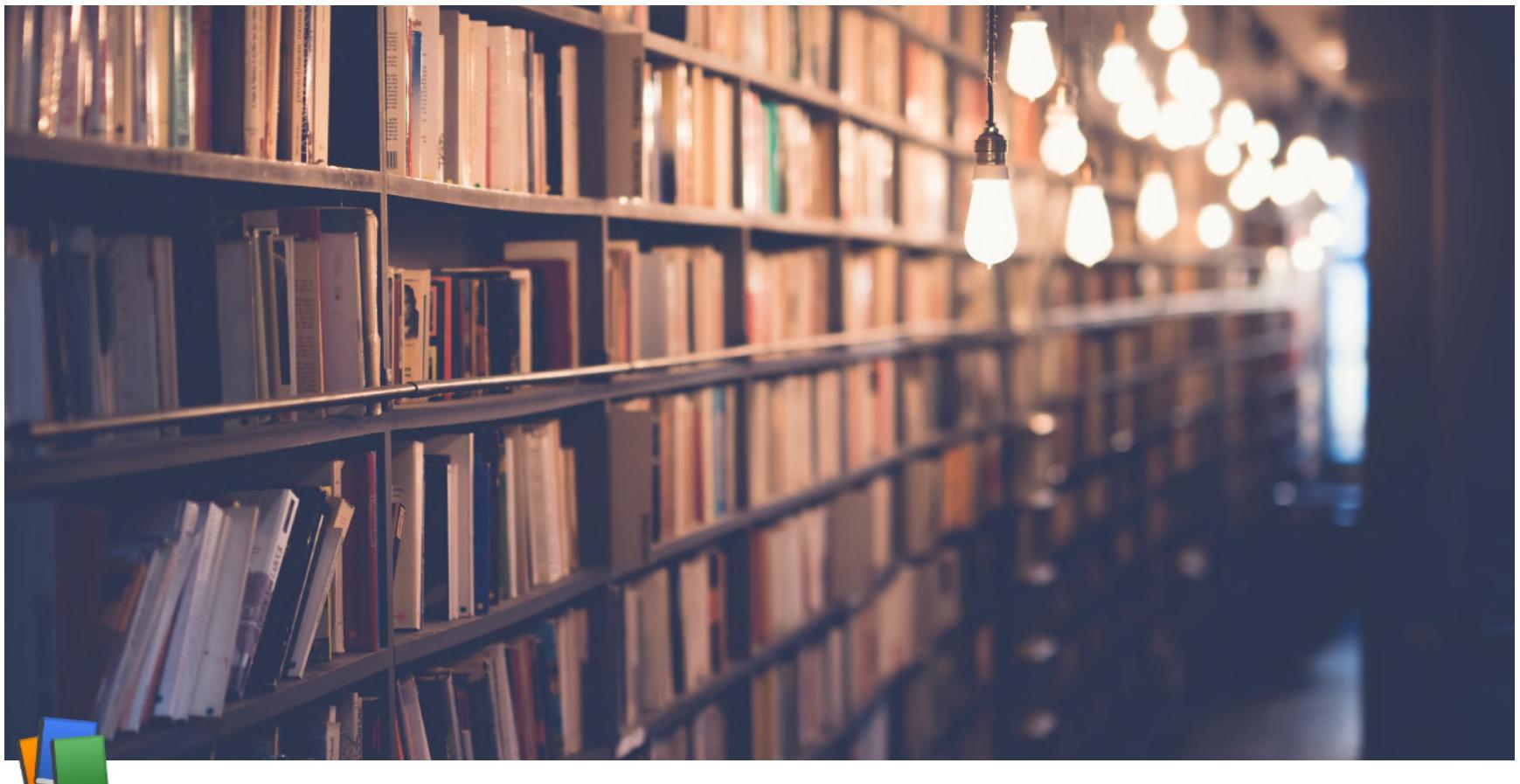
## Structured Query Language (SQL)

- Most widely used commercial language
- **SQL is NOT a Turing Machine equivalent language.** Read more [here](#)
  - Cannot be used to solve all problems that a C program, for example, can solve
- To be able to compute complex functions, SQL is usually embedded in some higher-level language
- Application programs generally access databases through one of ...
  - Language extensions to allow embedded SQL
  - Application Programming Interfaces or APIs (eg: ODBC / JDBC) which allow SQL queries to be sent to the databases

## Database Design

The process of designing the general structure of the database:

- **Logical Design** - Deciding on the database schema. Database design requires that we find a good collection of relation schema
  - Business decision
    - What attributes should we record in the databases?
  - Computer Science decision
    - What relation schemas should we have and how should the attributes be distributed among the various relation schemas?
- **Physical Design** - Deciding on the physical layout of the database



# Week 1 Lecture 5

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Created	@August 20, 2021 11:13 AM
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## Introduction to DBMS (part 2)

### Database Design

#### Design Approaches

- Need to come up with a methodology to ensure that each relation in the database is *good*
- Two ways of doing so:
  - Entity Relationship Model (*primarily tries to capture the business requirements*)
    - Models an enterprise as a collection of entities and relationships
    - Represented diagrammatically by an entity-relationship diagram
  - Normalization Theory (*this is the Computer Science perspective*)
    - Formalize what designs are bad and test for them

### Object-Relational Data Models

- Relational model: flat, atomic values
- Object Relational Data Models
  - Extend the relational data model by including object orientation and constructs to deal with added data types
  - Allow attributes of tuples to have complex types, including non-atomic values such as nested relations
  - Preserve relational foundations, in particular the declarative access to data, while extending modeling power
  - Provide upward compatibility with existing relational language

## XML: eXtensible Markup Language

- Defined by the **WWW Consortium (W3C)**
- What XML primarily says; XML is a description of name-value pair
  - It talks about a tag, so you can put a value on that
- Originally intended as a document markup language not a database language
- The ability to specify new tags and to create tag structures made XML a great way to exchange data, not just documents
- XML has become the basis for all new generation data interchange formats
- A wide variety of tools are available for parsing, browsing and querying XML documents

## Database Engine

3 major components are:

- Storage Manager
- Query processing
- Transaction Manager

### Storage Management

**Storage Manager** is a program module that provides the interface between the low-level data stored in the database and the application programs and queries submitted to the system

- The storage manager is responsible for the following tasks:
  - Interaction with the OS file manager
  - Efficient storing, retrieving and updating of data
- Issues:
  - Storage access
  - File organization
  - Indexing and hashing

### Query Processing

- Parsing and Translation
- Optimization
- Evaluation

### How a query is processed?

- Alternative ways of evaluating a given query
  - Equivalent expressions
  - Different algorithms for each operation
- Cost difference between a good and a bad way of evaluating a query can be enormous
- Need to estimate the cost of operations
  - Depends critically on statistical information about relations which the database must maintain
  - Need to estimate statistics for intermediate results to compute cost of complex expressions

### Transaction Management

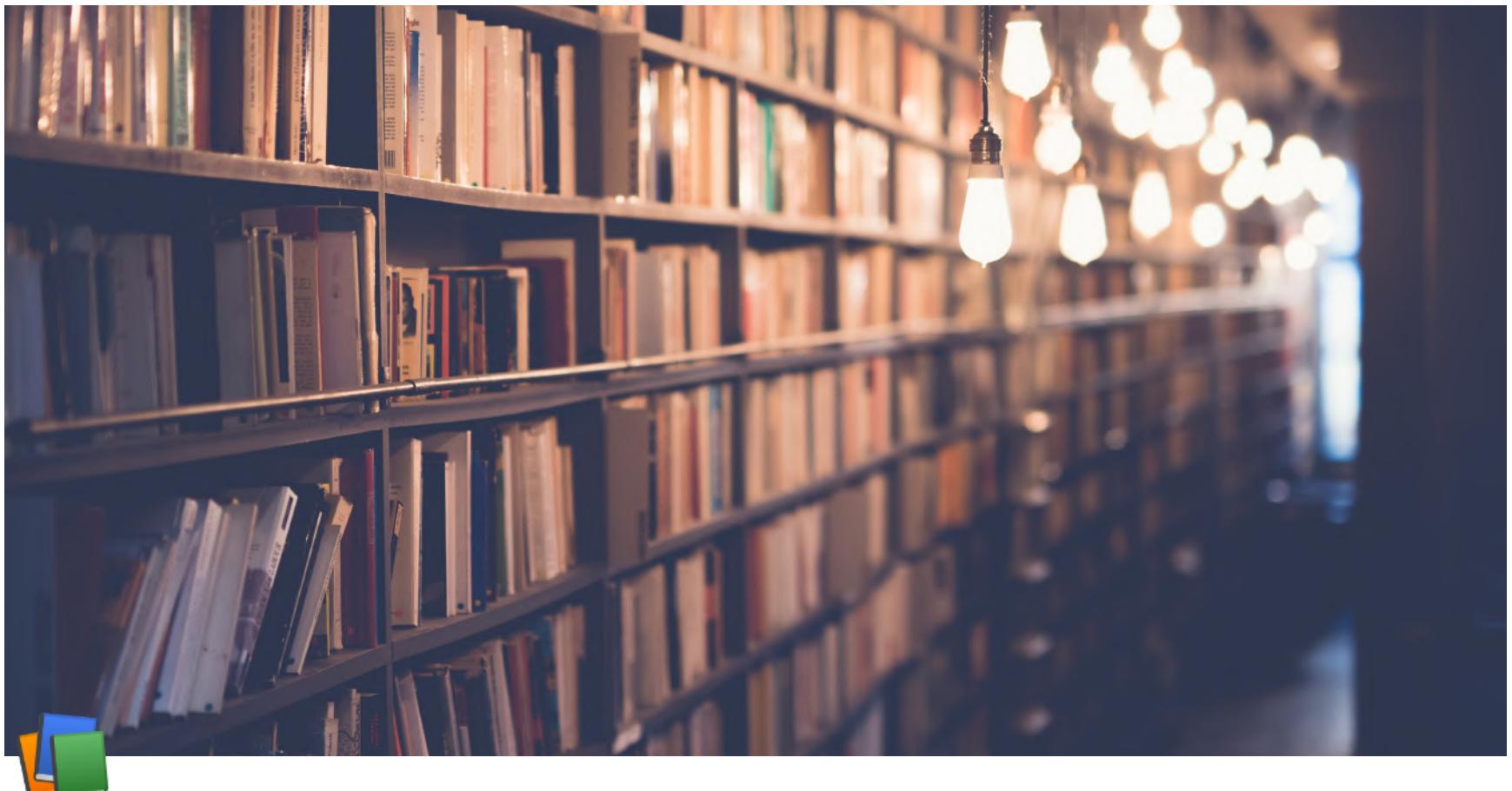
- What is the system fails?
- What if more than one user is concurrently updating the same file?
- A transaction is a collection of operations that perform single logical function in a database application
- Transaction-Management component ensure that the database remains in a consistent (correct) state despite system failures (eg: power failures and operating system crashes) and transaction failures

- **Concurrency-control manager** controls the interaction among the concurrent transactions to ensure consistency of the database

## Database Architecture

The architecture of a database system is greatly influenced by the underlying computer system on which the database is running:

- Centralized
- Client-Server
- Parallel (multi-processor)
- Distributed
- Cloud



## Week 2 Lecture 1

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Module #	6
Type	Lecture
Week #	2

## Introduction to Relational Model

### Attribute Types

- Consider

*Student = Roll #, First Name, Last Name, DoB, Passport #, Aadhaar #, Department*  
relation

- The set of allowed values for each attribute is called the domain of the attribute
  - Roll #** - Alphanumeric string
  - First Name, Last Name** - Alpha string
  - DoB** - Date
  - Passport #** - String (Letter followed by 7 digits) - nullable (Optional)
  - Aadhaar #** - 12-digit number
  - Department** - Alpha string
- Attribute values are (normally) required to be atomic; this is, indivisible
- The special value null is a member of every domain. Indicates that the value is *unknown*
- the *null* value may cause complications in the definition of many operations

Aa	Roll #	First Name	Last Name	DoB	Passport	Aadhaar	Dept.
	15CS10026	Lalit	Dubey	27-Mar-1997	L4032464	172861749239	Computer

Aa	Roll #	First Name	Last Name	DoB	Passport	Aadhaar	Dept.
	16EE30029	Jatin	Chopra	17-Nov-1996	null	391718363816	Electrical

## Relational Schema and Instance

- $A_1, A_2, \dots, A_n$  are the attributes
- $R = (A_1, A_2, \dots, A_n)$  is a relation schema
- Example: `instructor = (ID, name, dept_name, salary)`
- Formally, given as  $D_1, D_2, \dots, D_n$  a relation r is a subset of  $D_1 \times D_2 \times \dots \times D_n$

Thus, a relation is a set of n-tuples  $(a_1, a_2, \dots, a_n)$  where each  $a_i \in D_i$

- The current values (**relation instance**) of a relation are specified by a table
- An element  $t$  or  $r$  is a tuple, represented by a row in a table
- Example

`instructor`  $\equiv$   $(\text{String}(5) \times \text{String} \times \text{String} \times \text{Number}^+)$ , where  $\text{ID} \in \text{String}(5)$ ,  $\text{name} \in \text{String}$ ,  $\text{dept\_name} \in \text{String}$  and  $\text{salary} \in \text{Number}^+$

## Keys

- Let  $K \subseteq R$ , where  $R$  is the set of attributes in the relation
- $K$  is a **superkey** of  $R$  if values of  $K$  are sufficient to identify a unique tuple of each possible relation  $r(R)$ 
  - Example:  $\{\text{ID}\}$  and  $\{\text{ID}, \text{name}\}$  are both superkeys of `instructor`
- Superkey  $K$  is a **candidate key** if  $K$  is minimal
- Example:  $\{\text{ID}\}$  is a candidate key for `instructor`
- One of the candidate keys is selected to be the **primary key**
- A **surrogate key** (or synthetic key) in a database is a unique identifier for either an entity in the modeled world or an object in the database
  - The surrogate key is not derived from application data, unlike a natural (or business) key which is derived from application data

## Keys: Examples

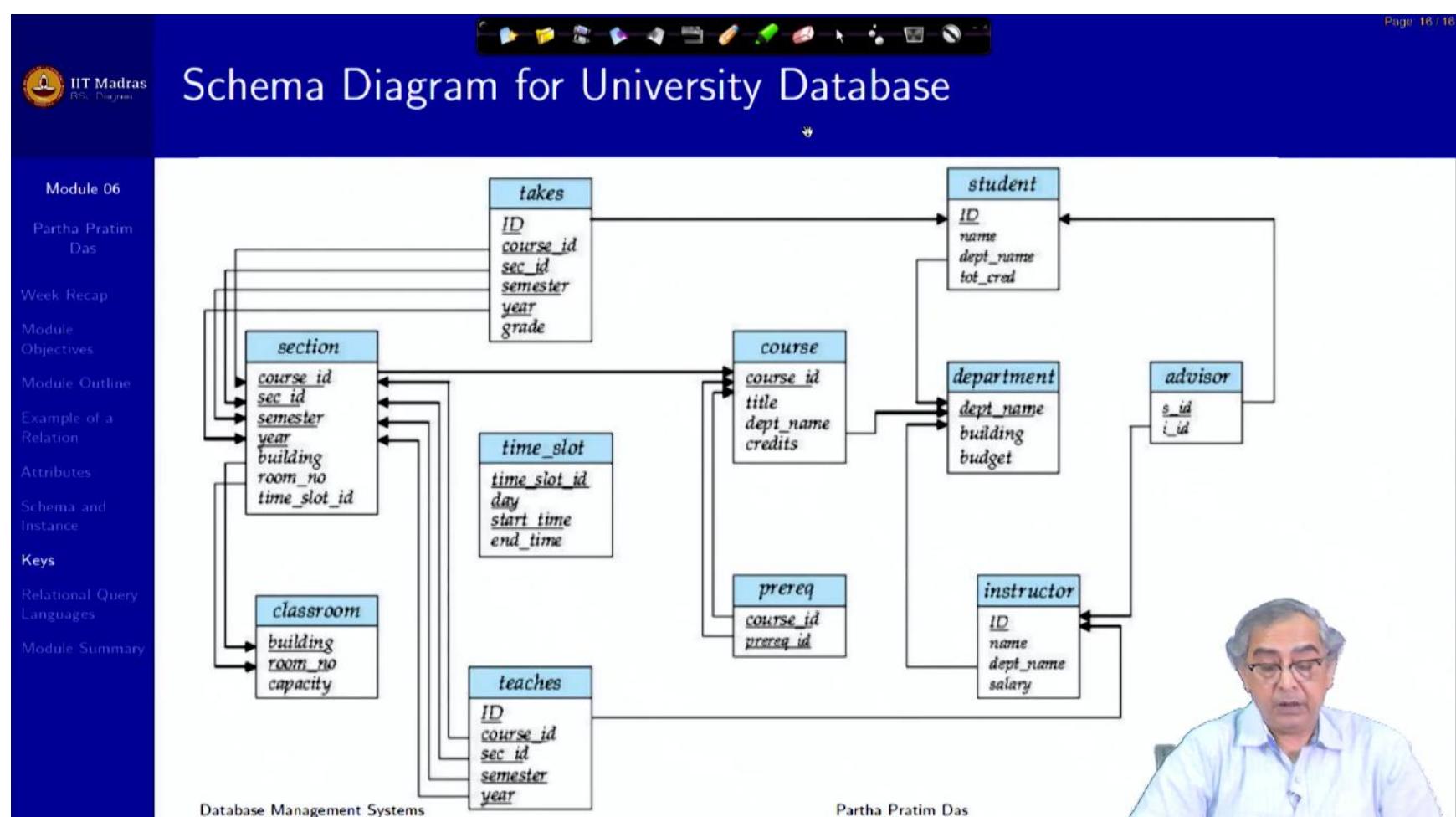
- Students = Roll #, First Name, Last Name, DoB, Passport #, Aadhaar #, Department
- **Super Key**: Roll #, {Roll #, DoB}
- **Candidate Keys**: Roll #, {First Name, Last Name}, Aadhaar #
  - Passport # cannot be a key because it is an optional field and can take null values, but an ID can never be null
- **Primary Key**: Roll #
  - Can Aadhaar # be a key?
  - It may suffice for unique identification, but Roll # may have additional useful information.
  - For example: 14CS92P01
    - Read it as 14-CS-92-P-01
    - 14 - Admission in 2014
    - CS - Department: Computer Science
    - 92 - Category of the Student
    - P - Type of admission: Project
    - 01 - Serial Number
- **Secondary / Alternate Key**: {First Name, Last Name}, Aadhaar #
- **Simple Key**: Consists of a single attribute

- **Composite Key:** {First Name, Last Name}
  - Consists of more than one attribute to uniquely identify an entity occurrence
  - One or more of the attributes, which make up the key are not simple keys in their own right

Aa Roll #	First Name	Last Name	DoB	Passport	Aadhaar	Dept
15CS10026	Lalit	Dubey	27-Mar-1997	L4032464	172861749239	Computer
16EE30029	Jatin	Chopra	17-Nov-1996	null	391718363816	Electrical
15EC10016	Smriti	Mongra	23-Dec-1996	G5432849	204592710914	Electronics
16CE10038	Dipti	Dutta	02-Feb-1997	null	571919482918	Civil
15CS30021	Ramdin	Minz	10-Jan-1997	X8811623	492849275924	Computer

- **Foreign key constraint:** Value in one relation must appear in another (in other words, when a particular attribute is a key in a different table)
  - **Referencing relation**
    - Enrolment: Foreign Keys - Roll #, Course #
  - **Referenced relation**
    - Students, Courses
- A **compound key** consists of more than one attribute to uniquely identify an entity occurrence
  - Each attribute, which makes up the key, is a simple key in its own right
  - {Roll #, Course #}

## Schema Diagram for University Database



## Relational Query Languages

Procedural viz-a-viz Non-procedural or Declarative Paradigms

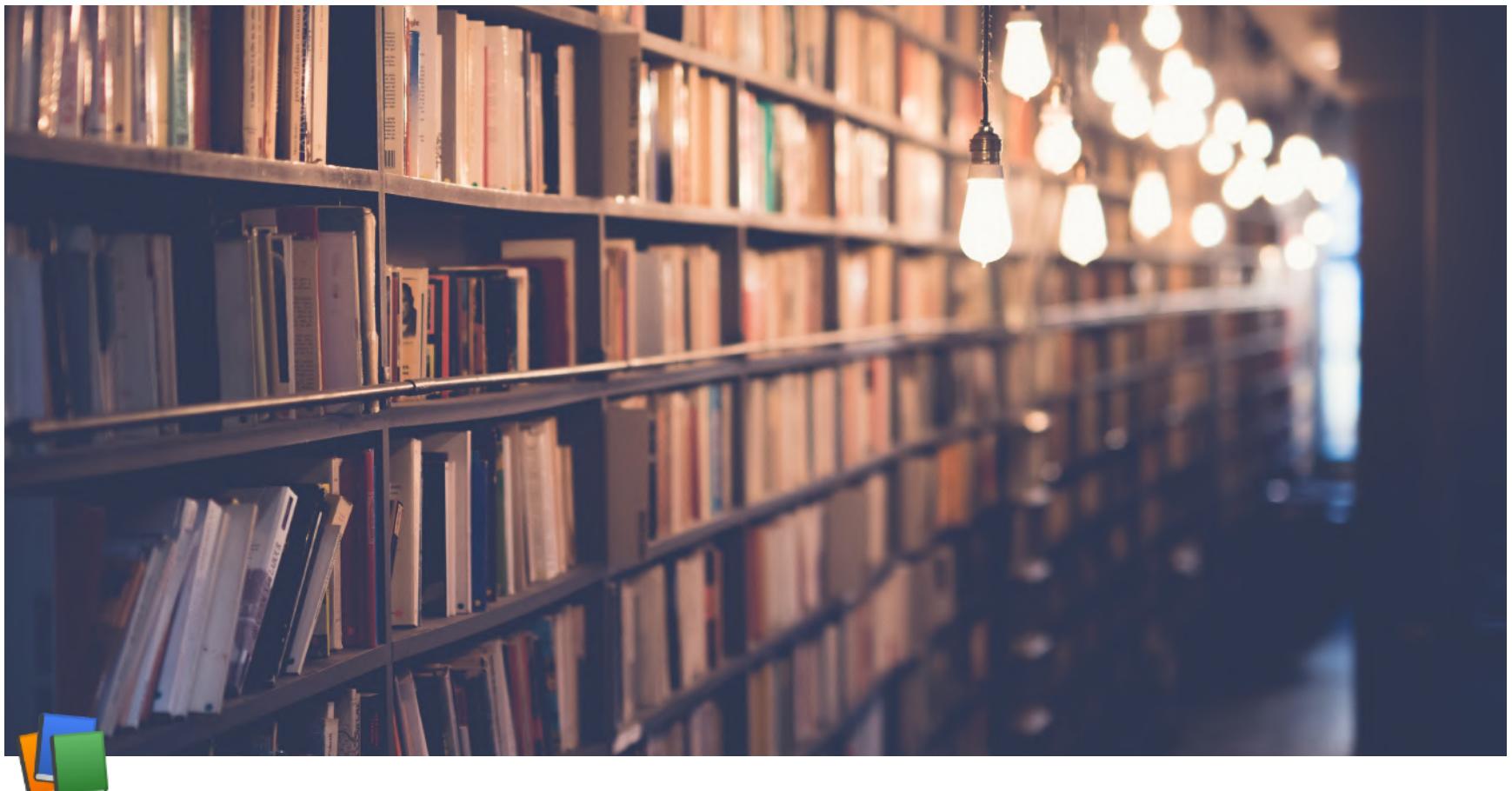
- Procedural programming requires that the programmer tell the computer what to do
  - That is, how to get the output for the range of required inputs
  - The programmer must know an appropriate algorithm
- Declarative programming requires a more descriptive style
  - The programmer must know what relationships hold between various entities

## Relational Query Language: Example

### Procedural vs. Non-procedural or Declarative Paradigms

- **Example: Square root of  $n$** 
  - Procedural
    - a) Guess  $x_0$  (close to root of  $n$ )
    - b)  $i \leftarrow 0$
    - c)  $x_{i+1} \leftarrow (x_i + n/x_i)/2$
    - d) Repeat Step 2 if  $|x_{i+1} - x_i| > delta$
  - Declarative
    - ▷ Root of  $n$  is  $m$  such that  $m^2 = n$

- "Pure" languages:
  - Relational Algebra
  - Tuple relational calculus
  - Domain relational calculus
- The above 3 pure languages are equivalent in computing power
- We will concentrate on relational algebra
  - Not Turing-machine equivalent
    - Not all algorithms can be expressed in Relational Algebra
  - Consists of 6 basic operations



## Week 2 Lecture 2

Class	BSCCS2001
Created	@August 22, 2021 6:57 PM
Materials	<a href="https://www.caam.rice.edu/~heinken/latex/symbols.pdf">https://www.caam.rice.edu/~heinken/latex/symbols.pdf</a>
Module #	7
Type	Lecture
Week #	2

## Introduction to Relational Model (part 2)

### Relational Operators

#### Basic properties of relations

- A relation is a set. Hence,
- Ordering of rows / tuples is inconsequential
- All rows / tuples must be distinct

#### Select operation - selection of rows (tuples)

- Relation  $r$  on the following table

$A$	$B$	$C$	$D$
$\alpha$	$\alpha$	1	7
$\alpha$	$\beta$	5	7
$\beta$	$\beta$	12	3
$\beta$	$\beta$	23	10

- The select operation is defined as

$$\sigma_{A=B \wedge D>5}(r)$$

- And it returns the following table as a result

<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>
$\alpha$	$\alpha$	1	7
$\beta$	$\beta$	23	10

## Project operation - selection of columns (Attributes)

- Relation  $r$

<i>A</i>	<i>B</i>	<i>C</i>
$\alpha$	10	1
$\alpha$	20	1
$\beta$	30	1
$\beta$	40	2

- The projection operation is defined as

$$\pi_{A,C}(r)$$

- And it returns the following table as a result

<i>A</i>	<i>C</i>
$\alpha$	1
$\alpha$	1
$\beta$	1
$\beta$	2

=

<i>A</i>	<i>C</i>
$\alpha$	1
$\beta$	1
$\beta$	2

Partha Pratim Das

## Union of two relations

- Relation  $r, s$

$A$	$B$
$\alpha$	1
$\alpha$	2
$\beta$	1

$r$

$A$	$B$
$\alpha$	2
$\beta$	3

$s$

- The union of two relation is defined as

$$r \cup s$$

- And it returns the following result

$A$	$B$
$\alpha$	1
$\alpha$	2
$\beta$	1
$\beta$	3

## Set difference of two relations

- Relation  $r, s$

$A$	$B$
$\alpha$	1
$\alpha$	2
$\beta$	1

$r$

$A$	$B$
$\alpha$	2
$\beta$	3

$s$

- The set difference of two relations is defined as

$$r - s$$

- And it returns the following result

A	B
$\alpha$	1
$\beta$	1

**Note:**  $r \cap s = r - (r - s)$

### Joining two relations - Cartesian-product

- Relation  $r, s$

A	B	C	D	E
$\alpha$	1	$\alpha$	10	a
$\beta$	2	$\beta$	10	a
		$\beta$	20	b
		$\gamma$	10	b

$r$                              $s$

- The cartesian product is defined as

$$r \times s$$

- And it returns the following result

A	B	C	D	E
$\alpha$	1	$\alpha$	10	a
$\alpha$	1	$\beta$	10	a
$\alpha$	1	$\beta$	20	b
$\alpha$	1	$\gamma$	10	b
$\beta$	2	$\alpha$	10	a
$\beta$	2	$\beta$	10	a
$\beta$	2	$\beta$	20	b
$\beta$	2	$\gamma$	10	b

### Cartesian-product - Naming issue

A	B	C	D	E
$\alpha$	1	$\alpha$	10	a
$\beta$	2	$\beta$	10	a
		$\beta$	20	b
		$\gamma$	10	b

$r$                              $s$

<i>A</i>	<i>r.B</i>	<i>s.B</i>	<i>D</i>	<i>E</i>
$\alpha$	1	$\alpha$	10	a
$\alpha$	1	$\beta$	10	a
$\alpha$	1	$\beta$	20	b
$\alpha$	1	$\gamma$	10	b
$\beta$	2	$\alpha$	10	a
$\beta$	2	$\beta$	10	a
$\beta$	2	$\beta$	20	b
$\beta$	2	$\gamma$	10	b

## Renaming a Table

- Allows us to refer to a relation, say  $E$ , by more than one name

$$\rho_X(E)$$

returns the expression  $E$  under the name  $X$

- Relations  $r$

<i>A</i>	<i>B</i>
$\alpha$	1
$\beta$	2

- Self product

$$r \times \rho_s(r)$$

<i>r.A</i>	<i>r.B</i>	<i>s.A</i>	<i>s.B</i>
$\alpha$	1	$\alpha$	1
$\alpha$	1	$\beta$	2
$\beta$	2	$\alpha$	1
$\beta$	2	$\beta$	2

## Composition of Operations

- Can build expressions using multiple operations
- Example:

$$\sigma_{A=C}(r \times s)$$

- $r \times s$

A	B	C	D	E
$\alpha$	1	$\alpha$	10	a
$\alpha$	1	$\beta$	10	a
$\alpha$	1	$\beta$	20	b
$\alpha$	1	$\gamma$	10	b
$\beta$	2	$\alpha$	10	a
$\beta$	2	$\beta$	10	a
$\beta$	2	$\beta$	20	b
$\beta$	2	$\gamma$	10	b

$$\sigma_{A=C}(r \times s)$$

A	B	C	D	E
$\alpha$	1	$\alpha$	10	a
$\beta$	2	$\beta$	10	a
$\beta$	2	$\beta$	20	b

## Joining two relations - Natural Join

- Let  $r$  and  $s$  be relations on schemas  $R$  and  $S$  respectively. Then, the "natural join" of relations  $R$  and  $S$  is a relation on schema  $R \cup S$ 
  - Consider each pair of tuples  $t_r$  from  $r$  and  $t_s$  from  $s$
  - If  $t_r$  and  $t_s$  have the same value on each of the attributes in  $R \cap S$ , add a tuple  $t$  to the result, where
    - $t$  has the same value as  $t_r$  on  $r$
    - $t$  has the same value as  $t_s$  on  $s$

## Natural join example

- Relations  $r, s$ :

r				s		
A	B	C	D	B	D	E
$\alpha$	1	$\alpha$	a	1	a	$\alpha$
$\beta$	2	$\gamma$	a	3	a	$\beta$
$\gamma$	4	$\beta$	b	1	a	$\gamma$
$\alpha$	1	$\gamma$	a	2	b	$\delta$
$\delta$	2	$\beta$	b	3	b	$\epsilon$

- Natural join

$$r \bowtie s$$

A	B	C	D	E
$\alpha$	1	$\alpha$	a	$\alpha$
$\alpha$	1	$\alpha$	a	$\gamma$
$\alpha$	1	$\gamma$	a	$\alpha$
$\alpha$	1	$\gamma$	a	$\gamma$
$\delta$	2	$\beta$	b	$\delta$

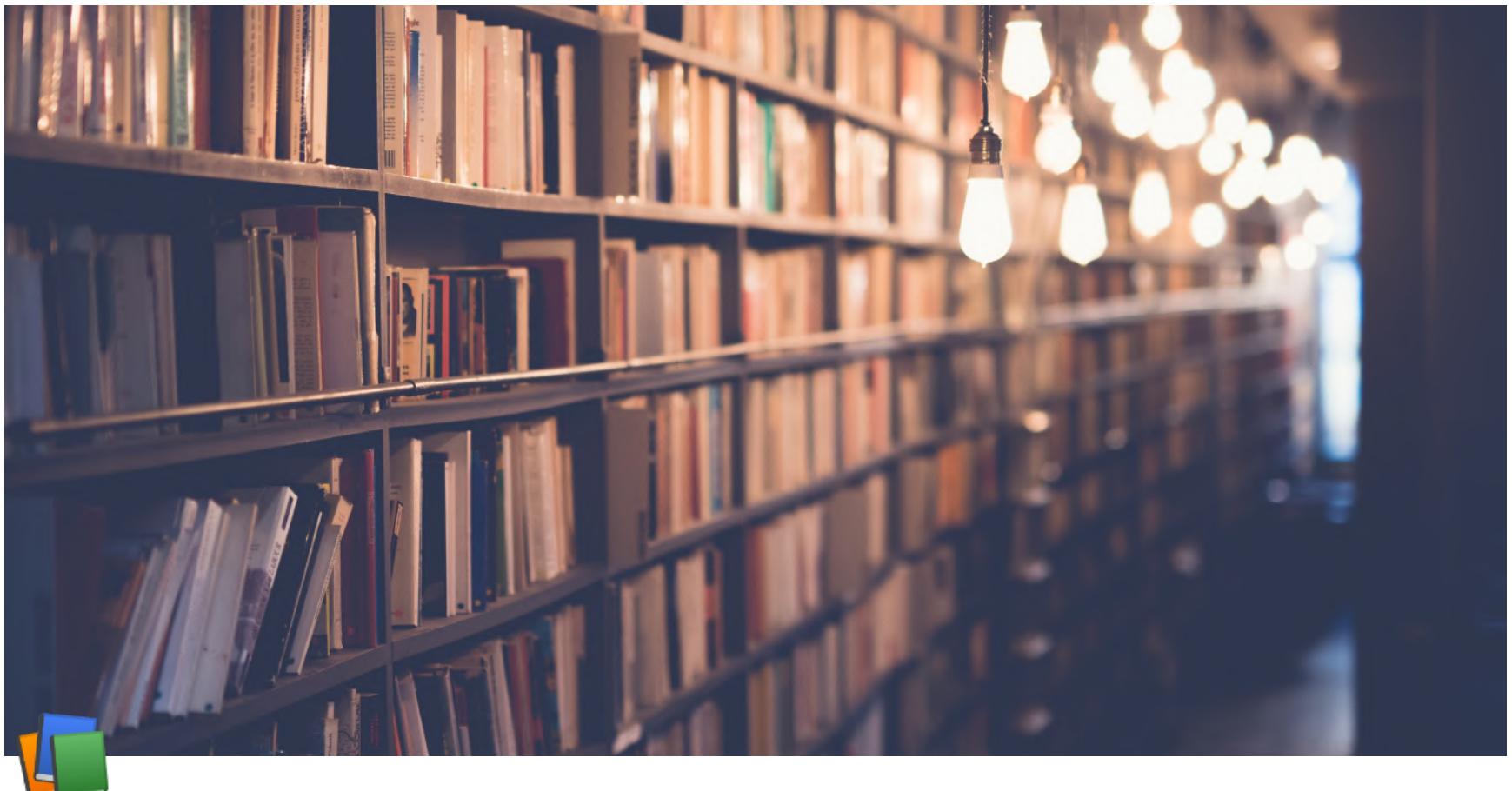
$$\pi_{A,r.B,C,r.D,E}(\sigma_{r.B=s.B \wedge r.D=s.D}(r \times s))$$

## Aggregation Operators

- Can we compute:
  - SUM
  - AVG
  - MAX
  - MIN

## Notes about Relational Languages

- Each query input is a table (or a set of tables)
- Each query output is a table
- All data in the output table appears in one of the input tables
- Relational Algebra is not Turing complete



## Week 2 Lecture 3

Class	BSCCS2001
Created	@August 22, 2021 8:38 PM
Materials	
# Module #	8
Type	Lecture
Week #	2

## Introduction to Structured Query Language (SQL)

### History of SQL

- IBM developed Structured English Query Language (SEQUEL) as a part of System R project.
- Renamed Structured Query Language (SQL: *still pronounced as SEQUEL*)

ANSI and ISO standard SQL:

Aa Name	≡ Description
<u>SQL - 86</u>	First formalized by <b>ANSI</b>
<u>SQL - 89</u>	+ <b>Integrity Constraints</b>
<u>SQL - 92</u>	Major revision ( <b>ISO/IEC 9075 standard</b> ), <b>De-facto Industry Standard</b>
<u>SQL : 1999</u>	+ <b>Regular Expression Matching, Recursive Queries, Triggers, Support for Procedural and Control Flow Statements</b> , Non-scalar types (Arrays) and some OO features (structured types), <b>Embedding SQL in Java (SQL/OLB)</b> and <b>Embedding Java in SQL (SQL/JRT)</b>
<u>SQL : 2003</u>	+ <b>XML features (SQL/XML)</b> , Window functions, Standardized sequences and columns with auto-generated values (identity columns)
<u>SQL : 2006</u>	+ Way of <b>importing and storing XML data</b> in a SQL database, <b>manipulating it</b> within the database, and <b>publishing both XML and conventional SQL-data in XML form</b>
<u>SQL : 2008</u>	Legalizes <b>ORDER BY</b> outside Cursor Definitions + <b>INSTEAD OF</b> Triggers, <b>TRUNCATE</b> statements and <b>FETCH</b> clause

Aa Name	Description
<u>SQL : 2011</u>	+ Temporal data ( <b>PERIOD FOR</b> ) Enhancements for Window functions and <b>FETCH</b> clause
<u>SQL : 2016</u>	+ Row Pattern Matching, Polymorphic Table Functions and <b>JSON</b>
<u>SQL : 2019</u>	+ Multidimensional Arrays (MDarray type and operators)

## Compliance

- SQL is the de facto industry standard today for relational or structured data systems
- Commercial system as well as open system may be fully or partially compliant to one or more standards from SQL-92 onward
  - Not all examples here may work on your particular system. Check your system's SQL docs.

## Alternatives

- There aren't any alternatives to SQL for speaking to relational databases (i.e. SQL as a protocol)
  - There are alternatives to writing SQL in the applications
- These alternatives have been implemented in the form of front-ends for working with relational databases. Some examples of a front-end include (for a section of languages):
  - **SchemeQL** and **CLSQL**
    - Probably the most flexible, thanks to their Lisp heritage
    - They also look a lot more like SQL than other front-ends
  - **LINQ** (in .NET)
  - **ScalaQL** and **ScalaQuery** (in Scala)
  - **SqlStatement**, **ActiveRecord** and many others in Ruby
  - **HaskellIDB**
  - ... the list goes on for many other languages

## Derivatives

- There are several query languages that are derived from or inspired by SQL.
- Out of these, the most popular and effective is **SPARQL**.
- **SPARQL** (pronounced *sparkle*, a recursive acronym for *SPARQL Protocol and RDF Query Language*) is an RDF query language
  - A semantic query language for databases - able to retrieve and manipulate data stored in **Resource Description Framework (RDF)** format.
  - It has been standardized by the W3C Consortium as key technology of the semantic web
  - Versions
    - SPARQL 1.0 (Jan. 2008)
    - SPARQL 1.1 (Mar. 2013)
  - Used as the query languages for several NoSQL systems - particularly the Graph Databases that use RDF as store

## Data Definition Language (DDL)

The SQL data-definition language (DDL) allows the specification of information about relations, including:

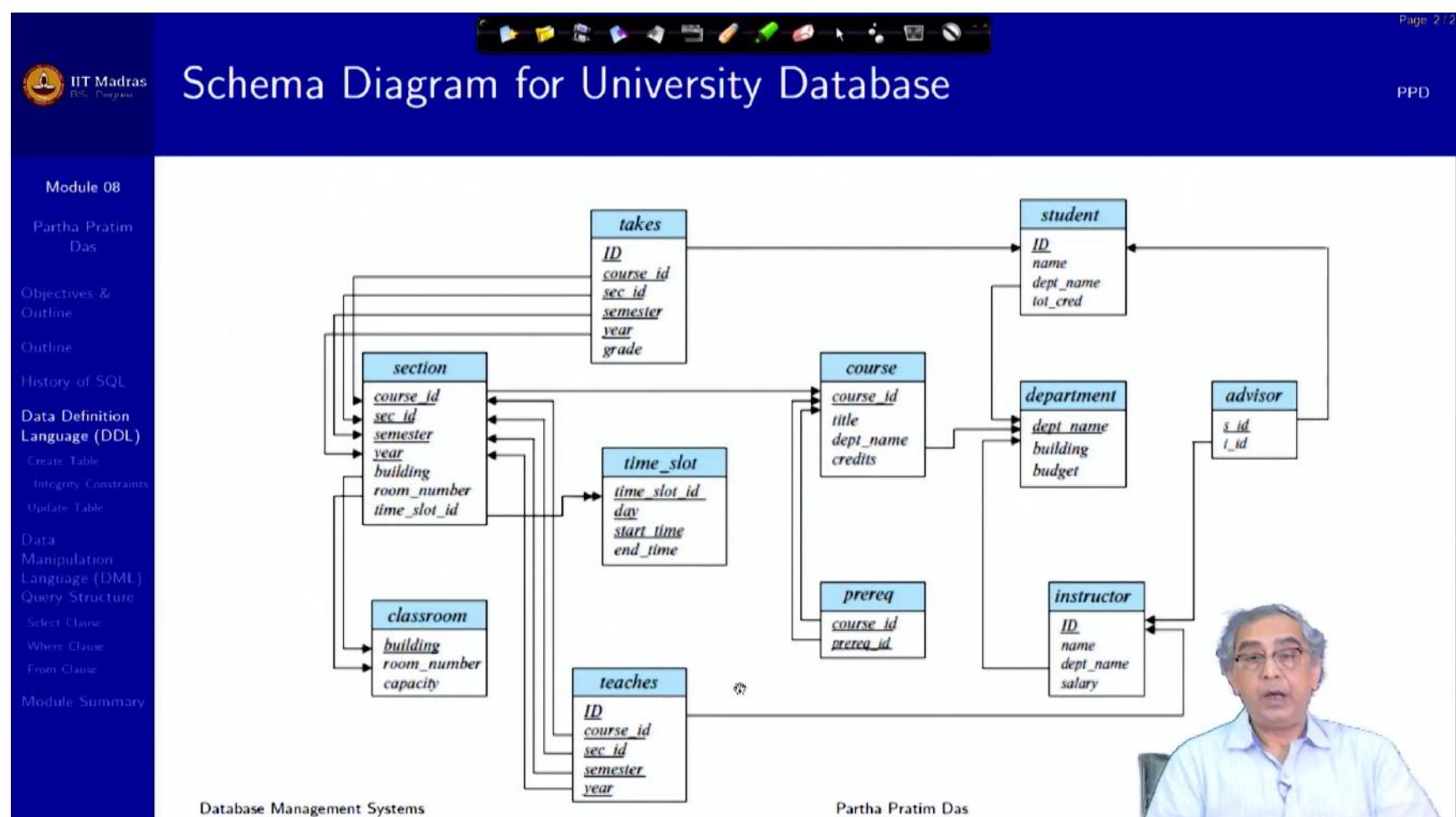
- The *Schema* for each *Relation*
- The *Domain* of values associated with each *Attribute*
- *Integrity Constraints*

- And, as we will see later, also other information such as ...
  - The set of *Indices* to be maintained for each relations
  - *Security and Authorization* information for each relation
  - The *Physical Storage Structure* of each relation on disk

## Domain types (or Data types) in SQL

- ***char(n)*** - Fixed length character string, with user-specified length *n*
- ***varchar(n)*** - Variable length character strings, with user-specified max length *n*
- ***int*** - Integer (a finite subset of the integers that is machine-dependent)
- ***smallint(n)*** - Small integer (a machine-dependent subset of the integer domain type)
- ***numeric(p, d)*** - Fixed point number, with user-specified precision of *p* digits, with *d* digits to the right of decimal point.  
(ex. *numeric(3, 1)* allows 44.5 to be stored exactly, but not 444.5 or 0.32)
- ***real, double precision*** - Floating point and double-precision floating point numbers, with machine-dependent precision
- ***float(n)*** - Floating point number with user specified precision of at-least *n* digits

## Schema diagram for a University database



## Create Table construct

- An SQL relation is defined using the **create table** command:

```
create table r (A1D1, A2D2, ..., AnDn),
```

```
(integrity – constraint1),
```

```
...
```

```
(integrity – constraintk));
```

- *r* is the name of the relation (table)
- each *A<sub>i</sub>* is an attribute name in the schema of relation *r*
- *D<sub>i</sub>* is the data type of values in the domain of attribute *A<sub>i</sub>*

## Example

```
create table instructor (
  ID char(5),
```

```
name varchar(20),
dept_name varchar(20),
salary numeric(8, 2));
```

## University DB

<u>Aa</u>	instructor
<u>ID</u>	
<u>name</u>	
<u>dept_name</u>	
<u>salary</u>	

## Create Table constructs: Integrity constraints

- **not null**
- **primary key ( $A_1, \dots, A_n$ )**
- **foreign key ( $A_m, \dots, A_n$ ) references  $r$**

```
create table instructor (
    ID char(5),
    name varchar(20),
    dept_name varchar(20),
    salary numeric(8, 2));
```

```
create table instructor (
    ID char(5),
    name varchar(20) not null,
    dept_name varchar(20),
    salary numeric(8, 2),
    primary key (ID),
    foreign key (dept_name) references department);
```

**primary key** declaration on an attribute automatically ensures **not null**

## Create Table construct: More relations

```
create table student (
    ID varchar(5),
    name varchar(20) not null,
    dept_name varchar(20),
    tot_cred numeric(3, 0),
    primary key (ID),
    foreign key (dept_name) references department);
```

```
create table course (
    course_id varchar(8),
    title varchar(50),
    dept_name varchar(20),
    credits numeric(2, 0),
    primary key (course_id),
    foreign key (dept_name) references department);
```

```
create table takes (
    ID varchar(5),
    course_id varchar(8),
    sec_id varchar(8),
    semester varchar(6),
    year numeric(4, 0),
    grade varchar(2),
    primary key (ID, course_id, sec_id, semester, year),
    foreign key (course_id, sec_id, semester, year) references section);
```

- **NOTE:**  $sec\_id$  can be dropped from primary key above to ensure a student cannot register for two sections of the same course in the same semester

## Update Tables

- **Insert** (DML command)

```
insert into instructor values ('10211', 'Smith', 'Biology', 66000);
```

- **Delete** (DML command)

- Remove all tuples from the *student* relation

```
delete from student
```

- **Drop Table** (DDL command)

```
drop table r
```

- **Alter** (DDL command) # to edit the schema

```
alter table r add A D
```

- Where *A* is the name of the attribute to be added to relation to *r* and *D* is the domain of *A*
  - All existing tuples in the relation are assigned **null** as the value for the new attribute

```
alter table r drop A
```

- Where *A* is the name of the attribute of relation *r*
  - Dropping of attributes not supported by many databases

## Data Manipulation Language (DML): Query Structure

### Basic query structure

- A typical SQL query has the form:

```
select A1, A2, ..., An,
```

```
from r1, r2, ..., rm
```

```
where P
```

- *A<sub>i</sub>* represents an attribute from *r<sub>i</sub>*'s
  - *r<sub>i</sub>* represents a relation
  - *P* is a predicate

- The result of an SQL query is a relation

### SELECT clause

- The **select** clause lists the attributes desired in the result of a query
  - Corresponds to the projection operation of relational algebra
- Example: find the names of all instructors

```
select name from instructor
```

- **NOTE:** SQL names are case insensitive
  - Name = NAME = name
  - Some people prefer to use UPPER CASE wherever we use the **bold font**
- **SQL allows duplicates in relations as well as in query results**

- To force the elimination of duplicates, insert the keyword **distinct** after **select**
- Find the department names of all instructors and remove duplicates

```
select distinct dept_name
from instructor
```

- The keyword **all** specifies that duplicates should not be removed

```
select all dept_name
from instructor
```

- An asterisk (\*) in the select denotes **all attributes**

```
select *
from instructor
```

- An attribute can be a literal with no **from** clause

```
select '437'
```

- Result is a table with one column and a single row with the value '437'
- Can give the column a name using:

```
select '437' as FOO
```

- An attribute can be a literal with **from** clause

```
select 'A'
from instructor
```

- Result is a table with one column and N rows (number of tuples in the *instructors* table), each row with value 'A'

The **select** clause can contain arithmetic expressions involving the operation +, -, \*, / and operating on constants or attributes of tuples

- The query:

```
select ID, name, salary/12
from instructor
```

- Would return a relation that is the same as the *instructor* relation, except that the value of the attribute *salary* is divided by 12
- Can rename "salary/12" using the **as** clause:

```
select ID, name, salary/12 as monthly_salary
```

## WHERE clause

- The **where** clause specifies conditions that the result must satisfy
  - Corresponds to the selection predicate of the relational algebra
- To find all instructors in the Computer Science department

```
select name
from instructor
where dept_name = 'Comp. Sci.'
```

- Comparison results can be combined using the logical connectives **and, or, not**

- To find all instructors in Comp. Sci. department with salary > 80000

```
select name  
from instructor  
where dept_name = 'Comp. Sci.' and salary > 80000
```

- Comparisons can be applied to results of arithmetic expressions

## FROM clause

- The **from** clause lists the relations involved in the query
    - Corresponds to the Cartesian product operation of the relational algebra
    - Find the Cartesian product *instructor X teaches*

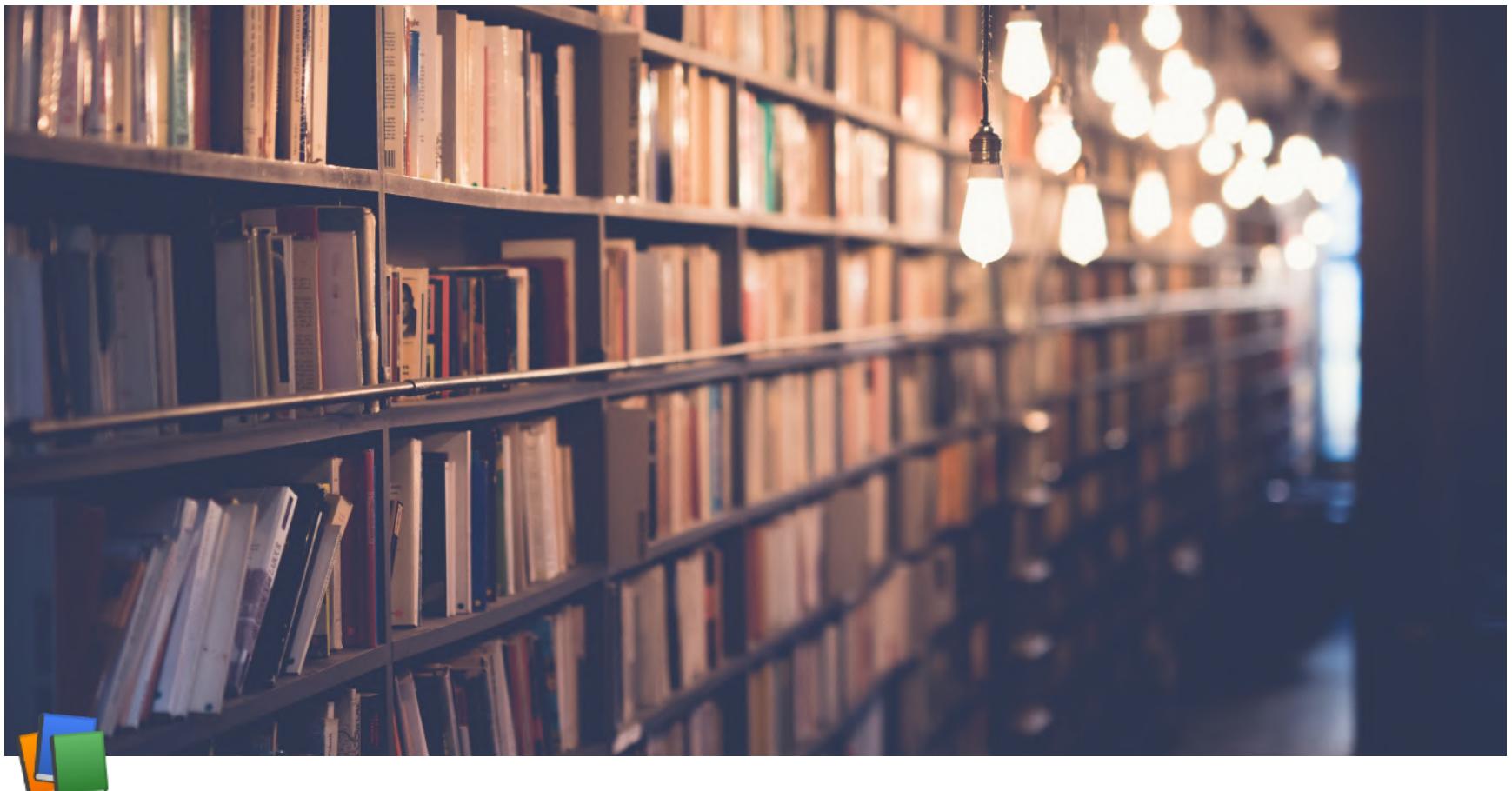
```
select *\nfrom instructor, teaches
```

- Generates every possible instructor-teaches pair with all attributes from both relations
  - For common attributes (for eg: ID), the attributes in the resulting table are renamed using the relation name (for eg: instructor.ID)
  - Cartesian product is not very useful directly, but useful when combined with the where-clause condition (selection operation in relational algebra)

## Cartesian product

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 <b>IIT Madras</b> BSc Degree	<h1>Cartesian Product</h1>	<div style="border: 1px solid black; padding: 5px; margin-bottom: 10px;">  </div> <div style="display: flex; justify-content: space-around;"> <div style="width: 45%;"> <p><b>Module 08</b></p> <ul style="list-style-type: none"> <li>Partha Pratim Das</li> <li>Objectives &amp; Outline</li> <li>Outline</li> <li>History of SQL</li> <li>Data Definition Language (DDL)</li> <li>Create Table</li> <li>Integrity Constraints</li> <li>Update Table</li> <li>Data Manipulation Language (DML)</li> <li>Query Structure</li> <li>Select Clause</li> <li>Where Clause</li> <li>From Clause</li> </ul> </div> <div style="width: 45%;"> <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th colspan="4" style="text-align: center;"><i>instructor</i></th> </tr> <tr> <th><i>ID</i></th> <th><i>name</i></th> <th><i>dept_name</i></th> <th><i>salary</i></th> </tr> </thead> <tbody> <tr><td>10101</td><td>Srinivasan</td><td>Comp. 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## Week 2 Lecture 4

Class	BSCCS2001
Created	@September 3, 2021 11:26 AM
Materials	
Module #	9
Type	Lecture
Week #	2

## Introduction to Structured Query Language (SQL) (part 2)

### Cartesian product (cont. from the previous lecture's end)

#### Example

- Find the names of all instructors who have taught some courses and the course\_id

```
select name, course_id  
from instructor, teaches  
where instructor.ID = teaches.ID
```

- Equi-Join, Natural Join

instructor				teaches				
ID	name	dept_name	salary	ID	course_id	sec_id	semester	year
10101	Srinivasan	Comp. Sci.	65000	10101	CS-101	1	Fall	2009
12121	Wu	Finance	90000	10101	CS-315	1	Spring	2010
15151	Mozart	Music	40000	10101	CS-347	1	Fall	2009
22222	Einstein	Physics	95000	12121	FIN-201	1	Spring	2010
32343	El Said	History	60000	15151	MU-199	1	Spring	2010
33456	Gold	Physics	87000	22222	PHY-101	1	Fall	2009
45565	Katz	Comp. Sci.	75000	32343	HIS-351	1	Spring	2010
58583	Califieri	History	62000	45565	CS-101	1	Spring	2010
76543	Singh	Finance	80000	45565	CS-319	1	Spring	2010
76766	Crick	Biology	72000	76766	BIO-101	1	Summer	2009
83821								2010
98345								2009
10101	Srinivasan	Comp. Sci.	65000	10101	CS-101	1	Fall	2009
10101	Srinivasan	Comp. Sci.	65000	10101	CS-315	1	Spring	2010
10101	Srinivasan	Comp. Sci.	65000	10101	CS-347	1	Fall	2009
10101	Srinivasan	Comp. Sci.	65000	12121	FIN-201	1	Spring	2010
10101	Srinivasan	Comp. Sci.	65000	15151	MU-199	1	Spring	2010
10101	Srinivasan	Comp. Sci.	65000	22222	PHY-101	1	Fall	2009
...	...	...	...	...	...	...	...	...
12121	Wu	Finance	90000	10101	CS-101	1	Fall	2009
12121	Wu	Finance	90000	10101	CS-315	1	Spring	2010
12121	Wu	Finance	90000	10101	CS-347	1	Fall	2009
12121	Wu	Finance	90000	12121	FIN-201	1	Spring	2010
12121	Wu	Finance	90000	15151	MU-199	1	Spring	2010
12121	Wu	Finance	90000	22222	PHY-101	1	Fall	2009
...	...	...	...	...	...	...	...	...

- Here in this table, we do not have the names of the courses
- If we want the name, we will again have to do a similar join operation with a table that has the names of the courses
  - This operations is known as **Natural Join**
- Example

Find the names of all the instructors in the Art dept. who have taught some courses and the *course\_id*

```
select name, course_id
from instructor, teaches
where instructor.ID = teaches.ID and instructor.dept_name = 'Art'
```

## Rename AS operation

- The SQL allows renaming relations and attributes using the **as** clause:

```
old_name as new_name
```

- Find the names of all the instructors who have a higher salary than some instructor in 'Comp. Sci.'

```
select distinct T.name
from instructor as T, instructor as S
where T.salary > S.salary and S.dept_name = 'Comp. Sci.'
```

- The keyword **as** is optional and may be omitted

*instructor as T*  $\equiv$  *instructor T*

## String Operations

- SQL includes a string-matching operator for comparisons on character strings.
- The operator **like** uses patterns that are described using two special characters:
  - percent (%)

The % character matches any sub-string

- underscore ( \_ )
 

The \_ character matches any character
- Find the names of all instructors whose name includes the sub-string "dar"

```
select name
from instructor
where name like '%dar%'
```

- Match the string "100%"

```
like '100%' escape '\'
```

in the above example, we use the backslash (\) as the escape character and '%dar%' could match **Darwin**, **Majumdar**, **Sardar** or **Uddarin** meanwhile, '%dar\_\_\_\_' (**dar** followed by 3 underscores), it will match **Darwin**, but not the others

- Patterns are case sensitive
- Pattern matching example
  - 'Intro%' matches any string beginning with "Intro"
  - '%Comp%' matches any string containing "Comp" as a substring
  - '\_\_\_\_' (3 underscores) many any string of exactly 3 characters
  - '\_\_\_\_%' (3 underscores and then a %) matches any string of at least 3 characters
- SQL supports variety of string operations such as
  - Concatenation (using "||") [double pipe symbol]
  - Converting from upper to lower case (and vice-versa)
  - Finding the string length, extracting substrings, etc...

## Ordering the display of tuples (ORDER BY clause)

- List in alphabetic order the names of all the instructors

```
select distinct name
from instructor
order by name
```

- We may specify **desc** for descending order or **asc** for ascending order, for each attribute; ascending order is the default
  - Example: **order by name desc**
- Can sort on multiple attributes
  - Example: **order by dept\_name, name**

## Selecting number of tuples in output

- The **Select Top** clause is used to specify the number of records to return
- The **Select Top** clause is useful on large tables with thousands of records.
  - Returning a large number of records can impact performance

```
select top 10 distinct name
from instructor
```

- Not all database systems support the **SELECT TOP** clause.
  - SQL Server & MS Access support **select top**
  - MySQL supports the **limit** clause

- Oracle uses **fetch first  $n$  rows only** and **rownum**

```
select distinct name
from instructor
order by name
fetch first 10 rows only
```

## WHERE clause predicates

- SQL includes a **between** comparison operator
- Example: Find the names of all the instructors with salary between \$90,000 and \$100,000  
(that is,  $\geq \$90,000$  and  $\leq \$100,000$ )

```
select name
from instructor
where salary between 90000 and 100000
```

- Tuple comparison

```
select name, course_id
from instructor, teaches
where (instructor.ID, dept_name) = (teaches.ID, 'Biology');
```

## IN operator

- The **in** operator allows you to specify multiple values in a **where** clause
- The **in** operator is a shorthand for multiple **or** conditions

```
select name
from instructor
where dept_name in ('Comp. Sci.', 'Biology')
```

## Duplicates

- In relations with duplicates, SQL can define how many copies of tuples appear in the result
- **Multiset** versions of some of the relational algebra operators - given multiset relations  $r_1$  and  $r_2$ :
  - SELECT**  $\sigma_\theta(r_1)$  : If there are  $c_1$  copies of tuple  $t_1$  in  $r_1$  and  $t_1$  satisfies selection  $\sigma_\theta$ , then there are  $c_1$  copies of  $t_1$  in  $\sigma_\theta(r_1)$
  - PROJECTION**  $\Pi_A(r)$  : For each copy of tuple  $t_1$  in  $r_1$ , there is a copy of tuple  $\Pi_A(t_1)$  in  $\Pi_A(r_1)$  where  $\Pi_A(t_1)$  denotes the projection of the single tuple  $t_1$
  - $r_1 \times r_2$  : If there are  $c_1$  copies of tuple  $t_1$  in  $r_1$  and  $c_2$  copies of tuples  $t_2$  in  $r_2$ , there are  $c_1 \times c_2$  copies of the tuple  $t_1 \cdot t_2$  in  $r_1 \times r_2$
- Example: Suppose multiset relations  $r_1(A, B)$  and  $r_2(C)$  are as follows:

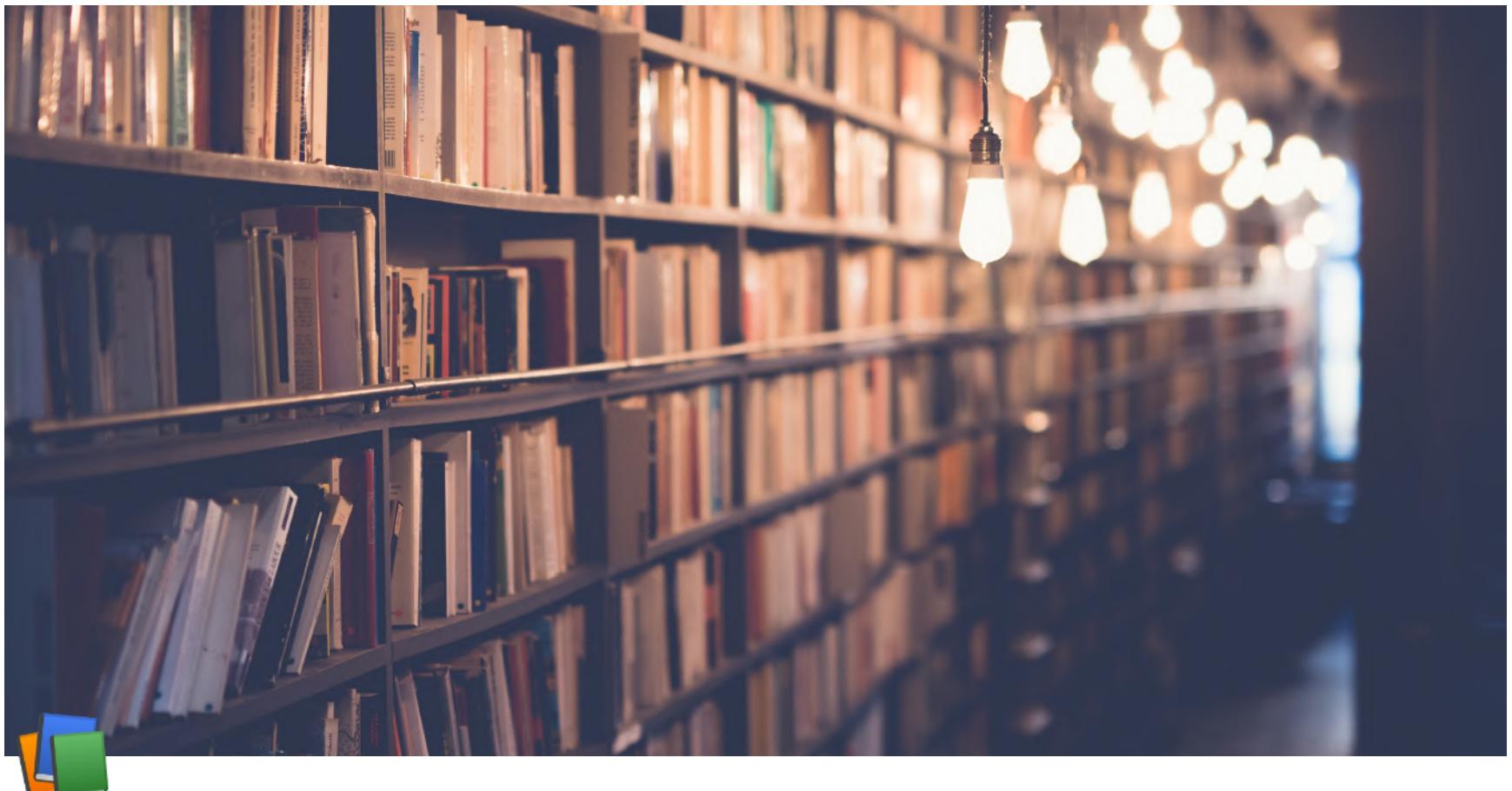
$$r_1 = \{(1, a)(2, a)\}; r_2 = \{(2), (3), (3)\}$$

- Then  $\Pi_B(r_1)$  would be  $\{(a), (a)\}$  while  $\Pi_B(r_1) \times r_2$  would be  $\{(a, 2), (a, 2), (a, 3), (a, 3), (a, 3), (a, 3)\}$
- SQL duplicate semantics:

```
select A1, A2, ..., An
from r1, r2, ..., rm
where P
```

is equivalent to the multiset version of the expression:

$$\Pi_{A_1, A_2, \dots, A_n}(\sigma_P(r_1 \times r_2 \times \dots \times r_m))$$



## Week 2 Lecture 5

Class	BSCCS2001
Created	@September 4, 2021 6:05 PM
Materials	
Module #	10
Type	Lecture
Week #	2

## Introduction to Structured Query Language (SQL) (part 3)

### Set operations

#### Example

- Find the courses that ran in Fall 2009 or in Spring 2010

```
(select course_id from section where sem = 'Fall' and year = 2009)
union
(select course_id from section where sem = 'Spring' and year = 2010)
```

- Find the courses that ran in Fall 2009 and in Spring 2010

```
(select course_id from section where sem = 'Fall' and year = 2009)
intersect
(select course_id from section where sem = 'Spring' and year = 2010)
```

- Find the courses that ran in Fall 2009 but not in Spring 2010

```
(select course_id from section where sem = 'Fall' and year = 2009)
except
(select course_id from section where sem = 'Spring' and year = 2010)
```

- Find the salaries of all the instructors that are less than the largest salary

```
select distinct T.salary
from instructor as T, instructor as S
where T.salary < S.salary
```

- Find the salaries of all the instructors

```
select distinct salary
from instructor
```

- Find the largest salary of all the instructors

```
(select distinct salary from instructor)
except
(select distinct T.salary from instructor as T, instructor as S where T.salary < S.salary)
```

- Set operations such as **union**, **intersect** and **except** automatically eliminate the duplicates
- To retain all the duplicates, use the corresponding multiset versions **union all**, **intersect all** and **except all**
- Suppose a tuple occurs  $m$  times in  $r$  and  $n$  times in  $s$ , then it occurs ...
  - $m + n$  times in  $r \text{ union all } s$
  - $\min(m, n)$  times in  $r \text{ intersect all } s$
  - $\max(0, m - n)$  times in  $r \text{ except all } s$

## NULL values

- What is a NULL value?

A NULL value is something unknown or a value that does not exist yet

- Why is NULL value so important?

- Certain values may not exist for everyone

For eg: Every student may not have a passport at the time of registration

- Often times while we are creating/inserting a record, we may not know all the values of all the fields

For eg: When a student joins, the student does not have any credit assigned to him/her, so the total credit is NULL

We can say 0 (zero), but 0 (zero) and NULL are different

0 (zero) means the student has not taken a credit

NULL means the credit has not been given yet

- Naturally, when we add an attribute to all the existing rows of a table, the value of the particular field cannot be known, cannot be set, so it will have to initialized as a NULL value
- It is possible for tuples to have a *null* value, denoted by **null**, for some of their attributes
- The predicate **is null** can be used to check for *null* values
  - Example: Find all the instructors whose salary is *null*

```
select name
from instructor
where salary is null
```

- It is not possible to test for *null* values with comparison operators such as  $=$ ,  $<$ ,  $>$  or  $<>$

We need to use the **is null** and **is not null** operators instead

## NULL values: Three valued logic

- Three values - **true**, **false**, **unknown**
- Any comparison with *null* returns *unknown*
  - Example:  $5 < \text{null}$  or  $\text{null} <> \text{null}$  or  $\text{null} = \text{null}$

- Three-valued logic using the value unknown:
  - **OR:**
    - $(\text{unknown or true}) = \text{true}$
    - $(\text{unknown or false}) = \text{unknown}$
    - $(\text{unknown or unknown}) = \text{unknown}$
  - **AND:**
    - $(\text{true and unknown}) = \text{unknown}$
    - $(\text{false and unknown}) = \text{false}$
    - $(\text{unknown and unknown}) = \text{unknown}$
  - **NOT:**
    - $(\text{not unknown}) = \text{unknown}$
  - "P is unknown" evaluates to *true* if predicate P evaluates to *unknown*
- Result of **where** clause predicate is treated as *false* if it evaluates to *unknown*

## Aggregate functions

- These functions operate on the multiset of values of a column of a relation (table) and return a value
  - avg:** average value
  - min:** minimum value
  - max:** maximum value
  - sum:** sum of the values
  - count:** number of values

### Examples

- Find the average salary of instructors in the Computer Science department

```
select avg(salary)
from instructor
where dept_name = 'Comp. Sci.'
```

- Find the total number of instructors who teach a course in the Spring 2010 semester

```
select count(distinct ID)
from teaches
where semester = 'Spring' and year = 2010
```

- Find the number of tuples in the *course* relation (table)

```
select count(*)
from courses;
```

### Example (GROUP BY)

- Find the average salary of instructors in each department

```
select dept_name, avg(salary) as avg_salary
from instructor
group by dept_name;
```

ID	name	dept_name	salary
76766	Crick	Biology	72000
45565	Katz	Comp. Sci.	75000
10101	Srinivasan	Comp. Sci.	65000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000
12121	Wu	Finance	90000
76543	Singh	Finance	80000
32343	El Said	History	60000
58583	Califieri	History	62000
15151	Mozart	Music	40000
33456	Gold	Physics	87000
22222	Einstein	Physics	95000

dept_name	avg_salary
Biology	72000
Comp. Sci.	77333
Elec. Eng.	80000
Finance	85000
History	61000
Music	40000
Physics	91000

So, **group by** takes a column and makes sub-tables of all those records which have the same value on that particular group by attribute

It then applies the aggregate function on the column based on this sub-table

- Attributes in **select** clause outside of aggregate functions must appear in **group by** list

```
-- The following query is incorrect because of the 'ID' attribute
select dept_name, ID, avg(salary)
from instructor
group by dept_name;
```

## HAVING clause

- Find the names and average salaries of all departments whose average salary is greater than 42,000

```
select dept_name, ID, avg(salary)
from instructor
group by dept_name
having avg(salary) > 42000;
```

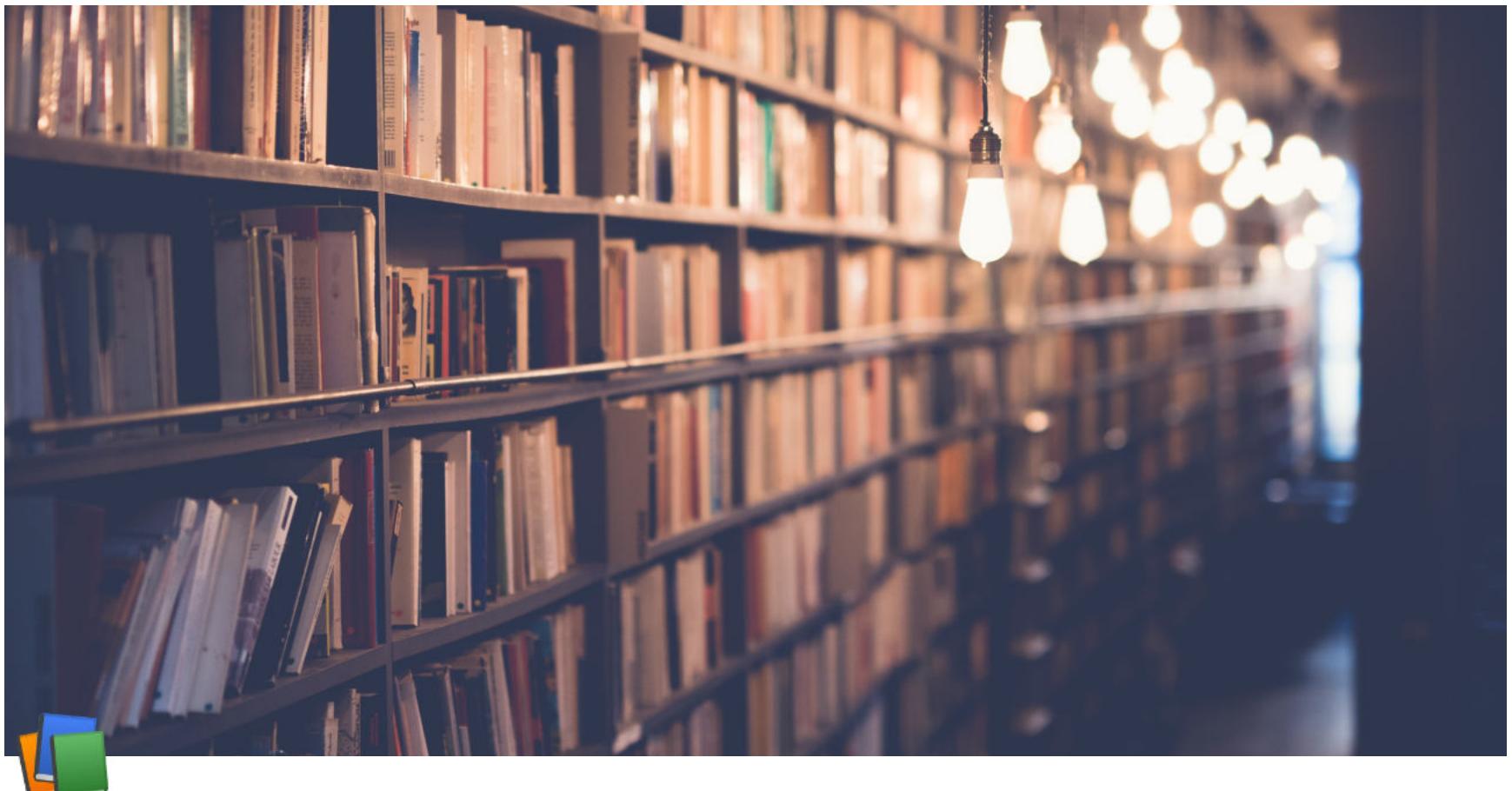
**NOTE:** Predicates in the **having** clause are applied after the formation of groups whereas predicates in the **where** clause are applied before forming groups

## NULL values and aggregates

- Total all salaries

```
select sum(salary)
from instructor;
```

- Above statement ignores null amounts
- Result is *null* if there is no non-null amount
- All aggregate operations except **count(\*)** ignore tuples with null values on the aggregated attributes
- What if collection has only null values?
  - count** returns 0 (zero)
  - all other aggregates return null



## Week 3 Lecture 1

▼ Class	BSCCS2001
⌚ Created	@September 25, 2021 9:05 AM
📎 Materials	
☰ Module #	11
▼ Type	Lecture
☰ Week #	3

## SQL Examples

### SELECT DISTINCT

- From the classroom relation, find the names of buildings in which every individual classroom has capacity less than 100 (removing the duplicates).
  - Relation:

**classroom**

Aa building	# room_number	# capacity
Packard	101	500
Painter	514	10
Taylor	3128	70
Watson	100	30
Watson	120	50

- Query:

```
SELECT DISTINCT building
FROM classroom
WHERE capacity < 100;
```

- Output:

Aa building

Aa building
<u>Painter</u>
<u>Taylor</u>
<u>Watson</u>

## SELECT ALL

- From the classroom relation, find the names of buildings in which every individual classroom has capacity less than 100 (without removing the duplicates).
  - Relation:

**classroom**

Aa building	# room_number	# capacity
Packard	101	500
<u>Painter</u>	514	10
<u>Taylor</u>	3128	70
<u>Watson</u>	100	30
<u>Watson</u>	120	50

- Query:

```
SELECT ALL building
FROM classroom
WHERE capacity < 100;
```

- Output:

Aa building
<u>Painter</u>
<u>Taylor</u>
<u>Watson</u>
<u>Watson</u>

**NOTE:** The duplicate retention is default and hence it is a common practice to skip **ALL** immediately after **SELECT**

## Cartesian Product

- Find the list of all students of departments which have a budget < \$100K

```
SELECT name, budget
FROM student, department
WHERE student.dept_name = department.dept_name AND budget < 100000;
```

Aa name	# budget
Brandt	50000
Peltier	70000
Levy	70000
Sanchez	80000
Snow	70000
Aoi	85000
Bourikas	85000
Tanaka	90000

- The above query generates every possible student-department pair, which is the Cartesian product of student and department.
- Then, it filters all the rows with `student.dept_name = department.dept_name AND budget < 100000`
- The common attribute `dept_name` in the resulting table are renamed using the relation name - `student.dept_name` and `department.dept_name`

## RENAME AS Operation

- The same query in the above case can be framed by renaming the table as shown below:

```
SELECT S.name AS studentname, budget AS deptbudget
FROM student AS S, department AS D
WHERE S.dept_name = D.dept_name AND budget < 100000;
```

<u>Aa</u> studentname	# deptbudget
<u>Brandt</u>	50000
<u>Peltier</u>	70000
<u>Levy</u>	70000
<u>Sanchez</u>	80000
<u>Snow</u>	70000
<u>Aoi</u>	85000
<u>Bourikas</u>	85000
<u>Tanaka</u>	90000

- The above query renames the relation `student AS S` and the relation `department AS D`
- It also displays the attribute `name` as `StudentName` and the `budget` as `DeptBudget`
- NOTE:** The budget attribute does not have any prefix because it occurs only in the department relation

## SELECT: AND and OR

- From the `instructor` and `department` relations in the figure, find out the names of all the instructors whose department is Finance or whose department is in any of the following buildings: Watson, Taylor

**instructor**

# id	<u>Aa</u> name	<u>E</u> dept_name	# salary
10101	<u>Srinivasan</u>	Comp. Sci.	65000
12121	<u>Wu</u>	Finance	90000
15151	<u>Mozart</u>	Music	40000
22222	<u>Einstein</u>	Physics	95000
32343	<u>El Said</u>	History	60000
33456	<u>Gold</u>	Physics	87000
45565	<u>Katz</u>	Comp. Sci.	75000
58583	<u>Califieri</u>	History	62000
76543	<u>Singh</u>	Finance	80000
76766	<u>Crick</u>	Biology	72000
83821	<u>Brandt</u>	Comp. Sci.	92000
98345	<u>Kim</u>	Elec. Eng.	80000

**department**

<u>Aa</u> dept_name	<u>E</u> building	# budget
<u>Biology</u>	Watson	90000
<u>Comp. Sci.</u>	Taylor	100000
<u>Elec. Eng.</u>	Taylor	85000

Aa dept_name	building	# budget
Finance	Painter	120000
History	Painter	50000
Music	Packard	80000
Physics	Watson	70000

- Query:

```
SELECT name
FROM instructor I, department D
WHERE D.dept_name = I.dept_name
AND (I.dept_name = 'Finance' OR building IN ('Watson', 'Taylor'));
```

- Output:

Aa name
Srinivasan
Wu
Einstein
Gold
Katz
Singh
Crick
Brandt
Kim

## String Operations

- From the `course` relation in the figure, find the titles of all the courses whose `course_id` has 3 alphabets indicating the department

### course

course_id	Aa title	dept_name	credits
BIO-101	Intro. to Biology	Biology	4
BIO-301	Genetics	Biology	4
BIO-399	Computational Biology	Biology	3
CS-101	Intro. to Computer Science	Comp. Sci.	4
CS-190	Game Design	Comp. Sci.	4
CS-315	Robotics	Comp. Sci.	3
CS-319	Image Processing	Comp. Sci.	3
CS-347	Database System Concepts	Comp. Sci.	3
EE-181	Intro. to Digital Systems	Elec. Eng.	3
FIN-201	Investment Banking	Finance	3
HIS-351	World History	History	3
MU-199	Music Video Production	Music	3
PHY-101	Physical Principles	Physics	4

- Query:

```
SELECT title
FROM course
WHERE course_id LIKE '___-%'; -- 3 underscores
```

- Output:

Aa title
<u>Intro. to Biology</u>
<u>Genetics</u>
<u>Computational Biology</u>
<u>Investment Banking</u>
<u>World History</u>
<u>Physical Principles</u>

- The `course_id` of each department has either 2 or 3 alphabets in the beginning followed by a hyphen and then followed by a 3-digit number. The above query returns the names of those departments that have 3 alphabets in the beginning

## ORDER BY

- From the `student` relation in the figure, obtain the list of all students in alphabetic order of departments and within each department, in decreasing order of total credits.

### student

≡ id	Aa name	≡ dept_name	# tot_cred
00128	Zhang	Comp. Sci.	102
12345	Shankar	Comp. Sci.	32
19991	Brandt	History	80
23121	Chavez	Finance	110
44553	Peltier	Physics	56
45678	Levy	Physics	46
54321	Williams	Comp. Sci.	54
55739	Sanchez	Music	38
70557	Snow	Physics	0
76543	Brown	Comp. Sci.	58
76653	Aoi	Elec. Eng.	60
98765	Bourikas	Elec. Eng.	98
98988	Tanaka	Biology	120

- Query:

```
SELECT name, dept_name, tot_cred
FROM student
ORDER BY dept_name ASC, tot_cred DESC;
```

- Output:

Aa name	≡ dept_name	# tot_cred
Tanaka	Biology	120
Zhang	Comp. Sci.	102
Brown	Comp. Sci.	58
Williams	Comp. Sci.	54
Shankar	Comp. Sci.	32
Bourikas	Elec. Eng.	98
Aoi	Elec. Eng.	60
Chavez	Finance	110
Brandt	History	80
Sanchez	Music	38
Peltier	Physics	56
Levy	Physics	46

Aa name	≡ dept_name	# tot_cred
Snow	Physics	0

How is this sort happening?

- The list is first sorted in alphabetic order of `dept_name`
- Within each department, it is sorted in decreasing order of total credits

## IN Operator

- From the `teaches` relation in the figure, find the IDs of all the courses taught in the Fall or Spring of 2018

`teaches`

≡ id	Aa course_id	# sec_id	≡ semester	# year
10101	<u>CS-101</u>	1	Fall	2017
10101	<u>CS-315</u>	1	Spring	2018
10101	<u>CS-347</u>	1	Fall	2017
12121	<u>FIN-201</u>	1	Spring	2018
15151	<u>MU-199</u>	1	Spring	2018
22222	<u>PHY-101</u>	1	Fall	2017
32343	<u>HIS-351</u>	1	Spring	2018
45565	<u>CS-101</u>	1	Spring	2018
45565	<u>CS-319</u>	1	Spring	2018
76766	<u>BIO-101</u>	1	Summer	2017
76766	<u>BIO-301</u>	1	Summer	2018
83821	<u>CS-190</u>	1	Spring	2017
83821	<u>CS-190</u>	2	Spring	2017
83821	<u>CS-319</u>	2	Spring	2018
98345	<u>EE-181</u>	1	Spring	2017

- Query:

```
SELECT course_id
FROM teaches
WHERE semester IN ('Fall', 'Spring')
AND year = 2018;
```

- Output:

Aa course_id
<u>CS-315</u>
<u>FIN-201</u>
<u>MU-199</u>
<u>HIS-351</u>
<u>CS-101</u>
<u>CS-319</u>
<u>CS-319</u>

- NOTE: Now we can use **DISTINCT** to remove duplicates

## Set Operations: UNION

- For the same question in the above table, we can find the solution using **UNION** operator as follows:

- Query:

```
SELECT course_id
FROM teaches
WHERE semester = 'Fall'
```

```

AND year = 2018
UNION
SELECT course_id
FROM teaches
WHERE semester = 'Spring'
AND year = 2018

```

- Output:

Aa course_id
<u>CS-101</u>
<u>CS-315</u>
<u>CS-319</u>
<u>FIN-201</u>
<u>HIS-351</u>
<u>MU-199</u>

- **NOTE:** **UNION** removes all the duplicates. If we use **UNION ALL** instead of **UNION**, we get the same set of tuples as in the above example

## Set Operations: INTERSECT

- From the **instructor** relation in the figure, find the names of all the instructors who taught in either Computer Science department or the Finance department and whose salary is > 80,000

**instructor**

# id	Aa name	≡ dept_name	# salary
10101	<u>Srinivasan</u>	Comp. Sci.	65000
12121	<u>Wu</u>	Finance	90000
15151	<u>Mozart</u>	Music	40000
22222	<u>Einstein</u>	Physics	95000
32343	<u>El Said</u>	History	60000
33456	<u>Gold</u>	Physics	87000
45565	<u>Katz</u>	Comp. Sci.	75000
58583	<u>Califieri</u>	History	62000
76543	<u>Singh</u>	Finance	80000
76766	<u>Crick</u>	Biology	72000
83821	<u>Brandt</u>	Comp. Sci.	92000
98345	<u>Kim</u>	Elec. Eng.	80000

- Query:

```

SELECT name
FROM instructor
WHERE dept_name IN ('Comp. Sci.', 'Finance')
INTERSECT
SELECT name
FROM instructor
WHERE salary > 80000;

```

- Output:

Aa name
<u>Srinivasan</u>
<u>Katz</u>

- **NOTE:** The same thing can be achieved by using the query:

```
SELECT name FROM instructor WHERE dept_name IN ('Comp. Sci.', 'Finance') AND salary < 80000;
```

## Set Operation: EXCEPT

- From the `instructor` relation in the figure, find the names of all the instructors who taught in either the Computer Science department or the Finance department and whose salary is either  $\geq 90,000$  or  $\leq 70,000$

**instructor**

# id	Aa name	≡ dept_name	# salary
10101	<u>Srinivasan</u>	Comp. Sci.	65000
12121	<u>Wu</u>	Finance	90000
15151	<u>Mozart</u>	Music	40000
22222	<u>Einstein</u>	Physics	95000
32343	<u>El Said</u>	History	60000
33456	<u>Gold</u>	Physics	87000
45565	<u>Katz</u>	Comp. Sci.	75000
58583	<u>Califieri</u>	History	62000
76543	<u>Singh</u>	Finance	80000
76766	<u>Crick</u>	Biology	72000
83821	<u>Brandt</u>	Comp. Sci.	92000
98345	<u>Kim</u>	Elec. Eng.	80000

- Query:

```
SELECT name
FROM instructor
WHERE dept_name IN ('Comp. Sci.', 'Finance')
EXCEPT
SELECT name
FROM instructor
WHERE salary < 90000 AND salary > 70000;
```

- Output:

Aa name
<u>Srinivasan</u>
<u>Brandt</u>
<u>Wu</u>

- NOTE:** The same can be achieved by using the following query

```
SELECT name FROM instructor
WHERE dept_name IN ('Comp. Sci.', 'Finance')
AND (salary >= 90000 OR salary <= 70000);
```

## Aggregate function: AVG

- From the `classroom` relation given in the figure, find the names and the average capacity of each building whose average capacity is greater than 25

**classroom**

Aa building	# room_number	# capacity
<u>Packard</u>	101	500
<u>Painter</u>	514	10
<u>Taylor</u>	3128	70
<u>Watson</u>	100	30
<u>Watson</u>	120	50

- Query:

```
SELECT building, AVG(capacity)
FROM classroom
GROUP BY building
HAVING AVG(capacity) > 25;
```

- Output:

<u>Aa</u> bulding	<u>≡</u> avg
<u>Taylor</u>	70.00
<u>Packard</u>	500.00
<u>Watson</u>	40.00

## Aggregate function: MIN

- From the `instructor` relation given in the figure, find the least salary drawn by any instructor among all the instructors
- instructor**

# id	<u>Aa</u> name	<u>≡</u> dept_name	# salary
10101	<u>Srinivasan</u>	Comp. Sci.	65000
12121	<u>Wu</u>	Finance	90000
15151	<u>Mozart</u>	Music	40000
22222	<u>Einstein</u>	Physics	95000
32343	<u>El Said</u>	History	60000
33456	<u>Gold</u>	Physics	87000
45565	<u>Katz</u>	Comp. Sci.	75000
58583	<u>Califieri</u>	History	62000
76543	<u>Singh</u>	Finance	80000
76766	<u>Crick</u>	Biology	72000
83821	<u>Brandt</u>	Comp. Sci.	92000
98345	<u>Kim</u>	Elec. Eng.	80000

- Query:

```
SELECT MIN(salary) AS least_salary FROM instructor;
```

- Output:

<u>Aa</u> least_salary
<u>40000</u>

## Aggregate function: MAX

- From the `instructor` relation given above, find the highest salary drawn by any instructor among all the instructors

  - Query:

```
SELECT MAX(salary) AS highest_salary FROM instructor;
```

- Output:

<u>Aa</u> highest_salary
<u>95000</u>

## Aggregate function: COUNT

- From the `instructor` relation given above, find the number of instructors in each department
  - Query:

```
SELECT dept_name, COUNT(id) AS ins_count
FROM instructor
GROUP BY dept_name;
```

- Output:

<u>Aa</u> dept_name	# ins_count
<u>Comp. Sci.</u>	3
<u>Finance</u>	2
<u>Music</u>	1
<u>Physics</u>	2
<u>History</u>	2
<u>Biology</u>	1
<u>Elec. Eng.</u>	1

## Aggregate function: SUM

- From the `course` relation given in the figure, find the total credits offered by each department

**course**

<u>course_id</u>	<u>Aa</u> title	<u>dept_name</u>	# credits
BIO-101	<u>Intro. to Biology</u>	Biology	4
BIO-301	<u>Genetics</u>	Biology	4
BIO-399	<u>Computational Biology</u>	Biology	3
CS-101	<u>Intro. to Computer Science</u>	Comp. Sci.	4
CS-190	<u>Game Design</u>	Comp. Sci.	4
CS-315	<u>Robotics</u>	Comp. Sci.	3
CS-319	<u>Image Processing</u>	Comp. Sci.	3
CS-347	<u>Database System Concepts</u>	Comp. Sci.	3
EE-181	<u>Intro. to Digital Systems</u>	Elec. Eng.	3
FIN-201	<u>Investment Banking</u>	Finance	3
HIS-351	<u>World History</u>	History	3
MU-199	<u>Music Video Production</u>	Music	3
PHY-101	<u>Physical Principles</u>	Physics	4

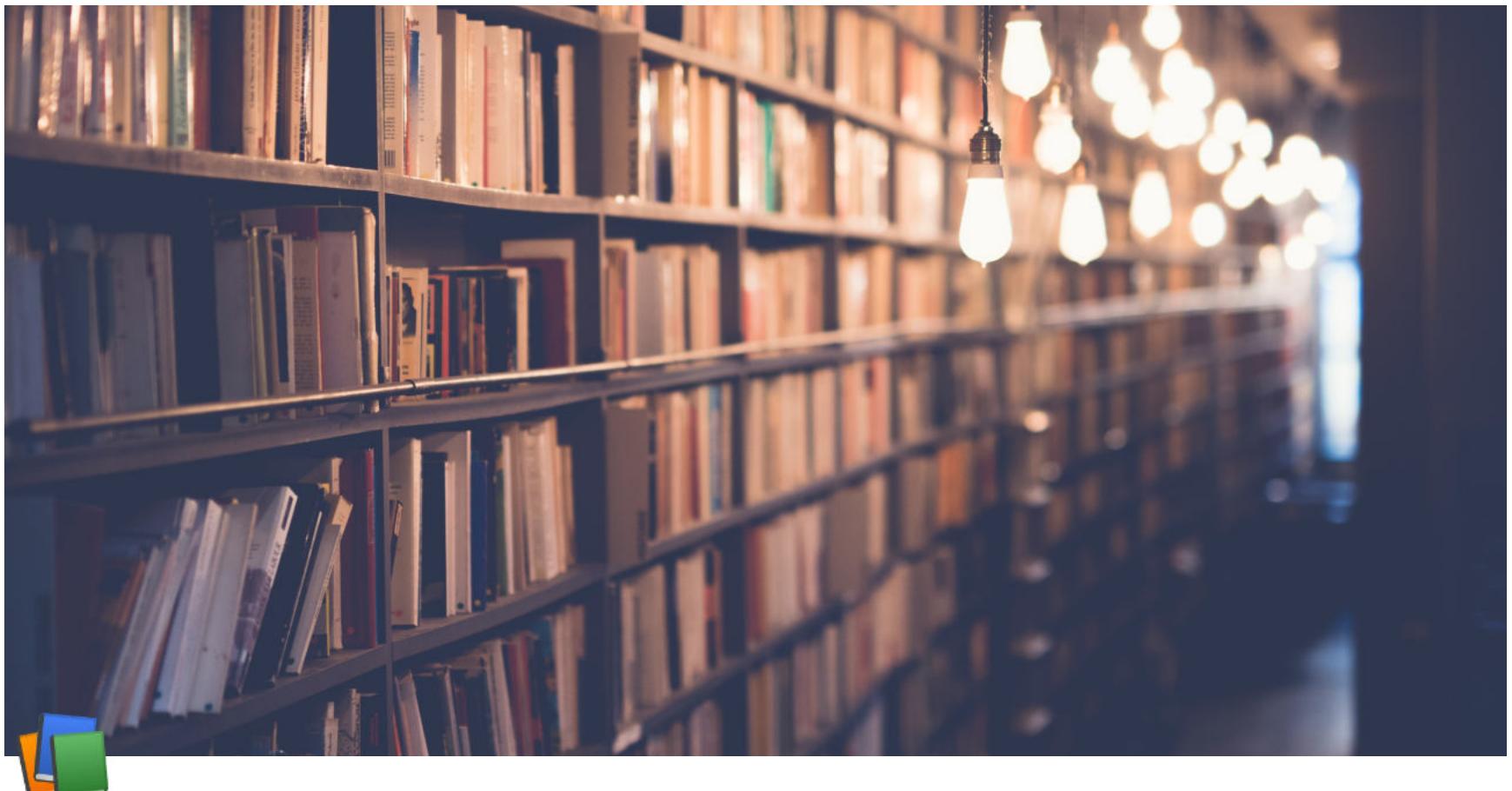
- Query:

```
SELECT dept_name, SUM(credits) AS sum_credits
FROM course
GROUP BY dept_name;
```

- Output:

<u>Aa</u> dept_name	# sum_credits
<u>Finance</u>	3
<u>History</u>	3
<u>Physics</u>	4
<u>Music</u>	3
<u>Comp. Sci.</u>	17
<u>Biology</u>	11
<u>Elec. Eng.</u>	3





## Week 3 Lecture 2

Class	BSCCS2001
Created	@September 25, 2021 5:30 PM
Materials	
Module #	12
Type	Lecture
Week #	3

## Intermediate SQL

### Nested sub-queries

- SQL provides a mechanism for the nesting of sub-queries
- A **sub-query** is a **SELECT-FROM-WHERE** expression that is nested within another query
- The nesting can be done in the following SQL query

```
SELECT A1, A2, ..., An
```

```
FROM r1, r2, ..., rm
```

```
WHERE P
```

as follows:

- A<sub>i</sub> can be replaced by a sub-query that generates a single value
- r<sub>i</sub> can be replace by any valid sub-query
- P can be replaced with an expression of the form:

B <operation> (sub-query)

where B is an attribute and <operation> is to be defined later

- Input of a query → One or more relations
- Output of a query → Always a single relation

### Subqueries in WHERE clause

- Typical use of subqueries is to perform tests

- For set membership
- For set comparisons
- For set cardinality

## Set Membership

- Find the courses offered in Fall 2009 and in Spring 2010 (**INTERSECT** example)

```
SELECT DISTINCT course_id
FROM section
WHERE semester = 'Fall'
AND year = 2009
AND course_id IN (
    SELECT course_id
    FROM section
    WHERE semester = 'Spring' AND year = 2010);
```

- Find courses offered in Fall 2009 but not in Spring 2010 (**EXCEPT** example)

```
SELECT DISTINCT course_id
FROM section
WHERE semester = 'Fall'
AND year = 2009
AND course_id NOT IN (
    SELECT course_id
    FROM section
    WHERE semester = 'Spring' AND year = 2010);
```

- Find the total number of (distinct) students who have taken course sections taught by the instructor with ID 10101

```
SELECT COUNT(DISTINCT id)
FROM takes
WHERE (course_id, sec_id, semester, year) IN (
    SELECT course_id, sec_id, semester, year
    FROM teaches
    WHERE teaches.id = 10101);
```

**NOTE:** Above query can be written in a simple manner. The formulation above is just to simply illustrate SQL features

## Set comparison - "SOME" clause

- Find names of instructors with salary greater than that of some (at least one) instructor in the Biology department

```
SELECT DISTINCT T.name
FROM instructor AS T, instructor AS S
WHERE T.salary > S.salary AND S.dept_name = 'Biology';
```

- The same above query using **SOME** clause

```
SELECT name
FROM instructor
WHERE salary > SOME (
    SELECT salary
    FROM instructor
    WHERE dept_name = 'Biology');
```

## Definition of "SOME" clause

- $F \text{ } \text{comp} \text{ } \text{SOME } r \Leftrightarrow \exists t \in r \text{ such that } (F \text{ } \text{comp} \text{ } t)$   
where  $\text{comp}$  can be:  $<$ ,  $\leq$ ,  $>$ ,  $\geq$ ,  $=$ ,  $\neq$
  - **SOME** represents existential quantification [The entity in  $"( )"$  is a tuple here]
- 5  $<$  **SOME** (0, 5, 6)  $\rightarrow$  true  
 5  $<$  **SOME** (0, 5)  $\rightarrow$  false  
 5 = **SOME** (0, 5)  $\rightarrow$  true  
 5  $\neq$  **SOME** (0, 5)  $\rightarrow$  true # as 0  $\neq$  5

$(= \text{SOME}) \equiv \text{IN}$

However,  $(\neq \text{SOME}) \not\equiv \text{NOT IN}$

## Set Comparison - "ALL" clause

- Find the names of all the instructors whose salary is greater than the salary of all instructors in the Biology department

```
SELECT name
  FROM instructor
 WHERE salary > ALL (
   SELECT salary
     FROM instructor
    WHERE dept_name = 'Biology');
```

## Definition of "ALL" clause

- $F <\text{comp}> \text{ALL } r \Leftrightarrow \forall t \in r \text{ such that } (F <\text{comp}> t)$   
where  $\text{comp}$  can be:  $<$ ,  $\leq$ ,  $>$ ,  $\geq$ ,  $=$ ,  $\neq$
- ALL** represents universal quantification [The entity in  $"()"$  is a tuple here]

$5 < \text{ALL} (0, 5, 6) \rightarrow \text{false}$

$5 < \text{ALL}(6, 10) \rightarrow \text{true}$

$5 = \text{ALL}(4, 5) \rightarrow \text{false}$

$5 \neq \text{ALL}(4, 5) \rightarrow \text{true}$

$(\neq \text{ALL}) \equiv \text{NOT IN}$

However,  $(= \text{ALL}) \not\equiv \text{IN}$

## Test for empty relations: "EXISTS"

- The **EXISTS** construct returns the value true if the argument subquery is non-empty
  - $\text{EXISTS } r \Leftrightarrow r \neq \emptyset$
  - $\text{NOT EXISTS } r \Leftrightarrow r = \emptyset$

## Use of "EXISTS" clause

- Yet another way of specifying the query "Find all the courses taught in both the Fall 2009 semester and in the Spring 2010 semester"

```
SELECT course_id
  FROM section AS S
 WHERE semester = 'Fall' AND year = 2009
 AND EXISTS (
   SELECT * FROM section AS T
  WHERE semester = 'Spring' AND year = 2010
  AND S.course_id = T.course_id);
```

- Correlation name** - variable S in the outer query
- Correlated subquery** - the inner query

## Use of "NOT EXISTS" clause

- Find all students who have taken all courses offered by the Biology department

```
SELECT DISTINCT S.id, S.name
  FROM student AS S
 WHERE NOT EXISTS (
  (
    SELECT course_id
      FROM course
     WHERE dept_name = 'Biology')
 EXCEPT
  (
    SELECT T.course_id
      FROM takes AS T
     WHERE S.id = T.id));
```

- First nested query lists all the courses offered by the Biology department
- Second nested query lists all the courses a particular student has taken
- **NOTE:**  $X - Y = \emptyset \Leftrightarrow X \subseteq Y$
- **NOTE:** Cannot write this query string = **ALL** and its variants

## Test for absence of duplicate tuples: "UNIQUE"

- The **UNIQUE** construct tests whether a subquery has any duplicate tuples in its results
- The **UNIQUE** construct evaluates to "true" if a given subquery contains no duplicates
- Find all the courses that were offered at most once in 2009

```
SELECT T.course_id
FROM course AS T
WHERE UNIQUE (
    SELECT R.course_id
    FROM course AS R
    WHERE T.course_id = R.course_id
    AND R.year = 2009);
```

## Subqueries in the "FROM" clause

- SQL allows a subquery expression to be used in the **FROM** clause
- Find the average instructors' salaries of those departments where the average salary is greater than \$42,000

```
SELECT dept_name, avg_salary
FROM (
    SELECT dept_name, AVG(salary) AS avg_salary
    FROM instructor
    GROUP BY dept_name)
WHERE avg_salary > 42000;
```

- **NOTE:** We do not need a **HAVING** clause
- Another way to write the above query

```
SELECT dept_name, avg_salary
FROM (
    SELECT dept_name, AVG(salary)
    FROM instructor
    GROUP BY dept_name) AS dept_avg(dept_name, avg_salary)
WHERE avg_salary > 42000;
```

## WITH clause

- The **WITH** clause provides a way of defining a temporary relation whose definition is available only to the query in which the **WITH** clause occurs
- Find all the departments with the maximum budget

```
WITH max_budget(value) AS
(
    SELECT MAX(budget)
    FROM department)
SELECT department.name
FROM department, max_budget
WHERE department.budget = max_budget.value;
```

## Complex queries using **WITH** clause

- Find all departments where the total salary is greater than the average of the total salary at all departments

```
WITH dept_total(dept_name, value) AS
    SELECT dept_name, SUM(salary)
    FROM instructor
    GROUP BY dept_name,
dept_total_avg(value) AS
```

```

(
    SELECT AVG(value)
    FROM dept_total)
SELECT dept_name
FROM dept_total, dept_total_avg
WHERE dept_total.value > dept_total_avg.value;

```

## Subqueries in the SELECT clause

- Scalar subquery: Where a single value is expected
- List all departments along with the number of instructors in each department

```

SELECT dept_name, (
    SELECT COUNT(*)
    FROM instructor
    WHERE department.dept_name = instructor.dept_name)
AS num_instructors
FROM department;

```

- Runtime error occurs if subquery returns more than one result tuple

## Modifications of the Database

- Deletion of tuples from a given relation
- Insertion of new tuples into a given relation
- Updating of values in some tuples in a given relation

### Deletion

- Delete all instructors

```
DELETE FROM instructors;
```

- Delete all instructors from the Finance department

```
DELETE FROM instructor
WHERE dept_name = 'Finance';
```

- Delete all tuples in the instructor relation for those instructors associated with a department located in the Watson building

```
DELETE FROM instructor
WHERE dept_name IN (SELECT dept_name
    FROM department
    WHERE building = 'Watson');
```

- Delete all instructors whose salary is less than the average salary of instructors

```
DELETE FROM instructor
WHERE salary < (SELECT AVG(salary) FROM instructor);
```

- **Problem:** As we delete tuples from deposit, the average salary changes

- **Solution:**

- First, compute `AVG ( salary )` and find all the tuples to delete
- Next, delete all the tuples found above (without recomputing **AVG** or retesting the tuples)

### Insertion

- Add a new tuple to the course

```
INSERT INTO course  
VALUES ('CS-437', 'Database Systems', 'Comp. Sci.', 4);
```

- or equivalently

```
INSERT INTO course (course_id, title, dept_name, credits)  
VALUES ('CS-437', 'Database Systems', 'Comp. Sci.', 4);
```

- Add a new tuple to student with `tot_creds` set to `null`

```
INSERT INTO student  
VALUES ('3003', 'Green', 'Finance', null);
```

- Add all instructors to the student relation with `tot_creds` set to 0

```
INSERT INTO student  
SELECT id, name, dept_name, 0  
FROM instructor;
```

- The **SELECT FROM WHERE** statement is evaluated fully before any of its results are inserted into the relation
- Otherwise queries like

```
INSERT INTO table1 SELECT * FROM table1;
```

would cause problems

## Updates

- Increase salaries of instructors whose salary is over \$100,000 by 3% and all other by 5%
- Write two **UPDATE** statements

```
UPDATE instructor  
SET salary = salary * 1.03  
WHERE salary > 100000;
```

```
UPDATE instructor  
SET salary = salary * 1.05  
WHERE salary <= 100000;
```

- The order is important
- Can be done better using the **CASE** statement

## CASE statement for conditional updates

- Same query as before but with **CASE** statement

```
UPDATE instructor  
SET salary = CASE  
    WHEN salary <= 100000  
    THEN salary * 1.05  
    ELSE salary * 1.03  
    END;
```

## Updates with scalar subqueries

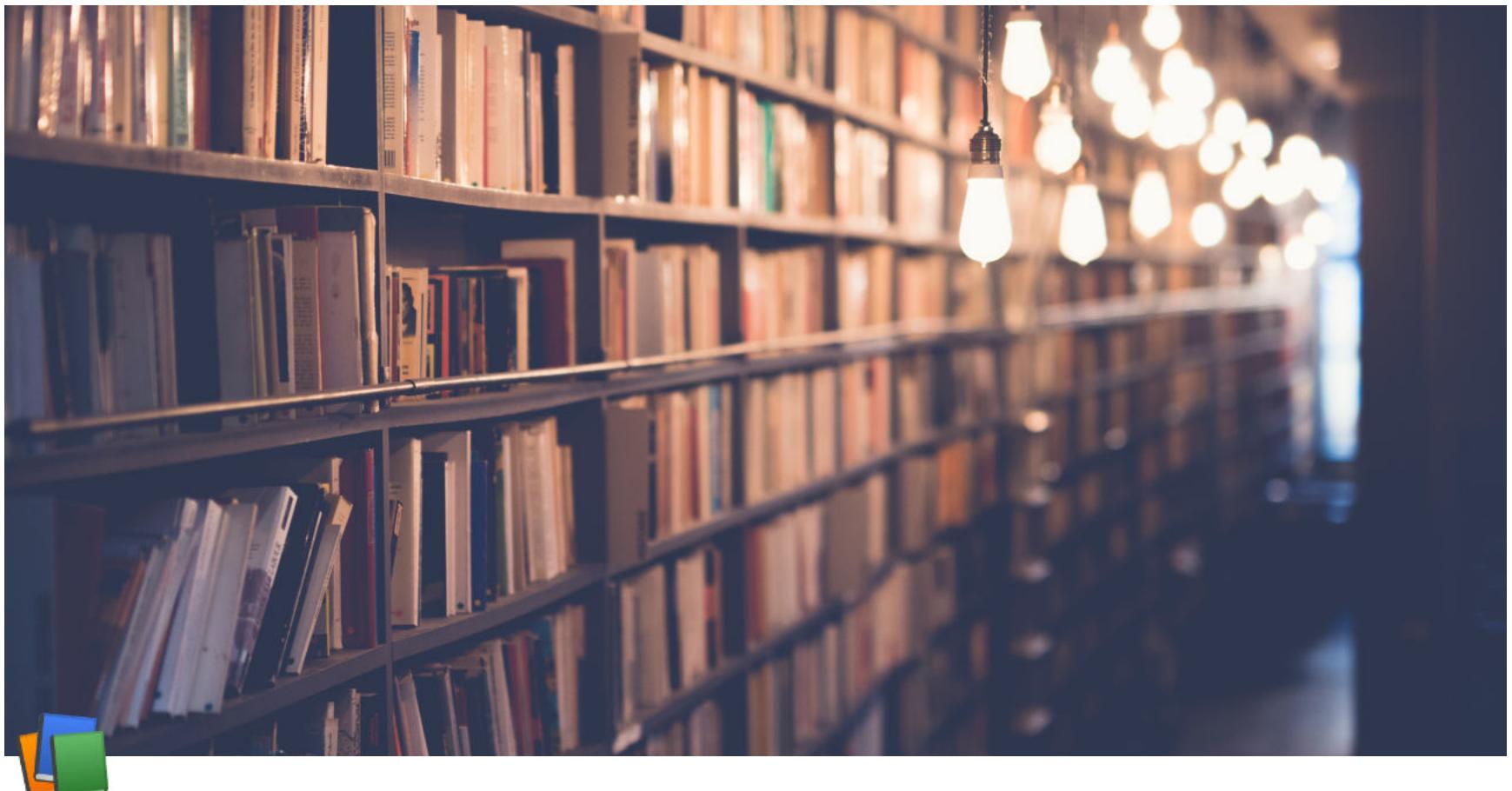
- Recompute and update `tot_creds` value for all the students

```
UPDATE student S  
SET tot_creds = (SELECT SUM(credits)  
                 FROM takes, course  
                 WHERE takes.course_id = course.course_id AND
```

```
S.id = takes.id AND  
takes.grade <> 'F' AND  
takes.grade IS NOT NULL;
```

- Set `tot_creds` to null for students who have not taken any course
- Instead of `SUM (credits)`, use:

```
CASE  
WHEN SUM(credits) IS NOT NULL THEN SUM(credits)  
ELSE 0  
END;
```



## Week 3 Lecture 3

Class	BSCCS2001
Created	@September 26, 2021 11:24 AM
Materials	
Module #	13
Type	Lecture
Week #	3

## Intermediate SQL (part 2)

### Joined Relations

- **Join operations** take two relations and return as a result another relation
- A join operation is a Cartesian product which requires that tuples in the two relations match (under some conditions)
- It also specifies the attributes that are present in the result of the join
- The join operations are typically used as subquery expressions in the **FROM** clause

### Types of JOIN relations

- Cross join
- Inner join
  - Equi-join
    - Natural join
- Outer join
  - Left outer join
  - Right outer join
  - Full outer join
- Self-join

### Cross JOIN

- CROSS JOIN returns the Cartesian product of rows from tables in the join

- Explicit

```
SELECT *
FROM employee CROSS JOIN department;
```

- Implicit

```
SELECT *
FROM employee, department;
```

## JOIN Operations - Example

- Relation course

Aa course_id	≡ title	≡ dept_name	# credits
BIO-301	Genetics	Biology	4
CS-190	Game Design	Comp. Sci.	4
CS-315	Robotics	Comp. Sci.	3

- Relation *prereq*

Aa course_id	≡ prereq_id
BIO-301	BIO-101
CS-190	CS-101
CS-347	CS-101

- Observe that

*prereq* information is missing from CS-315 and  
course information is missing from CS-347

## Inner JOIN

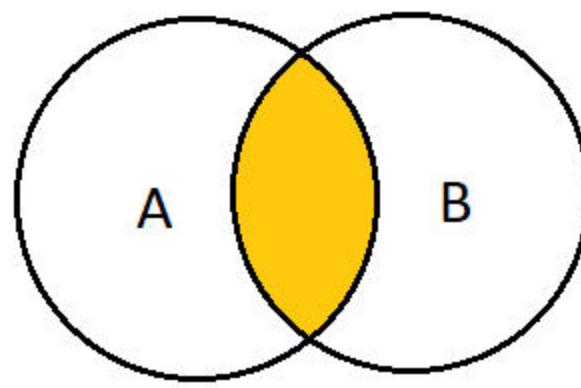
- *course INNER JOIN prereq*

Aa Name	≡ title	≡ dept_name	# credits	≡ prereq_id	≡ course_id
BIO-301	Genetics	Biology	4	BIO-101	BIO-301
CS-190	Game Design	Comp. Sci.	4	CS-101	CS-190

- If specified as **NATURAL**, the 2<sup>nd</sup> *course\_id* field is skipped

Aa course_id	≡ title	≡ Column	# credits
BIO-301	Genetics	Biology	4
CS-190	Game Design	Comp. Sci.	4
CS-315	Robotics	Comp. Sci.	3

Aa course_id	≡ prereq_id
BIO-301	BIO-101
CS-190	CS-101
CS-347	CS-101



## Outer JOIN

- An extension of the join operation that avoids loss of information
- Computes the join and then adds tuples, from one relation that does not match tuples in the other relation, to the results of the join
- Uses null values

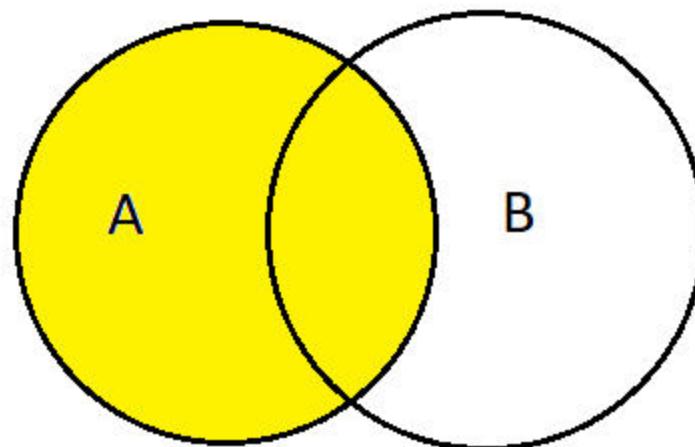
### Left Outer JOIN

- course NATURAL LEFT OUTER JOIN prereq

Aa course_id	≡ title	≡ dept_name	# credits	≡ prere_id
BIO-301	Genetics	Biology	4	BIO-101
CS-190	Game Design	Comp. Sci.	4	CS-101
CS-315	Robotics	Comp. Sci.	3	null

Aa course_id	≡ title	≡ dept_name	# credits
BIO-301	Genetics	Biology	4
CS-190	Game Design	Comp. Sci.	4
CS-315	Robotics	Comp. Sci.	3

Aa course_id	≡ prereq_id
BIO-301	BIO-101
CS-190	CS-101
CS-347	CS-101



### Right Outer JOIN

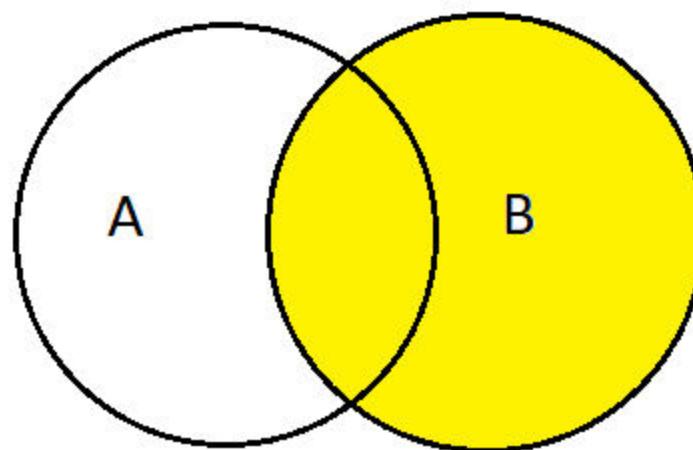
- course NATURAL RIGHT OUTER JOIN prereq

Aa course_id	≡ title	≡ dept_name	≡ credits	≡ prere_id
BIO-301	Genetics	Biology	4	BIO-101

<u>A</u> a course_id	≡ title	≡ dept_name	≡ credits	≡ prere_id
<u>CS-190</u>	Game Design	Comp. Sci.	4	CS-101
<u>CS-347</u>	null	null	null	CS-101

<u>A</u> a course_id	≡ title	≡ dept_name	# credits
<u>BIO-301</u>	Genetics	Biology	4
<u>CS-190</u>	Game Design	Comp. Sci.	4
<u>CS-315</u>	Robotics	Comp. Sci.	3

<u>A</u> a course_id	≡ prereq_id
<u>BIO-301</u>	BIO-101
<u>CS-190</u>	CS-101
<u>CS-347</u>	CS-101



## Joined relations

- **Join operations** take two relations and return a relation as the result
- These additional operations are typically used as subquery expressions in the **FROM** clause
- **Join condition** - defines which tuples in the two relations match, and what attributes are present in the result of the join
- **Join type** - defines how tuples in each relation, that do not match any tuple in the other relation (based on the join condition), are treated
  - **Join types**
    - inner join
    - left outer join
    - right outer join
    - full outer join
  - **Join conditions**
    - natural
    - on <predicate>
    - using ( $A_1, A_2, \dots, A_n$ )

## Full outer JOIN

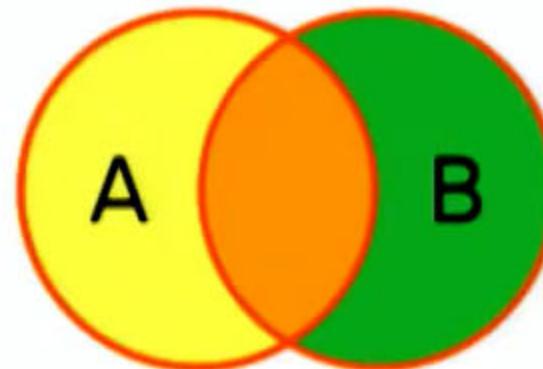
- course NATURAL FULL OUTER JOIN prereq

<u>A</u> a course_id	≡ title	≡ dept_name	≡ credits	≡ prereq_id
<u>BIO-301</u>	Genetics	Biology	4	BIO-101
<u>CS-190</u>	Game Design	Comp. Sci.	4	CS-101
<u>CS-315</u>	Robotics	Comp. Sci.	3	null

Aa course_id	≡ title	≡ dept_name	≡ credits	≡ prereq_id
<u>CS-347</u>	null	null	null	CS-101

Aa course_id	≡ title	≡ dept_name	# credits
<u>BIO-301</u>	Genetics	Biology	4
<u>CS-190</u>	Game Design	Comp. Sci.	4
<u>CS-315</u>	Robotics	Comp. Sci.	3

Aa course_id	≡ prereq_id
<u>BIO-301</u>	BIO-101
<u>CS-190</u>	CS-101
<u>CS-347</u>	CS-101



### Joined Relations - Example

- **course INNER JOIN prereq ON**

*course.course\_id = prereq.course\_id*

Aa course_id	≡ title	≡ dept_name	# credits	≡ prere_id	≡ courseid
<u>BIO-301</u>	Genetics	Biology	4	BIO-101	BIO-301
<u>CS-190</u>	Game Design	Comp. Sci.	4	CS-101	CS-190

- What is the difference between the above (equi\_join) and a natural join?

- **course LEFT OUTER JOIN prereq ON**

*course.course\_id = prereq.course\_id*

Aa course_id	≡ title	≡ dept_name	# credits	≡ prere_id	≡ courseid
<u>BIO-301</u>	Genetics	Biology	4	BIO-101	BIO-301
<u>CS-190</u>	Game Design	Comp. Sci.	4	CS-101	CS-190
<u>CS-315</u>	Robotics	Comp. Sci.	3	null	null

- **course NATURAL RIGHT OUTER JOIN prereq**

Aa course_id	≡ title	≡ dept_name	≡ credits	≡ prere_id
<u>BIO-301</u>	Genetics	Biology	4	BIO-101
<u>CS-190</u>	Game Design	Comp. Sci.	4	CS-101
<u>CS-347</u>	null	null	null	CS-101

- **course FULL OUTER JOIN prereq USING (course\_id)**

Aa course_id	≡ title	≡ dept_name	≡ credits	≡ prere_id
<u>BIO-301</u>	Genetics	Biology	4	BIO-101
<u>CS-190</u>	Game Design	Comp. Sci.	4	CS-101

Aa course_id	title	dept_name	credits	prere_id
CS-315	Robotics	Comp. Sci.	3	null
CS-347	null	null	null	CS-101

## Views

- In some cases, it is not desirable for all users to see the entire logical model (that is, all the actual relations stored in the database)
- Consider a person who needs to know an instructors name and department, but not the salary. This person should see a relation described, in SQL, by

```
SELECT id, name, dept_name
FROM instructor;
```

- A **VIEW** provides a mechanism to hide certain data from the view of certain users
- Any relation that is not of the conceptual model but is made visible to a user as a "virtual relation" is called a **VIEW**

## View definition

- A view is defined using the **CREATE VIEW** statement which has the form

```
CREATE VIEW v AS <query expression>
```

where `<query expression>` is any legal SQL expression

- The view name is represented by v
- Once a view is defined, the view name can be used to refer to the virtual relation that the view generates
- View definition is not the same as creating a new relation by evaluating the query expression
  - Rather, a view definition causes the saving of an expression; the expression is substituted into queries using the view

## Example views

- A view of instructors without their salary

```
CREATE VIEW faculty AS
  SELECT id, name, dept_name
  FROM instructor;
```

- Find all the instructors in the biology department

```
SELECT name
  FROM faculty
 WHERE dept_name = 'Biology'
```

- Create a view of department salary totals

```
CREATE VIEW departments_total_salary(dept_name, total_salary) AS
  SELECT dept_name, SUM(salary)
  FROM instructor
  GROUP BY dept_name;
```

## View defined using other views

```
CREATE VIEW physics_fall_2009 AS
  SELECT course.course_id, sec_id, building, room_number
  FROM course, section
 WHERE course.course_id = section.course_id
   AND course.dept_name = 'Physics'
   AND section.semester = 'Fall'
   AND section.year = '2009';
```

```

CREATE VIEW physics_fall_2009_watson AS
    SELECT course_id, room_number
    FROM phsics_fall_2009
    WHERE building = 'Watson';

```

## View expansion

- Expand use of a view in a query / another view

```

CREATE VIEW physics_fall_2009_watson AS
    (SELECT course_id, room_number
     FROM (SELECT course.course_id, building, room_number
           FROM course, section
          WHERE course.course_id = section.course_id
            AND course.dept_name = 'Physics'
            AND section.semester = 'Fall'
            AND section.year = '2009')
      WHERE building = 'Watson');

```

## Views defined using other views

- One view may be used in the expression defining another view
- A view relation  $v_1$  is said to **depend directly** on a view relation  $v_2$  if  $v_2$  is used in the expression defining  $v_1$
- A view relation  $v_1$  is said to **depend on** view relation  $v_2$  if either  $v_1$  depends directly on  $v_2$  or there is a path of dependencies from  $v_1$  to  $v_2$
- A view relation  $v$  is said to be **recursive** if it depends on itself

## View expansion

- A way to define the meaning of views defined in terms of other views
- Let view  $v_1$  be defined by an expression  $e_1$  that may itself contain uses of view relations
- View expansion of an expression repeats the following replacement step:

**repeat**

Find any view relation  $v_i$  in  $e_1$

Replace the view relation  $v_i$  by the expression defining  $v_i$

**until** no more view relations are present in  $e_1$

- As long as the view definitions are not recursive, this loop will terminate

## Update of a view

- Add a new tuple to *faculty* view which we defined earlier

```

INSERT INTO faculty VALUES ('30765', 'Green', 'Music');

```

- This insertion must be represented by the insertion of the tuple

```
('30765', 'Green', 'Music', null)
```

into the *instructor* relation

## Some updates cannot be translated uniquely

```

CREATE VIEW instructor_info AS
    SELECT id, name, building
    FROM instructor, department
    WHERE instructor.dept_name = department.dept_name;

```

```

INSERT INTO instructor_info VALUE('69987', 'White', 'Taylor');

```

- Which department, if multiple departments in Taylor?

- What if no department is present in Taylor?
- Most SQL implementations allow updates only on simple views
  - The **FROM** clause has only one database relation
  - The **SELECT** clause contains only attribute names of the relation and does not have any expressions, aggregates or **DISTINCT** specification
  - Any attribute not listed in the **SELECT** clause can be set to *null*
  - The query does not have a **GROUP BY** or **HAVING** clause

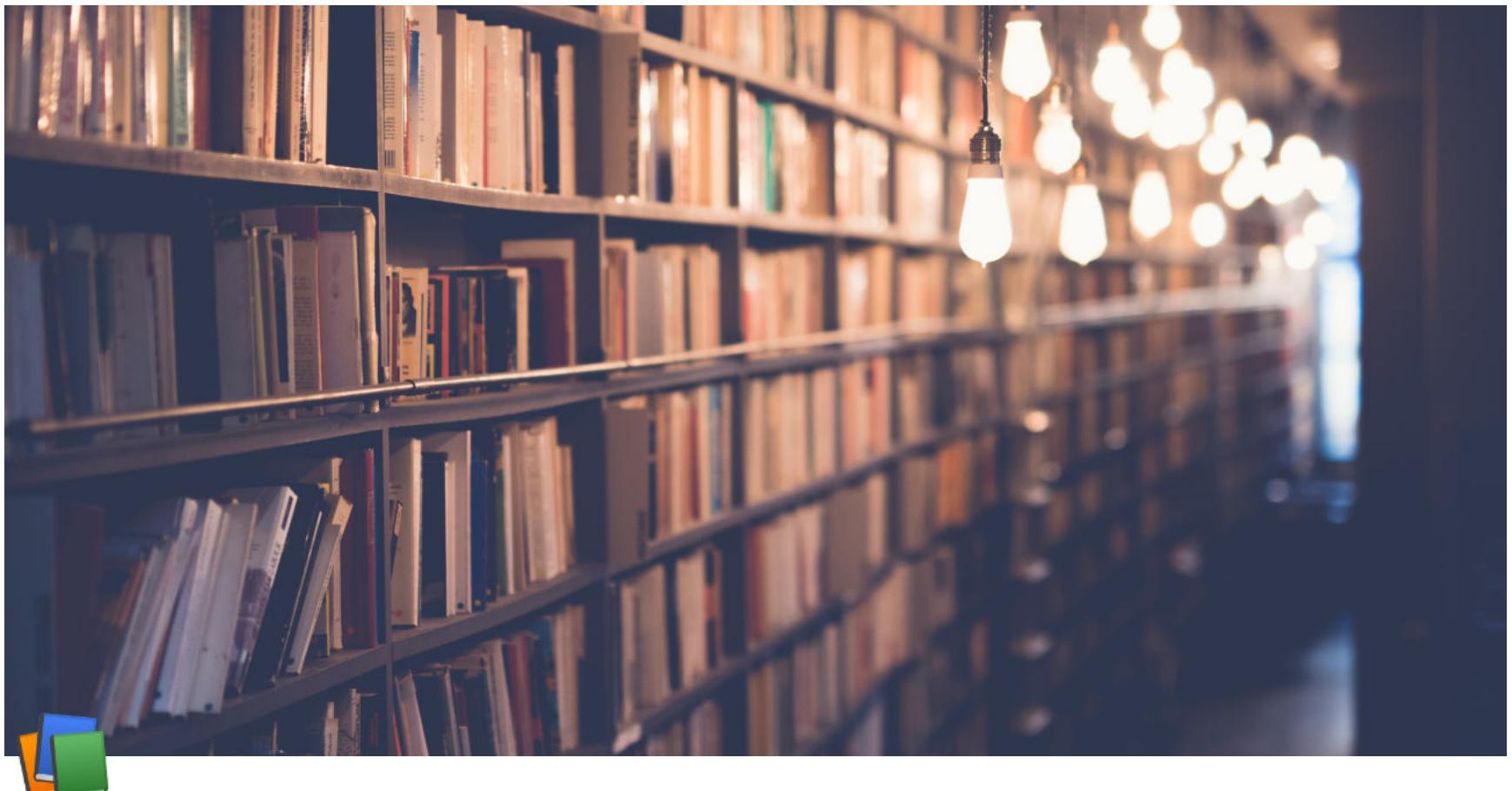
## And some not at all

```
CREATE VIEW history_instructors AS
  SELECT * FROM instructor
  WHERE dept_name = 'History';
```

- What happens when we insert `('25566', 'Brown', 'Biology', 100000)` into the `history_instructors` ?

## Materialized views

- **Materializing a view:** Create a physical table containing all the tuples in the result of the query defining the view
- If relations used in the query are updated, the materialized view result becomes out of date
  - Need to maintain the view, by updating the view whenever the underlying relations are updated



## Week 3 Lecture 4

Class	BSCCS2001
Created	@September 26, 2021 3:18 PM
Materials	
Module #	14
Type	Lecture
Week #	3

## Intermediate SQL (part 3)

### Transactions

- It is a unit of work
- Atomic transaction
  - Either something is fully executed or it is rolled back as if it never occurred
  - **Example:** Bank account transactions, when transferring money from one account to another, the transaction should either happen or not happen at all.  
It should not fail at a stage where money is deducted from one account and not added to the other account
- Isolation from concurrent transactions
- Transactions begin implicitly
  - Ended by **COMMIT WORK** or **ROLLBACK WORK**
- But default on most databases: each SQL statement commits automatically
  - Can turn off auto-commit for a session (for example, using API)
  - In SQL:1999, can use: **BEGIN ATOMIC ... END**
    - Not supported on most databases

### Integrity Constraints

- Integrity constraints guard against accidental damage to the database by ensuring that the authorized changes to the database do not result in a loss of data consistency
  - A checking account must have a balance greater than Rs. 10,000.00

- A salary of a bank employee must be at least Rs. 250.00 an hour
- A customer must have a (non-null) phone number

## Integrity constraints on a single relation

- NOT NULL
- PRIMARY KEY
- UNIQUE
- CHECK( $P$ ), where  $P$  is a predicate

## NOT NULL and UNIQUE constraints

- NOT NULL
  - Declare *name* and *budget* to be NOT NULL

```
name VARCHAR(20) NOT NULL
budget NUMERIC(12, 2) NOT NULL
```

- UNIQUE( $A_1, A_2, \dots, A_m$ )
  - The unique specification states that the attributes  $A_1, A_2, \dots, A_m$  form a candidate key
  - Candidate keys are permitted to be null (in contrast to primary keys)

## The CHECK clause

- CHECK( $P$ ), where  $P$  is a predicate
- Ensure that semester is one of fall, winter, spring or summer

```
CREATE TABLE section (
    course_id VARCHAR(8),
    sec_id VARCHAR(8),
    semester VARCHAR(6),
    year NUMERIC(4, 0),
    building VARCHAR(15),
    room_number VARCHAR(7),
    time_slot_id VARCHAR(4),
    PRIMARY KEY (course_id, sec_id, semester, year)
    CHECK (semester IN ('Fall', 'Winter', 'Spring', 'Summer'))
);
```

## Referential Integrity

- Ensures that a value that appears in one relation for a given set of attributes also appears for a certain set of attributes in another relation
- Example: If "Biology" is a department name appearing in one of the tuples in the instructor relation, then there exists a tuple in the department relation for "Biology"
- Let A be a set of attributes. Let R and S be two relations than contain attributes A.
  - Here, A is the primary key of S.
  - A is said to be a FOREIGN KEY of R if for any values of A appearing in R these values also appear in S

## Cascading Actions in Referential Integrity

- With cascading, you can define the actions that the Database Engine takes when a user tries to delete or update a key to which existing foreign keys point

```
CREATE TABLE course (
    course_id CHAR(5) PRIMARY KEY,
    title VARCHAR(20),
    dept_name VARCHAR(20) REFERENCES department
)
```

```

CREATE TABLE course (
    ...
    dept_name VARCHAR(20),
    FOREIGN KEY (dept_name) REFERENCES department
        ON DELETE CASCADE
        ON UPDATE
    ...
)

```

- Alternative actions to cascade: **NO ACTION**, **SET NULL**, **SET DEFAULT**

## Integrity constraint violation during transactions

```

CREATE TABLE person (
    id CHAR(10),
    name CHAR(40),
    mother CHAR(10),
    father CHAR(10),
    PRIMARY KEY id,
    FOREIGN KEY father REFERENCES person,
    FOREIGN KEY mother REFERENCES person)

```

- How to insert a tuple without causing constraint violation?
  - Insert father and mother of a person before inserting person
  - OR, set father and mother to null initially, update after inserting all persons (not possible if father and mother attributes declared to be **NOT NULL**)
  - OR defer constraint checking

## SQL Data Types and Schemas

### Built-in data types in SQL

- **DATE:** Dates, containing an (4 digit) year, month and date
  - Example: **DATE** '2005-7-27'
- **TIME:** Time of day in hours, minutes and seconds
  - Example: **TIME** '09:00:30' **TIME** '09:00:30.75'
- **TIMESTAMP:** Date plus time of the day
  - Example: **TIMESTAMP** '2005-7-27 09:00:30.75'
- **INTERVAL:** Period of time
  - Example: **INTERVAL** '1' day
  - Subtracting a date/time/timestamp value from another gives an interval value
  - Interval values can be added to date/time/timestamp values

### Index creation

```

CREATE TABLE student
( id VARCHAR(5),
  name VARCHAR(20) NOT NULL,
  dept_name VARCHAR(20),
  tot_cred NUMERIC(3, 0) DEFAULT 0,
  PRIMARY KEY (id));

```

```
CREATE INDEX studentid_index ON student(id);
```

- Indices are data structures used to speed up access to records with specified values for index attributes

```

SELECT * FROM student
WHERE id = '12345';

```

- Can be executed by using the index to find the required record, without looking at all records of students

## User-defined types

- **CREATE TYPE** construct in SQL creates user-defined type (alias, like `typedef` in C)

```
CREATE TYPE Dollars AS NUMERIC(2, 2) FINAL;
```

```
CREATE TABLE department (
    dept_name VARCHAR(20),
    building VARCHAR(15),
    budget Dollars);
```

## Domains

- **CREATE TYPE** construct in SQL-92 creates user-defined domain types

```
CREATE DOMAIN person_name CHAR(20) NOT NULL;
```

- Types and domains are similar
- Domains can have constraints such as **NOT NULL** specified on them

```
CREATE DOMAIN degree_level VARCHAR(10)
CONSTRAINT degree_level_test
CHECK (VALUE IN('Bachelors', 'Masters', 'Doctorate'));
```

## Large-object types

- Large objects (photos, videos, CAD files, etc.) are stored as a large object:
  - **blob:** binary large object - object is a large collection of uninterpreted binary data (whose interpretation is left to an application outside of the database system)
  - **clob:** character large object - object is a large collection of character data
  - When a query returns a large object, a pointer is returned than the large object itself

## Authorization

- Forms of authorization on parts of the database:
  - **Read:** allows reading, but not modification of data
  - **Insert:** allows insertion of new data, but not modification of existing data
  - **Update:** allows modification, but not deletion of data
  - **Delete:** allows deletion of data
- Forms of authorization to modify the database schema
  - **Index:** allows creation and deletion of indices
  - **Resources:** allows creation of new relations
  - **Alteration:** allows addition or deletion of attributes in a relation
  - **Drop:** allows deletion of relations

## Authorization Specification of SQL

- The **GRANT** statement is used to confer authorization

```
GRANT <privilege list>
ON <relation name or view name> TO <user list>
```

- `<user list>` is:
  - A user-id

- **PUBLIC**, which allows all valid users the privilege granted
- A role
- Granting a privilege on a view does not imply granting any privileges on the underlying relations
- The grantor of the privilege must already hold the privilege on specified item (or be the database administrator)

## Privileges in SQL

- **SELECT**: allows read access to relation or the ability to query using the view
  - Example: grant users  $U_1, U_2$  and  $U_3$  **SELECT** authorization on the *instructor* relation:

```
GRANT SELECT ON instructor TO  $U_1, U_2, U_3$ 
```

- **INSERT**: the ability to insert tuples
- **UPDATE**: the ability to update using the SQL update statement
- **DELETE**: the ability to delete tuples
- **ALL PRIVILEGES**: used as a short form for all the allowable privileges

## Revoking authorization in SQL

- The **REVOKE** statement is used to revoke authorization

```
REVOKE <privilege list>
ON <relation name or view name> FROM <user list>
```

- Example:

```
REVOKE SELECT ON branch FROM  $U_1, U_2, U_3$ 
```

- **<privilege list>** may be **all** to revoke all privileges the revoker may hold
- If **<revoker list>** includes **public**, all users lose the privilege except those granted it explicitly
- If the same privilege was granted twice to the same user by different grantors, the user may retain the privilege after the revocation
- All privileges that depend on the privilege being revoked are also revoked

## Roles

- `CREATE ROLE instructor;`

```
GRANT instructor TO Amit;
```

- Privileges can be granted to roles:

```
GRANT SELECT ON takes TO instructor;
```

- Roles can be granted to users as well as to other roles

```
CREATE ROLE teaching_assistant
GRANT teaching_assistant TO instructor;
```

- *Instructor* inherits all privileges of *teaching\_assistant*
- Chain of roles

- `CREATE ROLE dean;`
- `GRANT instructor TO dean;`
- `GRANT dean TO Satoshi;`

## Authorization on views

```
CREATE VIEW geo_instructor AS
(SELECT *
FROM instructor
WHERE dept_name = 'Geology');
GRANT SELECT ON geo_instructor TO geo_staff;
```

- Suppose that a *geo\_staff* member issues

```
SELECT *
FROM geo_instructor;
```

- What is
  - *geo\_staff* does not have permissions on *instructor*?
  - creator of view did not have some permissions on *instructor*?

## Other authorization features

- **REFERENCES** privilege to create foreign key

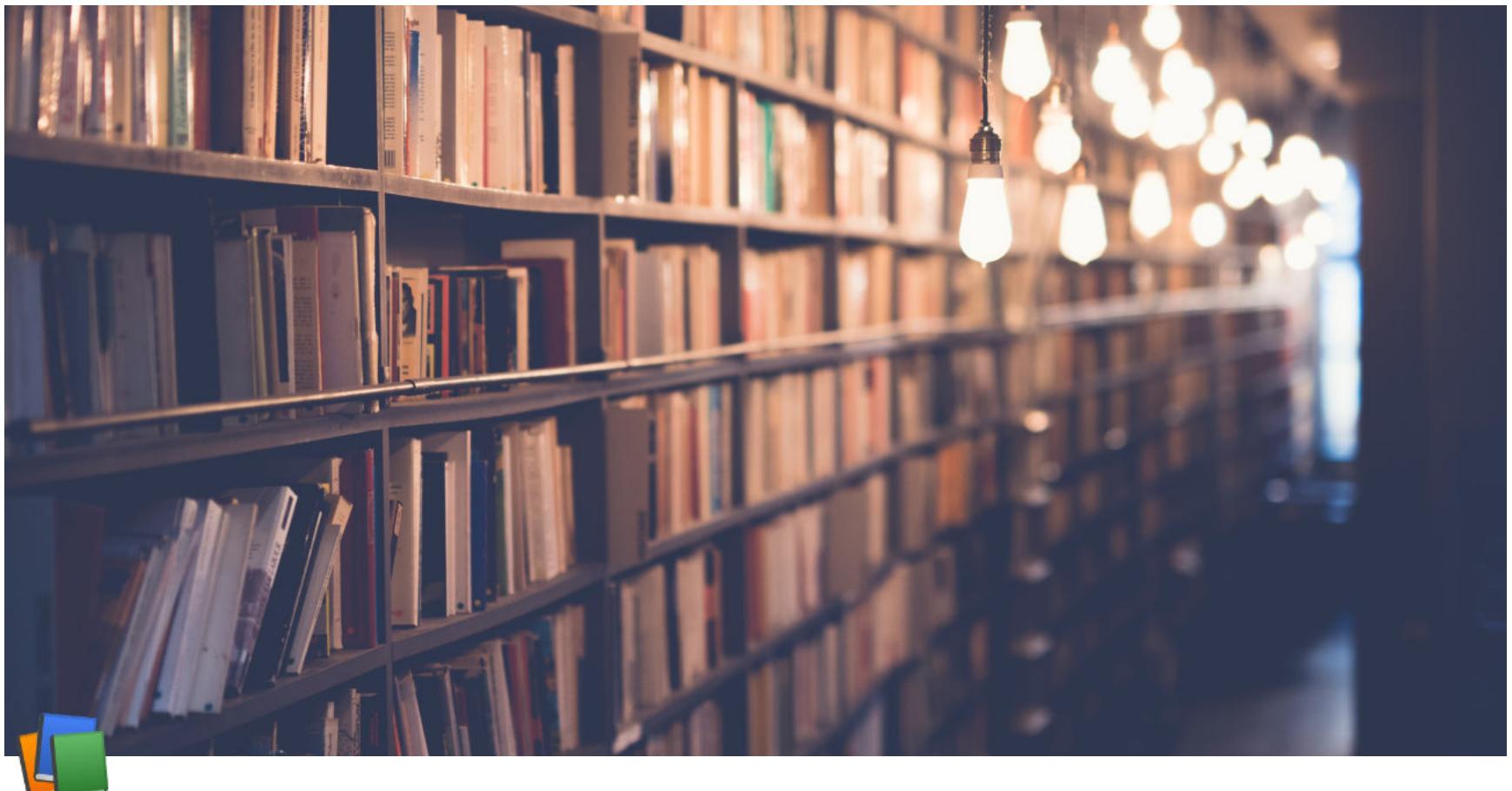
```
GRANT REFERENCE (dept_name) ON department TO Mariano;
```

- Why is this required?
- Transfer of privileges

```
GRANT SELECT ON department TO Amit WITH GRANT OPTION;
```

```
REVOKE SELECT ON department FROM Amit, Satoshi CASCADE;
```

```
REVOKE SELECT ON department FROM Amit, Satoshi RESTRICT;
```



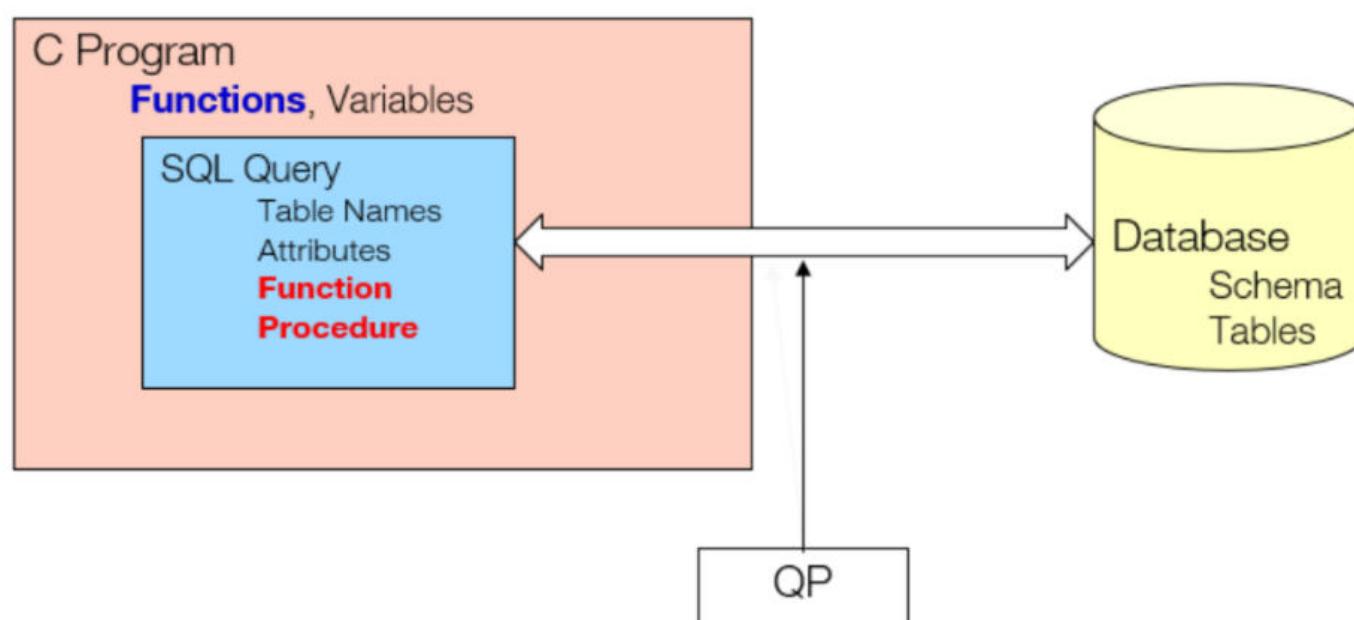
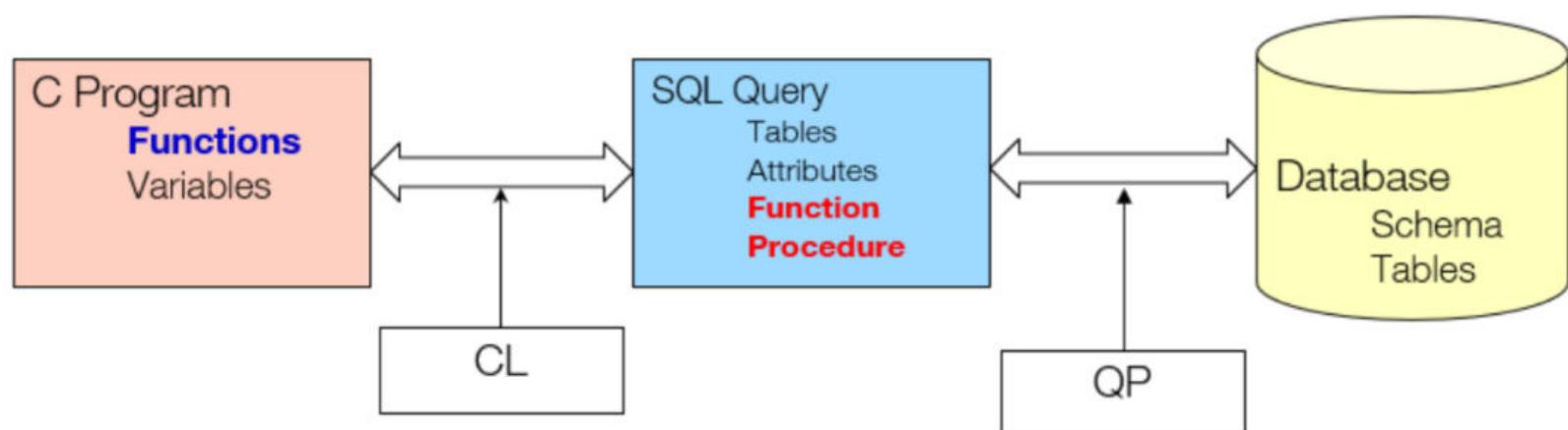
## Week 3 Lecture 5

Class	BSCCS2001
Created	@September 26, 2021 10:24 PM
Materials	
Module #	15
Type	Lecture
Week #	3

## Advanced SQL

**Functions and Procedural Constructs**

**Native Language  $\leftarrow \rightarrow$  Query Language**



## Functions and Procedures

- Functions / Procedures and Control Flow statements were added in SQL:1999
  - **Functions/Procedures** can be written in SQL itself or in an external programming language like C, Java, etc
  - Functions written in an external language are particularly useful with specialized data types such as images and geometric objects
    - Example: Functions to check if polygons overlap or to compare images for similarity
  - Some database systems support **table-valued functions** which can return a relation as a result
- SQL:1999 also supports a rich set of imperative constructs, including **loops**, **if-then-else** and **assignment**
- Many databases have proprietary procedural extensions to SQL that differ from SQL:1999

## SQL Functions

- Define a function that, given the name of a department, returns the count of the number of instructors in that department

```

CREATE FUNCTION dept_count (dept_name VARCHAR(20))
  RETURN INTEGER
BEGIN
  DECLARE d_count integer;
  SELECT COUNT(*) INTO d_count
  FROM instructor
  WHERE instructor.dept_name = dept_name
  RETURN d_count;
END
  
```

- The function `dept_count` can be used to find the department names and budget of all departments with more than 12 instructors:

```

SELECT dept_name, budget
FROM department
WHERE dept_count (dept_name) > 12;
  
```

- Compound statement: **BEGIN ... END**

May contain multiple SQL statements between **BEGIN** and **END**

- **RETURNS:** indicates the variable-type that is returned (eg: integer)
- **RETURN:** specifies the values are to be returned as result of invoking the function
- SQL function are in fact parameterized views that generalize the regular notion of views by allowing parameters

## Table functions

- Functions that return a relation as a result added in SQL:2003
- Return all instructors in a given department:

```
CREATE FUNCTION instructor_of (dept_name CHAR(20))
    RETURNS TABLE (
        id VARCHAR(5),
        name VARCHAR(20),
        dept_name VARCHAR(20)
        salary NUMERIC(8, 2))
    RETURN TABLE
    ( SELECT id, name, dept_name, salary
        FROM instructor
        WHERE instructor.dept_name = instructor_of.dept_name)
```

- Usage

```
SELECT *
FROM TABLE (instructor_of('Music'))
```

## SQL procedures

- The dept\_count function could instead be written as procedure:

```
CREATE PROCEDURE dept_count_proc(
    IN dept_name VARCHAR(20), OUT d_count INTEGER)
BEGIN
    SELECT COUNT(*) INTO d_count
    FROM instructor
    WHERE instructor.dept_name = dept_count_proc.dept_name
END
```

- Procedures can be invoked either from an SQL procedure or from embedded SQL, using the **CALL** statement

```
DECLARE d_count INTEGER;
CALL dept_count_proc('Physics', d_count);
```

- Procedures and functions can be invoked also from dynamic SQL
- SQL:1999 allows **overloading** - more than one function/procedure of the same name as long as the number of arguments and/or the types of the arguments differ

## Language constructs for procedures and functions

- SQL supports constructs that gives it almost all the power of a general purpose programming language
  - **Warning:** Most database systems implement their own variant of the standard syntax
- Compound statement: **BEGIN ... END**
  - May contain multiple SQL statements between **BEGIN** and **END**
  - Local variables can be declared within a compound statements
- **WHILE** loop:

```
WHILE boolean expression DO
    sequence of statements;
END WHILE;
```

- **REPEAT** loop:

```

REPEAT
    sequence of statements;
UNTIL boolean expression
END REPEAT;

```

- **FOR** loop:
  - Permits iteration over all results of a query
- Find the budget of all departments

```

DECLARE n INTEGER DEFAULT 0;
FOR r AS
    SELECT budget FROM department
DO
    SET n = n + r.budget
END FOR;

```

- Conditional statements
  - **if-then-else**
  - **case**
- **if-then-else** statement

```

IF boolean expression THEN
    sequence of statements;
ELSEIF boolean expression THEN
    sequence of statements;
...
ELSE
    sequence of statements;
END IF;

```

- The **IF** statement supports the use of optional **ELSEIF** clauses and a default **ELSE** clause
- Example procedure: registers student after ensuring classroom capacity is not exceeded
  - Returns 0 on success and -1 if the capacity is exceeded
- Simple **CASE** statement

```

CASE variable
    WHEN value1 THEN
        sequence of statements;
    WHEN value2 THEN
        sequence of statements;
    ...
    ELSE
        sequence of statements;
END CASE;

```

- The **WHEN** clause of the **CASE** statement defines the value that when satisfied determines the flow of control
- Searched **CASE** statement

```

CASE
    WHEN sql-expression = value1 THEN
        sequence of statements;
    WHEN sql-expression = value2 THEN
        sequence of statements;
    ...
    ELSE
        sequence of statements;
END CASE;

```

- Any supported SQL expression can be used here. These expressions can contain references to variables, parameters, special registers and more.
- Signaling of exception conditions and declaring handlers for exceptions

```

DECLARE out_of_classroom_seats CONDITION
DECLARE EXIT HANDLER FOR out_of_classroom_seats
BEGIN
    ...
    SIGNAL out_of_classroom_seats
    ...
END

```

- The handler here is **EXIT** - causes enclosing **BEGIN ... END** to terminate and exit
- Other actions possible on exception

## External Language Routines

- SQL:1999 allows the definition of functions/procedures in an imperative programming language (Java, C#, C or C++) which can be invoked from SQL queries
- Such functions can be more efficient than functions defined in SQL. The computations that cannot be carried out in SQL can be executed by these functions
- Declaring external language procedures and functions

```

CREATE PROCEDURE dept_count_proc(
    IN dept_count VARCHAR(20),
    OUT count INTEGER
)
LANGUAGE C
EXTERNAL NAME '/usr/avi/bin/dept_count_proc'

```

```

CREATE FUNCTION dept_count(dept_name VARCHAR(20))
RETURNS integer
LANGUAGE C
EXTERNAL NAME '/usr/avi/bin/dept_count'

```

- Benefits of external language functions/procedures:
  - More efficient for many operations and more expressive power
- Drawbacks:
  - Code to implement function may need to be loaded into the DB system and executed in the DB system's address space
    - Risk of accidental corruption of the DB structures
    - Security risk, allowing users access to unauthorized data
  - There are alternatives, which provide good security at the cost of performance
  - Direct execution in the DB system's space is used when efficiency is more important than security

## External Language Routines: Security

- To deal with security problems, we can do one of the following:
  - Use **sandbox** techniques:
    - That is, use a safe language like Java, which cannot be used to access/damage other parts of the DB code
  - Run external language functions/procedures in a separate process, with no access to the DB process' memory
    - Parameters and results communicated via the inter-process communication
- Both have performance overheads
- Many DB systems support both above approaches as well as direct executing in DB system address space

## Triggers

- A **TRIGGER** defines a set of actions that are performed in response to an **INSERT**, **UPDATE** or **DELETE** operation on a specified table
  - When such an SQL operation is executed, the trigger is said to have been activated
  - Triggers are optional

- Triggers are defined using the **CREATE TRIGGER** statement
- Triggers can be used
  - To enforce data integrity rules via referential constraints and check constraints
  - To cause updates to other tables, automatically generate or transform values for inserted or updated rows, or invoke functions to perform tasks such as issuing alerts
- To design a trigger mechanism, we must:
  - Specify the events / (like **UPDATE**, **INSERT** or **DELETE**) for the trigger to execute
  - Specify the time (**BEFORE** or **AFTER**) of execution
  - Specify the actions to be taken when the trigger executes
- Syntax of triggers may vary across systems

## Types of Triggers: BEFORE

- **BEFORE** triggers
  - Run before an **UPDATE** or **INSERT**
  - Values that are being updated or inserted can be modified before the DB is actually modified.

You can use triggers that run before an **UPDATE** or **INSERT** to ...

  - Check or modify the values before they are actually updated or inserted in the DB
    - Useful if user-view and internal DB format differs
  - Run other non-DB operations coded in user-defined functions
- **BEFORE DELETE** triggers
  - Run before a **DELETE**
    - Checks value (and raises an error, if necessary)

## Types of Triggers: AFTER

- **AFTER** triggers
  - Run after an **UPDATE**, **INSERT** or **DELETE**
  - You can use triggers than run after an update or insert to:
    - Update data in other tables
      - Useful to maintain relationships between data or keep audit trail
    - Check against other data in the table or in other tables
      - Useful to ensure data integrity when referential integrity constraints aren't appropriate
      - When table check constraints limit checking to the current table only
    - Run non-DB operations coded in user-defined functions
      - Useful when issuing alerts or to update information outside the DB

## Row level and Statement level Triggers

There are two types of triggers based on the level at which the triggers are applied:

- **Row level triggers** are executed whenever a row is affected by the event on which the trigger is defined
  - Let *Employee* be a table with 100 rows.
  - Suppose an **UPDATE** statement is executed to increase the salary of each employee by 10%
  - Any row level **UPDATE** trigger configured on the table *Employee* will affect all the 100 rows in the table during this update
- **Statement level triggers** perform a single action for all the rows affected by a statement, instead of executing a separate action for each affected row
  - Used for each statement instead of for each row

- Uses referencing old table or referencing new table to refer to temporary tables called **transition tables** containing the affected rows
- Can be more efficient when dealing with SQL statements that update a large number of rows

## Triggering Events and Actions in SQL

- Triggering event can be an **INSERT, DELETE or UPDATE**
- Triggers on update can be restricted to specific attributes
  - For example: after update of takes on grade
- Values of attributes before and after an update can be referenced
  - **referencing old row as:** for deletes and updates
  - **referencing new row as:** for inserts and updates
- Triggers can be activated before an event, which can serve as extra constraints

For example: convert blank grades to null

```
CREATE TRIGGER setnull_trigger BEFORE UPDATE OF takes
REFERENCING NEW ROW AS nrow
FOR EACH ROW
WHEN (nrow.grade = '')
BEGIN ATOMIC
  SET nrow.grade = null;
END;
```

## Trigger to maintain **credits\_earned** value

```
CREATE TRIGGER credits_earned AFTER UPDATE OF takes ON (grade)
REFERENCING NEW ROW AS nrow
REFERENCING OLD ROW AS orow
FOR EACH ROW
WHEN nrow.grade <> 'F' AND nrow.grade IS NOT NULL
  AND (orow.grade = 'F' OR orow.grade IS NULL)
BEGIN ATOMIC
  UPDATE student
  SET tot_cred = tot_cred +
    ( SELECT credits
      FROM course
      WHERE course.course_id = nrow.course_id)
      WHERE student.id = nrow.id;
END;
```

## How to use triggers?

- The optimal use of DML triggers is for short, simple and easy to maintain write operations that act largely independent of an application business logic
- Typical and recommended uses of triggers include:
  - Logging changes to a history table
  - Auditing users and their actions against sensitive tables
  - Adding additional values to a table that may not be available to an application (due to security restrictions or other limitations), such as:
    - Login/user name
    - Time an operation occurs
    - Server/database name
  - Simple validation

**Source:** [SQL Server triggers: The good and the scary](#)

## How not to use triggers?

- Triggers are like Lays: Once you pop, you cannot stop



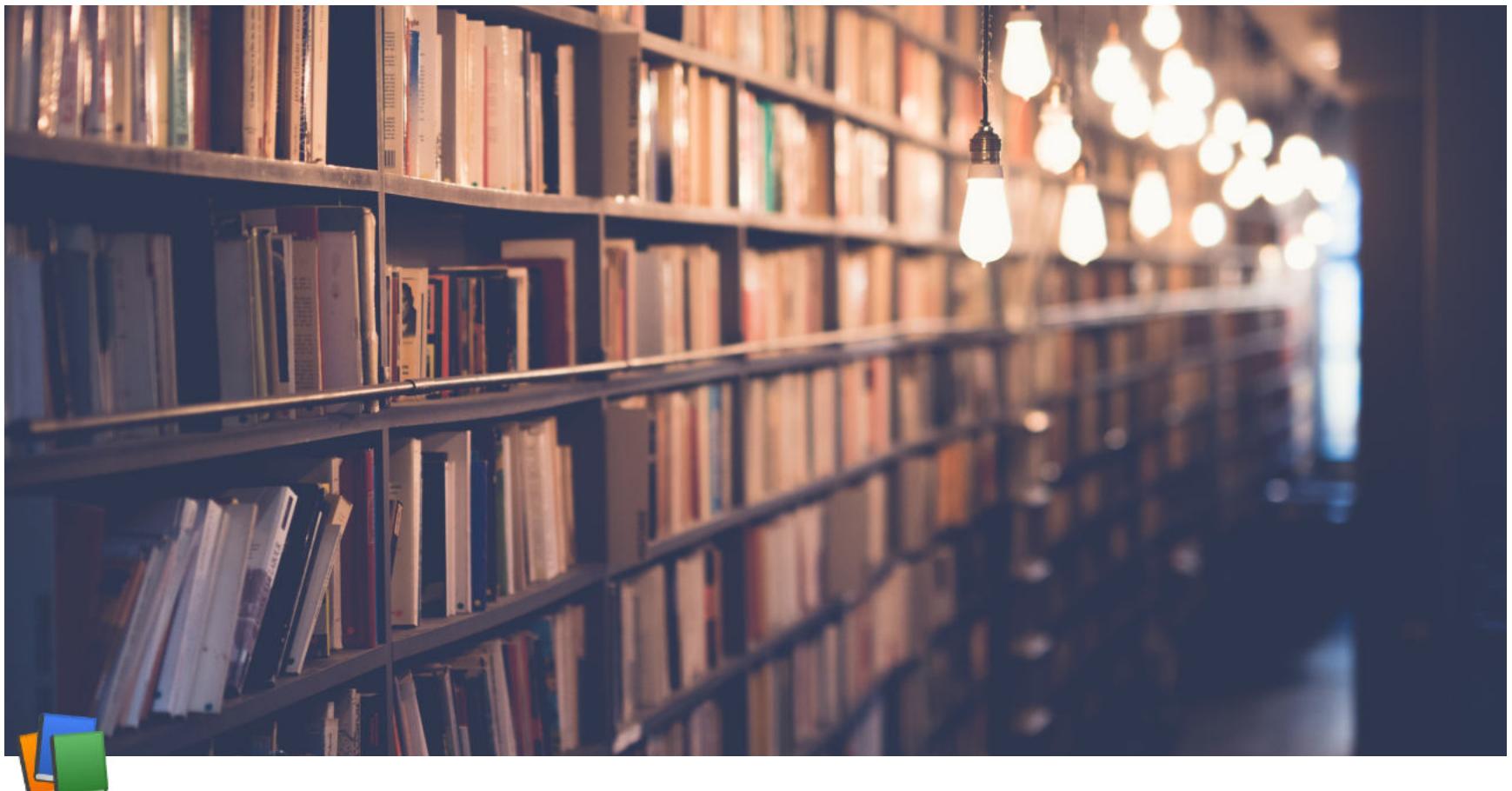
- One of the greatest challenges for architects and developers is to ensure that
  - triggers are used only as needed, and
  - to not allow them to become a one-size-fits-all solution for any data needs that happen to come along
- Adding triggers is often seen as faster and easier than adding code to an application, but the cost of doing so is compounded over time with each added line of code.

**Source:** [SQL Server triggers: The good and the scary](#)

## Alright then, how to use triggers?

- Trigger can become dangerous when:
  - There are too many
  - Trigger code becomes complex
  - Triggers go cross-server - across DBs over networks
  - Triggers call other triggers
  - Recursive triggers are set to ON. The DB-level setting is set to off by default
  - Functions, stored procedures or views are in triggers
  - Iteration occurs

**Source:** [SQL Server triggers: The good and the scary](#)



## Week 4 Lecture 1

Class	BSCCS2001
Created	@September 29, 2021 11:42 AM
Materials	
Module #	16
Type	Lecture
Week #	4

## Formal Relational Query Languages

- Relational Algebra
  - Procedural and Algebra based
- Tuple Relational Calculus
  - Non-procedural and Predicate Calculus based
- Domain Relational Calculus
  - Non-procedural and Predicate Calculus based

### Relational Algebra

- Created by Edgar F. Codd at IBM in 1970
- Procedural Language
- Six basic operators
  - Select:  $\sigma$
  - Project:  $\Pi$
  - Union:  $\cup$
  - Set difference:  $-$
  - Cartesian product:  $\times$
  - Rename:  $\rho$
- The operators take one or two relations as inputs and produce a new relation as the result

## SELECT operation

- Notation:  $\sigma_p(r)$
- $p$  is called the **selection predicate**
- Defined as:

$$\sigma_p(r) = \{t | t \in r \text{ and } p(t)\}$$

where  $p$  is a formula in propositional calculus consisting of terms connected by

$\wedge$  (**and**)

$\vee$  (**or**)

$\neg$  (**not**)

Each term is one of:

$< \text{attribute} > op < \text{attribute} > \text{ or } < \text{constant} >$

where  $op$  is one of:  $=, \neq, >, \geq, . <, . \leq$

- Example of selection:

$$\sigma_{\text{dept\_name} = 'Physics'}(\text{instructor})$$

A	B	C	D
$\alpha$	$\alpha$	1	7
$\alpha$	$\beta$	5	7
$\beta$	$\beta$	12	3
$\beta$	$\beta$	23	10

A	B	C	D
$\alpha$	$\alpha$	1	7
$\beta$	$\beta$	23	10

$$\sigma_{A=B \wedge D > 5}(r)$$

## PROJECT operation

- Notation:  $\Pi_{A_1, A_2, \dots, A_k}(r)$   
where  $A_1, A_2$  are attribute names and  $r$  is a relation
- The result is defined as the relation of  $k$  columns obtained by erasing the columns that are not listed.
- Duplicate rows removed from result, since relations are sets
- Example:** To eliminate the `dept_name` attribute of `instructor`

$$\Pi_{ID, name, salary}(\text{instructor})$$

A	B	C
$\alpha$	10	1
$\alpha$	20	1
$\beta$	30	1
$\beta$	40	2

A	C
$\alpha$	1
$\alpha$	1
$\beta$	1
$\beta$	2

=

A	C
$\alpha$	1
$\beta$	1
$\beta$	2

## UNION operation

- Notation:  $r \cup s$
- Defined as:  $r \cup s = \{t | t \in r \text{ or } t \in s\}$
- For  $r \cup s$  to be valid:
  - $r, s$  must have the same **arity** (same number of attributes)
  - The attribute domains must be compatible (ie: same data type)
  - Example:** To find all the courses taught in the Fall 2009 semester or in the Spring 2010 semester or in both  
 $\Pi_{course\_id}(\sigma_{semester='Fall'} \wedge year=2009(section)) \cup \Pi_{course\_id}(\sigma_{semester='Spring'} \wedge year=2010(section))$

A	B
$\alpha$	1
$\alpha$	2
$\beta$	1

*r*

A	B
$\alpha$	2
$\beta$	3

*s*

A	B
$\alpha$	1
$\alpha$	2
$\beta$	1
$\beta$	3

*r  $\cup$  s*

## DIFFERENCE operation

- Notation:  $r - s$
- Defined as:  $r - s = \{t | t \in r \text{ and } t \notin s\}$
- Set differences must be taken between compatible relations
  - $r$  and  $s$  must have the same **arity**
  - Attribute domains of  $r$  and  $s$  must be compatible
- Example:** To find all the courses taught in the Fall 2009 semester, but not in the Spring 2010 semester

$$\Pi_{course\_id}(\sigma_{semester="Fall"} \wedge year=2009(section)) - \Pi_{course\_id}(\sigma_{semester="Spring"} \wedge year=2010(section))$$

<table border="1" style="border-collapse: collapse; width: 100px; margin: auto;"> <thead> <tr> <th style="padding: 2px;">A</th> <th style="padding: 2px;">B</th> </tr> </thead> <tbody> <tr> <td style="padding: 10px;"><math>\alpha</math></td> <td style="padding: 10px;">1</td> </tr> <tr> <td style="padding: 10px;"><math>\alpha</math></td> <td style="padding: 10px;">2</td> </tr> <tr> <td style="padding: 10px;"><math>\beta</math></td> <td style="padding: 10px;">1</td> </tr> </tbody> </table> <p style="margin-top: 10px;"><math>r</math></p>	A	B	$\alpha$	1	$\alpha$	2	$\beta$	1	<table border="1" style="border-collapse: collapse; width: 100px; margin: auto;"> <thead> <tr> <th style="padding: 2px;">A</th> <th style="padding: 2px;">B</th> </tr> </thead> <tbody> <tr> <td style="padding: 10px;"><math>\alpha</math></td> <td style="padding: 10px;">2</td> </tr> <tr> <td style="padding: 10px;"><math>\beta</math></td> <td style="padding: 10px;">3</td> </tr> </tbody> </table> <p style="margin-top: 10px;"><math>s</math></p>	A	B	$\alpha$	2	$\beta$	3
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A	B														
$\alpha$	1														
$\beta$	1														

## INTERSECTION operation

- Notation:  $r \cap s$
- Defined as:
 
$$r \cap s = \{t | t \in r \text{ and } t \in s\}$$
- Assume:
  - $r, s$  have the same arity
  - Attributes of  $r$  and  $s$  are compatible
- Note:  $r \cap s = r - (r - s)$

<i>A</i>	<i>B</i>
$\alpha$	1
$\alpha$	2
$\beta$	1

*r*

<i>A</i>	<i>B</i>
$\alpha$	2
$\beta$	3

*s*

<i>A</i>	<i>B</i>
$\alpha$	2

*r*  $\cap$  *s*

### CARTESIAN-PRODUCT operation

- Notation:  $r \times s$
  - Defined as:
- $$r \times s = \{t \mid q \mid t \in r \text{ and } q \in s\}$$
- Assume that attributes of  $r(R)$  and  $s(S)$  are disjoint  
That is,  $R \cap S = \emptyset$
  - If attributes of  $r(R)$  and  $s(S)$  are not disjoint, then renaming must be used.

<i>A</i>	<i>B</i>		<i>C</i>	<i>D</i>	<i>E</i>
$\alpha$	1		$\alpha$	10	a
$\beta$	2		$\beta$	10	a

*r*

<i>A</i>	<i>B</i>	<i>C</i>	<i>D</i>	<i>E</i>
$\alpha$	1	$\alpha$	10	a
$\alpha$	1	$\beta$	10	a
$\alpha$	1	$\beta$	20	b
$\alpha$	1	$\gamma$	10	b
$\beta$	2	$\alpha$	10	a
$\beta$	2	$\beta$	10	a
$\beta$	2	$\beta$	20	b
$\beta$	2	$\gamma$	10	b

*r*  $\times$  *s*

## RENAME operation

- Allows us to name and, therefore, refer to the results of relational-algebra expressions
- Allows us to refer to a relation by more than one name
- **Example:**

$\rho_x(E)$

returns the expression  $E$  under the name  $X$

- If a relational algebra expression  $E$  has arity  $n$ , then

$\rho_{x(A_1, A_2, \dots, A_n)}(E)$

returns the result of the expression  $E$  under the name  $X$  and with the attributes renamed to  $A_1, A_2, \dots, A_n$

## DIVISION operation

- The division operation is applied to two relations
- $R(Z) \div S(X)$ , where  $X$  subset  $Z$
- Let  $Y = Z - X$  (and hence  $Z = X \cup Y$ )  
that is, let  $Y$  be the set of attributes of  $R$  that are not attributes of  $S$
- The result of **DIVISION** is a relation  $T(Y)$  that includes a tuple  $t$  if tuples  $t_R$  appear in  $R$  with  $t_R[Y] = t$ , and with
  - $t_R[X] = t_s$  for every tuple  $t_S$  in  $S$
- For a tuple  $t$  to appear in the result  $T$  of the **DIVISION**, the value in  $t$  must appear in  $R$  in combination with every tuple in  $S$
- Division is a derived operation and can be expressed in terms of other operations
- $r \div s \equiv \Pi_{R-S}(r) - \Pi_{R-S}(r)((\Pi_{R-S}(r) \times s) - \Pi_{R-S,S}(r))$

## DIVISION Example #1

R	S	$R \mid S$
<u>Aa</u> Lecturer $\equiv$ Module		
Brown	Compilers	
Brown	Databases	
Green	Prolog	
Green	Databases	
Lewis	Prolog	
Smith	Databases	

<u>Aa</u> Subject
Prolog

<u>Aa</u> Lecturer
Green
Lewis

## DIVISION Example #2

R	S	$R \mid S$
<u>Aa</u> Lecturer $\equiv$ Module		
Brown	Compilers	
Brown	Databases	
Green	Prolog	
Green	Databases	
Lewis	Prolog	
Smith	Databases	

<u>Aa</u> Subject
Databases
Prolog

<u>Aa</u> Lecturer
Green

## DIVISION Example #3

A	B1	$A \mid B1$
<u>Aa</u> sno $\equiv$ pno	<u>Aa</u> pno	<u>Aa</u> sno

Aa	sno	pno
s1	p1	
s1	p2	
s1	p3	
s1	p4	
s2	p1	
s2	p2	
s3	p2	
s4	p2	
s4	p4	

Aa	pno
p2	

B2

Aa	pno
p2	
p4	

B3

Aa	pno
p1	
p2	
p4	

Aa	sno
s1	
s2	
s3	
s4	

A / B2

Aa	sno
s1	
s4	

A / B3

Aa	sno
s1	

## DIVISION Example #4

- Relation  $r, s$

r

Aa	A	$\equiv$	B
$\underline{\alpha}$	1		
$\underline{\alpha}$	2		
$\underline{\alpha}$	3		
$\underline{\beta}$	1		
$\underline{\gamma}$	1		
$\underline{\delta}$	1		
$\underline{\delta}$	3		
$\underline{\delta}$	4		
$\underline{\equiv}$	6		
$\underline{\equiv}$	1		
$\underline{\beta}$	2		

s

Aa	B
1	
$\underline{2}$	

$r \div s$

Aa	A
$\underline{\alpha}$	
$\underline{\beta}$	

## DIVISION Example #5

- Relation  $r, s$ :

r

Aa	A	$\equiv$	B	$\equiv$	C	$\equiv$	D	$\equiv$	E
$\underline{\alpha}$	a		$\alpha$		a		1		
$\underline{\alpha}$	a		$\gamma$		a		1		
$\underline{\alpha}$	a		$\gamma$		b		1		
$\underline{\beta}$	a		$\gamma$		a		1		
$\underline{\beta}$	a		$\gamma$		b		3		
$\underline{\gamma}$	a		$\gamma$		a		1		
$\underline{\gamma}$	a		$\gamma$		b		1		
$\underline{\gamma}$	a		$\beta$		b		1		

s

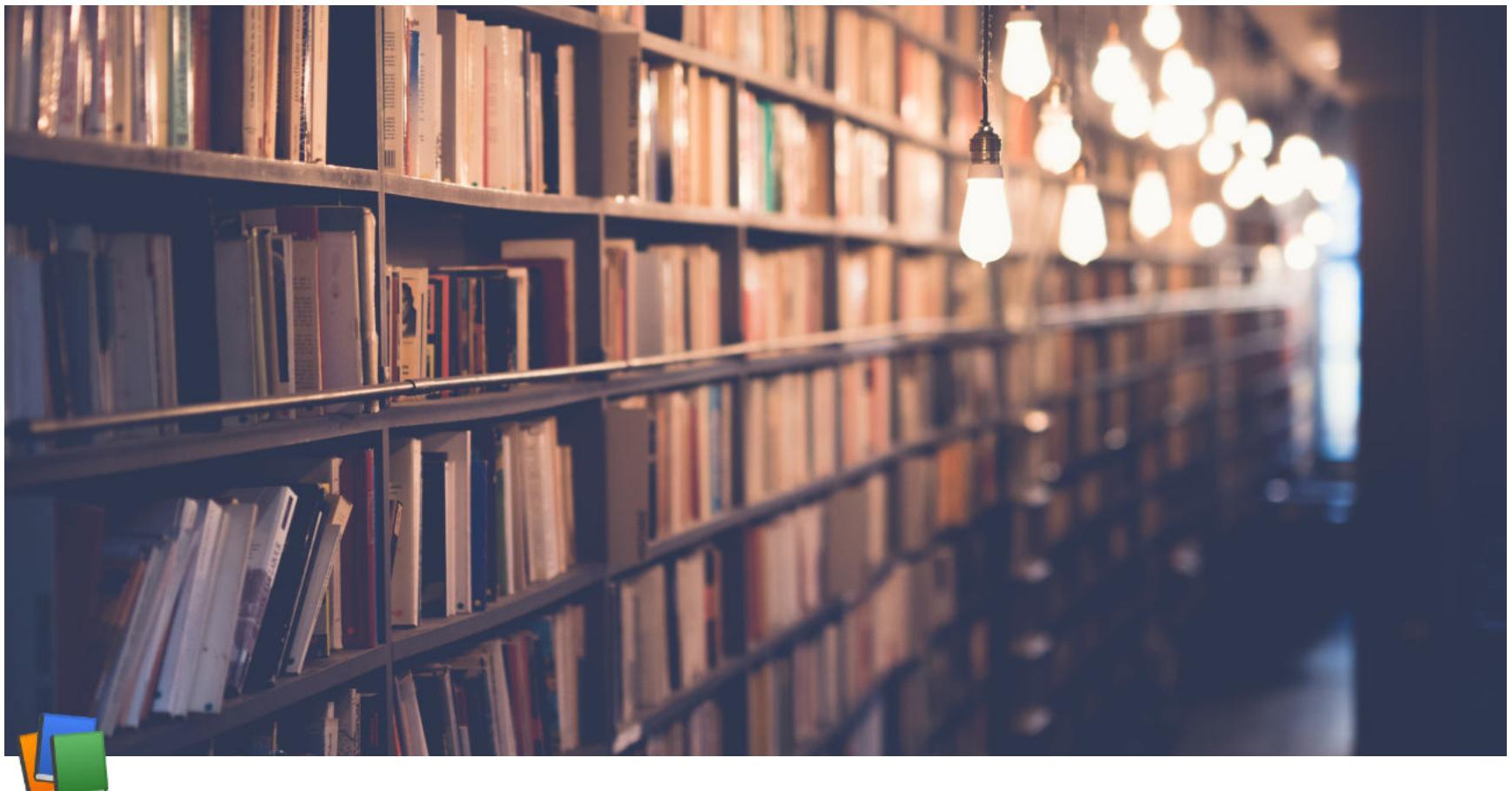
Aa	D	$\equiv$	E
$\underline{a}$			1
$\underline{b}$			1

$r \div s$

Aa	A	$\equiv$	B	$\equiv$	C
$\underline{\alpha}$	a		$\gamma$		
$\underline{\gamma}$	a		$\gamma$		

eg: Students who have taken both "a" and "b" courses, with instructor "1"

(Find all the students who have taken all courses given by the instructor 1)



## Week 4 Lecture 2

Class	BSCCS2001
Created	@September 30, 2021 10:23 AM
Materials	
Module #	17
Type	Lecture
Week #	4

## Formal Relational Query Languages (part 2)

### Predicate Logic

**Predicate Logic** or **Predicate Calculus** is an extension of **Propositional Logic** or **Boolean Algebra**

It adds the concept of predicates and quantifiers to better capture the meaning of statements that cannot be adequately expressed by propositional logic

**Tuple Relational Calculus** and **Domain Relational Calculus** are based on **Predicate Calculus**

### Predicate

- Consider the statement: "x is greater than 3"
  - It has 2 parts
  - The first part is the variable **x**
    - It is the subject of the statement
  - The second part "**is greater than 3**"
    - It is the predicate of the statement
    - This refers to the property that the subject of the statement can have
- The statement "x is greater than 3" can be denoted by  $P(x)$  where  $P$  denotes the predicate "is greater than 3" and  $x$  is the variable
- The predicate  $P$  can be considered as a function. It tells the truth value of the statement  $P(x)$  at  $x$ 
  - Once a value has been assigned to the variable  $x$ , the statement  $P(x)$  becomes a proposition and has a *truth* or *false* value

- In general, a statement involving  $n$  variables  $x_1, x_2, x_3, \dots, x_n$  can be denoted by  $P(x_1, x_2, x_3, \dots, x_n)$ 
  - Here,  $P$  is also referred to as the  $n$ -place predicate or an  $n$ -ary predicate

## Quantifiers

In predicate logic, predicates are used alongside quantifiers to express the extent to which a predicate is true over a range of elements

Using **quantifiers** to create such propositions is called **quantification**

There are 2 types of quantifiers:

- **Universal Quantifier**
- **Existential Quantifier**

## Universal Quantifier

**Universal Quantification:** Mathematical statements sometimes assert that a property is true for all the values of a variable in a particular domain, called the **Domain of Discourse**

- Such a statement is expressed using universal quantification
- The universal quantification of  $P(x)$  for a particular domain is the proposition that assert that  $P(x)$  is *true* for all values of  $x$  in this domain
- The domain is very important here since it decides the possible values of  $x$
- Formally, the universal quantification of  $P(x)$  is the statement " $P(x)$  for all values of  $x$  in the domain"
- The notation  $\forall P(x)$  denotes the universal quantification of  $P(x)$ 
  - Here,  $\forall$  is called the **universal quantifier**
  - $\forall P(x)$  is read as "**for all  $x$   $P(x)$** "
- **Example:** Let  $P(x)$  be the statement " $x + 2 > x$ "
  - What is the truth value of the statement  $\forall x P(x)$ ?
- **Solution:** As  $x + 2$  is greater than  $x$  for any real number, so  $P(x) \equiv T$  for all  $x$  or  $\forall x P(x) \equiv T$

## Existential Quantifier

**Existential Quantification:** Some mathematical statements assert that there is an element with a certain property

Such statements are expressed by existential quantification

Existential quantification can be used to form a proposition that is true if and only if  $P(x)$  is *true* for at least one value of  $x$  in the domain

- Formally, the existential quantification of  $P(x)$  is the statement "There exists an element  $x$  in the domain such that  $P(x)$ "
- The notation  $\exists P(x)$  denotes the existential quantification of  $P(x)$ 
  - Here  $\exists$  is called the existential quantifier
  - $\exists P(x)$  is read as "There is at least one such  $x$  such that  $P(x)$ "
- **Example:** Let  $P(x)$  be the statement " $x > 5$ "
  - What is the truth value of the statement  $\exists x P(x)$ ?
- **Solution:**  $P(x)$  is *true* for all real numbers greater than 5 and *false* for all real numbers less than 5
  - So,  $\exists x P(x) \equiv T$

## Tuple Relational Calculus

TRC is a non-procedural query language, where each query is of the form

$\{t | P(t)\}$

where  $t$  = resulting tuples

$P(t)$  = known as predicate and these are the conditions that are used to fetch  $t$

$P(t)$  may have various conditions logically combined with **OR**( $\vee$ ), **AND**( $\wedge$ ), **NOT**( $\neg$ )

It also uses quantifiers:

$\exists t \in r(Q(t))$  = "there exists" a tuple in  $t$  in relation  $r$  such that predicate  $Q(t)$  is true

$\forall t \in r(Q(t))$  =  $Q(t)$  is true "for all" tuples in relation  $r$

- $\{P | \exists S \in Students \text{ and } (S.CGPA > 8 \wedge P.name = S.name \wedge P.age = S.age)\}$  :

returns the name and age of students with a CGPA above 8

## Predicate Calculus Formula

- Set of attributes and constants
- Set of comparison operators: (eg:  $<$ ,  $\leq$ ,  $=$ ,  $\neq$ ,  $>$ ,  $\geq$ )
- Set of connectives: and( $\wedge$ ), or( $\vee$ ), not( $\neg$ )
- Implication ( $\Rightarrow$ ):  $x \Rightarrow y$ , if  $x$  is true, then  $y$  is true  

$$x \Rightarrow y \equiv \neg x \vee y$$
- Set of quantifiers:
  - $\exists t \in r(Q(t)) \equiv$  "there exists" a tuple in  $t$  in relation  $r$  such that predicate  $Q(t)$  is true
  - $\forall t \in r(Q(t)) \equiv Q$  is true "for all" tuples  $t$  in relation  $r$

## TRC Example #1

### Student

Aa	Fname	≡	Lname	#	Age	≡	Course
<u>David</u>	Sharma		27		DBMS		
<u>Aaron</u>	Lilly		17		JAVA		
<u>Sahil</u>	Khan		19		Python		
<u>Sachin</u>	Rao		20		DBMS		
<u>Varun</u>	George		23		JAVA		
<u>Simi</u>	Verma		22		JAVA		

**Q. 1:** Obtain the first name of students whose age is greater than 21

### Solution:

$$\{t.Fname \mid Student \wedge t.age > 21\}$$

$$\{t.Fname \mid t \in Student \wedge t.age > 21\}$$

$$\{t \mid \exists s \in Student(s.age > 21 \wedge t.Fname = s.Fname)\}$$

Aa	Fname
<u>David</u>	
<u>Varun</u>	
<u>Simi</u>	

## TRC Example #2

Consider the relational schema

```
student(rollNo, name, year, courseId)
course(courseId, cname, teacher)
```

**Q. 2:** Find out the names of all the students who have taken the course named 'DBMS'

- $\{t \mid \exists s \in student \exists c \in course(s.courseId = c.courseId \wedge c cname = 'DBMS' \wedge t.name = s.name)\}$
- $\{s.name \mid s \in student \wedge \exists c \in course(s.courseId = c.courseId \wedge c cname = 'DBMS')\}$

**Q. 3:** Find out the names of all students and their rollNo who have taken the course named 'DBMS'

- $\{s.name, s.rollNo \mid s \in student \wedge \exists c \in course(s.courseId = c.courseId \wedge c cname = 'DBMS')\}$
- $\{t \mid \exists s \in student \exists c \in course(s.courseId = c.courseId \wedge c cname = 'DBMS' \wedge t.name = s.name \wedge t.rollNo = s.rollNo)\}$

### TRC Example #3

Consider the following relations:

```

Flights(flno, from, to, distance, departs, arrive)
Aircraft(aid, fname, cruisingrange)
Certified(eid, aid)
Employees(eid, ename, salary)

```

**Q. 4:** Find the eids of pilots certified for Boeing aircraft

**RA**

$$\Pi_{eid}(\sigma_{fname='Boeing'}(Aircraft \bowtie Certified))$$

**TRC**

- $\{C.eid \mid C \in Certified \wedge \exists A \in Aircraft(A.aid = C.aid \wedge A.fname = 'Boeing')\}$
- $\{T \mid \exists C \in Certified \exists A \in Aircraft(A.aid = C.aid \wedge A.fname = 'Boeing' \wedge T.eid = C.eid)\}$

### TRC Example #4

Consider the following relations:

```

Flights (flno, from, to, distance, departs, arrives)
Aircraft (aid, fname, cruisingrange)
Certified (eid, aid)
Employees (eid, ename, salary)

```

**Q. 5:** Find the names and salaries of certified pilots working on Boeing aircrafts

**RA**

$$\Pi_{ename, salary}(\sigma_{fname='Boeing'}(Aircraft \bowtie Certified \bowtie Employees))$$

**TRC**

$$\{P \mid \exists E \in Employees \exists C \in Certified \exists A \in Aircraft(A.aid = C.aid \wedge A.fname = 'Boeing' \wedge E.eid = C.eid \wedge P.ename = E.ename \wedge P.salary = E.salary)\}$$

### TRC Example #5

Consider the following relations:

```

Flights (flno, from, to, distance, departs, arrive)
Aircraft (aid, fname, cruisingrange)
Certified (eid, aid)
Employees (eid, ename, salary)

```

**Q. 6:** Identify the flights that can be piloted by every pilot whose salary is more than \$100,000

- $\{Fl.flno \mid F \in Flights \wedge \exists C \in Certified \exists E \in Employees(E.salary > 100,000 \wedge E.eid = C.eid)\}$

## Safety of Expressions

- It is possible to write tuple calculus expressions that generate infinite relations
- For example,  $\{t \mid \neg t \in r\}$  results in an infinite relation if the domain of any attribute of the relation  $r$  is infinite
- To guard against the problem, we restrict the set of allowable expressions to safe expressions
- An expression  $\{t \mid P(t)\}$  in the tuple relational calculus is safe if every component of  $t$  appears in one of the relations, tuples or constants that appear in  $P$ 
  - **NOTE:** This is more than just a syntax condition
  - Eg:  $\{t \mid t[A] = 5 \vee true\}$  is not safe → it defines an infinite set with attribute values that do not appear in any relation or tuples or constants in  $P$

## Domain Relational Calculus

- A non-procedural query language equivalent in power to the tuple relational calculus
- Each query is an expression of the form:

$$\{ < x_1, x_2, \dots, x_n > | P(x_1, x_2, \dots, x_n) \}$$

◦  $x_1, x_2, \dots, x_n$  represents domain variables

◦  $P$  represents a formula similar to that of the predicate calculus

## Equivalence of Relational Algebra, Tuple Relational Calculus & Domain Relational Calculus

### SELECT operation

$$R = (A, B)$$

**Relational Algebra:**  $\sigma_{B=17}(r)$

**Tuple Calculus:**  $\{t | t \in r \wedge B = 17\}$

**Domain Calculus:**  $\{ < a, b > | < a, b > \in r \wedge b = 17 \}$

### PROJECT operation

$$R = (A, B)$$

**Relational Algebra:**  $\Pi_A(r)$

**Tuple Calculus:**  $\{t | \exists p \in r (t[A] = p[A])\}$

**Domain Calculus:**  $\{ < a > | \exists b (< a, b > \in r) \}$

### COMBINING operation

$$R = (A, B)$$

**Relational Algebra:**  $\Pi_A(\sigma_{B=17}(r))$

**Tuple Calculus:**  $\{t | \exists p \in r (t[A] = p[A] \wedge p[B] = 17)\}$

**Domain Calculus:**  $\{ < a > | \exists b (< a, b > \in r \wedge b = 17) \}$

### UNION

$$R = (A, B, C) \quad S = (A, B, C)$$

**Relational Algebra:**  $r \cup s$

**Tuple Calculus:**  $\{t | t \in r \vee t \in s\}$

**Domain Calculus:**  $\{ < a, b, c > | < a, b, c > \in r \vee < a, b, c > \in s \}$

### SET DIFFERENCE

$$R = (A, B, C) \quad S = (A, B, C)$$

**Relational Algebra:**  $r - s$

**Tuple Calculus:**  $\{t | t \in r \wedge t \notin s\}$

**Domain Calculus:**  $\{ < a, b, c > | < a, b, c > \in r \wedge < a, b, c > \notin s \}$

### INTERSECTION

$$R = (A, B, C) \quad S = (A, B, C)$$

**Relational Algebra:**  $r \cap s$

**Tuple Calculus:**  $\{t | t \in r \wedge t \in s\}$

**Domain Calculus:**  $\{ < a, b, c > | < a, b, c > \in r \wedge < a, b, c > \in s \}$

### CARTESIAN / CROSS PRODUCT

$$R = (A, B) \quad S = (C, D)$$

**Relational Algebra:**  $r \times s$

**Tuple Calculus:**  $\{t \mid \exists p \in r \exists q \in s (t[A] = p[A] \wedge t[B] = p[B] \wedge t[C] = q[C] \wedge t[D] = q[D])\}$

**Domain Calculus:**  $\{\langle a, b, c, d \rangle \mid \langle a, b \rangle \in r \wedge \langle c, d \rangle \in s\}$

### NATURAL JOIN

$$R = (A, B, C, D) \quad S = (B, D, E)$$

**Relational Algebra:**

$$r \bowtie s$$

$$\Pi_{r.A, r.B, r.C, r.D, s.E} (\sigma_{r.B=s.B \wedge r.D=s.D} (r \times s))$$

**Tuple Calculus:**

$$\{t \mid \exists p \in r \exists q \in s (t[A] = p[A] \wedge t[B] = p[B] \wedge t[C] = p[C] \wedge t[D] = p[D] \wedge t[E] = q[E] \wedge p[B] = q[B] \wedge p[D] = q[D])\}$$

**Domain Calculus:**

$$\{\langle a, b, c, d, e \rangle \mid \langle a, b, c, d \rangle \in r \wedge \langle b, d, e \rangle \in s\}$$

### DIVISION

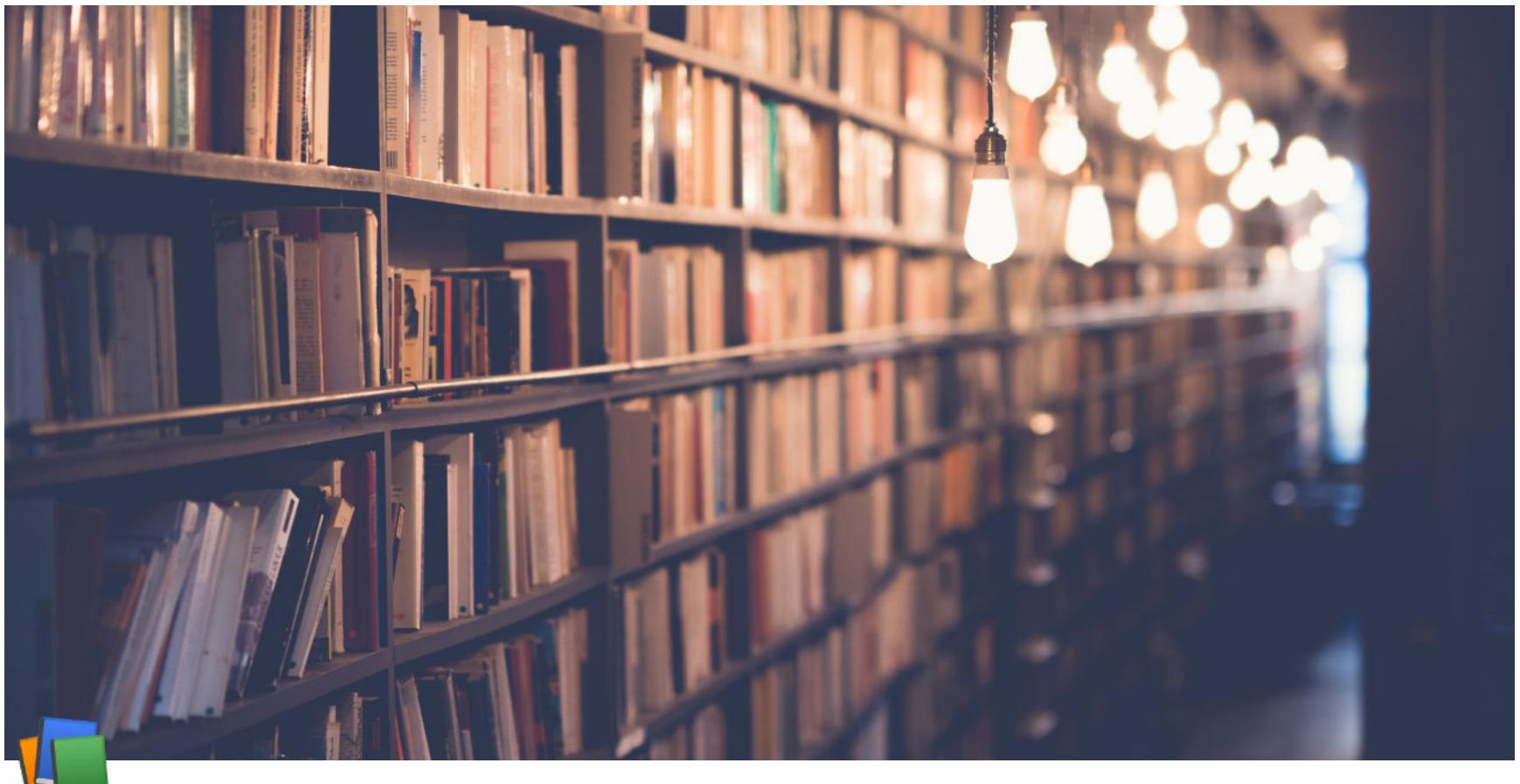
$$R = (A, B) \quad S = (B)$$

**Relational Algebra:**  $r \div s$

**Tuple Calculus:**  $\{t \mid \exists p \in r \forall q \in s (p[B] = q[B] \Rightarrow t[A] = p[A])\}$

**Domain Calculus:**  $\{\langle a \rangle \mid \langle a \rangle \in r \wedge \forall \langle b \rangle (\langle b \rangle \in s \Rightarrow \langle a, b \rangle \in r)\}$

**Source:** [https://www2.cs.sfu.ca/CourseCentral/354/louie/Equiv\\_Notations.pdf](https://www2.cs.sfu.ca/CourseCentral/354/louie/Equiv_Notations.pdf)



## Week 4 Lecture 3

Class	BSCCS2001
Created	@September 30, 2021 4:40 PM
Materials	
Module #	18
Type	Lecture
Week #	4

## Entity-Relationship Model

### Design Process

#### What is a Design?

A Design:

- Satisfies a given (perhaps informal) functional specification
- Conforms to the limitations of the target medium
- Meets implicit or explicit requirements on performance and resource usage
- Satisfies implicit or explicit design criteria on the form of the artifact
- Satisfies restrictions on the design itself, such as its length or cost, or the tools available for doing the design

#### Role of Abstraction

- Disorganized Complexity results from
  - Storage (STM) limitations of the human brain - an individual can simultaneously comprehend of the order of seven, plus or minus two chunks of information
  - Speed limitations of human brain - it takes the mind about five seconds to accept a new chunk of information
- **Abstraction** provides the major tool to handle Disorganized Complexity by chunking information
- Ignore in-essential details, deal only with the generalized, idealized model of the world

Consider: A binary number `110010101001`

Hard to remember

Try the octal form: `(110)(010)(101)(001)`  $\Rightarrow$  **6251**

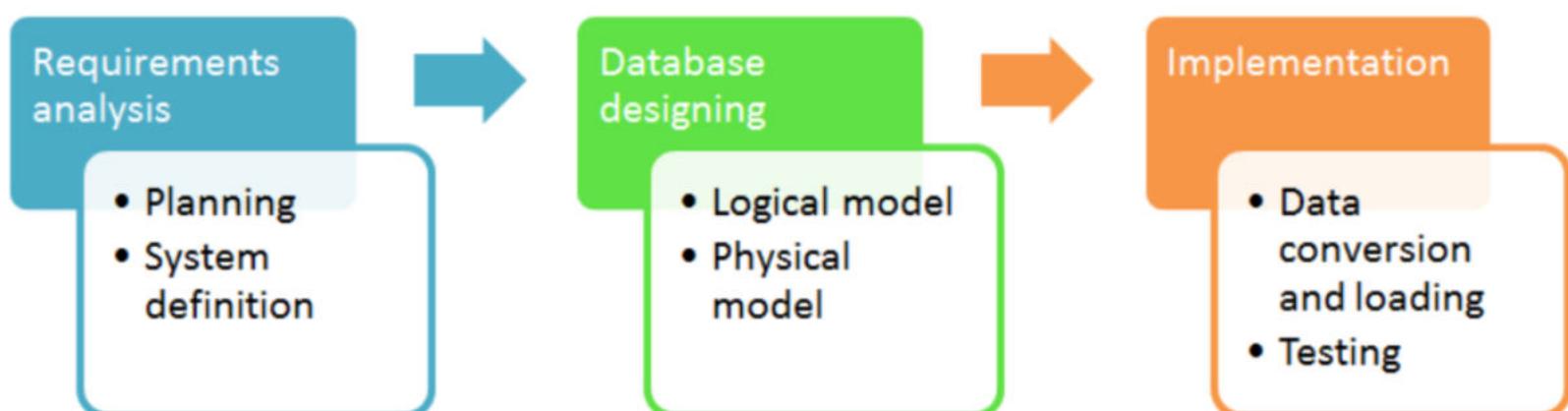
Or the hex form: `(1100)(1010)(1001)`  $\Rightarrow$  **CA9**

## Model Building

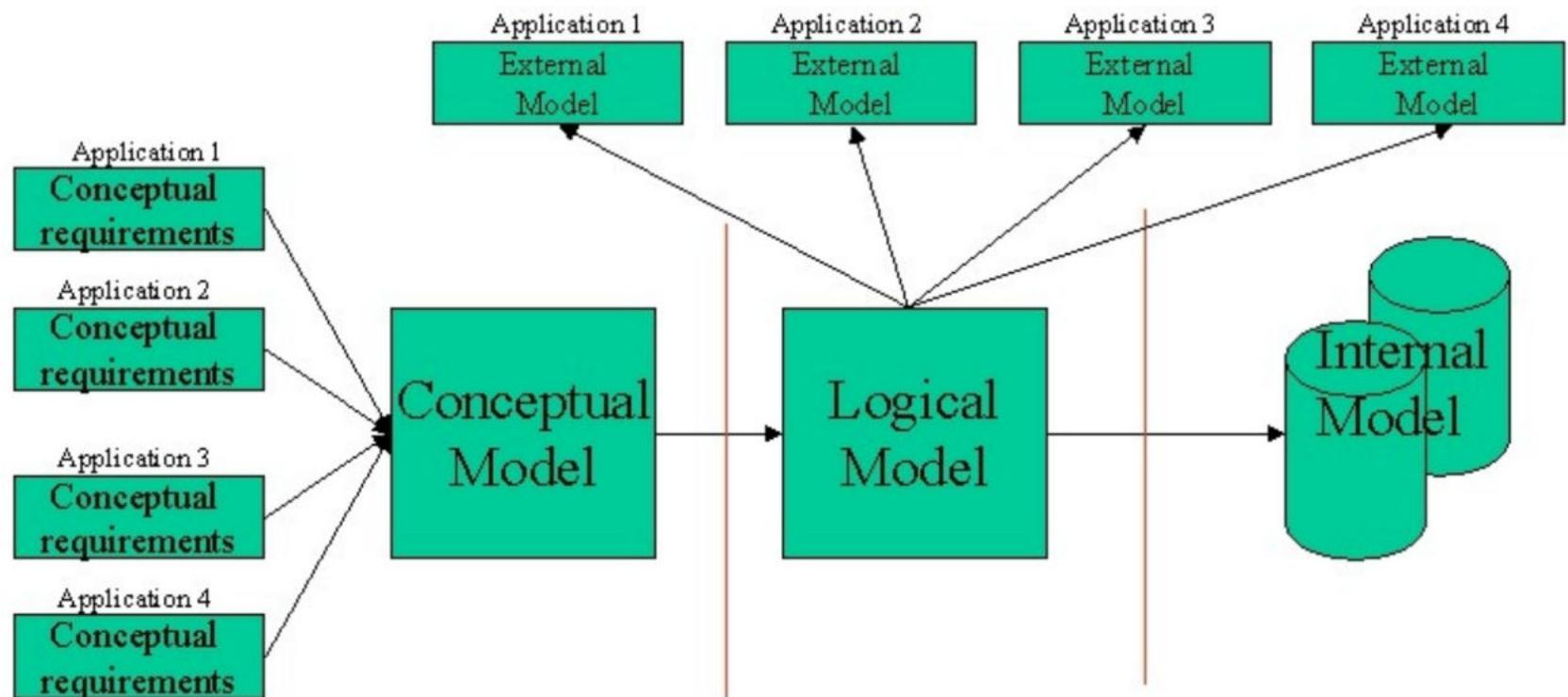
- Physics
  - Time-Distance Equation
  - Quantum Mechanics
- Chemistry
  - Valency-bond Structures
- Geography
  - Maps
  - Projections
- Electrical Circuits
  - Kirchoff's Loop Equations
  - Time Series Signals and FFT
  - Transistor Models
  - Schematic Diagrams
  - Interconnect Routing
- Building & Bridges
  - Drawings - Plan, Elevation, Side view
  - Finite Element Models
- Models are common in all engineering disciplines
- Model building follows principles of decomposition, abstraction and hierarchy
- Each model describes a specific aspect of the system
- Build new models upon old proven models

## Design Approach

- **Requirement Analysis:** Analyse the data needs of the prospective DB users
  - Planning
  - System Defining
- **DB Designing:** Use a modeling framework to create abstraction of the real world
  - Logical Model
  - Physical Model
- **Implementation**
  - Data Conversion and Loading
  - Testing



- **Logical Model:** Deciding on a good DB schema
  - Business Decision: What attributes should we record in the DB?
  - Computer Science Decision: What relation schema should we have and how should the attributes be distributed among the various relation schema?
- **Physical Model:** Deciding on the physical layout of the DB



- **Entity Relationship Model**
  - Models an enterprise as a collection of entities and relationships
    - Entity → A distinguishable "thing" or "object" in the enterprise
      - Described by a set of attributes
    - Relationship → An association among multiple entities
  - Represented by an **Entity-Relationship or ER diagram**
- **Database Normalization**
  - Formalize what designs are bad and test for them

## Entity Relationship (ER) Model

### ER Model: Database Modeling

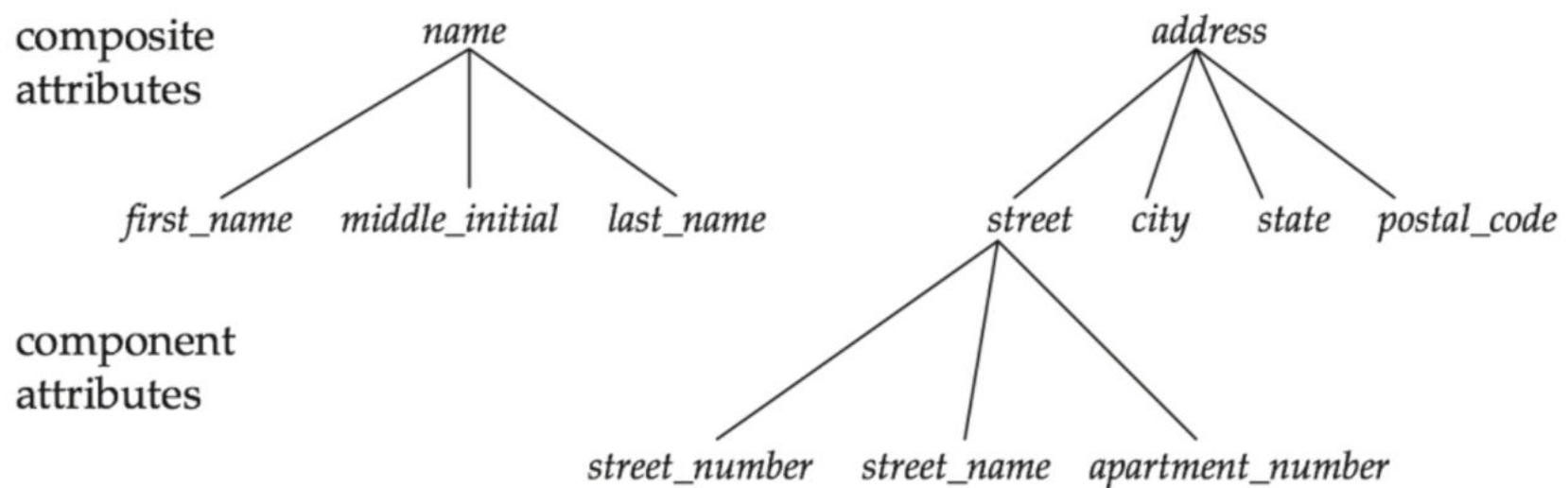
- The ER data model was developed to facilitate DB design by allowing specification of an enterprise schema that represents the overall logical structure of a DB
- The ER model is useful in mapping the meanings and interactions of the real world enterprises onto a conceptual schema
- The ER data model employs three basic concepts:
  - Attributes
  - Entity sets
  - Relationship sets
- The ER model also has an associated diagrammatic representation, the ER diagram, which can express the overall logical structure of a DB graphically

### Attributes

- An attribute is a property associated with an entity / entity set
- Based on the values of certain attributes, an entity can be identified uniquely
- Attribute types:
  - Simple and Composite attributes
  - Single-valued and Multi-valued attributes
    - **Example:** Multi-valued attribute: *phone\_numbers*
  - Derived attributes
    - Can be computed from other attributes
    - Example: *age*, *given date\_of\_birth*

- Domain: The set of permitted values for each attribute

## Attributes: Composite



## Entity sets

- An entity is an object that exists and is distinguishable from other objects
  - Example: specific person, company, event, plant
- An entity set is a set of entities of the same type that share the same properties
  - Example: set of all persons, companies, trees, holidays
- An entity is represented by a set of attributes: ie, descriptive properties possessed by all members of an entity set
  - Example:

```

instructor = (ID, name, street, city, salary)
course = (course_id, title, credits)

-- Here ID and course_id are the primary keys, but
-- the tool I am using to make PDFs is not marking them underline

```

- A subset of the attributes form a primary key of the entity set; that is, uniquely identifying each member of the set
  - Primary key of an entity set is represented by underlining it

## Entity sets - instructor and student

**instructor**

#	instructor_id	Aa instructor_name
76766	Crick	
45565	Katz	
10101	Srinivasan	
98345	Kim	
76543	Singh	
22222	Einstein	

**student**

	student_id	Aa student_name
98988	Tanaka	
12345	Shankar	
00128	Zhang	
76543	Brown	
76653	Aoi	
23121	Chavez	
44553	Peltier	

## Relationship sets

- A relationship is an association among several entities

Example:

44553 (Peltier)	<u>advisor</u>	22222 (Einstein)
student entity	relationship set	instructor entity

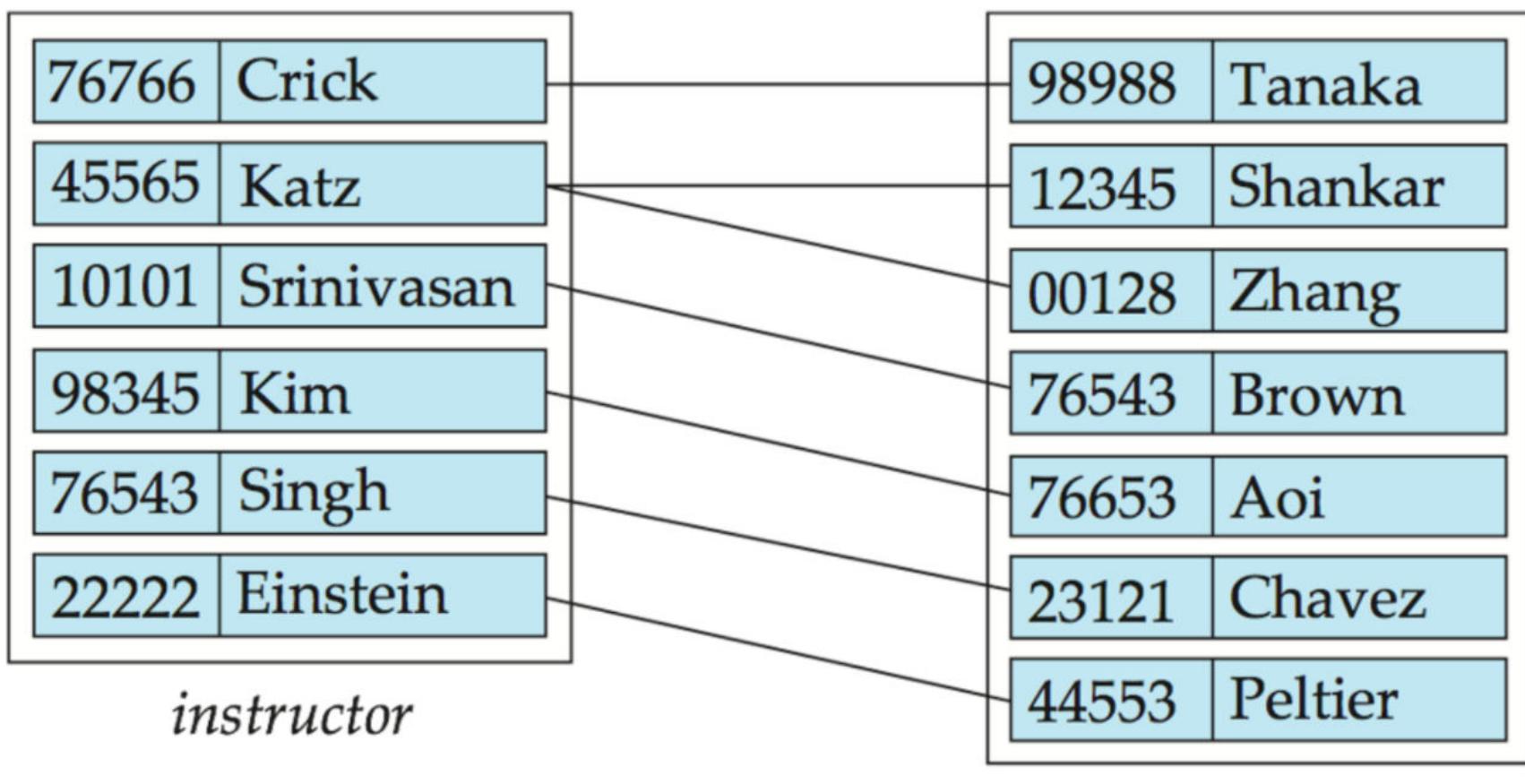
- A relationship set is a mathematical relation among  $n \geq 2$  entities, each taken from entity sets

$$\{(e_1, e_2, \dots, e_n) | e_1 \in E_1, e_2 \in E_2, \dots, e_n \in E_n\}$$

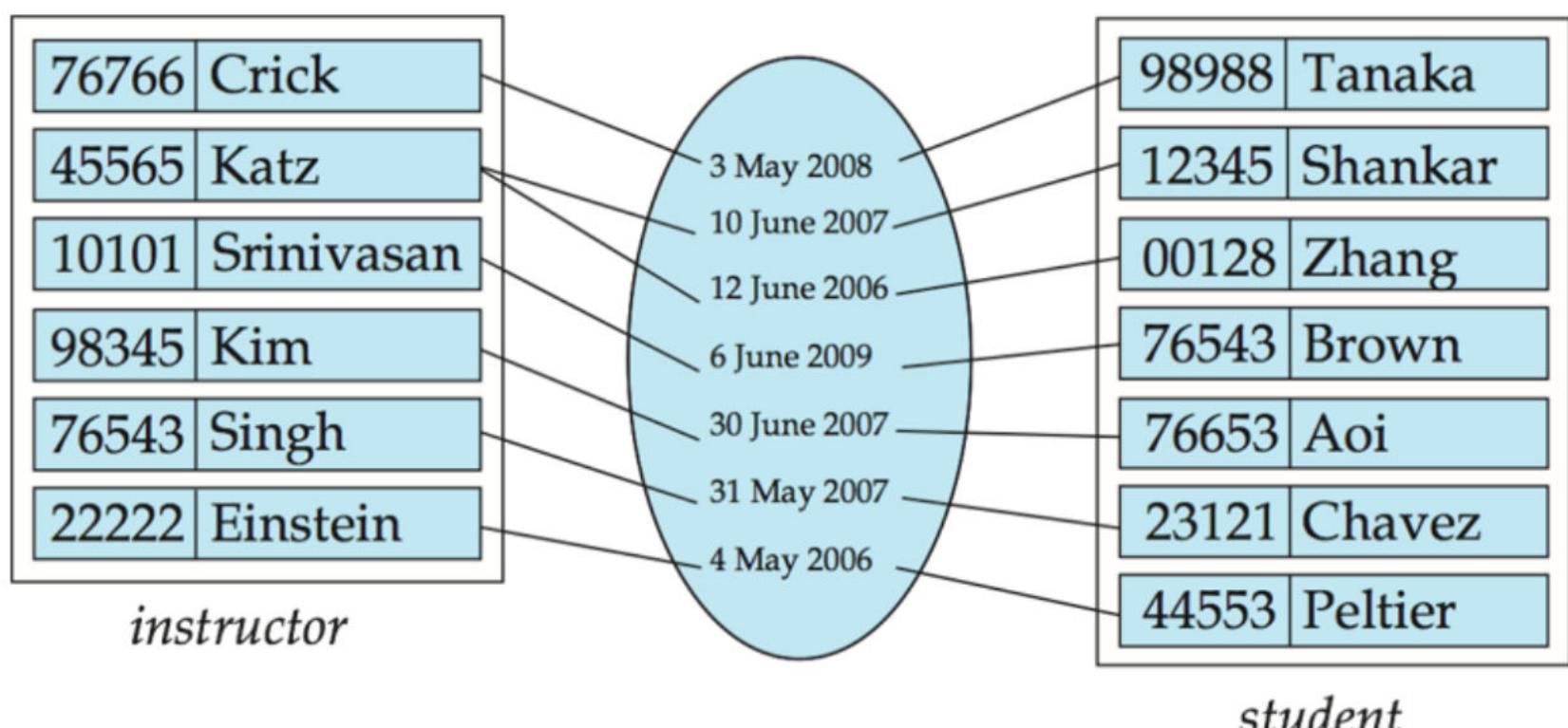
where  $(e_1, e_2, \dots, e_n)$  is a relationship

- Example:  $(44553, 22222) \in \text{advisor}$

### Relationship set: advisor



- An attribute can also be associated with a relationship set
- For instance, the `advisor` relationship set between entity sets `instructor` and `student` may have the attribute `date` which tracks when the student started being associated with the advisor



- **Binary relationship**
  - involves two entity sets (or degree two)
  - most relationship sets in a database systems are binary
- Relationships between more than two entity sets are rare
  - Most relationships are binary
  - Example: students work on research projects under the guidance of an instructor
  - Relationship `proj_guide` is a ternary relationship between `instructor`, `student` and `project`

### Attributes: Redundant

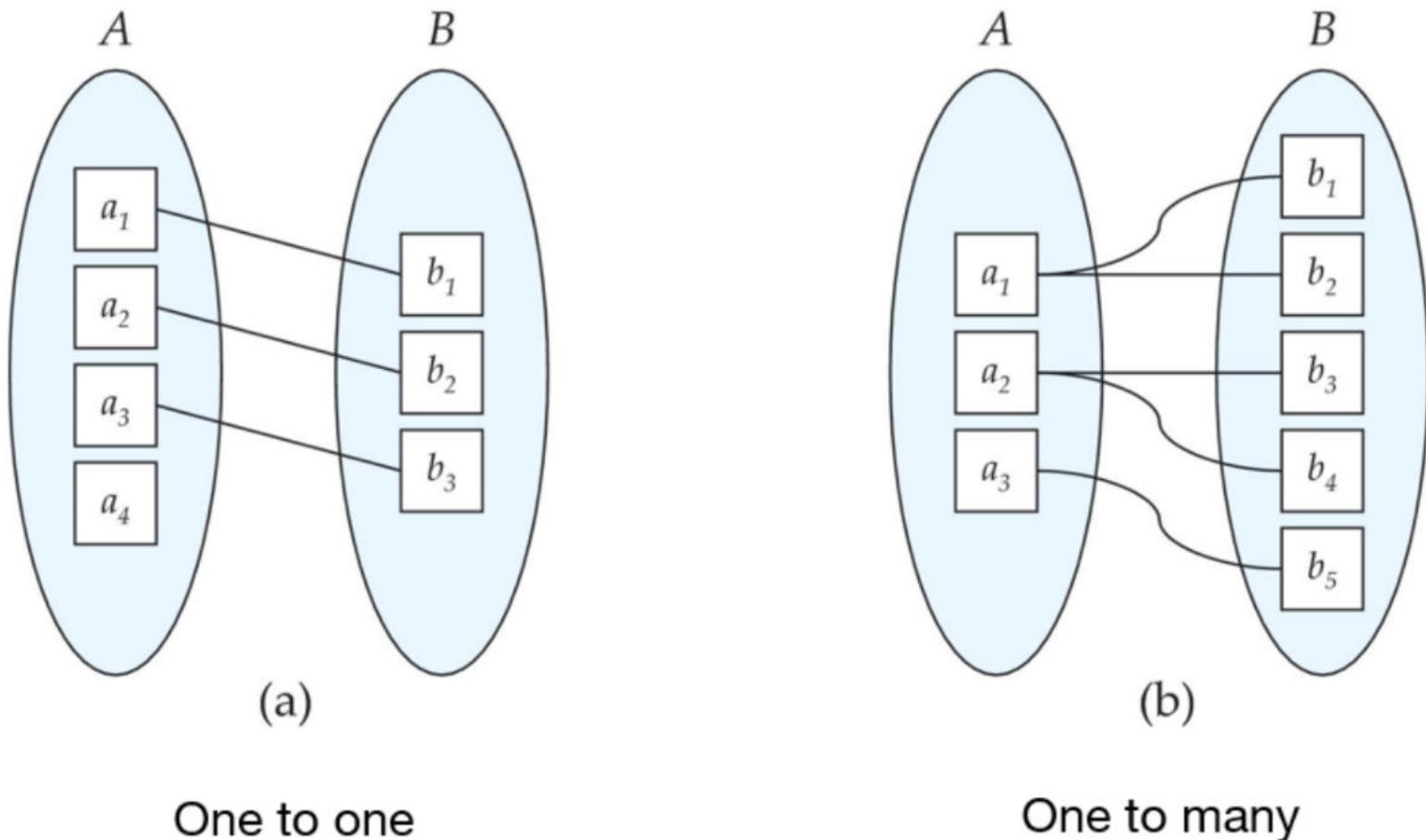
- Suppose we have entity sets:

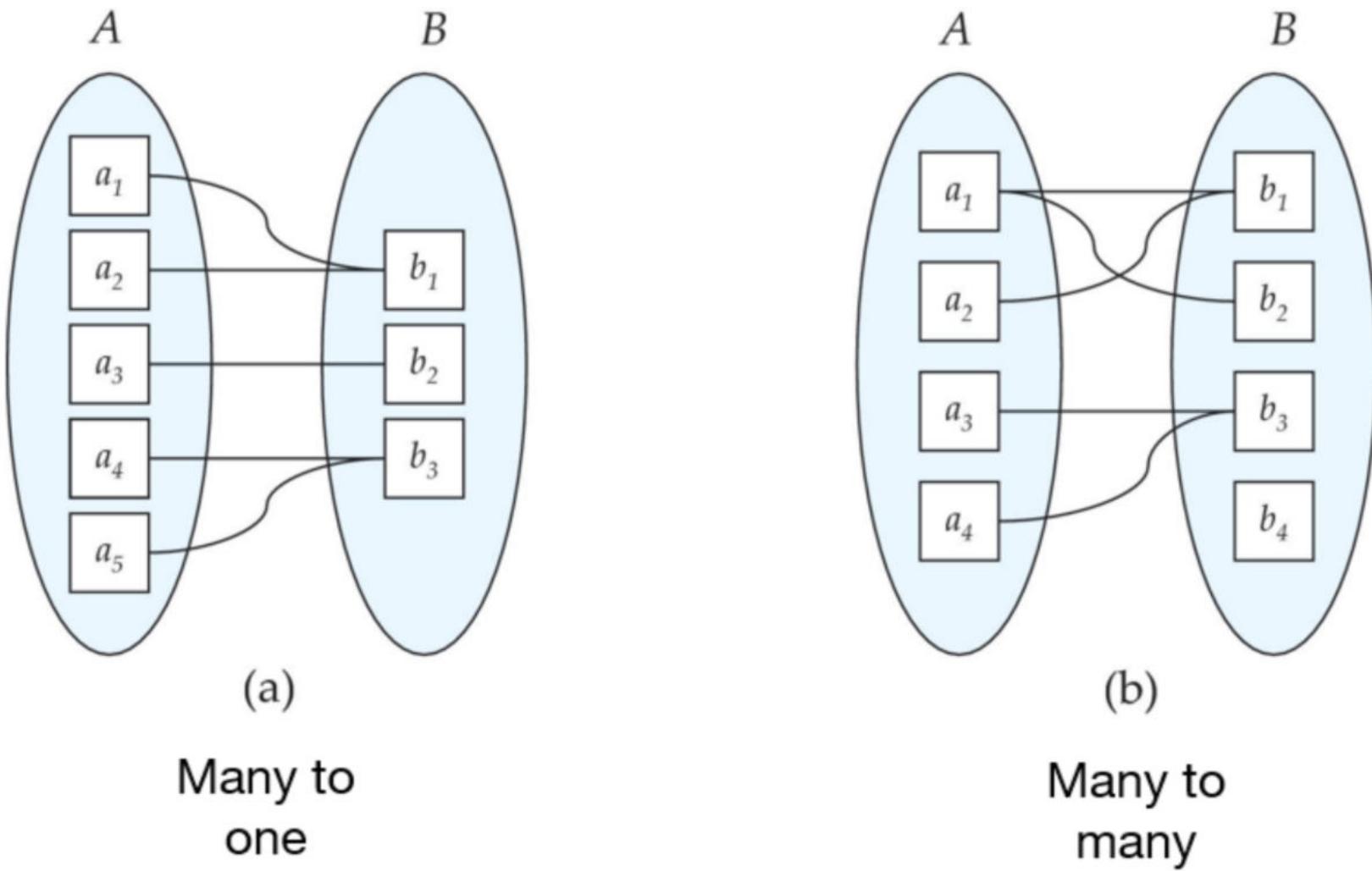
- *instructors*, with attributes: *ID*, *name*, *dept\_name*, *salary*
- *department*, with attributes: *dept\_name*, *building*, *budget*
- We model the fact that each instructor has an associated department using a relationship set *inst\_dept*
- The attribute *dept\_name* appears in both entity sets
  - Since it is the primary key for the entity set *department*, it replicates information present in the relationship and is therefore redundant in the entity set *instructor* and needs to be removed
- **BUT:** When converting back to tables, in some cases the attributes gets re-introduced, as we will see later

## Mapping Cardinality: Constraints

- Express the number of entities to which another entity can be associated via a relationship set
- Most useful in describing binary relationship sets
- For a binary relationship set the mapping cardinality must be one of the following types:
  - One to One
  - One to Many
  - Many to One
  - Many to Many

## Mapping Cardinalities





**NOTE:** Some elements in A and B may not be mapped to any elements in the other set

### Weak Entity sets

An entity set may be one of the two types:

- Strong entity set
  - A strong entity set is an entity set that contains sufficient attributes to uniquely identify all its entities
  - In other words, **a primary key exists for a strong entity set**
  - Primary key of a strong entity set is represented by underlining it
- Weak entity set
  - A weak entity set is an entity set that does not contain sufficient attributes to uniquely identify its entities
  - In other words, **a primary key does not exist for a weak entity set**
  - However, it contains a partial key called as the **discriminator**
  - Discriminator can identify a group of entities from the entity set
  - Discriminator is represented by underlining with a dashed line
- Since a weak entity set does not have a primary key, it cannot independently exist in the ER model
- It features in the model in relationship with a strong entity set
  - This is called as **the identifying relationship**
- Primary Key of a Weak entity set
  - The combination of discriminator and primary key of the strong entity set makes it possible to uniquely identify all entities of the weak entity set
  - Thus, this combination serves as a primary key for the weak entity set
  - Clearly, this primary key is not formed by the weak entity set completely
  - **Primary Key of a Weak Entity Set = Its own discriminator + Primary Key of Strong Entity Set**
- Weak entity set must have **total participation** in the identifying relationship
  - That is, all the entities must feature in the relationship

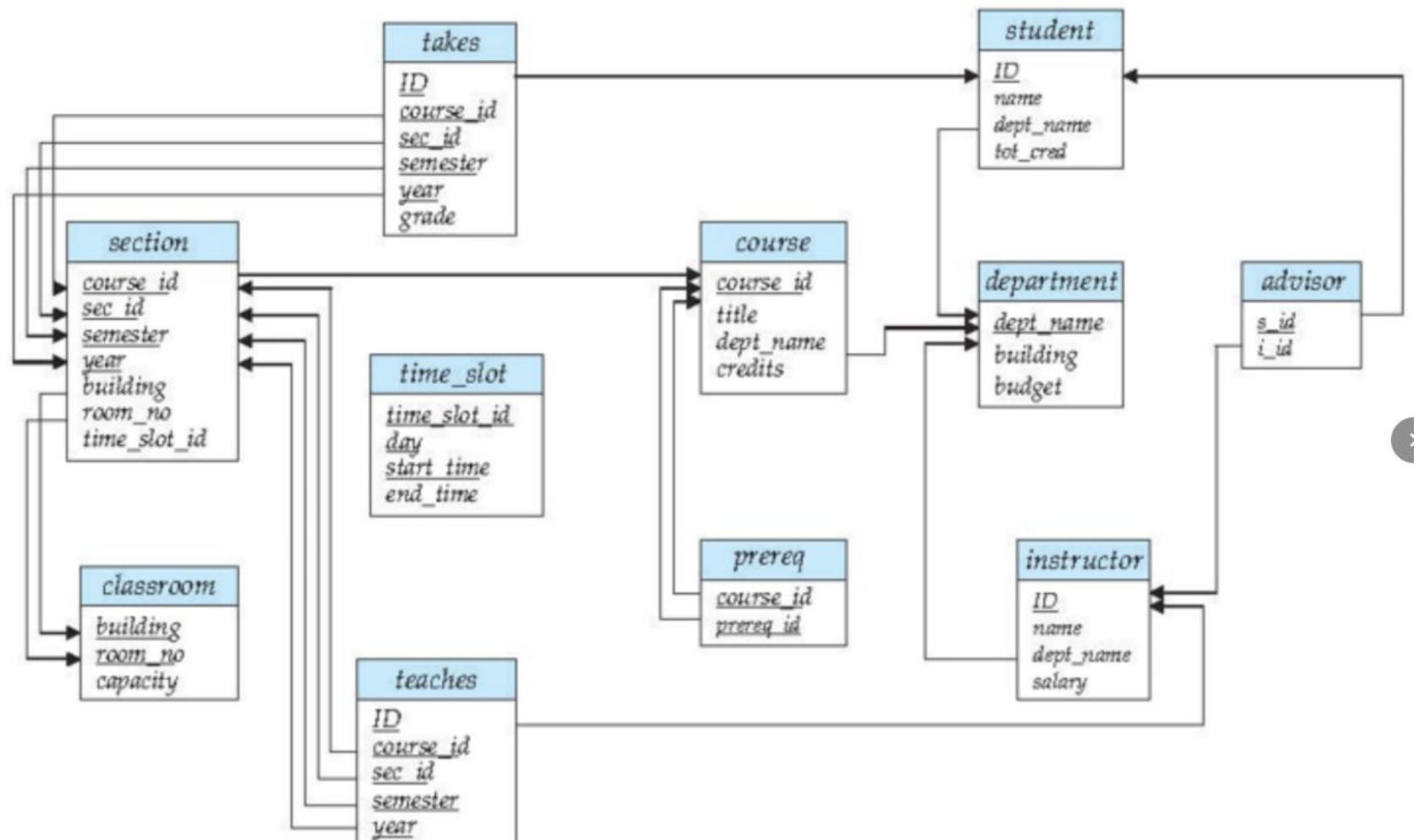
### Weak Entity set: Example

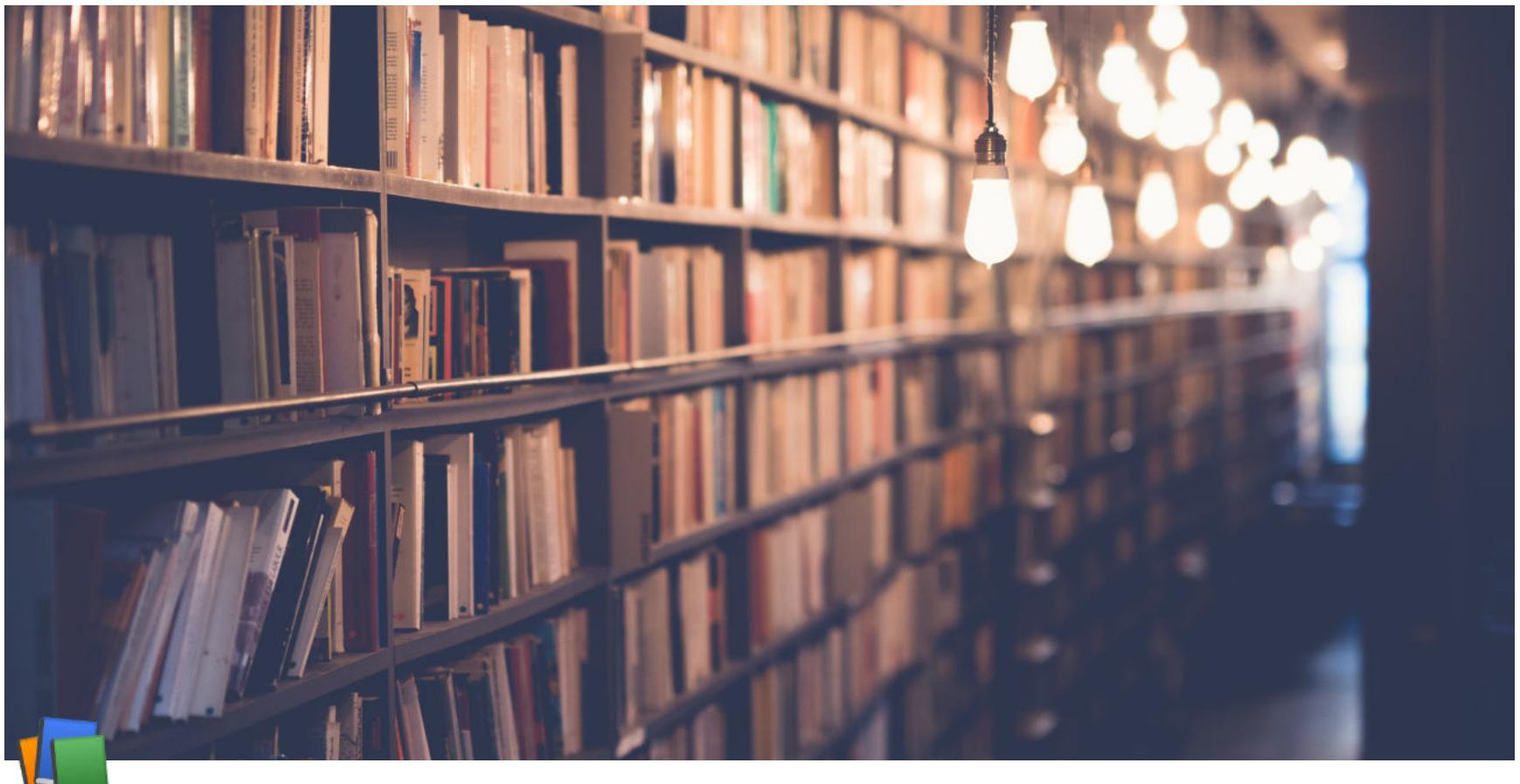
- **Strong Entity Set:** *Building*(building\_no, buildname, address)

- building\_no is the primary key here
- **Weak Entity Set:** *Apartment(door\_no, floor)*
  - door\_no is its discriminator as door\_no alone can not identify an apartment uniquely
  - There may be several other buildings having the same door number
- **Relationship:** *BA* between *Building* and *Apartment*
- By **total participation** in *BA*, each apartment must be present in at least one building
- In contrast, *Building* has **partial participation** in *BA* only as there might exist some buildings which has not apartment
- **Primary Key:** To uniquely identify an apartment
  - First, *building\_no* is required to identify the particular building
  - Second, *door\_no* of the apartment is required to uniquely identify the apartment
- Primary Key of Apartment = Primary Key of the Building + Its own discriminator = *building\_no* + *door\_no*

## Weak Entity set: Example #2

- Consider a section entity, which is uniquely identified by a *course\_id*, *semester*, *year* and *sec\_id*
- Clearly, section entities are related to course entities
  - Suppose we create a relationship set *sec\_course* between entity sets *section* and *course*
- Note that the information in *sec\_course* is redundant, since section already has an attribute *course\_id*, which identifies the course with which the section is related





## Week 4 Lecture 4

Class	BSCCS2001
Created	@September 30, 2021 6:29 PM
Materials	
Module #	19
Type	Lecture
Week #	4

## Entity-Relationship Model (part 2)

### ER Diagram

#### Entity Sets

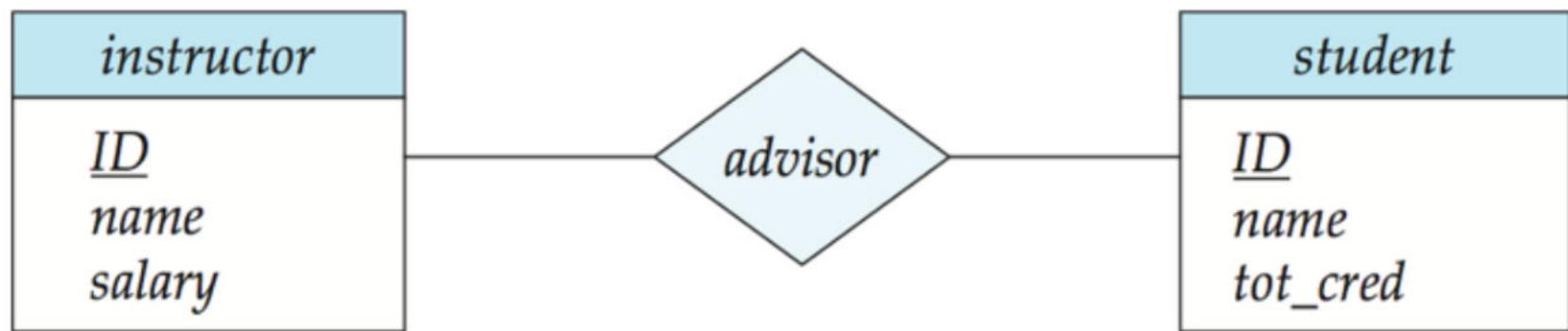
- Entities can be represented graphically as follows:
  - Rectangles represent entity set
  - Attributes are listed inside entity rectangle
  - Underline indicates primary key attributes

Aa	instructor
ID	
name	
salary	

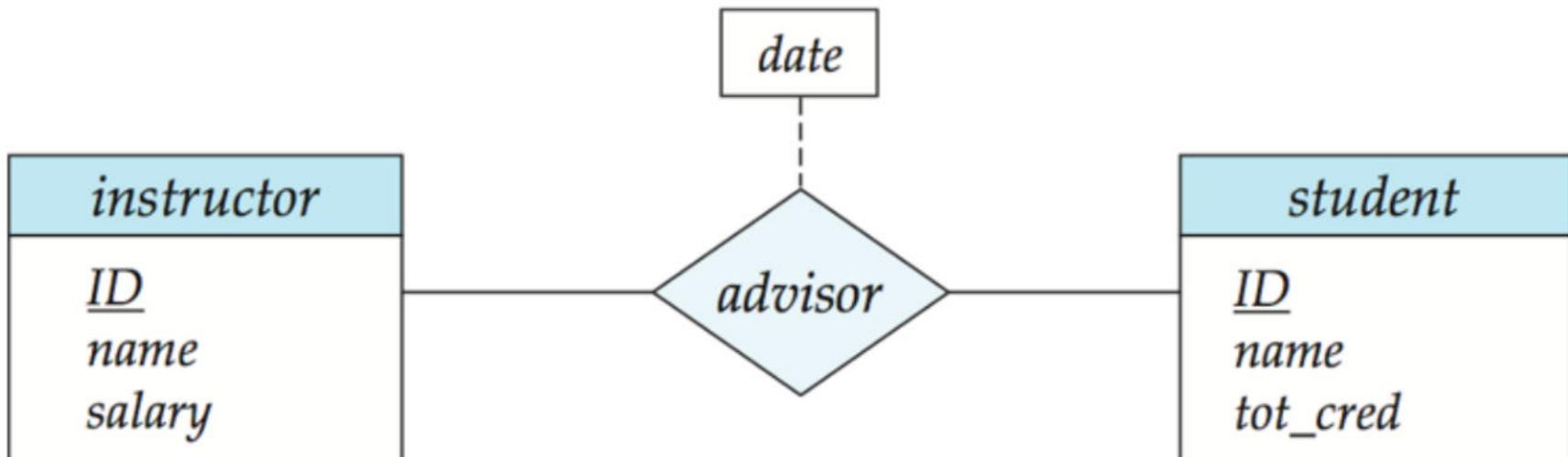
Aa	student
ID	
name	
tot_cred	

#### Relationship sets

- Diamonds represent relationship sets

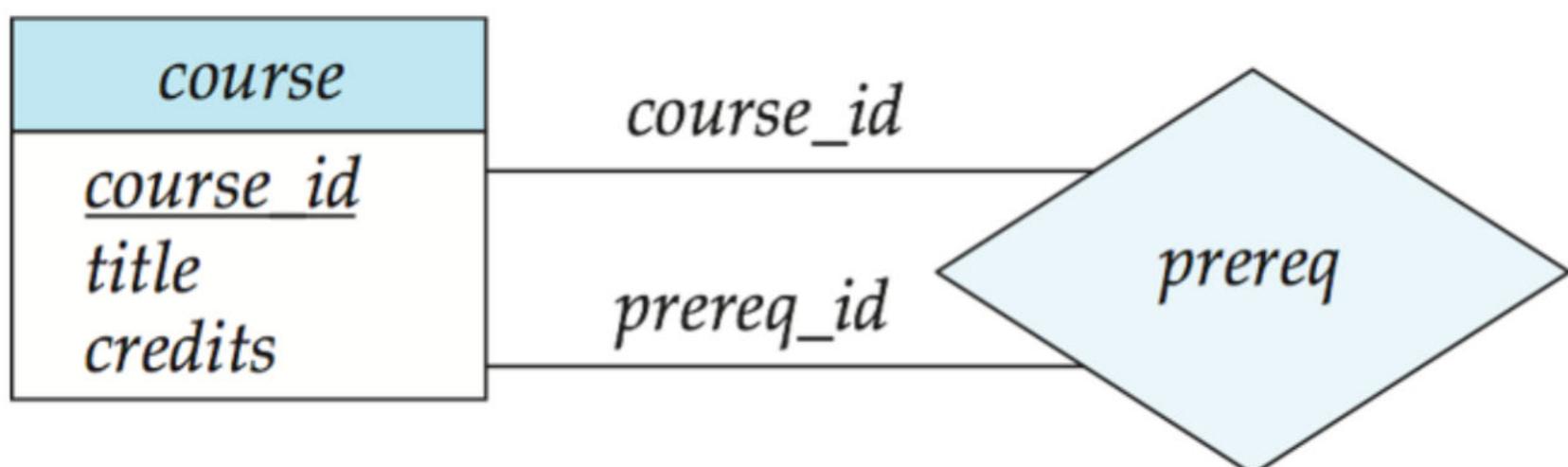


### Relationship sets with attributes



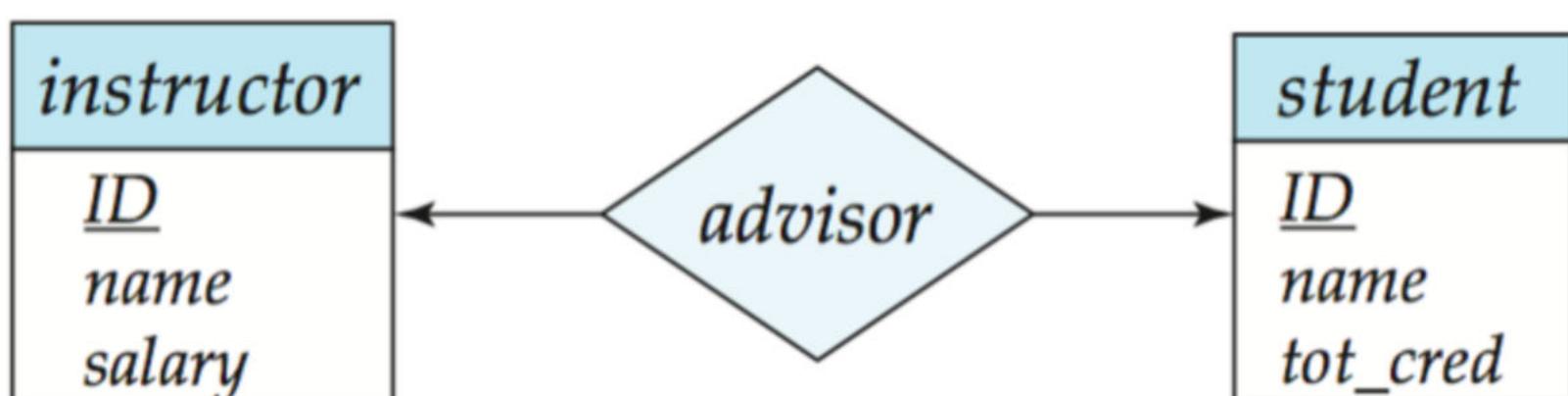
### Roles

- Entity sets of relationship need not be distinct
  - Each occurrence of an entity set plays a "role" in the relationship
- The labels "*course\_id*" and "*prereq\_id*" are called **roles**



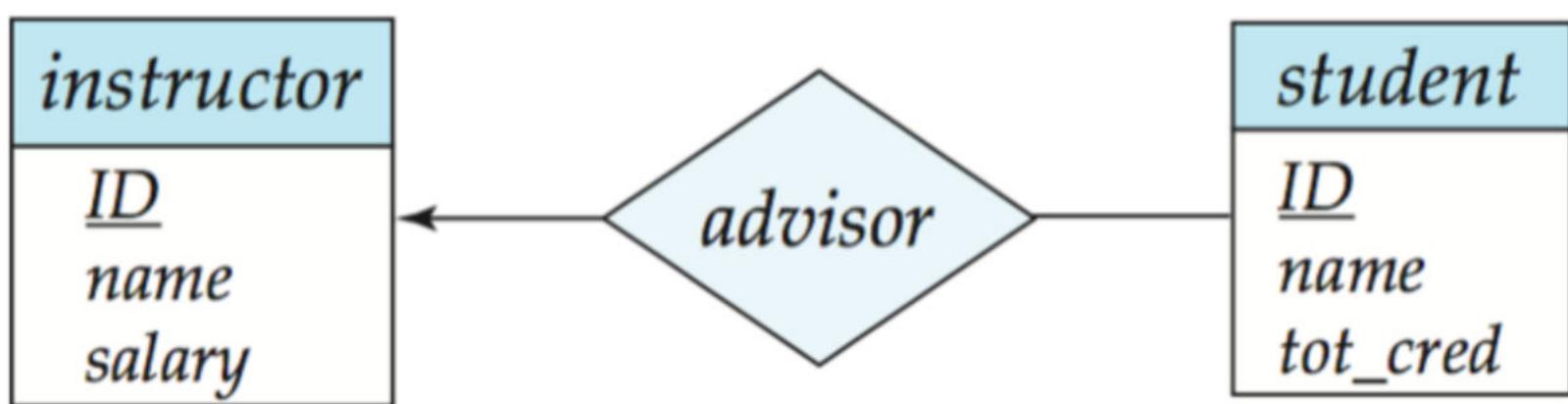
### Cardinality Constraints

- We express cardinality constraints by drawing either a directed line ( $\rightarrow$ ), signifying "one" or an undirected line ( $-$ ), signifying "many" between the relationship set and the entity set
- One to One relationship between an *instructor* and a *student*:
  - A student is associated with at most one instructor via the relationship *advisor*
  - An instructor is associated with at most one student via the relationship *advisor*



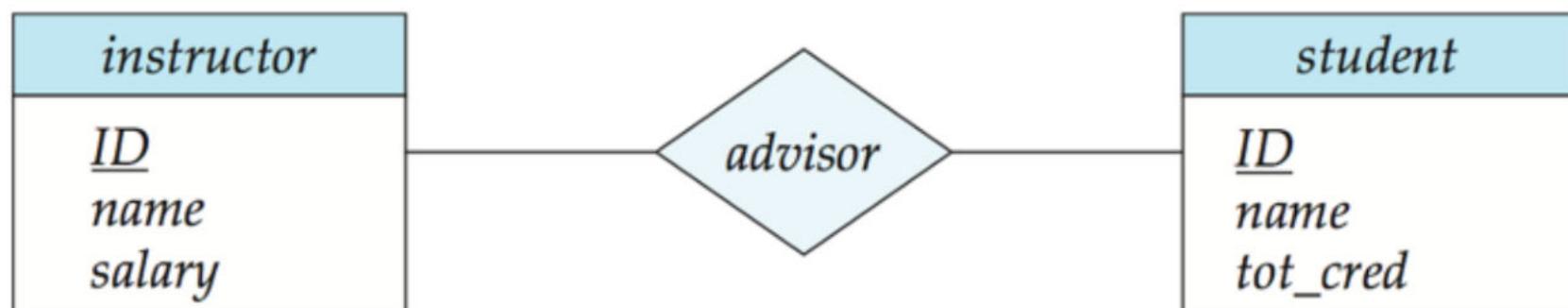
### One-to-Many relationship

- One-to-Many relationship between an *instructor* and a *student*
  - An instructor is associated with several (including 0) students via advisor
  - A student is associated with at most one instructor via advisor



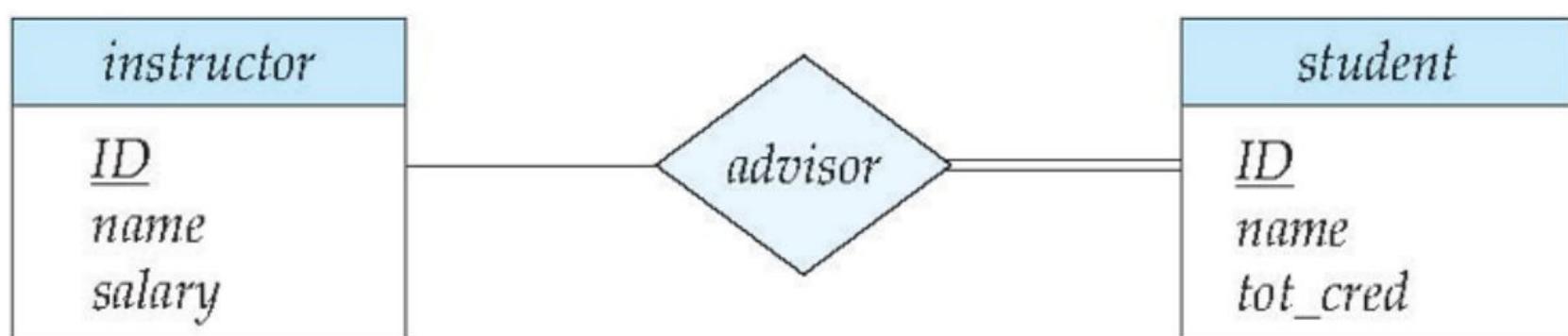
### Many-to-Many relationship

- An instructor is associated with several (including 0) students via advisor
- A student is associated with several (including 0) instructors via advisor



### Total and Partial participation

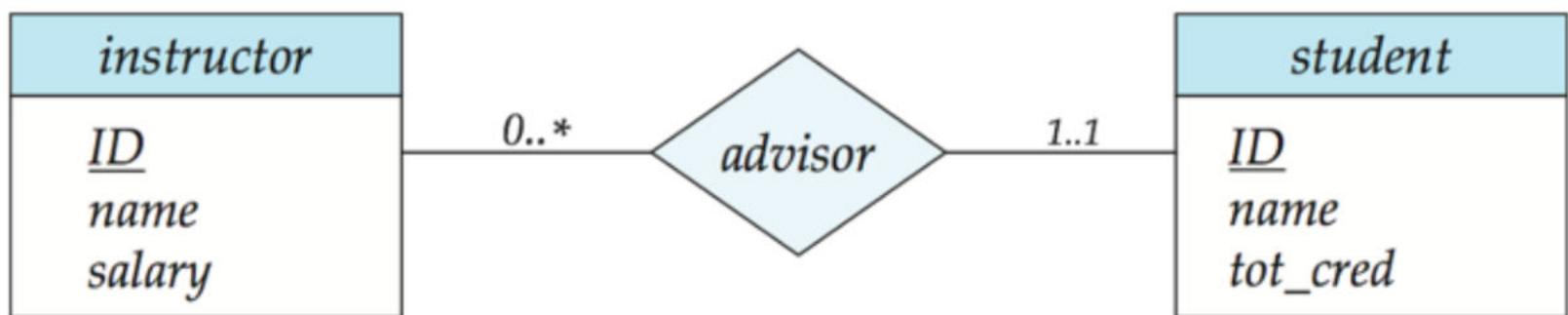
- Total participation (indicated by double line): every entity in the entity set participates in at least one relationship in the relationship set



- participation of student in *advisor* relation is total
  - every student must have an associated instructor
- Partial participation: some entities may not participate in any relationship in the relationship set
  - Example: participation of *instructor* in *advisor* is partial

### Notation for expressing more complex constraints

- A line may have an associated minimum and maximum cardinality, shown in the form *l..h*, where **l** is the minimum and **h** is the maximum cardinality
  - A minimum value of 1 indicates total participation
  - A maximum value of 1 indicates that the entity participation in at most one relationship
  - A maximum value of \* indicates no limit



Instructor can advise 0 or more students

A student must have 1 advisor; cannot have multiple advisors

### Notation to express entity with complex attributes

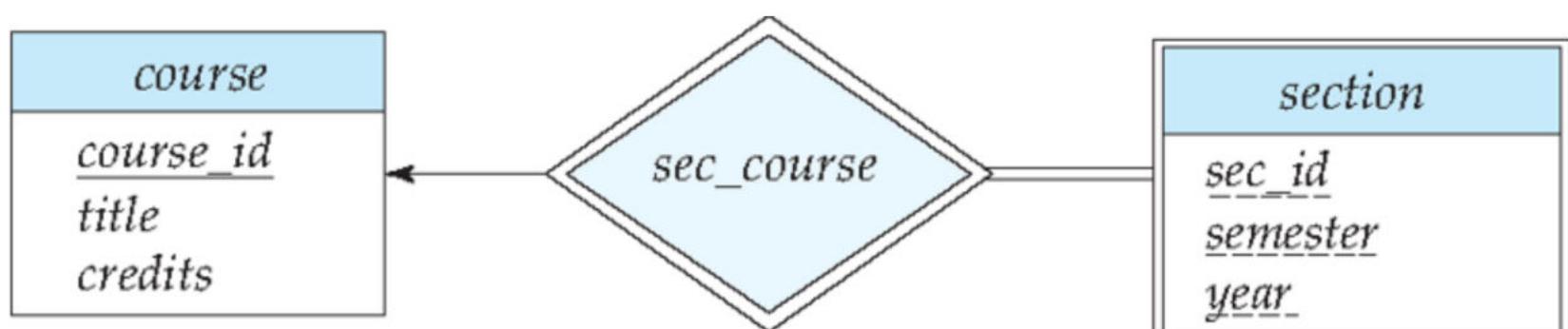
*instructor*

```

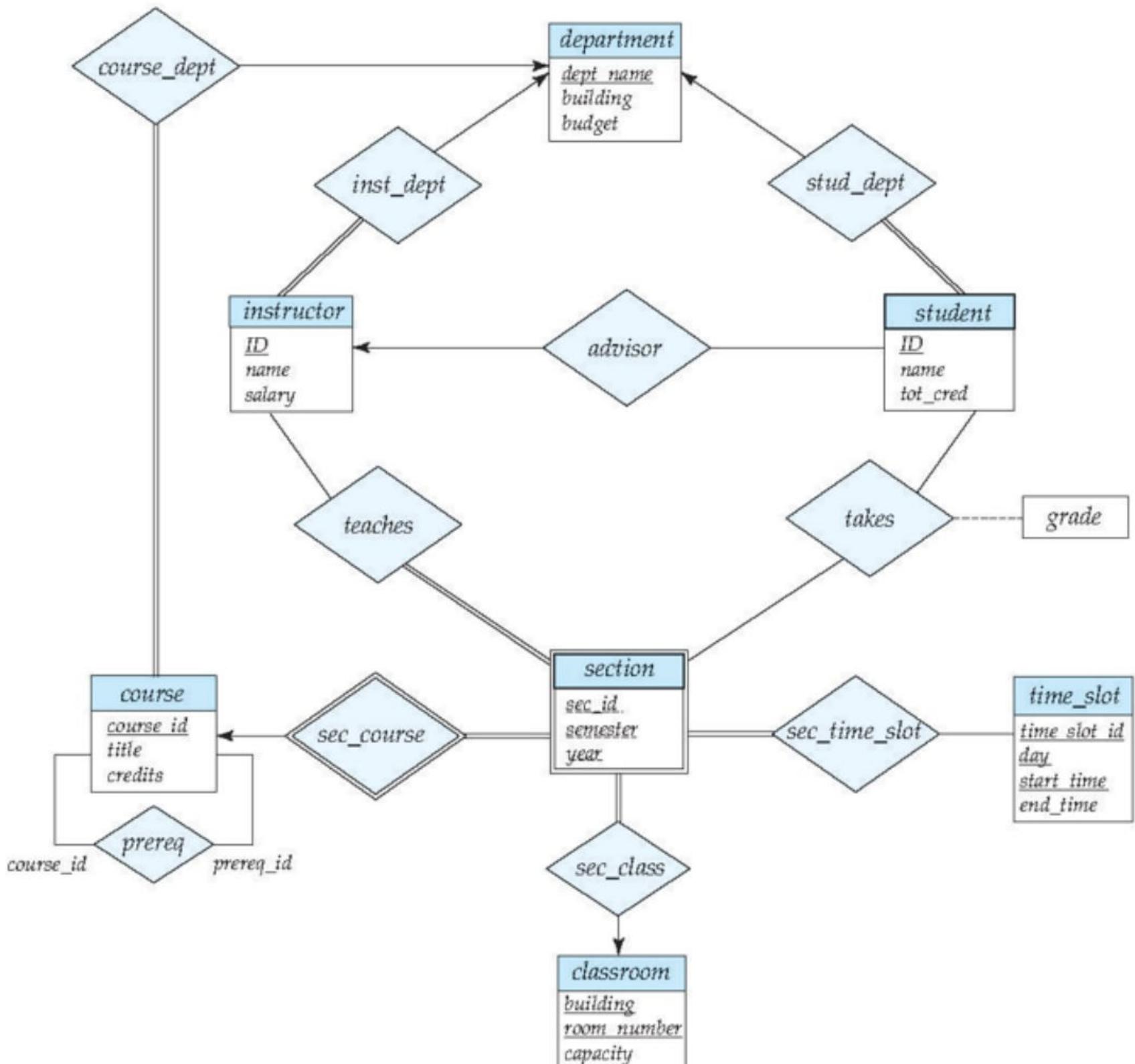
ID
name
first_name
middle_initial
last_name
address
street
street_number
street_name
apt_number
city
state
zip
{ phone_number }
date_of_birth
age()
    
```

### Expressing Weak entity sets

- In ER diagrams, a weak entity set is depicted via a double rectangle
- We underline the discriminator of a weak entity set with a dashed line
- The relationship set connecting the weak entity set to the identifying strong entity set is depicted by a double diamond
- Primary key for section - (course\_id, sec\_id, semester, year)



### ER diagram for a University enterprise



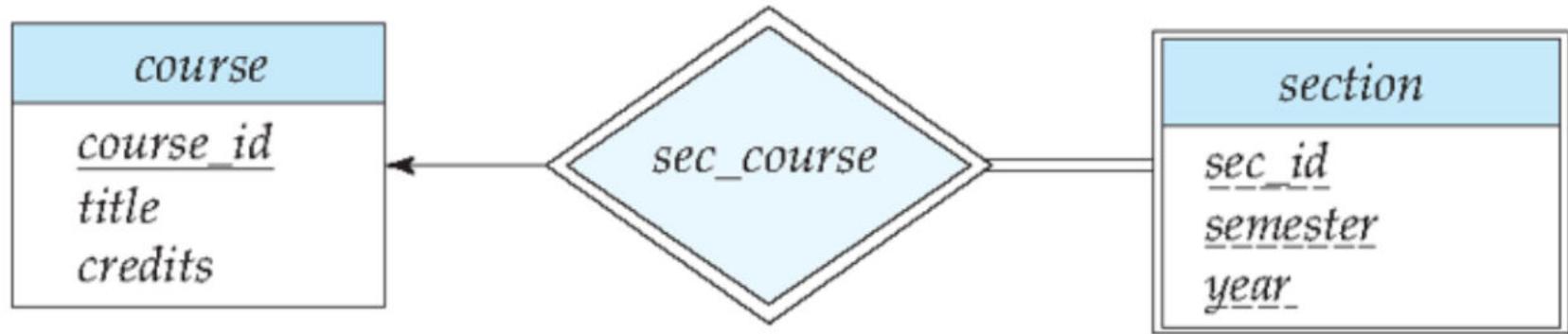
## ER Model to Relational Schema

### Reduction to Relation Schema

- Entity sets and relationship sets can be expressed uniformly as relation schemas that represent the contents of the DB
- A DB which conforms to an ER diagram can be represented by a collection of schemas
- For each entity set and relationship set there is a unique schema that is assigned the name of the corresponding entity set or relationship set
- Each schema has a number of columns (generally corresponding to attributes) which have unique names

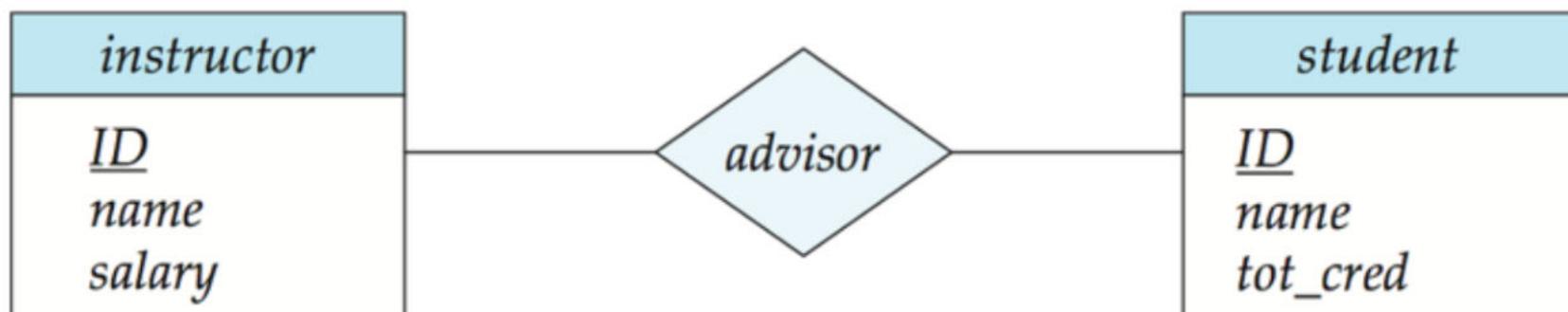
### Representing entity sets

- A strong entity set reduces to a schema with the same attributes  
*student (ID, name, tot\_cred)*
- A weak entity set becomes a table that includes a column for the primary key of the identifying strong entity set  
*section (course\_id, sec\_id, sem, year)*



## Representing relationship sets

- A many-to-many relationship set is represented as a schema with attributes for the primary keys of the two participating entity sets and any descriptive attributes of the relationship set
- Example:** schema for relationship set *advisor*  
 $\text{advisor} = (\underline{s\_id}, \underline{i\_id})$



## Representation of entity sets with composite attributes

- Composite attributes are flattened out by creating a separate attribute for each component attribute
  - Example:** Given entity set **instructor** with composite attribute name with component attributes first\_name and last\_name the schema corresponding to the entity set has two attributes name\_first\_name and name\_last\_name
    - Prefix omitted if there is no ambiguity (name\_first\_name could simply be first\_name)
- Ignoring multi-valued attributes, extended instructor schema is

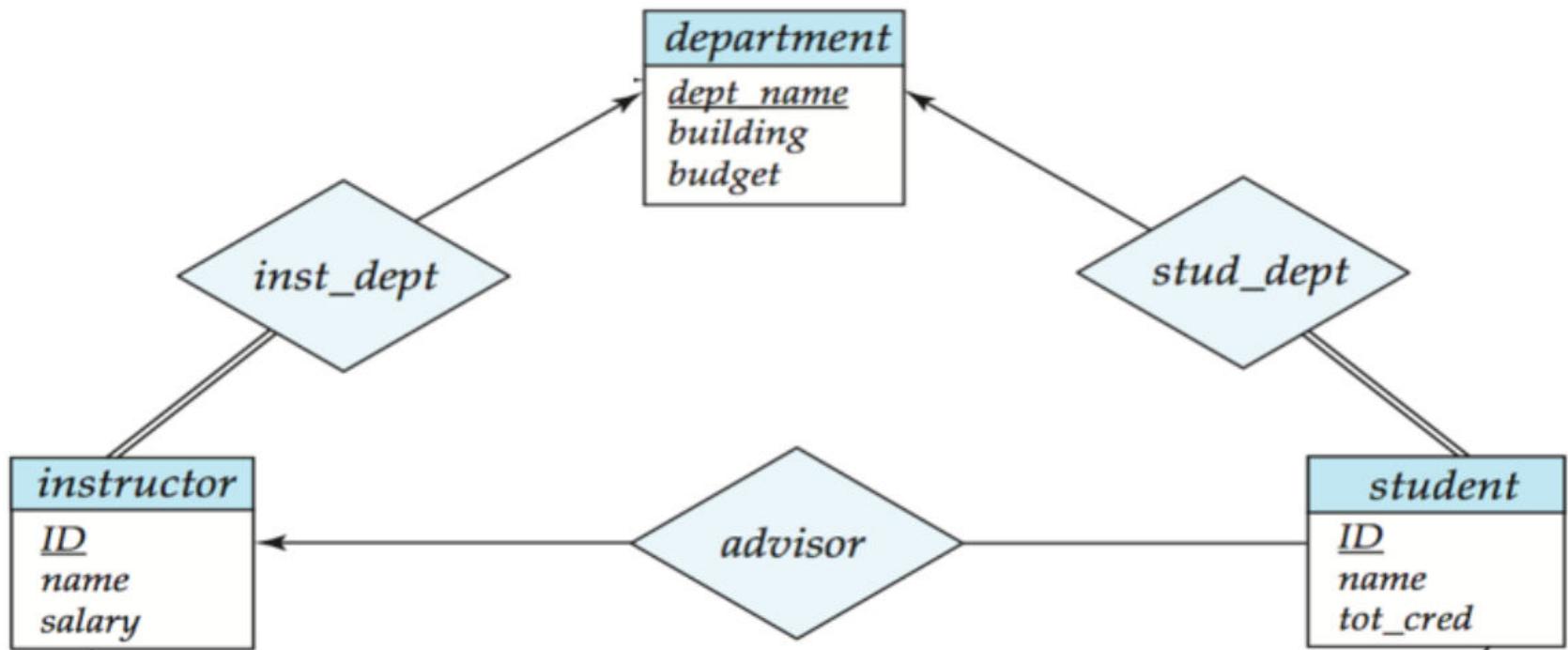
```
instructor (ID, first_name, middle_initial, last_name,
            street_number street_name, apt_number, city,
            state, zip_code, date_of_birth)
```

## Representation of Entity sets with multi-valued attributes

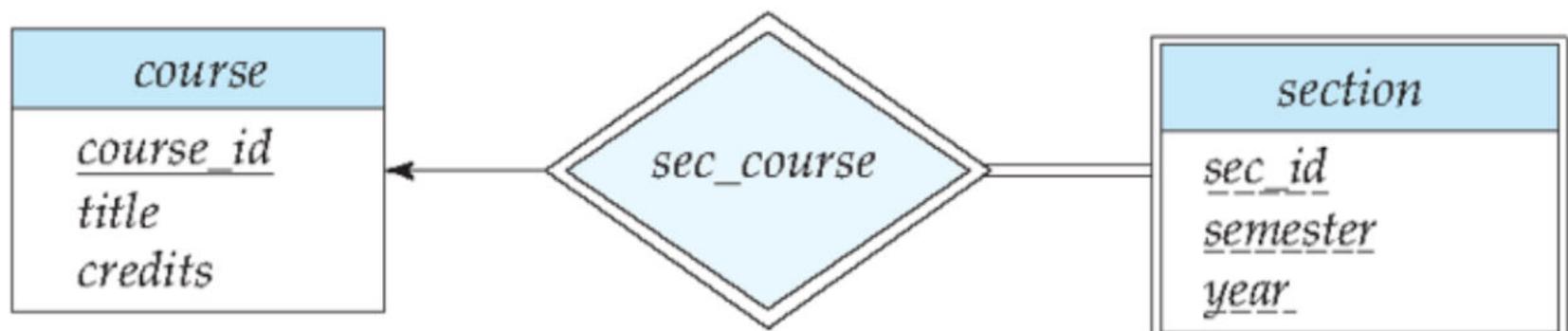
- A multi-valued attribute M of an entity E is represented by a separate schema EM
- Schema EM has attributes corresponding to the primary key of E and an attribute corresponding to multi-valued attribute M
- Example:** Multi-valued attribute phone\_number of **instructor** is represented by a schema:  
 $\text{inst\_phone} = (\underline{ID}, \underline{\text{phone\_number}})$
- Each value of the multi-valued attribute maps to a separate tuple of the relation on schema EM
  - For example:** an instructor entity with primary key 22222 and phone numbers 456-7890 and 123-4567 maps to two tuples: (22222, 456-7890) and (22222, 123-4567)

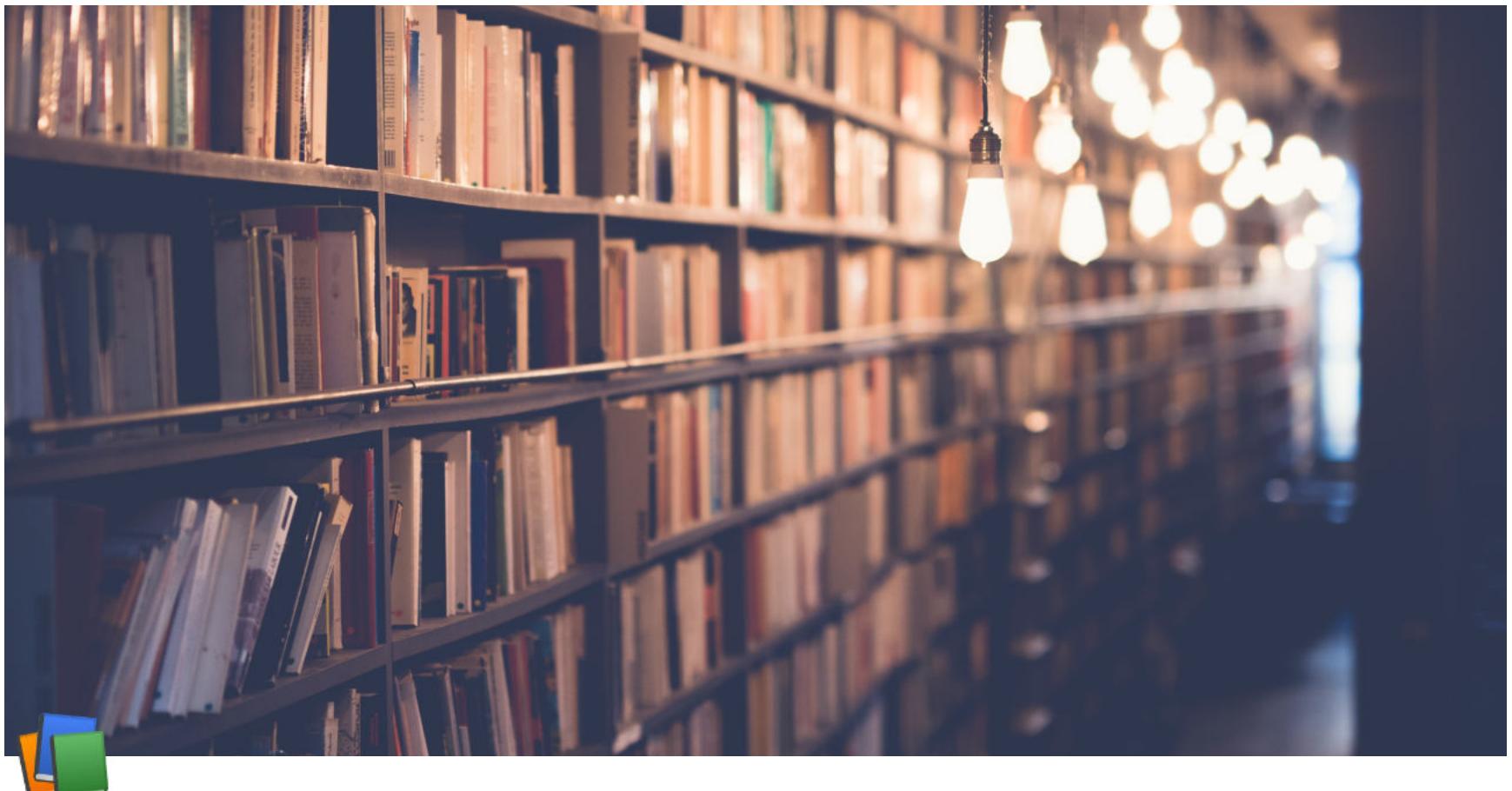
## Redundancy of the Schema

- Many-to-One and One-to-Many relationship sets that are total on the many-side can be represented by adding an extra attribute to the "many" side, containing the primary key of the "one" side
- Example:** Instead of creating a schema for relationship set *inst\_dept*, add an attribute dept\_name to the schema arising from entity set *instructor*



- For One-to-One relationship sets, either side can be chosen to act as the "many" side
  - That is, an extra attribute can be added to either of the tables corresponding to the two entity sets
- If participation is partial on the "many" side, replacing a schema by an extra attribute in the schema corresponding to the "many" side could result in null values
- The schema corresponding to a relationship set linking a weak entity set to its identifying strong entity set is redundant
- **Example:** The section schema already contains the attributes that would appear in the sec\_course schema





## Week 4 Lecture 5

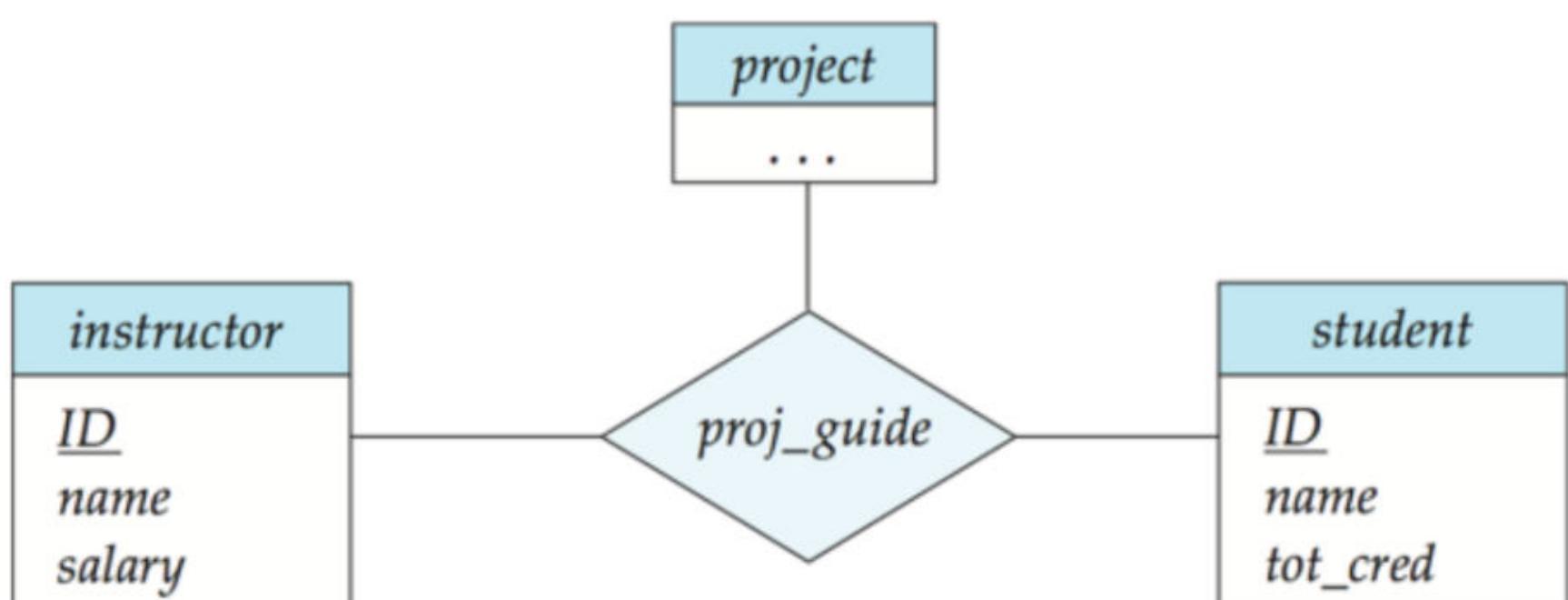
Class	BSCCS2001
Created	@September 30, 2021 8:37 PM
Materials	
Module #	20
Type	Lecture
Week #	4

## Entity-Relationship Model (part 3)

### Extended ER features

#### Non-binary Relationship sets

- Most relationship sets are binary
- There are occasions when it is more convenient to represent relationships as non-binary
- ER diagram with a Ternary Relationship

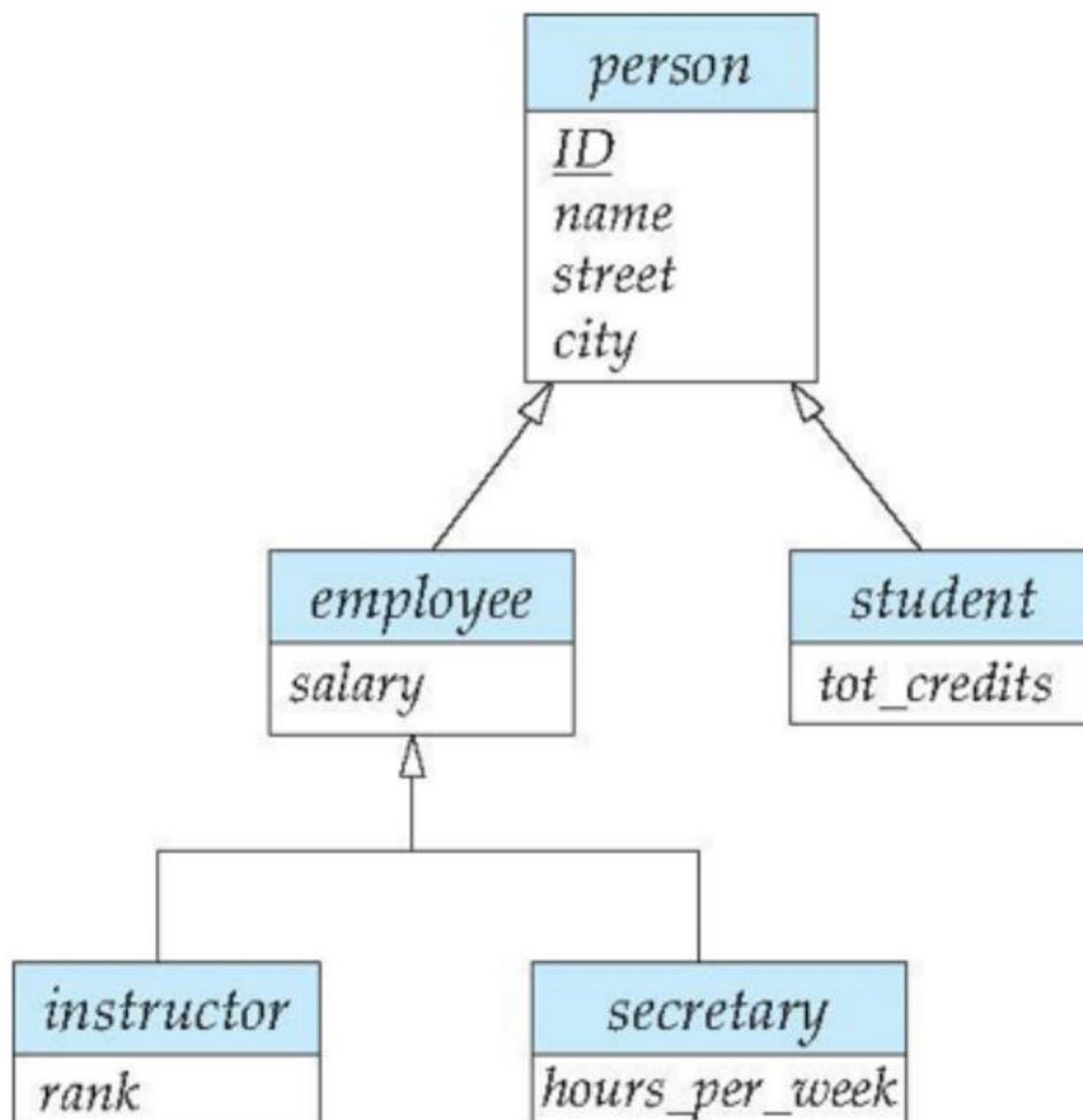


#### Cardinality constraints on Ternary Relationship

- We allow at most one arrow out of a ternary (or greater degree) relationship to indicate a cardinality constraint
- For example, an arrow from *proj\_guide* to *instructor* indicates each student has at most one guide for a project
- If there is more than one arrow, there are two ways of defining the meaning
  - For example, a ternary relationship R between A, B and C with arrows to B and C could mean
    - Each A entity is associated with a unique entity from B and C or
    - Each pair of entities form (A, B) is associated with a unique entity and each pair (A, C) is associated with a unique B
  - Each alternative has been used in different formalisms
  - To avoid confusion we outlaw more than one arrow

## Specialization: ISA

- **Top-down design process:** We designate sub-groupings within an entity set that are distinctive from other entities in the set
- These sub-groupings become lower-level entity sets that have attributes or participate in relationships that do not apply to the higher-level entity set
- Depicted by a triangle component leveled ISA (eg: instructor "is a" person)
- **Attribute inheritance:** A lower-level entity set inherits all the attributes and relationship participation of the higher-level entity set to which it is linked
- **Overlapping:** *employee* and *student*
- **Disjoint:** *instructor* and *secretary*
- Total and Partial



## Representing Specialization via Schema

- Method 1:
  - Form a schema for the higher-level entity

- Form a schema for each lower-level entity set, include primary key of higher-level entity set and local attributes

Aa schema	(attributes)
<u>person</u>	ID, name, street, city
<u>student</u>	ID, tot_cred
<u>employee</u>	ID, salary

- **Drawback:** Getting information about an employee requires accessing two relations, the one corresponding to the low-level schema and the one corresponding to the high-level schema

- Method 2:

- Form a schema for each entity set with all local and inherited attributes

Aa Name	Tags
<u>person</u>	ID, name, street, city
<u>student</u>	ID, name, street, city, tot_cred
<u>employee</u>	ID, name, street, city, salary

- **Drawback:** name, street and city may be stored redundantly for people who are both students and employees

## Generalization

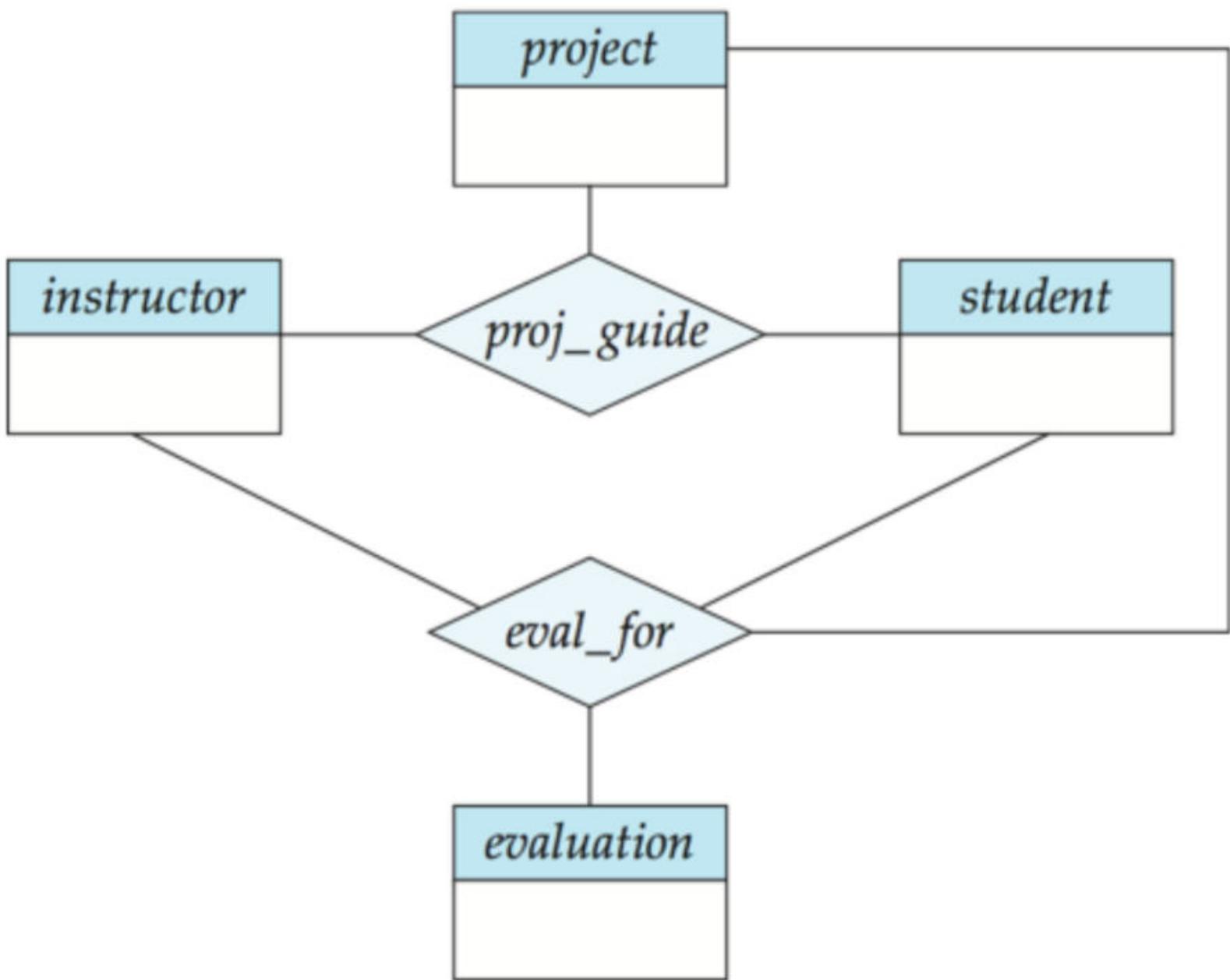
- **Bottom-up design process:** Combine a number of entity sets that share the same features into a higher-level entity set
- Specialization and generalization are simple inversions of each other; they are represented in an ER diagram in the same way
- The terms specialization and generalization are used interchangeably

## Design constraints on a specialization / generalization

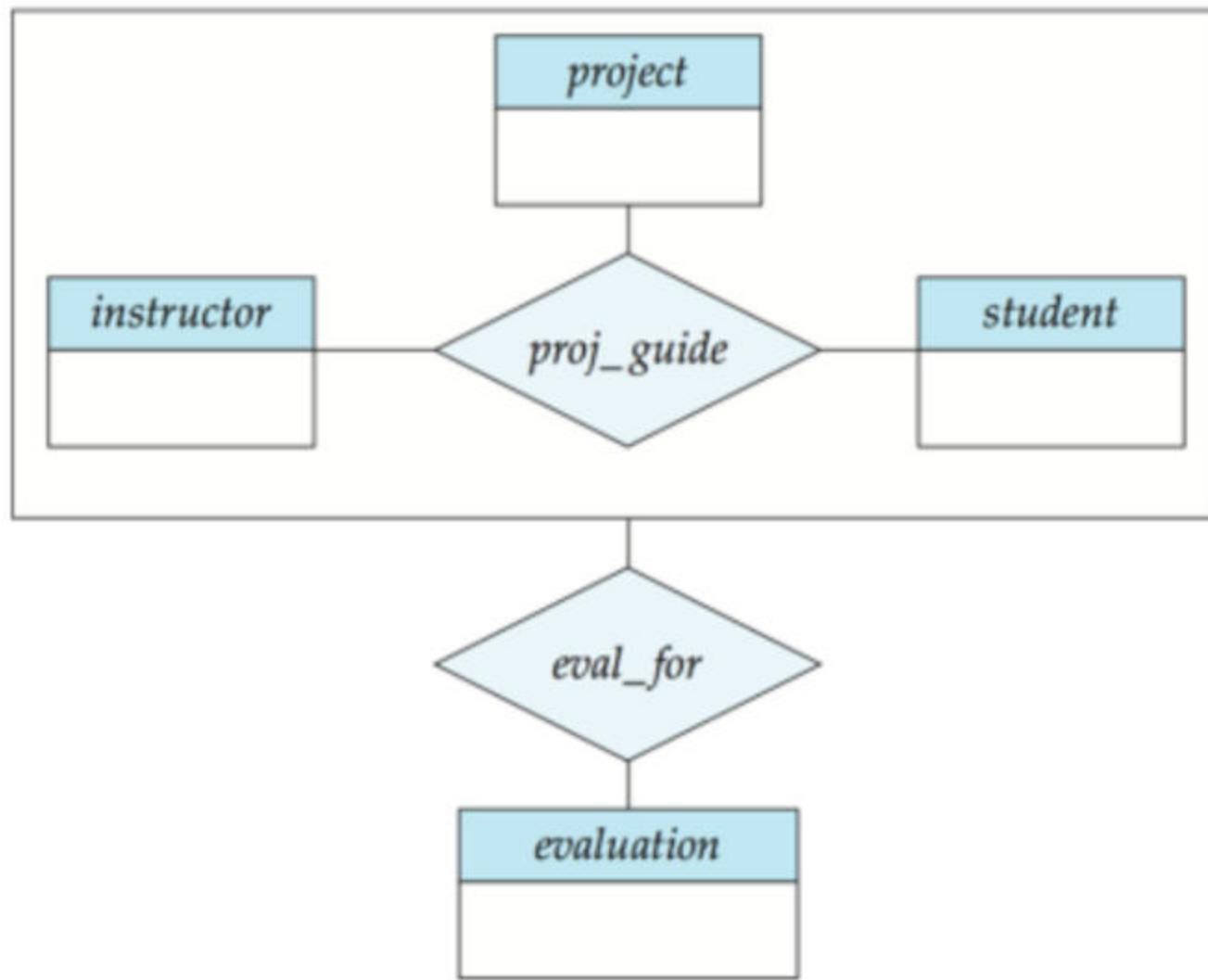
- **Completeness constraint:** Specifies whether or not an entity in the higher-level entity set must belong to at least one of the lower-level entity sets within a generalization
  - **total:** an entity must belong to one of the lower-level entity sets
  - **partial:** an entity need not belong to one of the lower-level entity sets
- Partial generalization is the default
  - We can specify total generalization in an ER diagram by adding the keyword **total** in the diagram
  - Drawing a dashed line from the keyword to the corresponding hollow arrow-head to which it applies (for a total generalization) or to the set of hollow arrow-heads to which it applies (for an overlapping generalization)
- The student generalization is total
  - All student entities must be either graduate or undergraduate
  - Because the higher-level entity set arrived at through generalization is generally composed of only those entities in the lower-level entity sets, the completeness constraint for a generalized higher-level entity set is usually total

## Aggregation

- Consider the ternary relationship *proj\_guide*, which we saw earlier
- Suppose we want to record evaluations of a student by a guide on a project



- Relationship sets *eval\_for* and *proj\_guide* represent overlapping information
  - Every *eval\_for* relationship corresponds to a *proj\_guide* relationship
  - However, some *proj\_guide* relationships may not correspond to any *eval\_for* relationships
    - So, we cannot discard the *proj\_guide* relationship
- Eliminate this redundancy via aggregation
  - Treat relationship as an abstract entity
  - Allows relationships between relationships
  - Abstraction of relationship into new entity
- Eliminate this redundancy via aggregation without introducing redundancy, the following diagram represents:
  - A student is guided by a particular instructor on a particular project
  - A student, instructor, project combination may have an associated evaluation



## Representing aggregation via Schema

- To represent aggregation, create a schema containing
  - Primary key of the aggregated relationship
  - The primary key of the associated entity set
  - Any descriptive attributes
- In our example
  - The schema `eval_for` is:

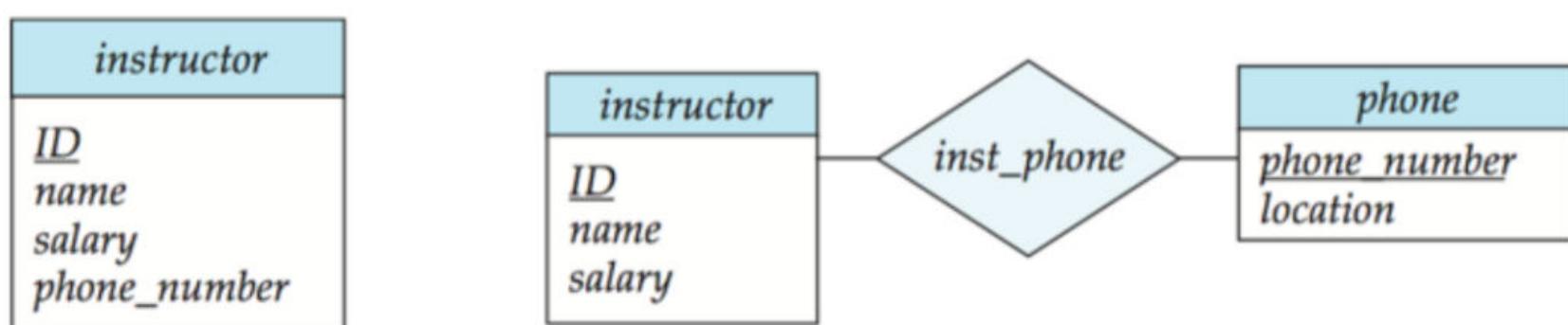
`eval_for (s_ID, project_id, i_ID, evaluation_id)`

- The schema `proj_guide` is redundant

## Design Issues

### Entities v/s Attributes

- Use of entity sets v/s attributes

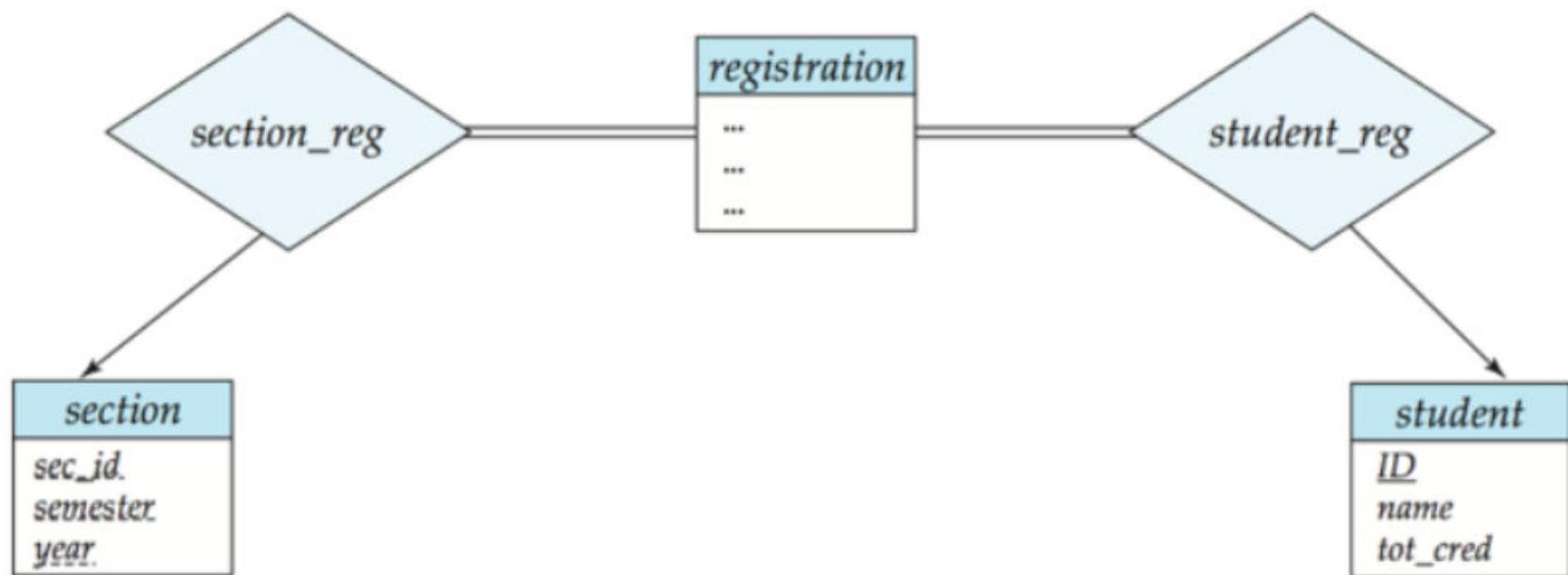


- Use of phone as an entity allows extra information about phone numbers (plus multiple phone numbers)

### Entities v/s Relationship sets

- **Use of entity sets v/s relationship sets**

Possible guideline is to designate a relationship set to describe an action that occurs between entities



- **Placement of relationship attributes**

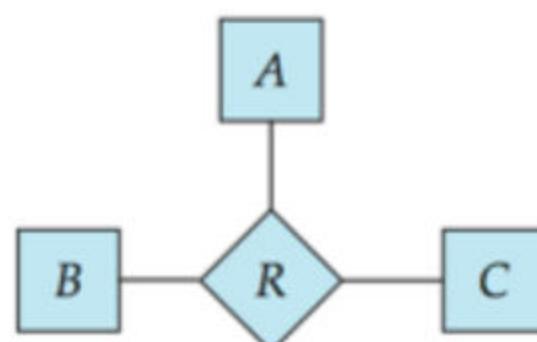
For example, attribute date as attribute of advisor or as attribute of student

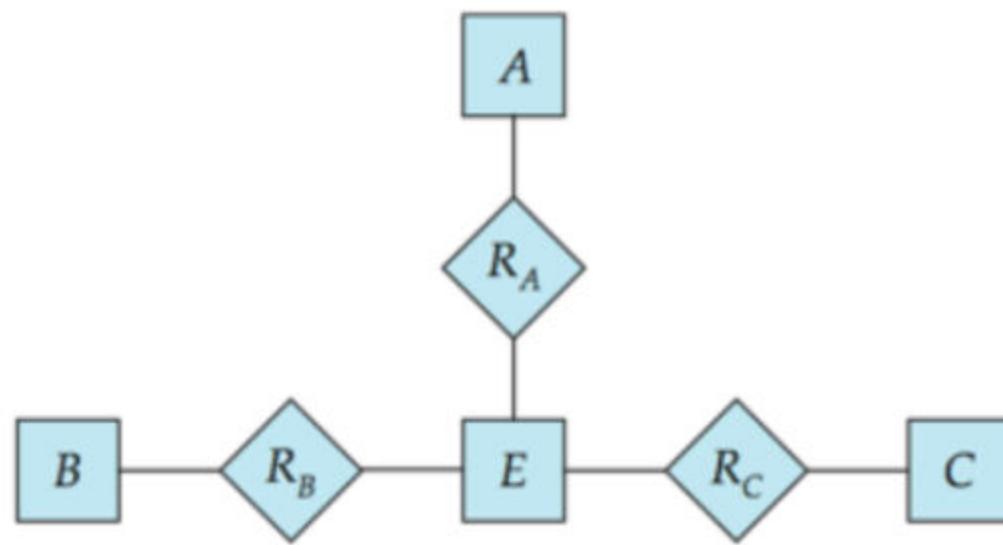
### Binary v/s Non-binary Relationships

- Although, it is possible to replace any non-binary ( $n$ -ary, for  $n > 2$ ) relationship set by a number of distinct binary relationship sets, an  $n$ -ary relationship set shows more clearly that several entities participate in a single relationship
- Some relationships that appear to be non-binary may be better represented using binary relationships
  - For example, a ternary relationship parents, relating a child to his/her father and mother, is best replaced by two binary relationships, father and mother
    - Using two binary relationships allows partial information (eg: only mother being known)
  - But there are some relationships that are naturally non-binary
    - Example: proj\_guide

### Binary v/s Non-binary Relationships: Conversion

- In general, any non-binary relationship can be represented using binary relationships by creating an artificial entity set
  - Replace  $R$  between entity sets  $A$ ,  $B$  and  $C$  by an entity set  $E$ , and three relationship sets:
    - $R_A$ , relating  $E$  and  $A$
    - $R_B$ , relating  $E$  and  $B$
    - $R_C$ , relating  $E$  and  $C$
  - Create an identifying attribute for  $E$  and add any attributes of  $R$  to  $E$
  - For each relationship  $(a_i, b_i, c_i)$  in  $R$ , create
    - A new entity  $e_i$  in the entity set  $E$
    - add  $(e_i, a_i)$  to  $R_A$
    - add  $(e_i, b_i)$  to  $R_B$
    - add  $(e_i, c_i)$  to  $R_C$



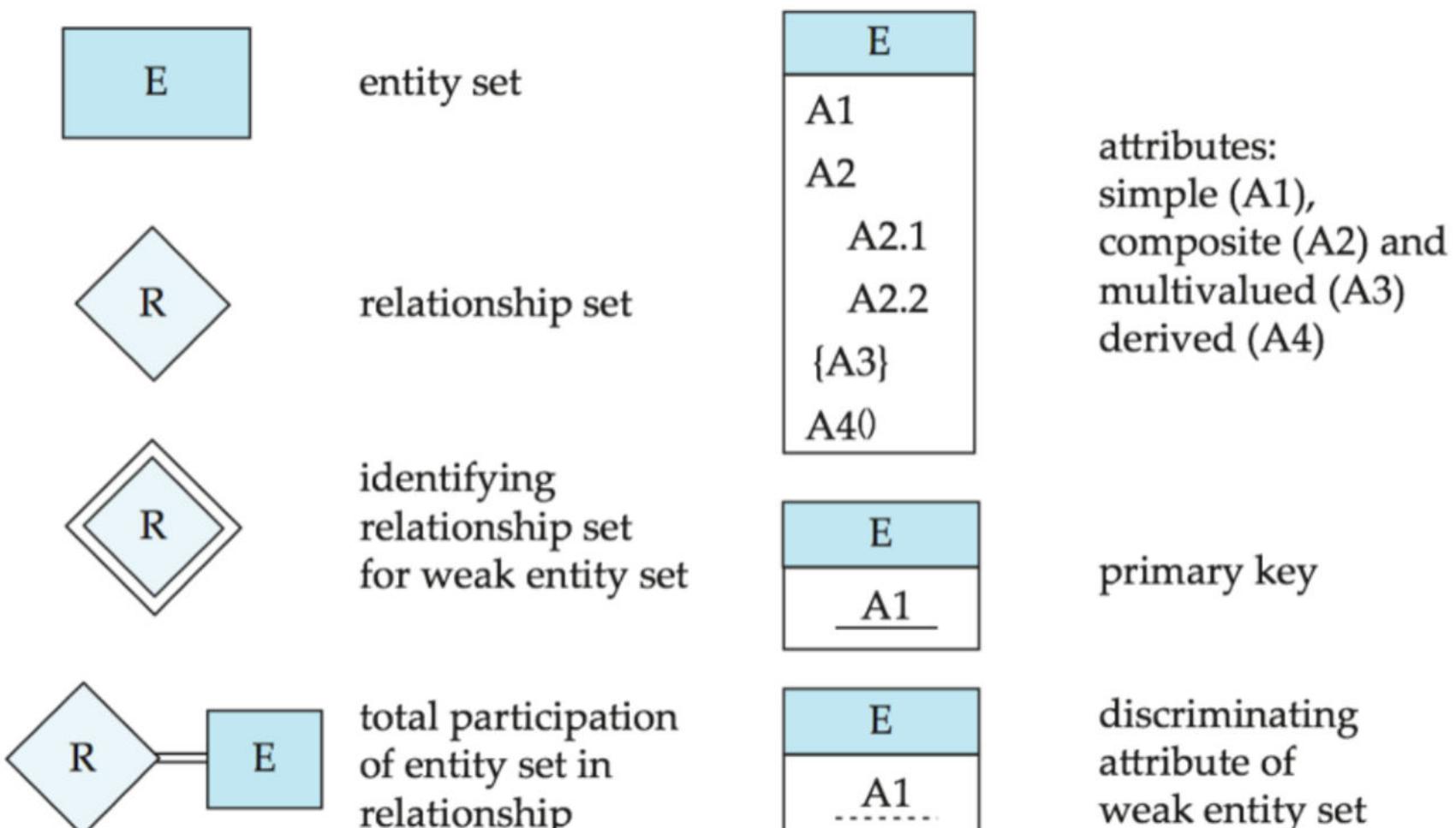


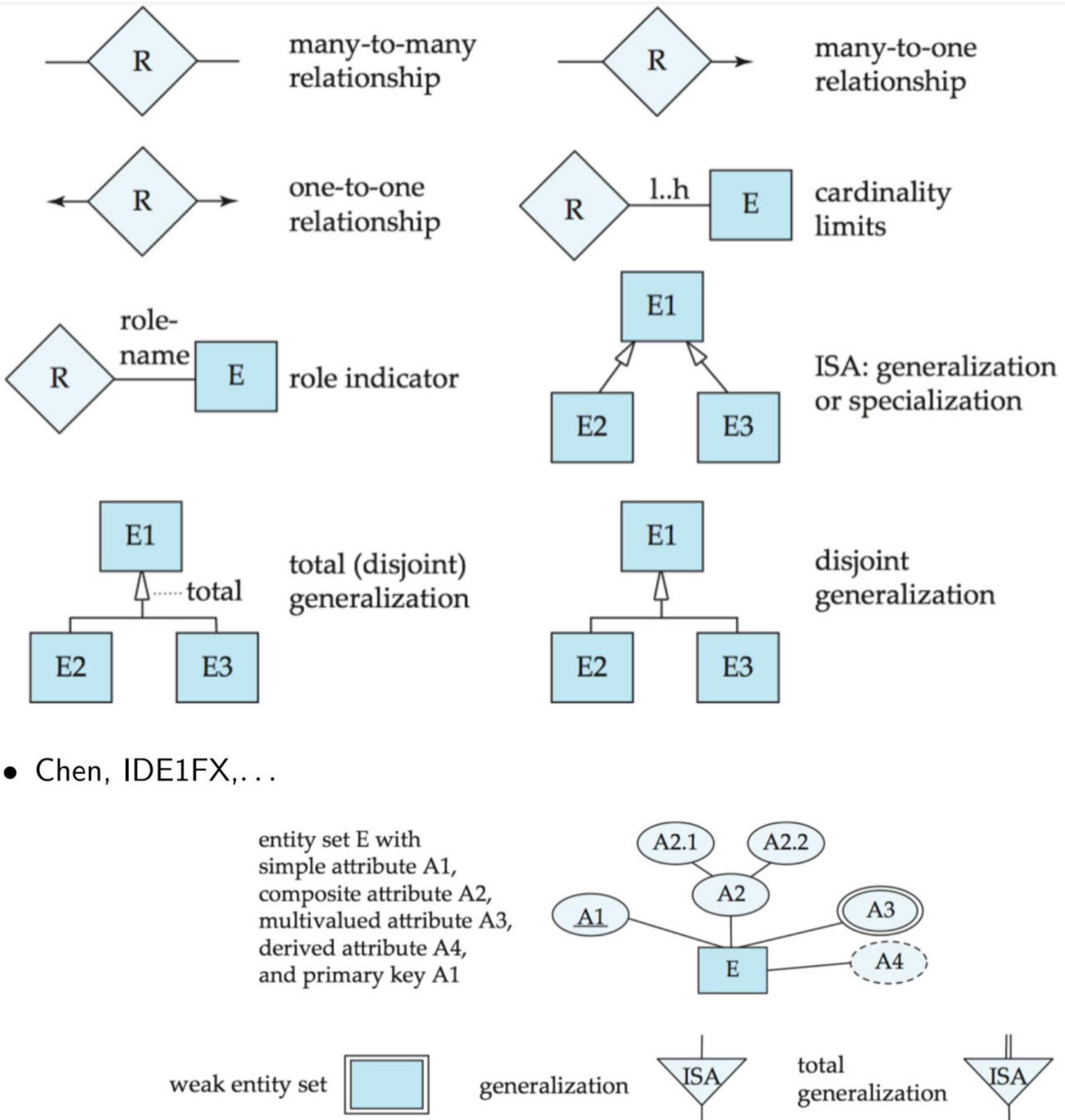
- Also need to translate constraints
  - Translating all constraints may not be possible
  - There may be instance in the translated schema that cannot correspond to any instance of R
    - **Exercise:** add constraints to the relationships  $R_A$ ,  $R_B$  and  $R_C$  to ensure that a newly created entity corresponds to exactly one entity in each of entity sets — A, B and C
  - We can avoid creating an identifying attribute by making E, a weak entity set identified by the three relationship sets

## ER Design Decisions

- The use of an attribute or entity set to represent an object
- Whether a real-world concept is best expressed by an entity or a relationship set
- The use of a ternary relationship versus a pair of binary relationships
- The use of strong or weak entity set
- The use of specialization/generalization — contributes to modularity in the design
- The use of aggregation — can treat the aggregate entity set as a single unit without concern for the details of its internal structure

## Symbols used in the ER Notation

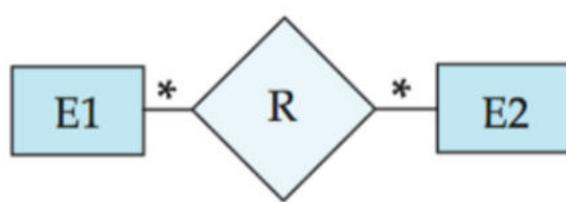
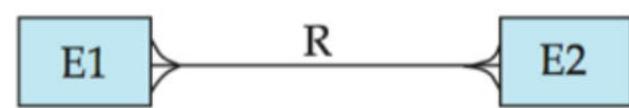




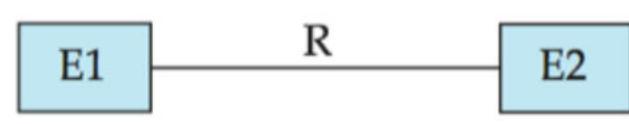
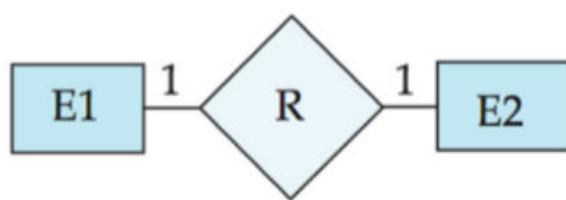
- Chen, IDE1FX, ...

**Chen**

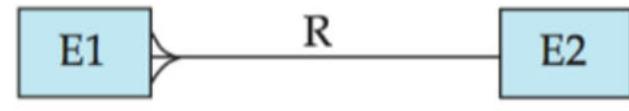
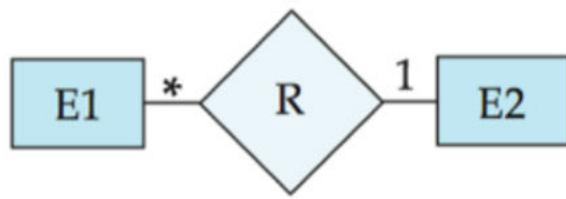
many-to-many  
relationship

**IDE1FX (Crows feet notation)**

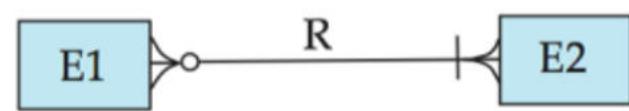
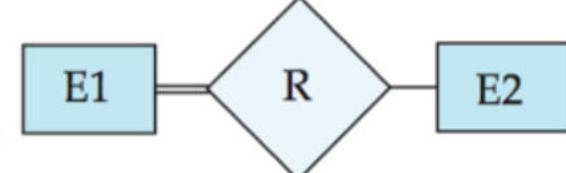
one-to-one  
relationship

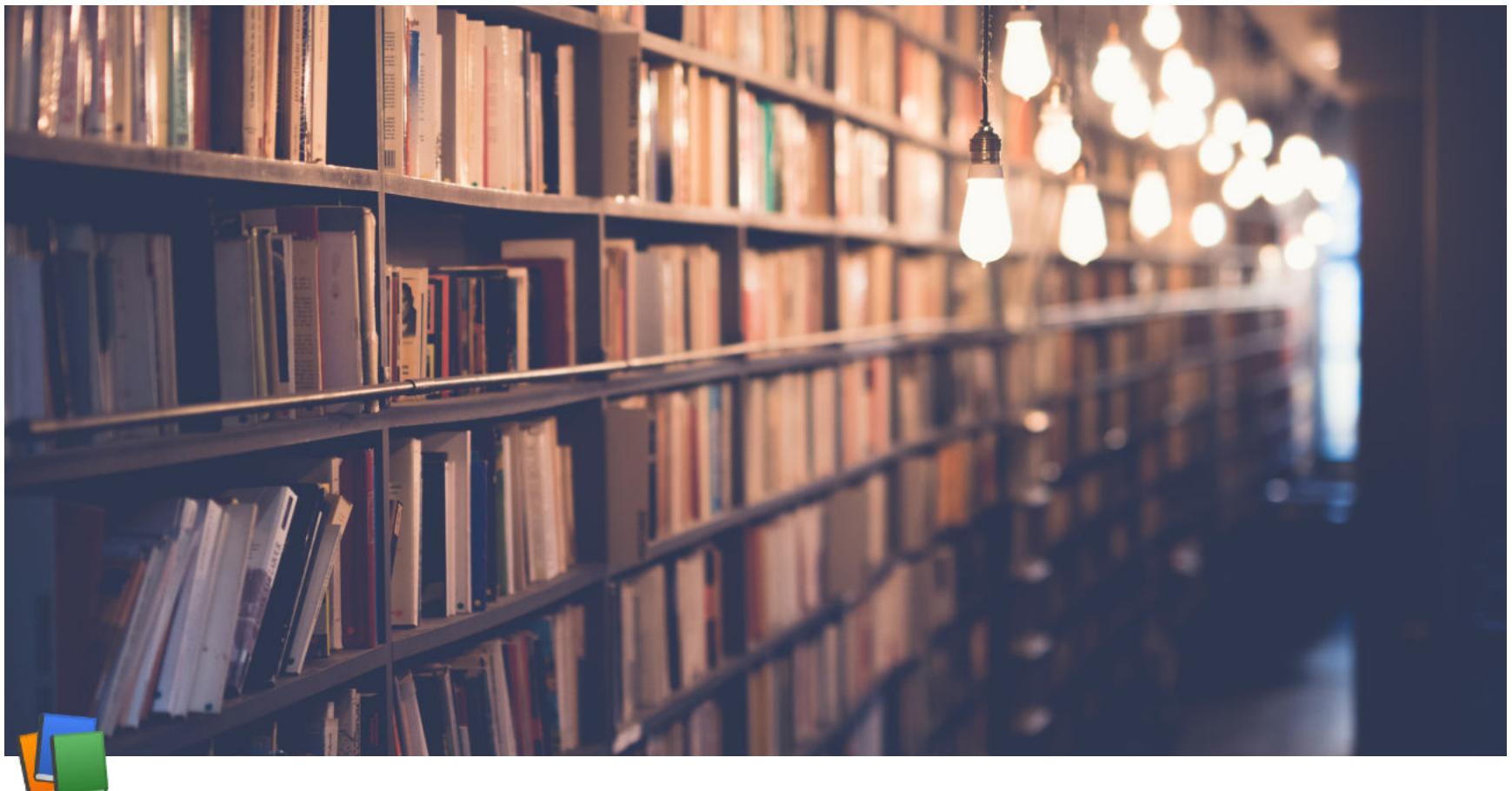


many-to-one  
relationship



participation  
in R: total (E1)  
and partial (E2)





## Week 5 Lecture 1

Class	BSCCS2001
Created	@October 4, 2021 11:55 AM
Materials	
Module #	21
Type	Lecture
Week #	5

## Relational Database Design

### Features of Good Relational Design

#### Good Relational Design

- Reflects real-world structure of the problem
- Can represent all expected data over time
- Avoids redundant storage of data over time
- Provides efficient access to data
- Supports the maintenance of data integrity over time
- Clean, consistent and easy to understand
- **NOTE:** These objectives are sometimes contradictory ☺

#### What is a good schema?

instructor_with_department					
ID	name	salary	dept_name	building	budget
22222	Einstein	95000	Physics	Watson	70000
12121	Wu	90000	Finance	Painter	120000
32343	El Said	60000	History	Painter	50000
45565	Katz	75000	Comp. Sci.	Taylor	100000
98345	Kim	80000	Elec. Eng.	Taylor	85000
76766	Crick	72000	Biology	Watson	90000
10101	Srinivasan	65000	Comp. Sci.	Taylor	100000
58583	Califieri	62000	History	Painter	50000
83821	Brandt	92000	Comp. Sci.	Taylor	100000
15151	Mozart	40000	Music	Packard	80000
33456	Gold	87000	Physics	Watson	70000
76543	Singh	80000	Finance	Painter	120000

instructor			
ID	name	dept_name	salary
10101	Srinivasan	Comp. Sci.	65000
12121	Wu	Finance	90000
15151	Mozart	Music	40000
22222	Einstein	Physics	95000
32343	El Said	History	60000
33456	Gold	Physics	87000
45565	Katz	Comp. Sci.	75000
58583	Califieri	History	62000
76543	Singh	Finance	80000
76766	Crick	Biology	72000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000

### department

dept_name	building	budget
Biology	Watson	90000
Comp. Sci.	Taylor	100000
Elec. Eng.	Taylor	85000
Finance	Painter	120000
History	Painter	50000
Music	Packard	80000
Physics	Watson	70000

- **ID:** Key
- **building, budget:** Redundant Information
- **name, salary, dept\_name:** No Redundant Information

Database Management Systems

Partha Pratim Das

- Consider combining relations
  - *sec\_class(sec\_id, building, room\_number)* and
  - *section(course\_id, sec\_id, semester, year)*
- No repetition in this case

## Redundancy and Anomaly

- **Redundancy:** Having multiple copies of the same data in the DB
  - This problem arises when a DB is not normalized
  - It leads to anomalies
- **Anomaly:** Inconsistencies that can arise due to data changes in a database with insertion, deletion and update
  - These problems occur in poorly planned, un-normalized DBs where all the data is stored in one table (a flat-file DB)

There can be 3 kinds of anomalies

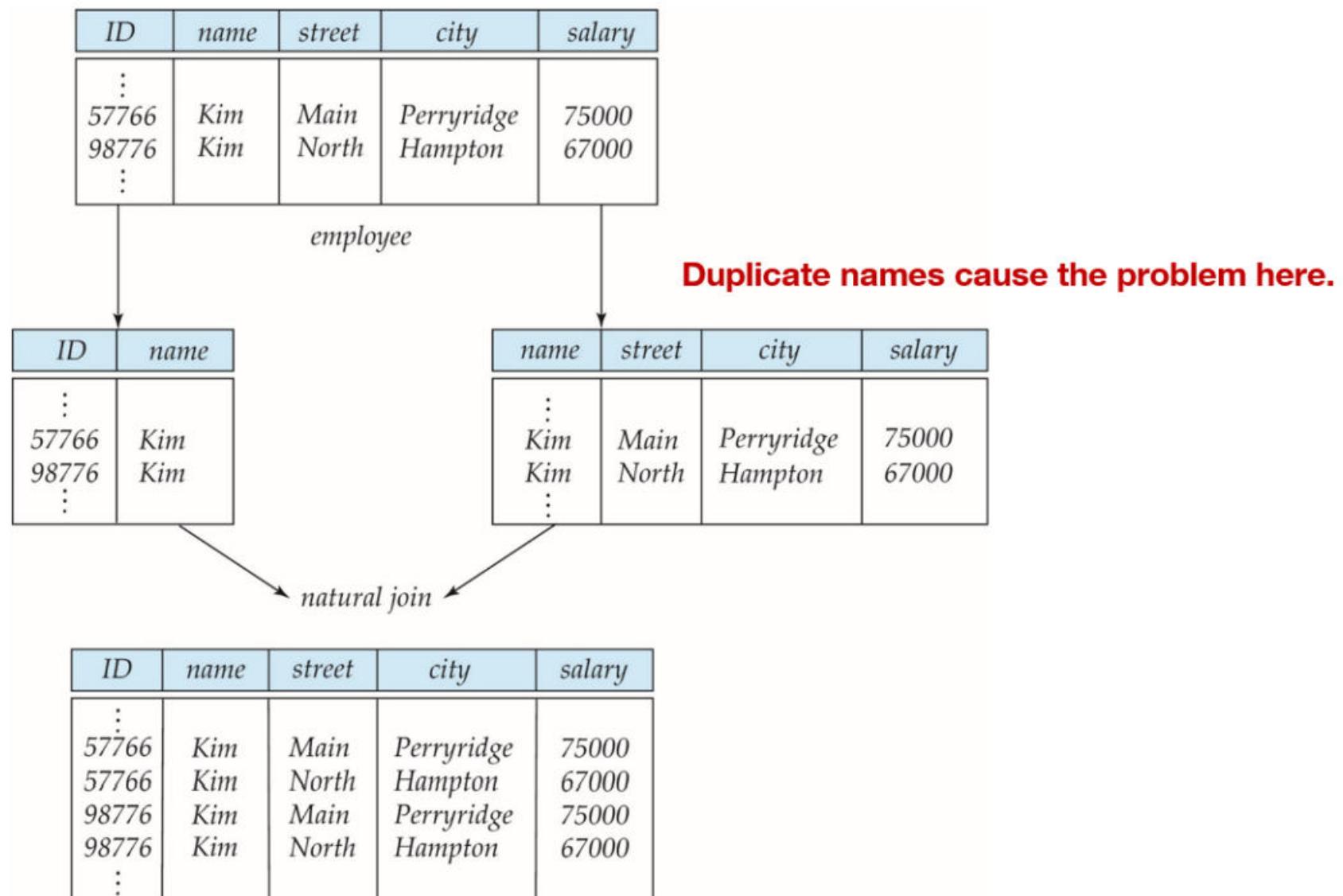
- Insertions anomaly
- Deletion anomaly
- Update anomaly
- **Insertions anomaly**
  - When the insertion of a data record is not possible without adding some additional unrelated data to the record
  - We cannot add an Instructor in *instructor\_with\_department* if the *department* does not have a *building* or *budget*
- **Deletion anomaly**
  - When deletion of a data record results in losing some unrelated information that was stored as part of the record that was deleted from a table
  - We delete the last Instructor of a Department from *instructor\_with\_department*, we lose *building* and *budget* information
- **Update anomaly**
  - When a data is changed, which could involve many records having to be changed, leading to the possibility of some changes being made incorrectly
  - When the *budget* changes for a Department having a large number of Instructors in *instructor\_with\_department* application may miss some of them

- We have observed the following:
  - **Redundancy**  $\Rightarrow$  **Anomaly**
  - Relations *instructor* and *department* is better than *instructor\_with\_department*
- What causes redundancy?
  - **Dependency**  $\Rightarrow$  **Redundancy**
  - *dept\_name* uniquely decides *building* and *budget*
  - A department cannot have two different budget or building
  - So, *building* and *budget* **depends on** *dept\_name*
- How to remove, or at least minimize, redundancy?
  - Decompose (partition) the relation into smaller relations
  - *instructor\_with\_department* can be decomposed into *instructor* and *department*
  - **Good Decomposition**  $\Rightarrow$  **Minimization of Dependency**
- Is every decomposition good?
  - No
  - It needs to preserve information, honor the dependencies, be efficient, etc
  - Various schemes of normalization ensure good decomposition
  - **Normalization**  $\Rightarrow$  **Good decomposition**

## Decomposition

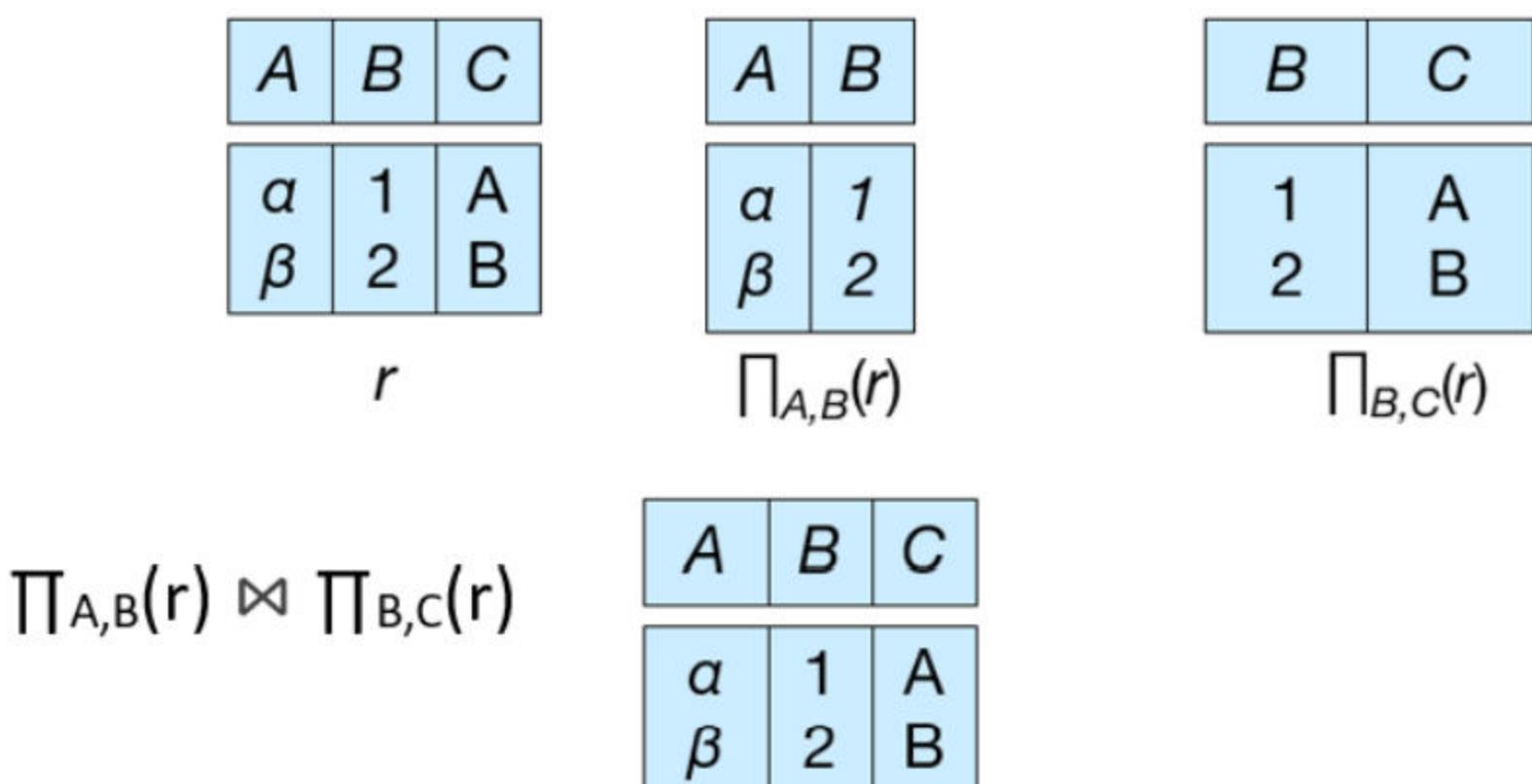
- Suppose we had started with *inst\_dept*
- How would we know to split up (**decompose**) it into *instructor* and *department*?
- Write a rule "if there were a schema (*dept\_name*, *building*, *budget*), then *dept\_name* would be a candidate key"
- Denote as a **functional dependency**:  $\text{dept\_name} \rightarrow \text{building}, \text{budget}$
- In *inst\_dept*, because *dept\_name* is not a candidate key, the *building* and *budget* of a *department* may have to be repeated
  - This indicates the need to decompose *inst\_dept*
- Not all decompositions are good
- Suppose we decompose  
 $\text{employee}(ID, name, street, city, salary)$  into
  - $\text{employee1}(ID, name)$
  - $\text{employee2}(name, street, city, salary)$
- Note that if *name* can be duplicate, then *employee2* is a weak entity set and cannot exist without an identifying relationship
- Consequently, this decomposition cannot preserve the information
- The next slide shows how we lose information — we cannot reconstruct the *original employee* relation — and so, this is a **lossy decomposition**

## Decomposition: Lossy Decomposition



### Decomposition: Lossless-join Decomposition

- **Lossless Join Decomposition**
  - Decomposition of  $R = (A, B, C)$
- $$R_1 = (A, B), R_2 = (B, C)$$



- **Lossless Join Decomposition** is a decomposition of a relation *R* into relations *R*<sub>1</sub>, *R*<sub>2</sub> such that if we perform natural join of two smaller relations it will return the original relation

$$R_1 \cup R_2 = R, R_1 \cap R_2 \neq \emptyset$$

$$\forall r \in R, r_1 = \Pi_{R_1}(r), r_2 = \Pi_{R_2}(r)$$

$$r_1 \bowtie r_2 = r$$

- This is effective in removing the redundancy from DBs while preserving the original data

- In other words, by lossless decomposition it becomes feasible to reconstruct the relation  $R$  from decomposed tables  $R_1$  and  $R_2$  by using Joins

## Atomic Domains and First Normal Form

### First Normal Form (1NF)

- A domain is atomic if its elements are considered to be indivisible units
  - Examples of non-atomic domains:
    - Set of names, composite attributes
    - Identification numbers like CS101 that can be broken up into parts
- A relational schema  $R$  is in **First Normal Form (1NF)** if
  - the domains of all attributes of  $R$  are **atomic**
  - the value of each attribute contains only a single value from that domain
- Non-atomic values complicate storage and encourage redundant (repeated) storage of data
  - **Example:** Set of accounts stored with each customer, and set of owners stored with each account
  - **We assume all relations are in the first normal form**
- **Atomicity** is actually a property of how the elements of the domain are used
  - Strings would normally be considered indivisible
  - Suppose that students are given roll numbers which are strings of the form CS0012 or EE1127
  - If the first two characters are extracted to find the department, the domain of the roll numbers is not atomic
  - *Doing so is a bad idea ...*
    - It leads to encoding of the information in application program rather than in the database
- The following is not in 1NF

**Customer**

Customer ID	First Name	Surname	Telephone Number
123	Pooja	Singh	555-861-2025, 192-122-1111
456	San	Zhang	(555) 403-1659 Ext. 53; 182-929-2929
789	John	Doe	555-808-9633

- A telephone number is composite
- Telephone number is multi-valued

- Consider:

**Customer**

Customer ID	First Name	Surname	Telephone Number1	Telephone Number2
123	Pooja	Singh	555-861-2025	192-122-1111
456	San	Zhang	(555) 403-1659 Ext. 53	182-929-2929
789	John	Doe	555-808-9633	

- is in 1NF if telephone number is not considered composite
- However, conceptually, we have two attributes for the same concept
  - Arbitrary and meaningless ordering of the attributes

- How to search telephone numbers
  - Why only two numbers?
- 
- Is the following in 1NF?

**Customer**

Customer ID	First Name	Surname	Telephone Number
123	Pooja	Singh	555-861-2025
123	Pooja	Singh	192-122-1111
456	San	Zhang	182-929-2929
456	San	Zhang	(555) 403-1659 Ext. 53
789	John	Doe	555-808-9633

- Duplicated information
  - ID is no more the key
    - Key is (ID, Telephone Number)
- 

- Better to have 2 relations:

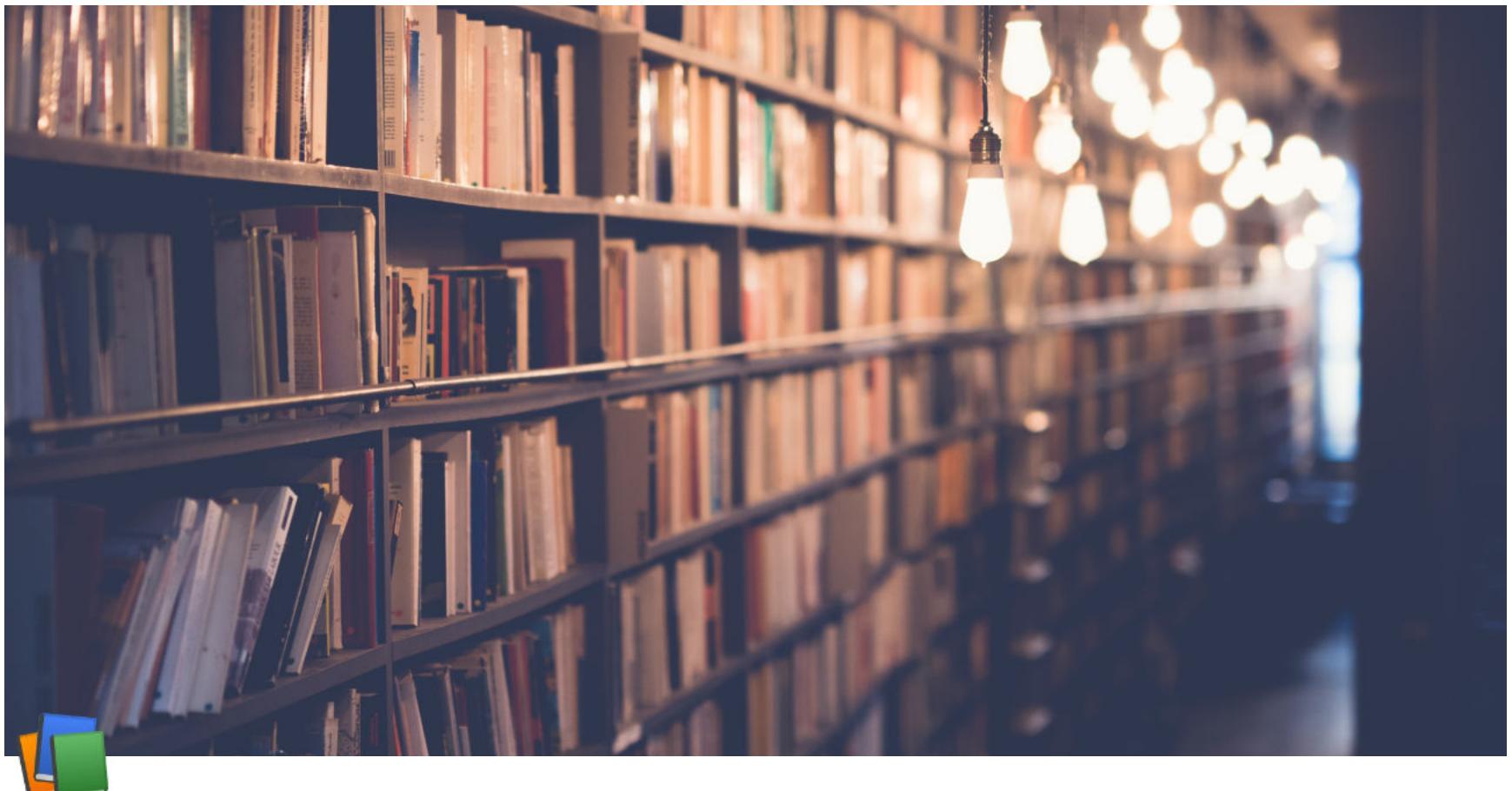
**Customer Name**

Customer ID	First Name	Surname
123	Pooja	Singh
456	San	Zhang
789	John	Doe

**Customer Telephone Number**

Customer ID	Telephone Number
123	555-861-2025
123	192-122-1111
456	(555) 403-1659 Ext. 53
456	182-929-2929
789	555-808-9633

- One-to-Many relationship between parent and child relations
  - Incidentally, satisfies 2NF and 3NF
- 
- Decomposition helps to attain 1NF for the embedded one-to-many relationship



## Week 5 Lecture 2

Class	BSCCS2001
Created	@October 4, 2021 2:41 PM
Materials	
Module #	22
Type	Lecture
Week #	5

## Relational Database Design (part 2)

### Functional Dependencies

#### Goal: Devise a theory for good relations

- Decide whether a particular relation  $R$  is in "good" form
- In the case that a relation  $R$  is not in "good" form, decompose it into a set of relations  $\{R_1, R_2, \dots, R_n\}$  such that
  - each relation is in good form
  - the decomposition is a lossless-join decomposition
- The theory is based on:
  - Functional dependencies
  - Multi-valued dependencies
  - Other dependencies

### Functional Dependencies

- Constraints on the set of legal relations
  - Require that the values for a certain set of attributes determines uniquely the value for another set of attributes
  - A functional dependency is a generalization of the notion of a key
  - Let  $R$  be a relation schema
- $$\alpha \subseteq R \text{ and } \beta \subseteq R$$

- The **functional dependency** or FD

$$\alpha \rightarrow \beta$$

holds on  $R$  if and only if for any legal relations  $r(R)$ , whenever any two tuples  $t_1$  and  $t_2$  on  $r$  agree on the attributes  $\alpha$ , they also agree on the attributes  $\beta$

That is:

$$t_1[\alpha] = t_2[\alpha] \Rightarrow t_2[\beta] = t_2[\beta]$$

- **Example:** Consider  $r(A, B)$  with the following instance of  $r$

A	B
1	4
1	5
3	7

- On this instance,  $A \rightarrow B$  does **NOT** hold, but  $B \rightarrow A$  does hold
- So, we cannot have tuples like  $(2, 4)$  or  $(3, 5)$  or  $(4, 7)$  added to the current instance
- $K$  is a superkey for relation schema  $R$  if and only if  $K \rightarrow R$
- $K$  is a candidate key for  $R$  if and only if
  - $K \rightarrow R$  and
  - for no  $\alpha \subset K, \alpha \rightarrow R$
- Functional dependencies allows us to express constraints that cannot be expressed using superkeys
- Consider the schema:  
 $inst\_dept(ID, name, salary, dept\_name, building, budget)$
- We expect these functional dependencies to hold:  
 $dept\_name \rightarrow building$   
 $dept\_name \rightarrow budget$   
 $ID \rightarrow budget$   
but would NOT expect the following to hold:  
 $dept\_name \rightarrow salary$
- We use functional dependencies to:
  - test relations to see if they are legal under a given set of functional dependencies
    - If a relation  $r$  is legal under a set  $F$  of functional dependencies, we say that  $r$  **satisfies**  $F$
  - specify constraints on the set of legal relations
    - We say that  $F$  holds on  $R$  if all legal relations on  $R$  satisfy the set of functional dependencies  $F$
- **NOTE:** A specific instance of a relation schema may satisfy a functional dependency even if the functional dependency does not hold on all legal instances
  - For example, a specific instance of instructor may, by chance, satisfy  
 $name \rightarrow ID$
  - In such cases, we do not say that  $F$  holds on  $R$
- A functional dependency is trivial if it is satisfied by all instance of the relation
  - Example:
    - $ID, name \rightarrow ID$
    - $name \rightarrow name$

- In general,  $\alpha \rightarrow \beta$  is trivial if  $\beta \subseteq \alpha$

- Functional dependencies are:

StudentID	Semester	Lecture	TA
1234	6	Numerical Methods	John
1221	4	Numerical Methods	Smith
1234	6	Visual Computing	Bob
1201	2	Numerical Methods	Peter
1201	2	Physics II	Simon

- $StudentID \rightarrow Semester$

$StudentID, Lecture \rightarrow TA$

$\{StudentID, Lecture\} \rightarrow \{TA, Semester\}$

- Functional dependencies are:

Employee ID	Employee Name	Department ID	Department Name
0001	John Doe	1	Human Resources
0002	Jane Doe	2	Marketing
0003	John Smith	1	Human Resources
0004	Jane Goodall	3	Sales

- $EmployeeID \rightarrow EmployeeName$

$EmployeeID \rightarrow DepartmentID$

$DepartmentID \rightarrow DepartmentName$

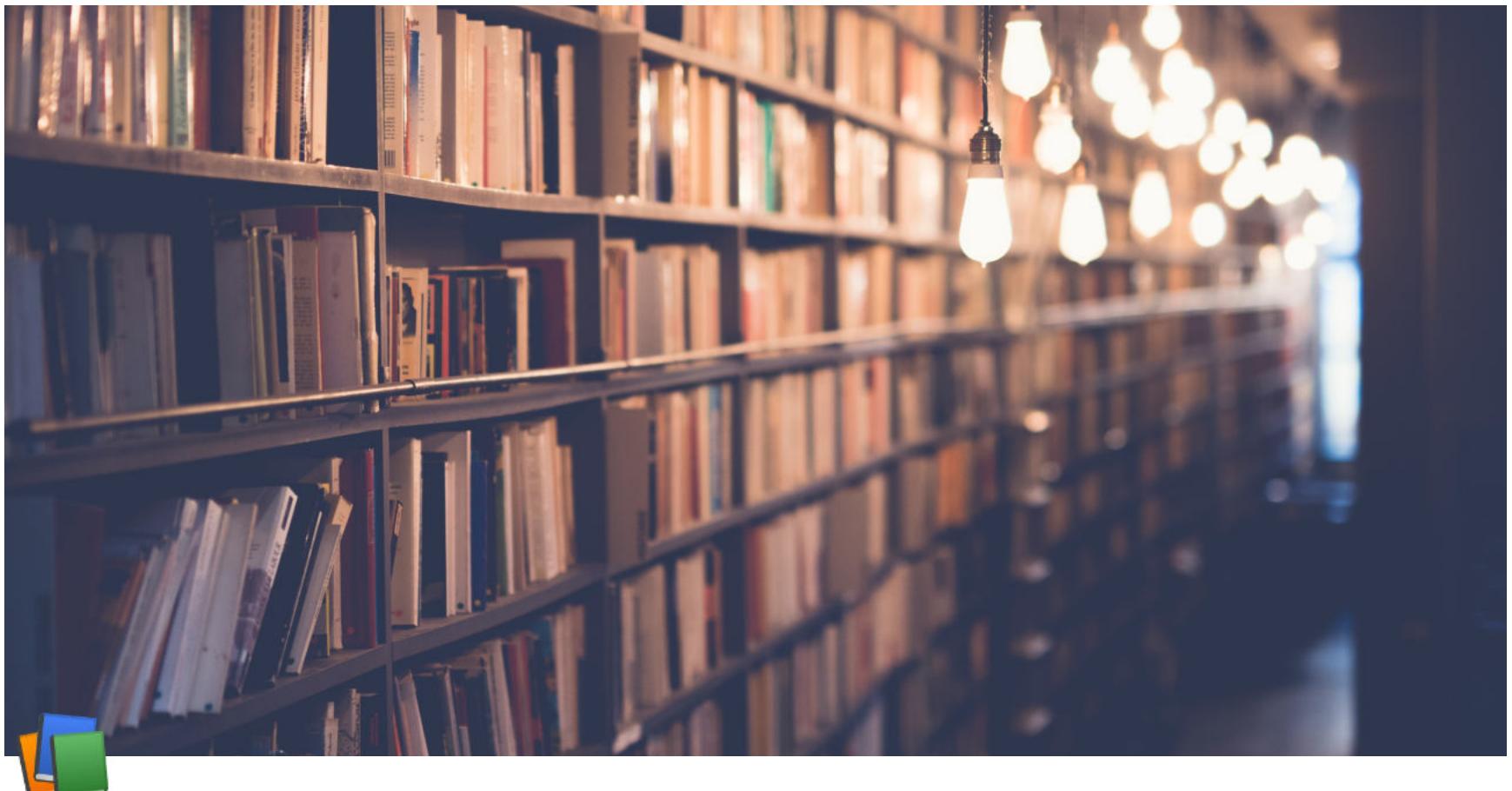
## Functional Dependencies: Armstrong's Axioms

- Given a set of Functional Dependencies  $F$ , we can infer new dependencies by the **Armstrong's Axioms**:
  - **Reflexivity:** if  $\beta \subseteq \alpha$ , then  $\alpha \rightarrow \beta$
  - **Augmentation:** if  $\alpha \rightarrow \beta$ , then  $\gamma\alpha \rightarrow \gamma\beta$
  - **Transitivity:** if  $\alpha \rightarrow \beta$  and  $\beta \rightarrow \gamma$ , then  $\alpha \rightarrow \gamma$
- These axioms can be repeatedly applied to generate new FDs and added to  $F$
- A new FD obtained by applying the axioms is said to the **logically implied** by  $F$
- The process of generations of FDs terminate after infinite number of steps and we call it the **Closure Set  $F^+$**  for FDs  $F$ 
  - This is the set of all FDs logically implied by  $F$
- Clearly,  $F \subseteq F^+$
- These axioms are:
  - **Sound** (generate only functional dependencies that actually hold) and

- **Complete** (eventually generate all functional dependencies that hold)
- Prove the axioms from definitions of FDs
- Prove the soundness and completeness of the axioms

### Functional Dependencies: Closure of a Set of FDs

- $F = \{A \rightarrow B, B \rightarrow C\}$
- $F^+ = \{A \rightarrow B, B \rightarrow C, A \rightarrow C\}$



## Week 5 Lecture 3

Class	BSCCS2001
Created	@October 4, 2021 3:28 PM
Materials	
Module #	23
Type	Lecture
Week #	5

## Relational Database Design (part 3)

### Functional Dependency Theory

#### Functional Dependencies: Closure of a Set FDs

- $R = (A, B, C, G, H, I)$

$$F = \{A \rightarrow B$$

$$A \rightarrow C$$

$$CG \rightarrow H$$

$$CG \rightarrow I$$

$$B \rightarrow H\}$$

- Some members of  $F^+$

- $A \rightarrow H$

- by transitivity from  $A \rightarrow B$  and  $B \rightarrow H$

- $AG \rightarrow I$

- by augmenting  $A \rightarrow C$  with  $G$ , to get  $AG \rightarrow CG$  and then transitivity with  $CG \rightarrow I$

- $CG \rightarrow HI$

- by augmenting  $CG \rightarrow I$  with  $CG$  to infer  $CG \rightarrow CGI$  and augmenting  $CG \rightarrow H$  with  $I$  to infer  $CGI \rightarrow HI$  and then transitivity

#### Functional Dependencies: Closure of a Set FDs: Computing $F^+$

- To compute the closure of a set of functional dependencies  $F$  :

$F^+ \leftarrow F$

**repeat**

**for each** functional dependency  $f$  in  $F^+$   
     apply reflexivity and augmentation rules on  $f$   
     add the resulting functional dependencies to  $F^+$   
**for each** pair of functional dependencies  $f_1$  and  $f_2$  in  $F^+$   
     **if**  $f_1$  and  $f_2$  can be continued using transitivity  
         **then** add the resulting functional dependency to  $F^+$

**until**  $F^+$  does not change any further

- **NOTE:** We shall see an alternative procedure for this task later

## Functional Dependencies: Armstrong's Axioms: Derived Rules

- Additional Derived Rules:
  - **Union:** if  $\alpha \rightarrow \beta$  holds and  $\alpha \rightarrow \gamma$  holds, then  $\alpha \rightarrow \beta\gamma$  holds
  - **Decomposition:** if  $\alpha \rightarrow \beta\gamma$  holds, then  $\alpha \rightarrow \beta$  holds and  $\alpha \rightarrow \gamma$  holds
  - **Pseudotransitivity:** if  $\alpha \rightarrow \beta$  holds and  $\gamma\beta \rightarrow \delta$  holds, then  $\alpha\gamma \rightarrow \delta$  holds
- The above rules can be inferred from basic Armstrong's axioms (and hence are not included in the basic set)
  - They can be proven independently too
  - **Reflexivity:** if  $\beta \subseteq \alpha$ , then  $\alpha \rightarrow \beta$
  - **Augmentation:** if  $\alpha \rightarrow \beta$ , then  $\gamma\alpha \rightarrow \gamma\beta$
  - **Transitivity:** if  $\alpha \rightarrow \beta$  and  $\beta \rightarrow \gamma$ , then  $\alpha \rightarrow \gamma$
- Prove the rules from:
  - Basic axioms
  - The definitions of FDs

## Functional Dependencies: Closure of Attribute Sets

- Given a set of attributes  $\alpha$ , define the closure of  $\alpha$  under  $F$  (denoted by  $\alpha^+$ ) as the set of attributes that are functionally determined by  $\alpha$  under  $F$
- Algorithm to compute  $\alpha^+$ , the closure of  $\alpha$  under  $F$

$result \leftarrow \alpha$

**while** (changes to result) **do**

**for each**  $\beta \rightarrow \gamma$  in  $F$  **do**  
     **begin**  
         **if**  $\beta \subseteq result$  **then**  $result \leftarrow result \cup \gamma$   
     **end**

## Functional Dependencies: Closure of Attribute Sets: Example

- $R = (A, B, C, G, H, I)$
- $F = \{A \rightarrow B, A \rightarrow C, CG \rightarrow H, CG \rightarrow I, B \rightarrow H\}$
- $(AG)^+$ 
  - result = AG
  - result = ABCG ( $A \rightarrow C$  and  $A \rightarrow B$ )
  - result = ABCGHI ( $CG \rightarrow H$  and  $CG \rightarrow I$ )
  - result = ABCGHI ( $CG \rightarrow I$  and  $CG \rightarrow AGBC$ )
- Is  $AG$  a candidate key?

- Is  $AG$  a super key?
  - Does  $AG \rightarrow R$ ? == Is  $(AG)^+ \supseteq R$
- Is any subset of  $AG$  a superkey?
  - Does  $A \rightarrow R$ ? == Is  $(A)^+ \supseteq R$
  - Does  $G \rightarrow R$ ? == Is  $(G)^+ \supseteq R$

## Functional Dependencies: Closure of Attribute Sets: Use

There are several uses of the attributes closure algorithm:

- Testing for superkey:
  - To test is  $\alpha$  is a superkey, we compute  $\alpha^+$  and check if  $\alpha^+$  contains all attributes of  $R$
- Testing functional dependencies
  - To check if a functional dependency  $\alpha \rightarrow \beta$  holds (or, in other words, is in  $F^+$ ), just check if  $\beta \subseteq \alpha^+$
  - That is, we compute  $\alpha^+$  by using attribute closure and then check if it contains  $\beta$
  - Is a simple and cheap test, and very useful
- Computing closure of  $F$ 
  - For each  $\gamma \subseteq R$ , we find the closure  $\gamma^+$  and for each  $S \subseteq \gamma^+$ , we output a functional dependency  $\gamma \rightarrow S$

## Decomposition using Functional Dependency

### BCNF: Boyce-Codd Normal Form

- A relations schema  $R$  is in BCNF w.r.t a set  $F$  of FDs if for all FDs in  $F^+$  of the form  $\alpha \rightarrow \beta$ , where  $\alpha \subseteq R$  and  $\beta \subseteq R$  at least one of the following holds:
  - $\alpha \rightarrow \beta$  is trivial (that is,  $\beta \subseteq \alpha$ )
  - $\alpha$  is a superkey for  $R$
- Example schema not in BCNF:
  - instr\_dept* (ID, name, salary, dept\_name, building, budget)
  - because the non-trivial dependency  $dept\_name \rightarrow building, budget$  holds on *instr\_dept*, but *dept\_name* is not a superkey

### BCNF: Decomposition

- If in schema  $R$  and non-trivial dependency  $\alpha \rightarrow \beta$  causes a violation of BCNF, we decompose  $R$  into:

- $\alpha \cup \beta$
- $(R - (\beta - \alpha))$

- In our example:

- $\alpha = dept\_name$
- $\beta = building, budget$
- $dept\_name \rightarrow building, budget$

*inst\_dept* is replaced by

- $(\alpha \cup \beta) = (dept\_name, building, budget)$ 
  - $dept\_name \rightarrow building, budget$
- $(R - (\beta - \alpha)) = (ID, name, salary, dept\_name)$ 
  - $ID \rightarrow name, salary, dept\_name$

### Lossless Join

- If we decompose a relation  $R$  into relations  $R_1$  and  $R_2$ :
  - Decomposition is lossy if  $R_1 \bowtie R_2 \supsetneq R$

- Decomposition is lossless if  $R_1 \bowtie R_2 = R$
- To check if lossless join decomposition using FD set, the following must hold:
  - Union of Attributes of  $R_1$  and  $R_2$  must be equal to attribute of  $R$
  - $$R_1 \cup R_2 = R$$
  - Intersection of Attributes of  $R_1$  and  $R_2$  must not be NULL
    - $R_1 \cap R_2 \neq \emptyset$
  - Common attribute must be a key for at least one relation ( $R_1$  or  $R_2$ )
 
$$R_1 \cap R_2 \rightarrow R_1 \text{ or } R_1 \cap R_2 \rightarrow R_2$$
- Prove that BCNF ensures Lossless Join

## BCNF: Dependency Preservation

- Constraints, including FDs, are costly to check in practice unless they pertain to only one relation
- If it is sufficient to test only those dependencies on each individual relation of a decomposition in order to ensure that all functional dependencies hold, then that decomposition is *dependency preserving*
- It is not always possible to achieve both BCNF and dependency preservation
- Consider:
  - $R = CSZ$ ,  $F = \{CS \rightarrow Z, Z \rightarrow C\}$
  - Key = CS
  - $CS \rightarrow Z$  satisfies BCNF, but  $Z \rightarrow C$  violates
  - Decompose as:  $R_1 = ZC$ ,  $R_2 = CSZ - (C - Z) = SZ$
  - $R_1 \cup R_2 = CSZ = R$ ,  $R_1 \cap R_2 = Z = \emptyset$  and  $R_1 \cap R_2 = Z \rightarrow ZC = R_1$ 
    - So, it has **lossless join**
  - However, we cannot check  $CS \rightarrow Z$  without doing a join
    - Hence, it is not **dependency preserving**
- We consider a weaker normal form, known as **Third Normal Form (3NF)**

## 3NF: Third Normal Form

- A relation schema  $R$  is in **third normal form (3NF)** if for all:
 
$$\alpha \rightarrow \beta \in F^+$$
 at least one of the following holds:
  - $\alpha \rightarrow \beta$  is trivial (that is,  $\beta \subseteq \alpha$ )
  - $\alpha$  is a superkey for  $R$
  - Each attribute  $A$  in  $\beta - \alpha$  is contained in a candidate key for  $R$

(**NOTE:** Each attribute may be in a different candidate key)
- If a relation is in BCNF it is in 3NF (since in BCNF one of the first two conditions must hold)
- Third condition is a minimal relaxation of BCNF to ensure dependency preservation

## Goals of Normalization

- Let  $R$  be a relation scheme with a set  $F$  of functional dependencies
- Decide whether a relation scheme  $R$  is in "good" form
- In the case that a relation scheme  $R$  is not in "good" form, decompose it into a set of relation scheme  $\{R_1, R_2, \dots, R_n\}$  such that
  - each relation scheme is in good form
  - the decomposition is a lossless-join decomposition
  - Preferably, the decomposition should be dependency preserving

## Problems with Decomposition

There are 3 potential problems to consider:

- May be impossible to re-construct the original relation (Lossiness)
- Dependency checking may require joins
- Some queries become more expensive
  - What is the building for an instructor?

**Tradeoff: Must consider these issues vs redundancy**

## How good is BCNF?

- There are DB schemas in BCNF that do not seem to be sufficiently normalized
- Consider a relation  
*inst\_info* (*ID*, *child\_name*, *phone*)
  - where an instructor may have more than one phone and can have multiple children

<i>ID</i>	<i>child_name</i>	<i>phone</i>
99999	David	512-555-1234
99999	David	512-555-4321
99999	William	512-555-1234
99999	Willian	512-555-4321

*inst\_info*

- There are no non-trivial functional dependencies and therefore the relation is in BCNF
- Insertion anomalies — that is, if we add a phone 981-992-3443 to 99999, we need to add two tuples  
(99999, David, 981-992-3443)  
(99999, William, 981-992-3443)
- Therefore, it is better to decompose *inst\_info* into:

*inst\_child*

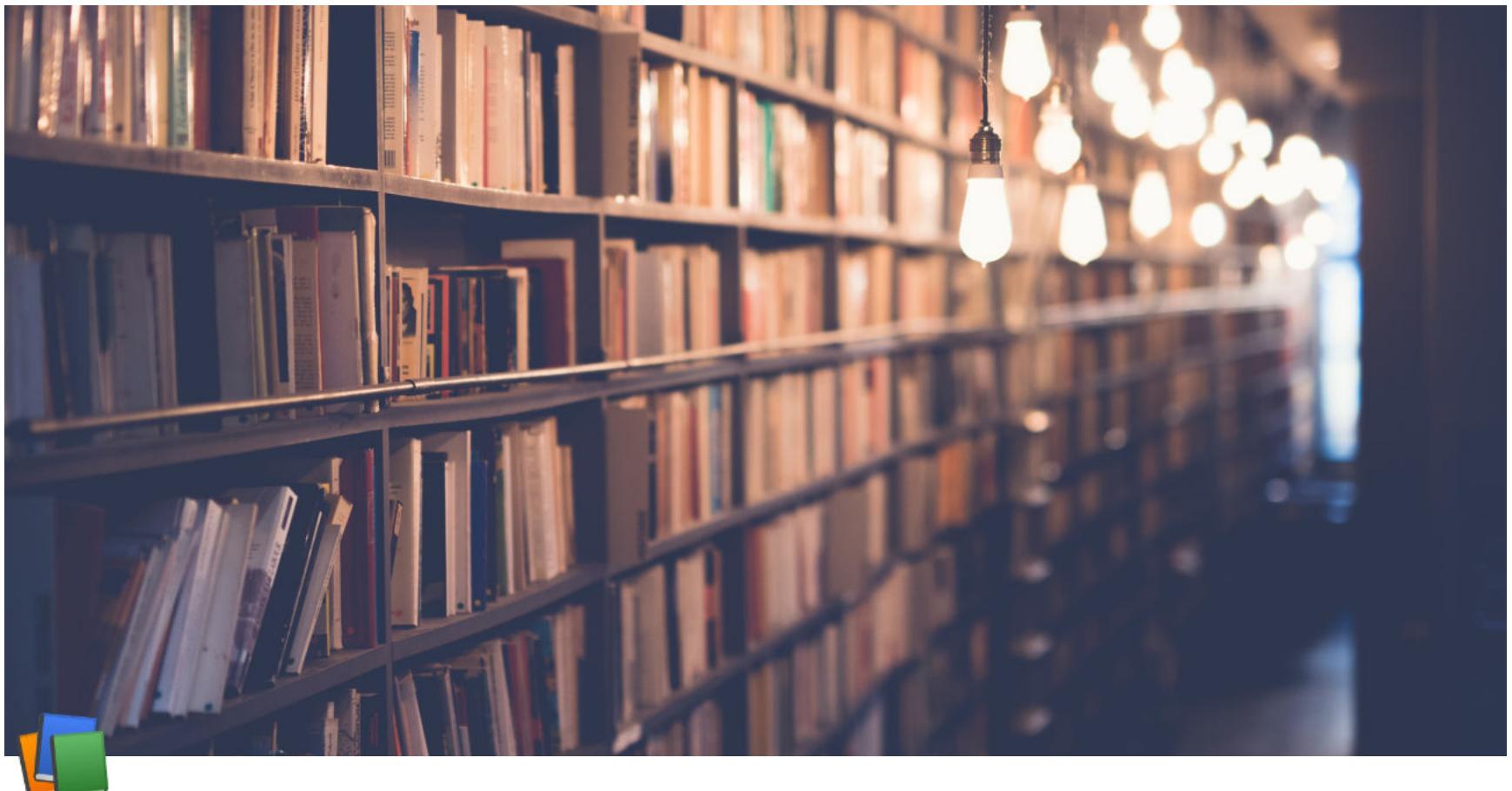
<i>ID</i>	<i>child_name</i>
99999	David
99999	William

*inst\_phone*

<i>ID</i>	<i>phone</i>
99999	512-555-1234
99999	512-555-4321

- This suggests the need for higher normal forms such as the Fourth Normal Form (4NF)





## Week 5 Lecture 4

Class	BSCCS2001
Created	@October 4, 2021 6:10 PM
Materials	
Module #	24
Type	Lecture
Week #	5

## Relational Database Design (part 4)

### Algorithms for Functional Dependencies

#### Attribute Set Closure

- $R = (A, B, C, G, H, I)$
- $F = \{A \rightarrow B, A \rightarrow C, CG \rightarrow H, CG \rightarrow I, B \rightarrow H\}$
- $(AG)^+$ 
  - result =  $AG$
  - result =  $ABCG$  ( $A \rightarrow C$  and  $A \rightarrow B$ )
  - result =  $ABCGH$  ( $CG \rightarrow H$  and  $CG \subseteq AGBC$ )
  - result =  $ABCGHI$  ( $CG \rightarrow I$  and  $CG \subseteq AGBCH$ )
- is  $AG$  a candidate key?
  - is  $AG$  a superkey?
    - Does  $AG \rightarrow R$ ? == is  $(AG)^+ \supseteq R$
    - is any subset of  $AG$  a superkey?
      - Does  $A \rightarrow R$ ? == is  $(A)^+ \supseteq R$
      - Does  $G \rightarrow R$ ? == is  $(G)^+ \supseteq R$

#### Attribute Set Closure: Uses

There are several uses of the attribute closure algorithm

- Testing for a superkey:
  - To test if  $\alpha$  is a superkey, we compute  $\alpha^+$  and check if  $\alpha^+$  contains all the attributes of  $R$
- Testing functional dependencies
  - To check if a functional dependency  $\alpha \rightarrow \beta$  holds (or, in other words, is in  $F^+$ ), just check if  $\beta \subseteq \alpha^+$
  - That is, we compute  $\alpha^+$  by using attribute closure and then check if it contains  $\beta$
  - It is a simple and cheap test, and very useful
- Computing closure of  $F$ 
  - For each  $\gamma \subseteq R$ , we find the closure  $\gamma^+$  and for each  $S \subseteq \gamma^+$ , we output a functional dependency  $\gamma \rightarrow S$

## Extraneous Attributes

- Consider a set  $F$  of FDs and the FD  $\alpha \rightarrow \beta$  in  $F$ 
  - Attribute  $A$  is extraneous in  $\alpha$  if  $A \in \alpha$  and  $F$  logically implies  $(F - \{\alpha \rightarrow \beta\}) \cup \{(\alpha - A) \rightarrow \beta\}$
  - Attribute  $A$  is extraneous in  $\beta$  if  $A \in \beta$  and the set of FDs  $(F - \{\alpha \rightarrow \beta\}) \cup \{\alpha \rightarrow (\beta - A)\}$  logically implies  $F$
- **NOTE:** Implication in the opposite direction is trivial in each of the cases above, since a "stronger" functional dependency always implies a weaker one
- **Example:** Given  $F = \{A \rightarrow C, AB \rightarrow C\}$ 
  - $B$  is extraneous in  $AB \rightarrow C$  because  $\{A \rightarrow C, AB \rightarrow C\}$  logically implies  $A \rightarrow C$   
(that is, the result of dropping  $B$  from  $AB \rightarrow C$ )
  - $A^+ = AC$  in  $\{A \rightarrow C, AB \rightarrow C\}$
- **Example:** Given  $F = \{A \rightarrow C, AB \rightarrow CD\}$ 
  - $C$  is extraneous in  $AB \rightarrow CD$  since  $AB \rightarrow C$  can be inferred even after deleting  $C$
  - $AB^+ = ABCD$  in  $\{A \rightarrow C, AB \rightarrow D\}$

## Extraneous Attributes: Tests

- Consider a set  $F$  of functional dependencies and the functional dependency  $\alpha \rightarrow \beta$  in  $F$
- To test if attribute  $A \in \alpha$  is extraneous in  $\alpha$ 
  - Compute  $(\{\alpha\} - A)^+$  using the dependencies in  $F$
  - Check that  $(\{\alpha\} - A)^+$  contains  $\beta$ ; if it does,  $A$  is extraneous in  $\alpha$
- To test if attribute  $A \in \beta$  is extraneous in  $\beta$ 
  - Compute  $\alpha^+$  using only the dependencies in  $F'$
  - Check that  $\alpha^+$  contains  $A$ ; if it does,  $A$  is extraneous in  $\beta$

## Equivalence of Sets of Functional Dependencies

- Let  $F$  &  $G$  are two functional dependency sets
  - These two sets  $F$  &  $G$  are equivalent  $F^+ = G^+$
  - That is:  $(F^+ = G^+) \Leftrightarrow (F^+ \Rightarrow G \text{ and } G^+ \Rightarrow F)$
  - Equivalence means that every functional dependency in  $F$  can be inferred from  $G$  and every functional dependency in  $G$  can be inferred from  $F$
- $F$  and  $G$  are equal only if
  - $F$  covers  $G$ : Means that all functional dependency of  $G$  are logically numbers of functional dependency set  $F \Rightarrow F^+ \supseteq G$

- $G$  covers  $F$ : Means that all functional dependency of  $F$  are logically numbers of functional dependency set  
 $G \Rightarrow G^+ \supseteq F$

Condition	CASES			
<b>F Covers G</b>	True	True	False	False
<b>G Covers F</b>	True	False	True	False
<b>Result</b>	$F=G$	$F \supsetneq G$	$G \supsetneq F$	No Comparison

### Canonical Cover

- Sets of FDs may have redundant dependencies that can be inferred from the others
- Can we have some kind of "optimal" or "minimal" set of FDs to work with?
- A **Canonical Cover** for  $F$  is a set of dependencies  $F_c$  such that ALL the following properties are satisfied:
  - $F^+ = F_c^+$ 
    - $F$  logically implies all dependencies in  $F_c$
    - $F_c$  logically implies all dependencies in  $F$
  - No functional dependency in  $F_c$  contains an irrelevant attribute
  - Each left side of functional dependency in  $F_c$  is unique
  - That is, there are no two dependencies  $\alpha_1 \rightarrow \beta_1$  and  $\alpha_2 \rightarrow \beta_2$  in such that  $\alpha_1 \rightarrow \alpha_2$
- Intuitively, a **Canonical cover** of  $F$  is a **minimal set** of FDs
  - Equivalent to  $F$
  - Having no redundant FDs
  - No redundant parts of FDs
- **Minimal / Irreducible Set of Functional Dependencies**

### Canonical Cover: Example

- For example:  $A \rightarrow C$  is redundant in  $\{A \rightarrow B, B \rightarrow C, A \rightarrow C\}$
- Parts of a functional dependency may be redundant
  - For example: on RHS:  $\{A \rightarrow B, B \rightarrow C, A \rightarrow CD\}$  can be simplified to  $\{A \rightarrow B, B \rightarrow C, A \rightarrow D\}$
  - In the forward: (1)  $A \rightarrow CD \Rightarrow A \rightarrow C$  and  $A \rightarrow D$   
 (2)  $A \rightarrow B, B \rightarrow C \Rightarrow A \rightarrow C$
  - In the reverse: (1)  $A \rightarrow B, B \rightarrow C \Rightarrow A \rightarrow C$   
 (2)  $A \rightarrow C, A \rightarrow D \Rightarrow A \rightarrow CD$
  - For example: on LHS:  $\{A \rightarrow B, B \rightarrow C, AC \rightarrow D\}$  can be simplified to  $\{A \rightarrow B, B \rightarrow C, A \rightarrow D\}$
  - In the forward: (1)  $A \rightarrow B, B \rightarrow C \Rightarrow A \rightarrow C \Rightarrow A \rightarrow AC$   
 (2)  $A \rightarrow AC, AC \rightarrow D \Rightarrow A \rightarrow D$
  - In the reverse:  $A \rightarrow D \Rightarrow AC \rightarrow D$

### Canonical Cover: RHS

- $\{A \rightarrow B, B \rightarrow C, A \rightarrow CD\} \Rightarrow \{A \rightarrow B, B \rightarrow C, A \rightarrow D\}$ 
  - (1)  $A \rightarrow CD \Rightarrow A \rightarrow C$  and  $A \rightarrow D$
  - (2)  $A \rightarrow B, B \rightarrow C \Rightarrow A \rightarrow C$
  - $A^+ = ABCD$
- $\{A \rightarrow B, B \rightarrow C, A \rightarrow D\} \Rightarrow \{A \rightarrow B, B \rightarrow C, A \rightarrow CD\}$ 
  - $A \rightarrow B, B \rightarrow C \Rightarrow A \rightarrow C$
  - $A \rightarrow C, A \rightarrow D \Rightarrow A \rightarrow CD$
  - $A^+ = ABCD$

### Canonical Cover: LHS

- $\{A \rightarrow B, B \rightarrow C, AC \rightarrow D\} \Rightarrow \{A \rightarrow B, B \rightarrow C, A \rightarrow D\}$ 
  - $A \rightarrow B, B \rightarrow C \Rightarrow A \rightarrow C \Rightarrow A \rightarrow AC$
  - $A \rightarrow AC, AC \rightarrow D \Rightarrow A \rightarrow D$
  - $A^+ = ABCD$
- $\{A \rightarrow B, B \rightarrow C, A \rightarrow D\} \Rightarrow \{A \rightarrow B, B \rightarrow C, AC \rightarrow D\}$ 
  - $A \rightarrow D \Rightarrow AC \rightarrow D$
  - $AC^+ = ABCD$

### Canonical Cover

- To compute a canonical cover for  $F$  :

**repeat**

    Use the union rule to replace any dependencies in  $F$

$\alpha_1 \rightarrow \beta_1$  and  $\alpha_1 \rightarrow \beta_2$  with  $\alpha_1 \rightarrow \beta_1\beta_2$

    Find a functional dependency  $\alpha \rightarrow \beta$  with an

        irrelevant attribute either in  $\alpha$  or in  $\beta$

        /\* NOTE: test for irrelevant attributes done using  $F_c$ , not  $F$  \*/

        If an irrelevant attribute is found, delete it from  $\alpha \rightarrow \beta$

**until**  $F$  does not change

- **NOTE:** Union rule may become applicable after some irrelevant attributes have been deleted, so it has to be re-applied

### Canonical Cover: Example

- $R = (A, B, C)$   
 $F = \{A \rightarrow BC, B \rightarrow C, A \rightarrow B, AB \rightarrow C\}$
- Combine  $A \rightarrow BC$  and  $A \rightarrow B$  into  $A \rightarrow BC$ 
  - Set is now  $\{A \rightarrow BC, B \rightarrow C, AB \rightarrow C\}$
- $A$  is extraneous in  $AB \rightarrow C$ 
  - Check if the result of deleting  $A$  from  $AB \rightarrow C$  is implied by the other dependencies  
 ▷ Yes: in fact,  $B \rightarrow C$  is already present!
  - Set is now  $\{A \rightarrow BC, B \rightarrow C\}$
- $C$  is extraneous in  $A \rightarrow BC$ 
  - Check if  $A \rightarrow C$  is logically implied by  $A \rightarrow B$  and the other dependencies  
 ▷ Yes: using transitivity on  $A \rightarrow B$  and  $B \rightarrow C$ .  
 – Can use attribute closure of  $A$  in more complex cases
- The canonical cover is:  $A \rightarrow B, B \rightarrow C$

### Practice Problems on Functional Dependencies

- **Find if a given functional dependency is implied from a set of Functional Dependencies:**
  - For:  $A \rightarrow BC, CD \rightarrow E, E \rightarrow C, D \rightarrow AEH, ABH \rightarrow BD, DH \rightarrow BC$ 
    - Check:  $BCD \rightarrow H$
    - Check:  $AED \rightarrow C$
  - For:  $AB \rightarrow CD, AF \rightarrow D, DE \rightarrow F, C \rightarrow G, F \rightarrow E, G \rightarrow A$ 
    - Check:  $CF \rightarrow DF$
    - Check:  $BG \rightarrow E$
    - Check:  $AF \rightarrow G$
    - Check:  $AB \rightarrow EF$
  - For:  $A \rightarrow BC, B \rightarrow E, CD \rightarrow EF$ 
    - Check:  $AD \rightarrow F$
- **Find Super Key using Functional Dependencies:**
  - Relational Schema  $R(ABCDE)$ . Functional dependencies:  
 $AB \rightarrow C, DE \rightarrow B, CD \rightarrow E$
  - Relational Schema  $R(ABCDE)$ . Functional dependencies:  
 $AB \rightarrow C, C \rightarrow D, B \rightarrow EA$
- **Find Candidate Key using Functional Dependencies:**
  - Relational Schema  $R(ABCDE)$ . Functional dependencies:  
 $AB \rightarrow C, DE \rightarrow B, CD \rightarrow E$
  - Relational Schema  $R(ABCDE)$ . Functional dependencies:  
 $AB \rightarrow C, C \rightarrow D, B \rightarrow EA$

- **Find Prime and Non Prime Attributes using Functional Dependencies:**

- $R(ABCDEF)$  having FDs  $\{AB \rightarrow C, C \rightarrow D, D \rightarrow E, F \rightarrow B, E \rightarrow F\}$
- $R(ABCDEF)$  having FDs  $\{AB \rightarrow C, C \rightarrow DE, E \rightarrow F, C \rightarrow B\}$
- $R(ABCDEFGHIJ)$  having FDs  $\{AB \rightarrow C, A \rightarrow DE, B \rightarrow F, F \rightarrow GH, D \rightarrow IJ\}$
- $R(ABDLPT)$  having FDs  $\{B \rightarrow PT, A \rightarrow D, T \rightarrow L\}$
- $R(ABCDEFGH)$  having FDs  
 $\{E \rightarrow G, AB \rightarrow C, AC \rightarrow B, AD \rightarrow E, B \rightarrow D, BC \rightarrow A\}$
- $R(ABCDE)$  having FDs  $\{A \rightarrow BC, CD \rightarrow E, B \rightarrow D, E \rightarrow A\}$
- $R(ABCDEH)$  having FDs  $\{A \rightarrow B, BC \rightarrow D, E \rightarrow C, D \rightarrow A\}$

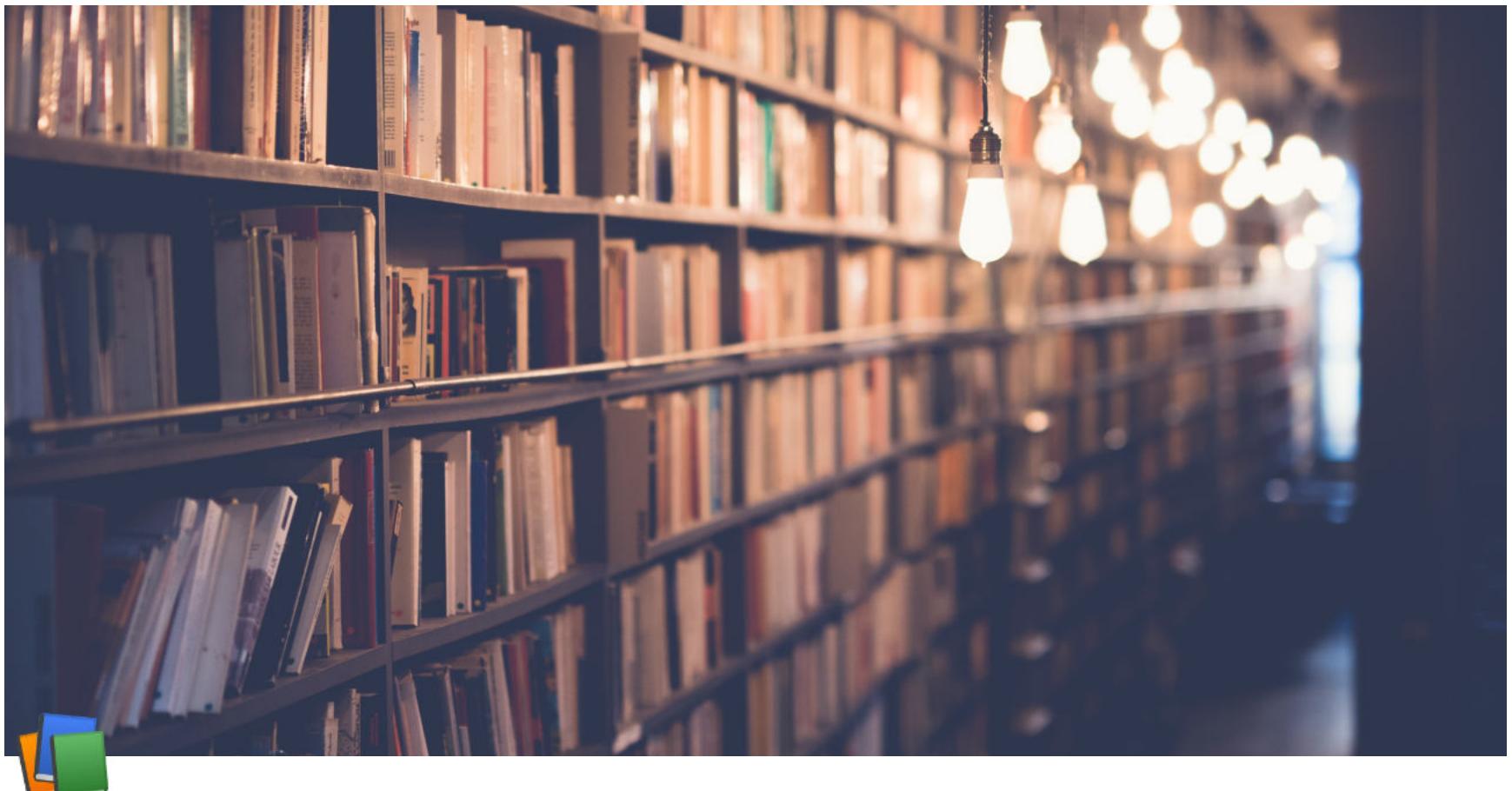
- **Prime Attributes:** Attribute set that belongs to any candidate key are called Prime Attributes
  - It is union of all the candidate key attribute:  $\{CK_1 \cup CK_2 \cup CK_3 \cup \dots\}$
  - If Prime attribute determined by other attribute set, then more than one candidate key is possible.
  - For example, If  $A$  is Candidate Key, and  $X \rightarrow A$ , then,  $X$  is also Candidate Key.
- **Non Prime Attribute:** Attribute set does not belong to any candidate key are called Non Prime Attributes

- **Check the Equivalence of a Pair of Sets of Functional Dependencies:**

- Consider the two sets  $F$  and  $G$  with their FDs as below :
  - $F : A \rightarrow C, AC \rightarrow D, E \rightarrow AD, E \rightarrow H$
  - $G : A \rightarrow CD, E \rightarrow AH$
- Consider the two sets  $P$  and  $Q$  with their FDs as below :
  - $P : A \rightarrow B, AB \rightarrow C, D \rightarrow ACE$
  - $Q : A \rightarrow BC, D \rightarrow AE$

- **Find the Minimal Cover or Irreducible Sets or Canonical Cover of a Set of Functional Dependencies:**

- $AB \rightarrow CD, BC \rightarrow D$
- $ABCD \rightarrow E, E \rightarrow D, AC \rightarrow D, A \rightarrow B$



## Week 5 Lecture 5

Class	BSCCS2001
Created	@October 4, 2021 8:05 PM
Materials	
Module #	25
Type	Lecture
Week #	5

## Relational Database Design (part 5)

### Lossless Join Decomposition

- For the case of  $R = (R_1, R_2)$ , we require that for all possible relations  $r$  on schema  $R$   
 $r = \pi_{R_1}(r) \bowtie \pi_{R_2}(r)$
- A decomposition of  $R$  into  $R_1$  and  $R_2$  is lossless join if at least one of the following dependencies is in  $F^+$ :
  - $R_1 \cap R_2 \rightarrow R_1$
  - $R_1 \cap R_2 \rightarrow R_2$
- The above functional dependencies are a sufficient condition for lossless join decomposition; the dependencies are a necessary condition only if all constraints are functional dependencies

*To Identify whether a decomposition is lossy or lossless, it must satisfy the following conditions:*

- $R_1 \cup R_2 = R$
- $R_1 \cap R_2 \neq \phi$  and
- $R_1 \cap R_2 \rightarrow R_1$  or  $R_1 \cap R_2 \rightarrow R_2$

### Lossless Join Decomposition: Example

- Consider **Supplier\_Parts** schema: **Supplier\_Parts(S#, Sname, City, P#, Qty)**
- Having dependencies: **S# → Sname**, **S# → City**, **(S#, P#) → Qty**
- Decompose as: **Supplier (S#, Sname, City, Qty)**: **Parts (P#, Qty)**

- Take natural join to reconstruct:  $\text{Supplier} \bowtie \text{Parts}$

S#	Sname	City	P#	Qty	S#	Sname	City	Qty	P#	Qty	S#	Sname	City	P#	Qty
3	Smith	London	301	20	3	Smith	London	20	301	20	3	Smith	London	301	20
5	Nick	NY	500	50	5	Nick	NY	50	500	50	5	Nick	NY	500	50
2	Steve	Boston	20	10	2	Steve	Boston	10	20	10	5	Nick	NY	20	10
5	Nick	NY	400	40	5	Nick	NY	40	400	40	2	Steve	Boston	20	10
5	Nick	NY	301	10	5	Nick	NY	10	301	10	5	Nick	NY	400	40
											5	Nick	NY	301	10
											2	Steve	Boston	301	10

- We get extra tuples! **Join is lossy**
- Common attribute Qty is not a superkey in **Supplier** or in **Parts**
- Does not preserve  $(S\#, P\#) \rightarrow Qty$
- Consider **Supplier\_Parts** schema: **Supplier\_Parts(S#, Sname, City, P#, Qty)**
- Having dependencies:  $S\# \rightarrow Sname$ ,  $S\# \rightarrow City$ ,  $(S\#, P\#) \rightarrow Qty$
- Decompose as: **Supplier (S#, Sname, City, Qty): Parts (P#, Qty)**
- Take natural join to reconstruct:  $\text{Supplier} \bowtie \text{Parts}$

S#	Sname	City	P#	Qty	S#	Sname	City	S#	P#	Qty	S#	Sname	City	P#	Qty
3	Smith	London	301	20	3	Smith	London	3	301	20	3	Smith	London	301	20
5	Nick	NY	500	50	5	Nick	NY	5	500	50	5	Nick	NY	500	50
2	Steve	Boston	20	10	2	Steve	Boston	2	20	10	2	Steve	Boston	20	10
5	Nick	NY	400	40	5	Nick	NY	5	400	40	5	Nick	NY	400	40
5	Nick	NY	301	10	5	Nick	NY	5	301	10	5	Nick	NY	301	10

- We get the original relation. **Join is lossless.**
- Common attribute **S#** is a superkey in **Supplier**
- Preserve all the dependencies
- $R = (A, B, C)$   
 $F = \{A \rightarrow B, B \rightarrow C\}$ 
  - Can be decomposed in two different ways
- $R_1 = (A, B), R_2 = (B, C)$ 
  - Lossless-join decomposition:  
 $R_1 \cap R_2 = \{B\}$  and  $B \rightarrow BC$
  - Dependency preserving
- $R_1 = (A, B), R_2 = (A, C)$ 
  - Lossless-join decomposition:  
 $R_1 \cap R_2 = \{A\}$  and  $A \rightarrow AB$
  - Not dependency preserving  
 (cannot check  $B \rightarrow C$  without computing  $R_1 \bowtie R_2$ )

### Practice Problem on Lossless join

- Check if the decomposition of  $R$  into  $D$  is lossless:
  - a)  $R(ABC) : F = \{A \rightarrow B, A \rightarrow C\}. D = R_1(AB), R_2(BC)$
  - b)  $R(ABCDEF) : F = \{A \rightarrow B, B \rightarrow C, C \rightarrow D, E \rightarrow F\}. D = R_1(AB), R_2(BCD), R_3(DEF)$
  - c)  $R(ABCDEF) : F = \{A \rightarrow B, C \rightarrow DE, AC \rightarrow F\}. D = R_1(BE), R_2(ACDEF)$
  - d)  $R(ABCDEG) : F = \{AB \rightarrow C, AC \rightarrow B, AD \rightarrow E, B \rightarrow D, BC \rightarrow A, E \rightarrow G\}$ 
    - i)  $D_1 = R_1(AB), R_2(BC), R_3(ABDE), R_4(EG)$
    - ii)  $D_2 = R_1(ABC), R_2(ACDE), R_3(ADG)$
  - e)  $R(ABCDEFGHIJ) : F = \{AB \rightarrow C, B \rightarrow F, D \rightarrow IJ, A \rightarrow DE, F \rightarrow GH\}$ 
    - i)  $D_1 = R_1(ABC), R_2(ADE), R_3(BF), R_4(FGH), R_5(DIJ)$
    - ii)  $D_2 = R_1(ABCDE), R_2(BFGH), R_3(DIJ)$
    - iii)  $D_3 = R_1(ABCD), R_2(DE), R_3(BF), R_4(FGH), R_5(DIJ)$

## Dependency Preservation

- Let  $F_i$  be the set of dependencies  $F^+$  that include only attributes in  $R_i$ 
  - A decomposition is **dependency preserving** if  $(F_1 \cup F_2 \cup \dots \cup F_n)^+ = F^+$
  - If it is not, then checking updates for violation of functional dependencies may require computing join, which is expensive

Let  $R$  be the original relational schema having FD set  $F$ . Let  $R_1$  and  $R_2$  having FD set  $F_1$  and  $F_2$  respectively, are the decomposed sub-relations of  $R$ . The decomposition of  $R$  is said to be preserving if

- $F_1 \cup F_2 \equiv F$  {Decomposition Preserving Dependency}
- If  $F_1 \cup F_2 \subset F$  {Decomposition NOT Preserving Dependency} and
- $F_1 \cup F_2 \supset F$  {this is not possible}

## Dependency Preservation: Testing

- To check if a dependency  $\alpha \rightarrow \beta$  is preserved in a decomposition of  $R$  into  $D = \{R_1, R_2, \dots, R_n\}$  we apply the following test (with attribute closure done with respect to  $F$ )
  - The **restriction** of  $F^+$  to  $R_i$  is the set of all functional dependencies in  $F^+$  that include only attributes of  $R_i$  compute  $F^+_i$ ;

**for each** schema  $R_i$  in  $D$  **do**

**begin**

$F_i$  = the restriction of  $F^+$  to  $R_i$ ;

**end**

$F' = \phi$

**for each** restriction  $F_i$  **do**

**begin**

$F' = F' \cup F_i$

**end**

compute  $F'^+$ ;

**if** ( $F'^+ = F^+$ ) **then** return (true)

**else** return (false);

- The procedure for checking dependency preservation takes exponential time to compute  $F^+$  and  $(F_1 \cup F_2 \cup \dots \cup F_n)^+$

## Dependency Preservation: Example

- $R(A, B, C, D, E, F)$

$$F = \{A \rightarrow BCD, A \rightarrow EF, BC \rightarrow AD, BC \rightarrow E, BC \rightarrow F, B \rightarrow F, D \rightarrow E\}$$

- Decomposition:  $R1(A, B, C, D)$   $R2(B, F)$   $R3(D, E)$ 
  - $A \rightarrow BCD, BC \rightarrow AD$  are preserved on table R1
  - $B \rightarrow F$  is preserved on table R2
  - $D \rightarrow E$  is preserved on table R3
  - We have to check whether the remaining FDs:  $A \rightarrow E, A \rightarrow F, BC \rightarrow E, BC \rightarrow F$  are preserved or not

R1	R2	R3
$F_1 = \{A \rightarrow ABCD, B \rightarrow B, C \rightarrow C, D \rightarrow D,$ $AB \rightarrow ABCD, BC \rightarrow ABCD, CD \rightarrow CD, AD \rightarrow ABCD$ $ABC \rightarrow ABCD, ABD \rightarrow ABCD, ACD \rightarrow ABCD$ $BCD \rightarrow ABCD\}$	$F_2 = \{B \rightarrow BF, F \rightarrow F\}$	$F_3 = \{D \rightarrow DE, E \rightarrow E\}$

- $F' = F_1 \cup F_2 \cup F_3$
- Checking for:  $A \rightarrow E, A \rightarrow F$  in  $F'^+$ 
  - $A \rightarrow D$  (from R1),  $D \rightarrow E$  (from R3) :  $A \rightarrow E$  (By transitivity)
  - $A \rightarrow B$  (from R1),  $B \rightarrow F$  (from R2) :  $A \rightarrow F$  (By transitivity)
- Checking for:  $BC \rightarrow E, BC \rightarrow F$  in  $F'^+$ 
  - $BC \rightarrow D$  (from R1),  $D \rightarrow E$  (from R3) :  $BC \rightarrow E$  (by transitivity)
  - $B \rightarrow F$  (from R2) :  $BC \rightarrow F$  (by augmentation)

#### • $R(A, B, C, D)$

$$F = \{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A\}$$

- Decomposition:  $R1(A, B)$   $R2(B, C)$   $R3(C, D)$ 
  - $A \rightarrow B$  is preserved on table R1
  - $B \rightarrow C$  is preserved on table R2
  - $C \rightarrow D$  is preserved on table R3
  - We have to check whether the one remaining FD:  $D \rightarrow A$  is preserved or not

R1	R2	R3
$F_1 = \{A \rightarrow AB, B \rightarrow BA\}$	$F_2 = \{B \rightarrow BC, C \rightarrow CB\}$	$F_3 = \{C \rightarrow CD, D \rightarrow DC\}$

- $F' = F_1 \cup F_2 \cup F_3$
- Checking for:  $D \rightarrow A$  in  $F'^+$ 
  - $D \rightarrow C$  (from R3),  $C \rightarrow B$  (from R2),  $B \rightarrow A$  (from R1) :  $D \rightarrow A$  (by transitivity)

Hence, all dependencies are preserved

## Dependency Preservation: Testing

- To check if a dependency  $\alpha \rightarrow \beta$  is preserved in a decomposition of  $R$  into  $R_1, R_2, \dots, R_n$ , we apply the following test (with attribute closure done with respect to  $F$ )
  - result =  $\alpha$
  - while (changes to result) do
    - for each  $R_i$  in the decomposition
 
$$t = (result \cap R_i)^+ \cap R_i$$

$$result = result \cup t$$
    - If result contains all attributes in  $\beta$ , then the functional dependency  $\alpha \rightarrow \beta$  is preserved
- We apply the test of all dependencies in  $F$  to check if a decomposition is dependency preserving

- This procedure takes polynomial time, instead of the exponential time required to compute  $F^+$  and  $(F_1 \cup F_2 \cup \dots \cup F_n)^+$

## Dependency Preservation: Example

- $R(ABCDEF) : F = \{A \rightarrow BCD, A \rightarrow EF, BC \rightarrow AD, BC \rightarrow E, BC \rightarrow F, B \rightarrow F, D \rightarrow E\}$
- $Decomp = \{ABCD, BF, DE\}$
- On projections:

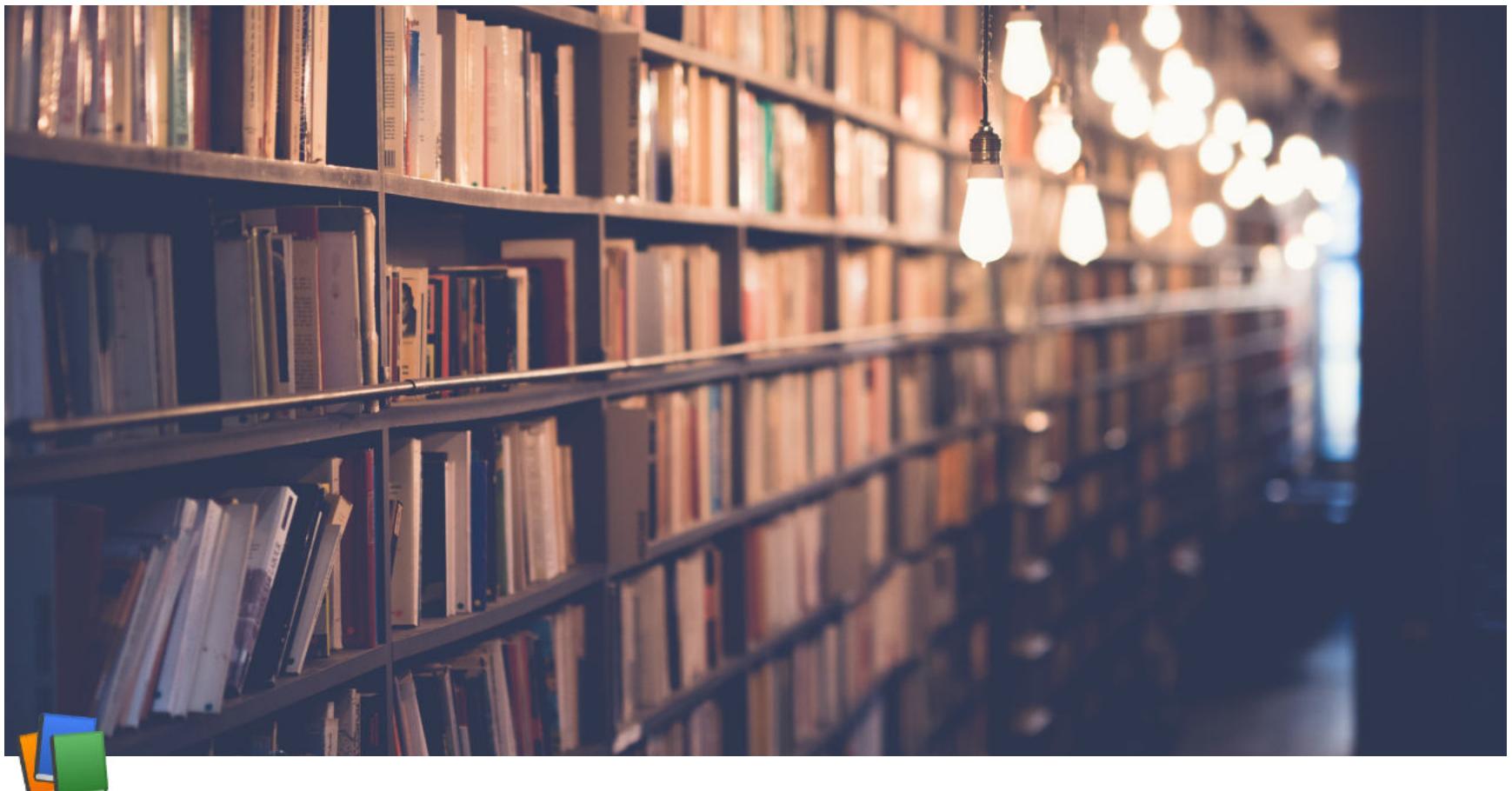
ABCD (R1)	BF (R2)	DE (R3)
$A \rightarrow BCD$ $BC \rightarrow AD$	$B \rightarrow F$	$D \rightarrow E$

- Need to check for:  $\cancel{A \rightarrow BCD}, \cancel{A \rightarrow EF}, \cancel{BC \rightarrow AD}, \cancel{BC \rightarrow E}, \cancel{BC \rightarrow F}, \cancel{B \rightarrow F}, \cancel{D \rightarrow E}$
- $(BC) + /F1 = ABCD$ .  $(ABCD) + /F2 = ABCDF$ .  $(ABCDF) + /F3 = ABCDEF$ . Preserves  $BC \rightarrow E, BC \rightarrow F$   
 $BC \rightarrow AD$  (R1),  $AD \rightarrow E$  (R3) implies  $BC \rightarrow E$   
 $B \rightarrow F$  (R2) implies  $BC \rightarrow F$
- $(A) + /F1 = ABCD$ .  $(ABCD) + /F2 = ABCDF$ .  $(ABCDF) + /F3 = ABCDEF$ . Preserves  $A \rightarrow EF$   
 $A \rightarrow B$  (R1),  $B \rightarrow F$  (R2) implies  $A \rightarrow F$   
 $A \rightarrow D$  (R1),  $D \rightarrow E$  (R3) implies  $A \rightarrow E$

- $R(ABCDEF) : F = \{A \rightarrow BCD, A \rightarrow EF, BC \rightarrow AD, BC \rightarrow E, BC \rightarrow F, B \rightarrow F, D \rightarrow E\}$ .  $Decomp = \{ABCD, BF, DE\}$
- On projections:

ABCD (R1)	BF (R2)	DE (R3)
$A \rightarrow B, A \rightarrow C, A \rightarrow D, BC \rightarrow A, BC \rightarrow D$	$B \rightarrow F$	$D \rightarrow E$

- Infer reverse FD's:
  - $B + /F = BF$  :  $B \rightarrow A$  cannot be inferred
  - $C + /F = C$  :  $C \rightarrow A$  cannot be inferred
  - $D + /F = DE$  :  $D \rightarrow A$  and  $D \rightarrow BC$  cannot be inferred
  - $A + /F = ABCDEF$  :  $A \rightarrow BC$  can be inferred, but it is equal to  $A \rightarrow B$  and  $A \rightarrow C$
  - $F + /F = F$  :  $F \rightarrow B$  cannot be inferred
  - $E + /F = E$  :  $E \rightarrow D$  cannot be inferred
- Need to check for:  $\cancel{A \rightarrow BCD}, \cancel{A \rightarrow EF}, \cancel{BC \rightarrow AD}, \cancel{BC \rightarrow E}, \cancel{BC \rightarrow F}, \cancel{B \rightarrow F}, \cancel{D \rightarrow E}$ 
  - $(BC) + /F = ABCDEF$ . Preserves  $BC \rightarrow E, BC \rightarrow F$
  - $(A) + /F = ABCDEF$ . Preserves  $A \rightarrow EF$



## Week 6 Lecture 1

Class	BSCCS2001
Created	@October 12, 2021 12:52 PM
Materials	
Module #	26
Type	Lecture
Week #	6

## Relational Database Design (part 6)

### Normal Forms

#### Normalization or Schema Refinement

- Normalization or Schema Refinement is a technique of organizing the data in the DB
- A systematic approach of decomposing tables to eliminate data redundancy and undesirable characteristics
  - Insertion Anomaly
  - Update Anomaly
  - Deletion Anomaly
- Most common technique for the Schema refinement is decomposition
  - Goal of Normalization: Eliminate redundancy
- Redundancy refers to the repetition of same data or duplicate copies of the same data stored in different locations
- Normalization is used for mainly 2 purposes:
  - Eliminating redundant (useless) data
  - Ensuring the data dependencies make sense, that is, data is logically stored

### Anomalies

- **Update Anomaly:** Employee 519 is shown as having different addresses on different records

## Employees' Skills

Employee ID	Employee Address	Skill
426	87 Sycamore Grove	Typing
426	87 Sycamore Grove	Shorthand
519	94 Chestnut Street	Public Speaking
519	96 Walnut Avenue	Carpentry

## Resolution: Decompose the Schema

- a) Update: (ID, Address), (ID, Skill)
- b) Insert: (ID, Name, Hire Date), (ID, Code)
- c) Delete: (ID, Name, Hire Date), (ID, Code)
- **Insertion Anomaly:** Until the new faculty member, Dr. Newsome, is assigned to teach at least one course, his details cannot be recorded

## Faculty and Their Courses

Faculty ID	Faculty Name	Faculty Hire Date	Course Code
389	Dr. Giddens	10-Feb-1985	ENG-206
407	Dr. Saperstein	19-Apr-1999	CMP-101
407	Dr. Saperstein	19-Apr-1999	CMP-201

424	Dr. Newsome	29-Mar-2007	?
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- **Deletion Anomaly:** All information about Dr. Giddens is lost if he temporarily ceases to be assigned to any courses

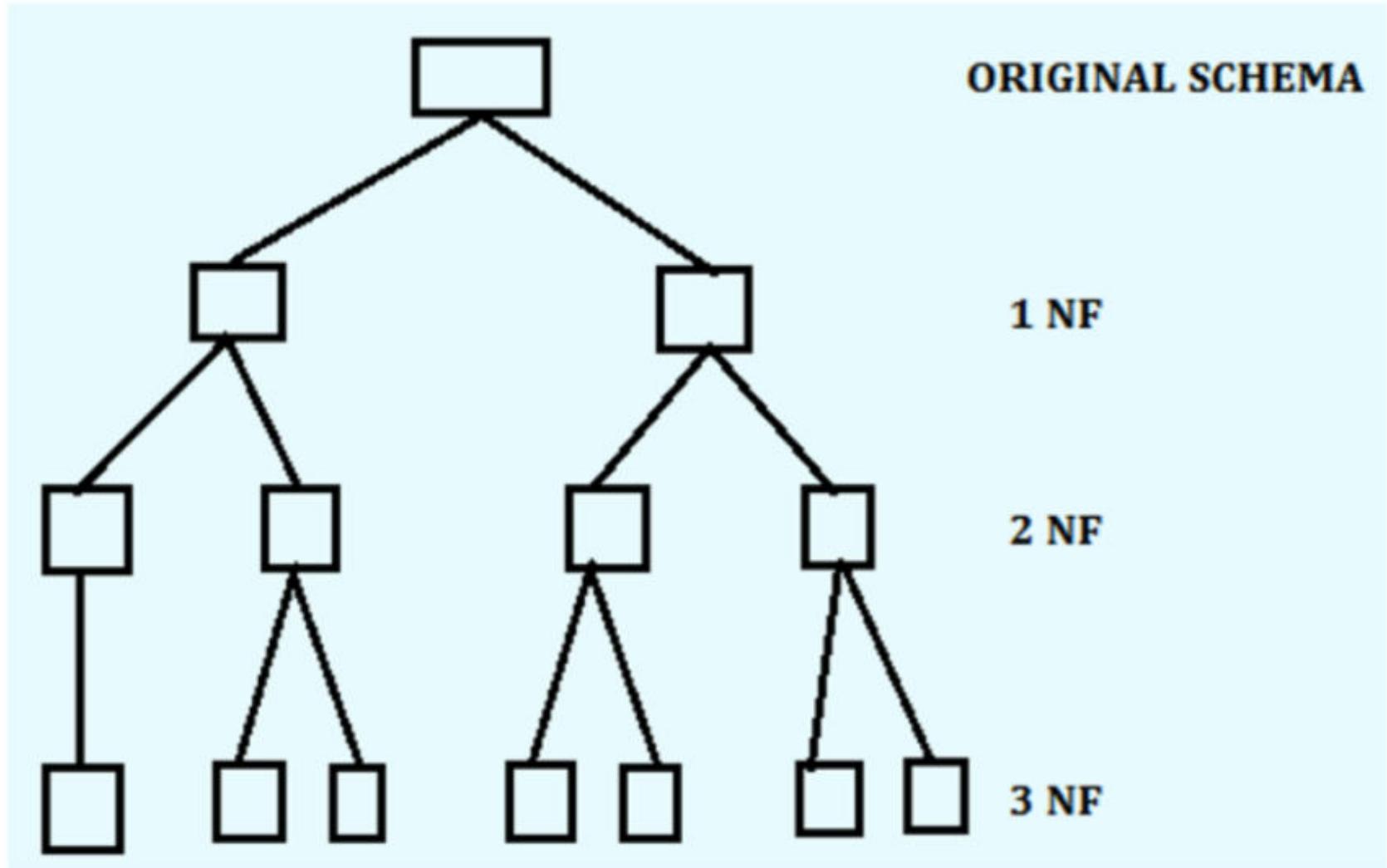
## Faculty and Their Courses

Faculty ID	Faculty Name	Faculty Hire Date	Course Code
389	Dr. Giddens	10-Feb-1985	ENG-206
407	Dr. Saperstein	19-Apr-1999	CMP-101
407	Dr. Saperstein	19-Apr-1999	CMP-201

DELETE

## Desirable Properties of Decomposition

- Lossless Join Decomposition Property
  - It should be possible to reconstruct the original table
- Dependency Preserving Property
  - No functional dependency (or other constraints should get violated)



## Normalization and Normal Forms

- A normal form specifies a set of conditions that the relational schema must satisfy in terms of its constraints — they offer varied levels of guarantee for the design
- Normalization rules are divided into various normal forms
- Most common normal forms are:
  - First Normal Form (1NF)
  - Second Normal Form (2NF)
  - Third Normal Form (3NF)
- Informally, a relational DB relation is often described as "normalized" if it meets the 3NF (Third Normal Form)
- Most 3NF are free from insertion, update and deletion anomalies
- Additional Normal Forms:
  - Elementary Key Normal Form (EKNF)
  - Boyce-codd Normal Form (BCNF)
  - Multi-valued Dependencies and Fourth Normal Form (4NF)
  - Essential Tuple Normal Form (ETNF)
  - Join Dependencies and Fifth Normal Form (5NF)
  - Sixth Normal Form (6NF)
  - Domain/Key Normal Form (DKNF)

### **1NF: First Normal Form**

- A relation is in First Normal Form if and only if all underlying domains contain atomic values only (doesn't have multi-valued attributes (MVA))
- **STUDENT (Sid, Sname, Cname)**

Students		
SID	Sname	Cname
S1	A	C,C++
S2	B	C++, DB
S3	A	DB
<b>SID : Primary Key</b>		

MVA exists  $\Rightarrow$  Not in 1NF

Students		
SID	Sname	Cname
S1	A	C
S1	A	C++
S2	B	C++
S2	B	DB
S3	A	DB
<b>SID, Cname : Primary Key</b>		

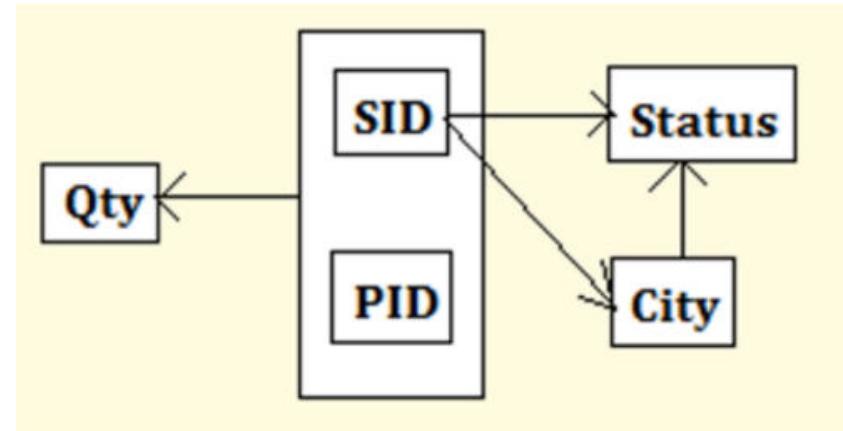
No MVA  $\Rightarrow$  In 1NF

### 1NF: Possible Redundancy

- Example: Supplier (SID, Status, City, PID, Qty)

#### Supplier

Aa	SID	# Status	≡ City	≡ PID	# Qty
S1	30	Delhi	P1	100	
S1	30	Delhi	P2	125	
S1	30	Delhi	P3	200	
S1	30	Delhi	P4	130	
S2	10	Karnal	P1	115	
S2	10	Karnal	P2	250	
S3	40	Rohtak	P1	245	
S4	30	Delhi	P4	300	
S4	30	Delhi	P5	315	



#### Drawbacks:

- Deletion Anomaly:** If we delete  $\langle S3, 40, \text{Rohtak}, P1, 245 \rangle$ , then we lose the information that S3 lives in Rohtak
- Insertion Anomaly:** We cannot insert a Supplier S5 located in Karnal, until S5 supplies at least one part
- Update Anomaly:** If Supplier S1 moves from Delhi to Kanpur, then it is difficult to update all the tuples having SID as S1 and City as Delhi

Normalization is a method to reduce redundancy

However, sometimes 1NF increases redundancy

### 1NF: Possible Redundancy

- When LHS is not a Superkey:**
  - Let  $X \rightarrow Y$  be a non-trivial FD over R with X is not a superkey of R, then redundancy exist between X and Y attribute set
  - Hence, in order to identify the redundancy, we need not to look at the actual data, it can be identified by given functional dependency
  - Example:  $X \rightarrow Y$  and X is not a Candidate Key
    - X can duplicate

- When LHS is a Superkey:**

- If  $X \rightarrow Y$  is a non-trivial FD over R with X is a superkey of R, then redundancy does not exist between X and Y attribute set
- Example:  $X \rightarrow Y$  and X is a Candidate Key
  - X cannot duplicate
  - Corresponding Y value may or may not duplicate

- Corresponding Y value would duplicate also

X	Y
1	3
1	3
2	3
2	3
4	6

X	Y
1	4
2	6
3	4

## 2NF: Second Normal Form

- Relation  $R$  is in Second Normal Form (2NF) only iff:
  - $R$  is in 1NF and
  - $R$  contains no Partial Dependency

### Partial Dependency:

Let  $R$  be a relational schema and  $X, Y, A$  be the attribute sets over  $R$  where  $X$ : Any Candidate Key,  $Y$ : Proper subset of Candidate Key and  $A$ : Non-prime attribute

If  $Y \rightarrow A$  exists in  $R$ , then  $R$  is not in 2NF

$(Y \rightarrow A)$  is a Partial dependency only if

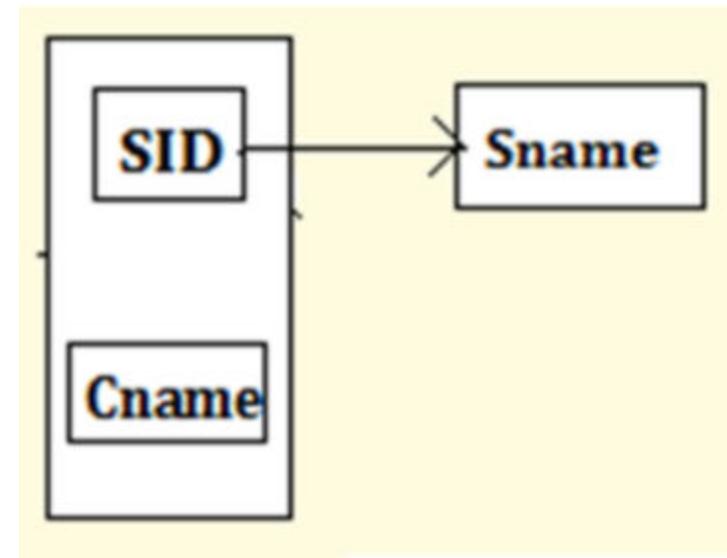
- $Y$ : Proper subset of Candidate Key
- $A$ : Non-Prime Attribute

A **prime attribute** of a relation is an attribute that is a part of a candidate key of the relation

- STUDENT (Sid, Sname, Cname) (already in 1NF)

Students

Aa	SID	Sname	Cname
S1	A	C	
S1	A	C++	
S2	B	C++	
S2	B	DB	
S3	A	DB	



- Redundancy?
  - Sname
- Anomaly?
  - Yes
- Hotel?
  - Trivage

### Functional Dependencies:

$\{SID, Cname\} \rightarrow Sname$

$SID \rightarrow Sname$

### Partial Dependencies:

$SID \rightarrow Sname$  (as SID is a Proper Subset of Candidate Key  $\{SID, Cname\}$ )

### Key Normalization

R1

Aa	SID	$\equiv$	Sname
	<u>S1</u>		A
	<u>S2</u>		B
	<u>S3</u>		A

$\{SID\}$ : Primary Key

R2

Aa	SID	$\equiv$	Cname
	<u>S1</u>		C
	<u>S1</u>		C++
	<u>S2</u>		C++
	<u>S2</u>		DB
	<u>S3</u>		DB

$\{SID, Cname\}$ : Primary Key

The above two relations R1 and R2 are

1. Lossless Join
2. 2NF
3. Dependency Preserving

### 2NF: Possible Redundancy

- Supplier (SID, Status, City, PID, Qty)

#### Supplier

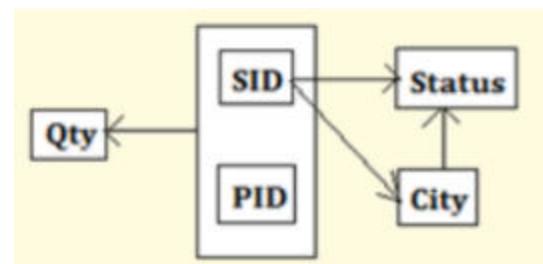
Aa	SID	#	Status	$\equiv$	City	$\equiv$	PID	#	Qty
	<u>S1</u>	30		Delhi	P1		100		
	<u>S1</u>	30		Delhi	P2		125		
	<u>S1</u>	30		Delhi	P3		200		
	<u>S1</u>	30		Delhi	P4		130		
	<u>S2</u>	10		Karnal	P1		115		
	<u>S2</u>	10		Karnal	P2		250		
	<u>S3</u>	40		Rohtak	P1		245		
	<u>S4</u>	30		Delhi	P4		300		
	<u>S4</u>	30		Delhi	P5		315		

**Key: (SID, PID)**

### Partial Dependencies:

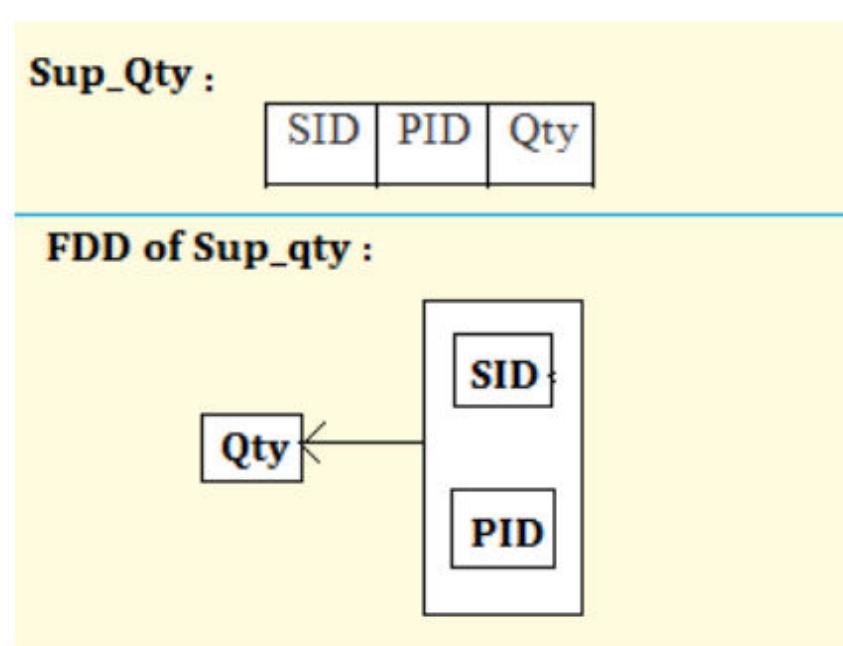
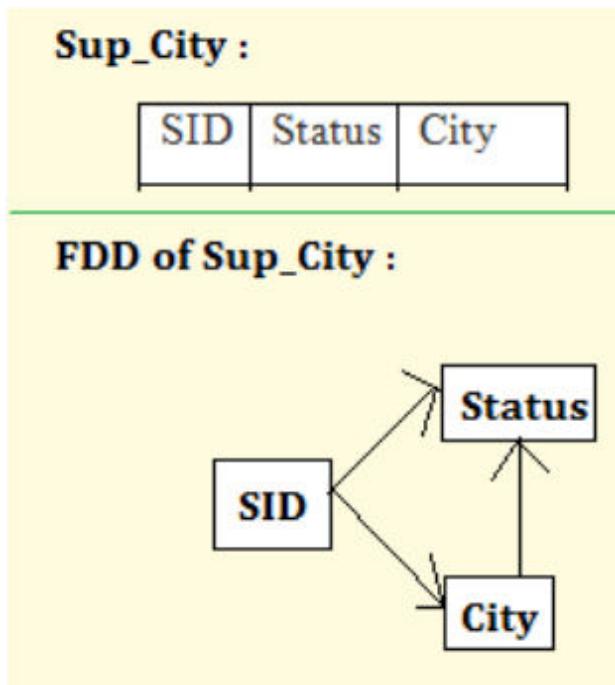
$SID \rightarrow Status$

$SID \rightarrow City$




---

### Post Normalization



### Drawbacks:

- **Deletion Anomaly:** If we delete a tuple in *Sup\_City*, then we not only lose the information about a supplier, but also lose the status value of a particular city
- **Insertion Anomaly:** We cannot insert a City and its status until a supplier supplies at least one part
- **Update Anomaly:** If the status value for a city is unchanged, then we will face the problem of searching every tuple for that city

## 3NF: Third Normal Form

Let  $R$  be the relational schema

- [E.F. Codd, 1971]  $R$  is in 3NF only if:
  - $R$  should be in 2NF
  - $R$  should not contain transitive dependencies (OR, Every non-prime attribute of  $R$  is non-transitively dependent on every day of  $R$ )
- [Carlo Zaniolo, 1982] Alternately,  $R$  is in 3NF iff for each of its functional dependency  $X \rightarrow A$ , at least one of the following conditions holds:
  - $X$  contains  $A$  (that is,  $A$  is a subset of  $X$ , meaning  $X \rightarrow A$  is trivial functional dependency) or
  - $X$  is a superkey or
  - Every element of  $A - X$ , the set difference between  $A$  and  $X$ , is a prime attribute (ie. each attribute of  $A - X$  is contained in some candidate key)
- [Simple Statement] A relational schema  $R$  is in 3NF if for every FD  $X \rightarrow A$  associated with  $R$  either
  - $A \subseteq X$  (that is, the FD is trivial) or
  - $X$  is a superkey of  $R$  or
  - $A$  is part of some candidate key (not just superkey)
- A relation is 3NF is naturally in 2NF

## 3NF: Transitive Dependency

- A transitive dependency is a functional dependency which holds by virtue of transitivity
- A transitive dependency can occur only in a relation that has 3 or more attributes
- Let  $A$ ,  $B$  and  $C$  designate 3 distinct attributes (or distinct collections of attributes) in the relation
- Suppose all 3 of the following conditions hold:
  - $A \rightarrow B$
  - It is not the case that  $B \rightarrow A$
  - $B \rightarrow C$
- Then the functional dependency  $A \rightarrow C$  (which follows from 1 and 3 by the axiom of transitivity) is a transitive dependency

- Example of transitive dependency
- The functional dependency  $\{Book\} \rightarrow \{\text{Author Nationality}\}$  applies; that is, if we know the book, we know the author's nationality
- Furthermore:
  - $\{Book\} \rightarrow \{\text{Author}\}$
  - $\{\text{Author}\}$  does not  $\rightarrow \{Book\}$
  - $\{\text{Author}\} \rightarrow \{\text{Author Nationality}\}$
- Therefore,  $\{Book\} \rightarrow \{\text{Author Nationality}\}$  is a transitive dependency
- Transitive dependency occurred because a non-key attribute (Author) was determining another non-key attribute (Author Nationality)

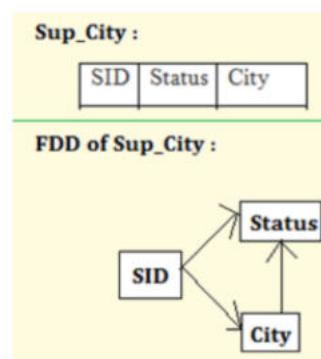
$\underline{\text{Aa Book}}$	$\equiv \text{Genre}$	$\equiv \text{Author}$	$\equiv \text{Author Nationality}$
<u>Twenty Thousand Leagues Under the Sea</u>	Science Fiction	Jules Verne	French
<u>Journey to the Center of the Earth</u>	Science Fiction	Jules Verne	French
<u>Leaves of Grass</u>	Poetry	Walt Whitman	American
<u>Anna Karenina</u>	Literary Fiction	Leo Tolstoy	Russian
<u>A Confession</u>	Religious Autobiography	Leo Tolstoy	Russian

### 3NF: Example

- Example:  
**Sup\_City(SID, Status, City) (already in 2NF)**

Sup_City:		
SID	Status	City
S1	30	Delhi
S2	10	Karnal
S3	40	Rohtak
S4	30	Delhi

SID: Primary Key



- Redundancy?
  - Status
- Anomaly?
  - Yes

**Functional Dependencies:**  
 $\text{SID} \rightarrow \text{Status}$ ,  
 $\text{SID} \rightarrow \text{City}$ ,  
 $\text{City} \rightarrow \text{Status}$   
**Transitive Dependency :**  
 $\text{SID} \rightarrow \text{Status}$   
{As  $\text{SID} \rightarrow \text{City}$  and  $\text{City} \rightarrow \text{Status}$ }

**Post Normalization**

SC:		CS:	
SID	City	City	Status
S1	Delhi	Delhi	30
S2	Karnal	Karnal	10
S3	Rohtak	Rohtak	40
S4	Delhi	Delhi	

**SC:**  
SID: Primary Key

**CS:**  
City: Primary Key

The above two relations SC and CS are

- Lossless Join
- 3NF
- Dependency Preserving

### 3NF: Example #2

- Relation **dept\_advisor (s\_ID, i\_ID, dept\_name)**
- $F = \{s\_ID, \text{dept\_name} \rightarrow i\_ID, i\_ID \rightarrow \text{dept\_name}\}$
- Two candidate keys: **s\_ID, dept\_name** and **i\_ID, s\_ID**
- R is in 3NF
  - $s\_ID, \text{dept\_name} \rightarrow i\_ID$ 
    - **s\_ID, dept\_name** is a superkey
  - $i\_ID \rightarrow \text{dept\_name}$ 
    - **dept\_name** is contained in a candidate key

A relational schema R is in 3NF if for every FD  $X \rightarrow A$  associated with R either

- $A \subseteq X$  (ie. the FD is trivial) or

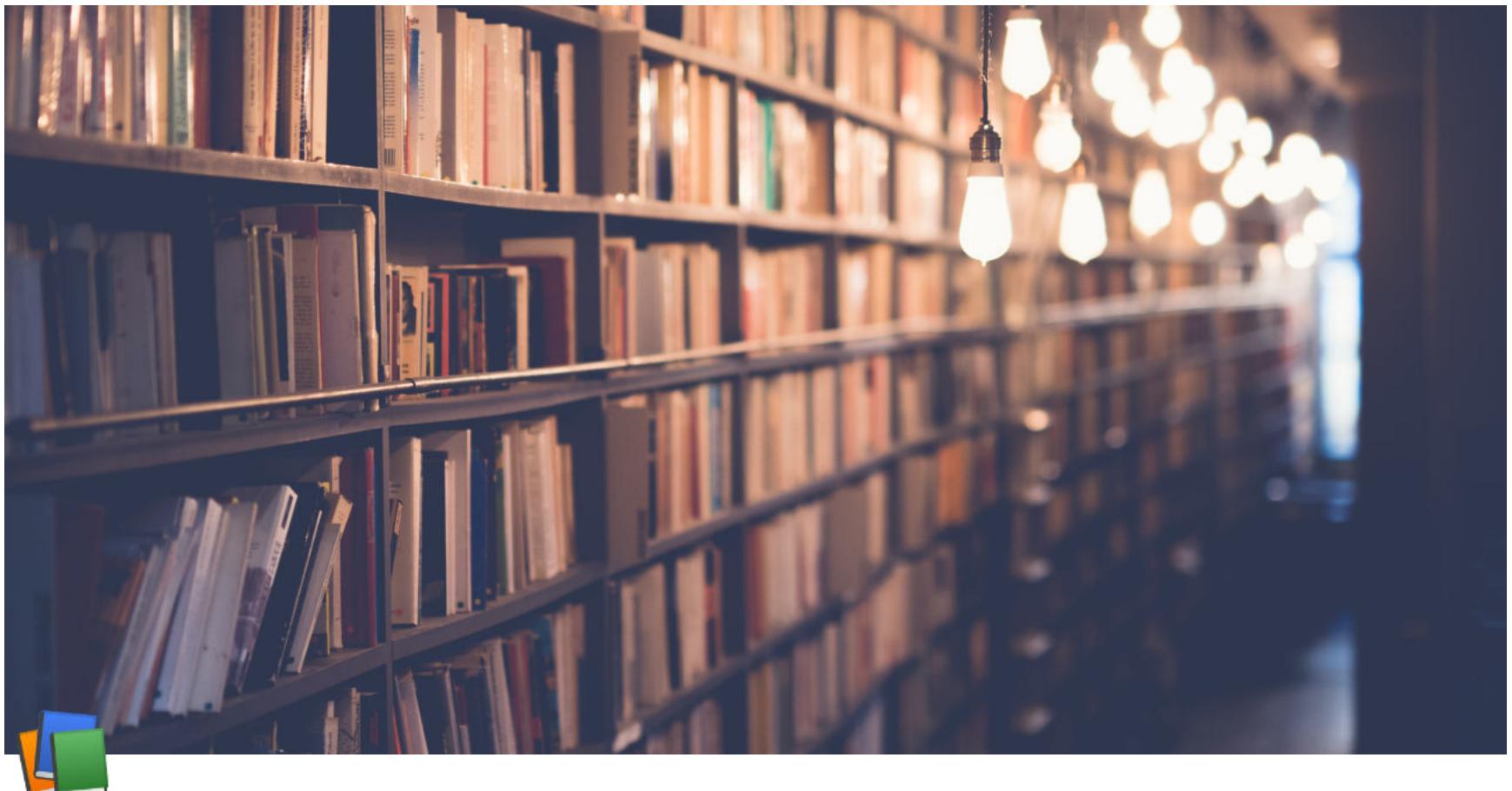
- X is a superkey of R or
- A is part of some key (not just superkey)

### 3NF: Redundancy

- There is some redundancy in this schema
- Example of problems due to redundancy in 3NF ( $J : s\_ID$ ,  $L : i\_ID$ ,  $K : dept\_name$ )
  - $R = (J, L, K)$
  - $F = \{JK \rightarrow L, L \rightarrow K\}$

$J$	$L$	$K$
$j_1$	$l_1$	$k_1$
$j_2$	$l_1$	$k_1$
$j_3$	$l_1$	$k_1$
$null$	$l_2$	$k_2$

- Repetition of information (for example, the relationship  $l_1, k_1$ )
  - $(i\_ID, dept\_name)$
- Need to use null values (for example, to represent the relationship  $l_2, k_2$  where there is no corresponding value for  $J$ )
  - $(i\_ID, dept\_name)$  if there is no separate relation mapping instructors to departments



## Week 6 Lecture 2

Class	BSCCS2001
Created	@October 12, 2021 6:11 PM
Materials	
Module #	27
Type	Lecture
Week #	6

## Relational Database Design (part 7)

### 3NF Decomposition: Motivation

- There are some situations where
  - BCNF is not dependency preserving, and
  - Efficient checking for FD violation on updates is important
- **Solution:** Define a weaker normal form, call Third Normal Form (3NF)
  - Allows some redundancy (with resultant problems, as seen above)
  - But functional dependencies can be checked on individual relations without computing a join
  - There is always lossless-join, dependency-preserving decomposition into 3NF

### 3NF Decomposition: 3NF Definition

- A relational schema  $R$  is in 3NF if for every FD  $X \rightarrow A$  associated with R either
  - $A \subseteq X$  (that is, the FD is trivial) or
  - $X$  is a superkey of R or
  - $A$  is part of some candidate key (not just superkey)
- A relation is 3NF is naturally in 2NF

### 3NF Decomposition: Testing for 3NF

- **Optimization:** Need to check only FDs in  $F$ , need not check all FDs in  $F^+$
- Use attribute closure to check for each dependency  $\alpha \rightarrow \beta$ , if  $\alpha$  is the superkey

- If  $\alpha$  is not a superkey, we have to verify if each attribute in  $\beta$  is contained in a candidate key of R
  - This test is rather more expensive, since it involves finding candidate keys
  - Testing for 3NF has been shown to be NP-hard
  - Decomposition into 3NF can be done in polynomial time

### 3NF Decomposition: Algorithm

- **Given:** relation R, set F of functional dependencies
- **Find:** decomposition of R into a set of 3NF relations  $R_i$
- **Algorithm:**
  - Eliminate redundant FDs, resulting in a canonical cover  $F_c$  of F
  - Create a relation  $R_i = XY$  for each FD  $X \rightarrow Y$  in  $F_c$
  - If the key K of R does not occur in any relation  $R_i$ , create one more relation  $R_i = K$

Let  $F_c$  be a canonical cover for F;

i := 0

```

for each functional dependency  $\alpha \rightarrow \beta$  in  $F_c$  do
  if none of the schemas  $R_j$ ,  $1 \leq j \leq i$  contains  $\alpha\beta$ 
    then begin
      i := i + 1
       $R_i := \alpha\beta$ 
    end
  if none of the schemas  $R_j$ ,  $1 \leq j \leq i$  contains a candidate key for R
    then begin
      i := i + 1
       $R_i :=$  any candidate key for R;
    end
  /* Optionally, remove redundant relations */
repeat
  if any schema  $R_j$  is contained in another schema  $R_k$ 
    then /* delete  $R_j$  */
       $R_j = R$ ;
      i = i - 1
  return ( $R_1, R_2, \dots, R_i$ )

```

### 3NF Decomposition: Algorithm

- Upon decomposition:
  - Each relation schema  $R_i$  is in 3NF
  - Decomposition is ...
    - Dependency Preserving
    - Lossless Join
- Prove these properties

### 3NF Decomposition: Example

- Relation schema:
 
$$\text{cust\_banker\_branch} = (\underline{\text{customer\_id}}, \underline{\text{employee\_id}}, \text{branch\_name}, \text{type})$$
- The functional dependencies for this relation schema are:
  - $\text{customer\_id}, \text{employee\_id} \rightarrow \text{branch\_name}, \text{type}$

- $employee\_id \rightarrow branch\_name$
    - $customer\_id, branch\_name \rightarrow employee\_id$
  - We first compute a canonical cover
    - $branch\_name$  is irrelevant in the RHS of the 1<sup>st</sup> dependency
    - No other attribute is irrelevant, so we get  $F_c =$   
 $customer\_id, employee\_id \rightarrow type$   
 $employee\_id \rightarrow branch\_name$   
 $customer\_id, branch\_name \rightarrow employee\_id$
  - The **for** loop generates the following 3NF schema:  
 $(customer\_id, employee\_id, type)$   
 $(employee\_id, branch\_name)$   
 $(customer\_id, branch\_name, employee\_id)$ 
    - Observing that  $(customer\_id, employee\_id, type)$  contains a candidate key of the original schema, so no further relation schema needs be added
  - At the end of for loop, detect and delete schemas, such as  $(employee\_name, branch\_name)$ , which are subsets of other schemas
    - Result will not depend on the order in which FDs are considered
  - The resultant simplified 3NF schema is:  
 $(customer\_id, employee\_id, type)$   
 $(customer\_id, branch\_name, employee\_id)$
- 

## BCNF Decomposition: BCNF Definition

- A relation schema R is in BCNF with respect to a set of F of FDs if for all FDs in  $F^+$  of the form  $\alpha \rightarrow \beta$ , where  $\alpha \subseteq R$  and  $\beta \subseteq R$  at least one of the following holds:
  - $\alpha \rightarrow \beta$  is trivial (that is,  $\beta \subseteq \alpha$ )
  - $\alpha$  is a superkey for R

## BCNF Decomposition: Testing for BCNF

- To check if a non-trivial dependency  $\alpha \rightarrow \beta$  causes a violation of BCNF
  - Compute  $\alpha^+$  (the attribute closure of  $\alpha$ ), and
  - Verify that it includes all attributes of R, that is, it is a superkey of R
- **Simplified test:** To check if a relation schema R is in BCNF, it suffices to check only the dependencies in the given set F for violation of BCNF, rather than checking all dependencies in  $F^+$ 
  - If none of the dependencies in F cause a violation in BCNF, then none of the dependencies in  $F^+$  will cause a violation of BCNF either
- However, simplified test using only F is incorrect when testing a relation in a decomposition of R
  - Consider R = (A, B, C, D, E) with F = {A → B, BC → D}
    - Decompose R into  $R_1 = (A, B)$  and  $R_2 = (A, C, D, E)$ 
      - Neither of the dependencies in F contain only attributes from (A, C, D, E) so we might be misled into thinking  $R_2$  satisfies BCNF
      - In fact, dependency AC → D in  $F^+$  shows  $R_2$  is not in BCNF

## BCNF Decomposition: Testing for BCNF Decomposition

- To check if a relation  $R_i$  in a decomposition of R is in BCNF
  - Either test  $R_i$  for BCNF w.r.t. the restriction of F to  $R_i$  (that is, all FDs in  $F^+$  that contain only attributes from  $R_i$ )
  - Or use the original set of dependencies F that hold on R, but with the following test:

- For every set of attributes  $\alpha \subseteq R_i$ , check that  $\alpha^+$  (the attribute closure of  $\alpha$ ) either includes no attribute of  $R_i$  —  $\alpha$  or includes all attributes of  $R_i$
- If the condition is violated by some  $\alpha \rightarrow \beta$  in  $F$ , the dependency  $\alpha \rightarrow (\alpha - \alpha^+) \cap R_i$  can be shown to hold  $R_i$  and  $R_i$  violates BCNF
- We use above dependency to decompose  $R_i$

### BCNF Decomposition: Testing Dependency Preservation: Using Closure Set of FD (Exp. Algo.):

Consider the example given below, we will apply both the algorithms to check preservation and will discuss the results

- $R(A, B, C, D)$
- $F = \{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A\}$
- Decomposition: **R1**(A, B) **R2**(B, C) **R3**(C, D)
  - $A \rightarrow B$  is preserved on table R1
  - $B \rightarrow C$  is preserved on table R2
  - $C \rightarrow D$  is preserved on table R3
  - We have to check whether the one remaining FD:  $D \rightarrow A$  is preserved or not

<b>R1</b>	<b>R2</b>	<b>R3</b>
$F_1 = \{A \rightarrow AB, B \rightarrow BA\}$	$F_2 = \{B \rightarrow BC, C \rightarrow CB\}$	$F_3 = \{C \rightarrow CD, D \rightarrow DC\}$

- $F' = F_1 \cup F_2 \cup F_3$
  - Checking for:  $D \rightarrow A$  in  $F'^+$ 
    - $D \rightarrow C$  (from R3),  $C \rightarrow B$  (from R2),  $B \rightarrow A$  (from R1) :  $D \rightarrow A$  (by transitivity)
- Hence, all the dependencies are preserved

### BCNF Decomposition: Testing Dependency Preservation: Using Closure of Attributes (Poly. Algo.)

- $R(ABCD) \therefore F = \{A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A\}$
- $Decomp = \{AB, BC, CD\}$
- On projections:

<b>R1</b>	<b>R2</b>	<b>R3</b>
<b>F1</b> $A \rightarrow B$	<b>F2</b> $B \rightarrow C$	<b>F3</b> $C \rightarrow D$

In this algo  $F1, F2, F3$  are not the closure sets, rather the sets of dependencies directly applicable on R1, R2, R3 respectively

- Need to check for:  $A \rightarrow B, B \rightarrow C, C \rightarrow D, D \rightarrow A$
- $(D)^+ / F1 = D$ .  $(D)^+ / F2 = D$ .  $(D)^+ / F3 = D$ . So,  $D \rightarrow A$  could not be preserved
- In the previous method we saw the dependency was preserved
- In reality also it is preserved
- Therefore, the polynomial time algorithm may not work in case of all examples
- To prove preservation, Algo 2 is sufficient but not necessary whereas Algo 1 is both sufficient as well as necessary

**NOTE:** This difference in result can occur in any example where a functional dependency of one decomposed table uses another functional dependency in its closure which is not applicable on any of the decomposed table because of the absence of all attributes in the table

## BCNF Decomposition: Algorithm

- For all dependencies  $A \rightarrow B$  in  $F^+$ , check if A is a superkey
  - By using attribute closure
- If not, then ...
  - Choose a dependency in  $F^+$  that breaks the BCNF rules, say  $A \rightarrow B$
  - Create  $R1 = AB$
  - Create  $R2 = (R - (B - A))$
  - **NOTE:**  $R1 \cap R2 = A$  and  $A \rightarrow AB (=R1)$ , so this is lossless decomposition
- Repeat for  $R1$  and  $R2$ 
  - By defining  $F1^+$  to be all the dependencies in F that contain only attributes in  $R1$
  - Similarly  $F2^+$

```
result := {R};  
done := false;  
compute  $F^+$ ;  
while (not done) do  
  if (there is schema  $R_i$  in result that is not in BCNF)  
    then begin
```

let  $\alpha \rightarrow \beta$  be a nontrivial functional dependency that  
 holds on  $R_i$  such that  $\alpha \rightarrow \beta$  is not in  $F^+$   
 and  $\alpha \cap \beta = \phi$ ;  
 result := (result —  $R_i$ )  $\cup$  ( $R_i - \beta$ )  $\cup$  ( $\alpha, \beta$ );

**end**

else done := true;

**NOTE:** each  $R_i$  is in BCNF and decomposition is lossless-join

## BCNF Decomposition: Example

- $R = (A, B, C)$
- $F = \{A \rightarrow B$   
     $B \rightarrow C\}$
- Key = {A}
- R is not in BCNF ( $B \rightarrow C$  but B is not superkey)
- Decomposition
  - $R_1 = (B, C)$
  - $R_2 = (A, B)$

## BCNF Decomposition: Example #2

- class (course\_id, title, dept\_name, credits, sec\_id, semester, year, building, room\_number, capacity, time\_slot\_id)
- Functional dependencies:
  - $course\_id \rightarrow title, dept\_name, credits$
  - $building, room\_number \rightarrow capacity$
  - $course\_id, sec\_id, semester, year \rightarrow building, room\_number, time\_slot\_id$
- A candidate key  $course\_id, sec\_id, semester, year$
- BCNF Decomposition:
  - $course\_id \rightarrow title, dept\_name, credits$  holds
    - but  $course\_id$  is not a superkey

- We replace *class* by:
  - *course* (*course\_id*, *title*, *dept\_name*, *credits*)
  - *class-1* (*course\_id*, *sec\_id*, *semester*, *year*, *building*, *room\_number*, *capacity*, *time\_slot\_id*)
- *course* is in BCNF
  - How do we know this?
- *building*, *room\_number* → *capacity* holds on  
 $\text{class-1}(\text{course\_id}, \text{sec\_id}, \text{semester}, \text{year}, \text{building}, \text{room\_number}, \text{capacity}, \text{time\_slot\_id})$ 
  - But  $\{\text{building}, \text{room\_number}\}$  is not a superkey for *class-1*
  - We replace *class-1* by:
    - *classroom* (*building*, *room\_number*, *capacity*)
    - *section* (*course\_id*, *sec\_id*, *semester*, *year*, *building*, *room\_number*, *time\_slot\_id*)
- *classroom* and *section* are in BCNF

### BCNF Decomposition: Dependency Preservation

- It is not always possible to get a BCNF Decomposition that is dependency preserving
- $R = (J, K, L)$

$$F = \{JK \rightarrow L\}$$

$$L \rightarrow K$$

Two candidate keys = JK and JL

- $R$  is not in BCNF
- Any decomposition of  $R$  will fail to preserve

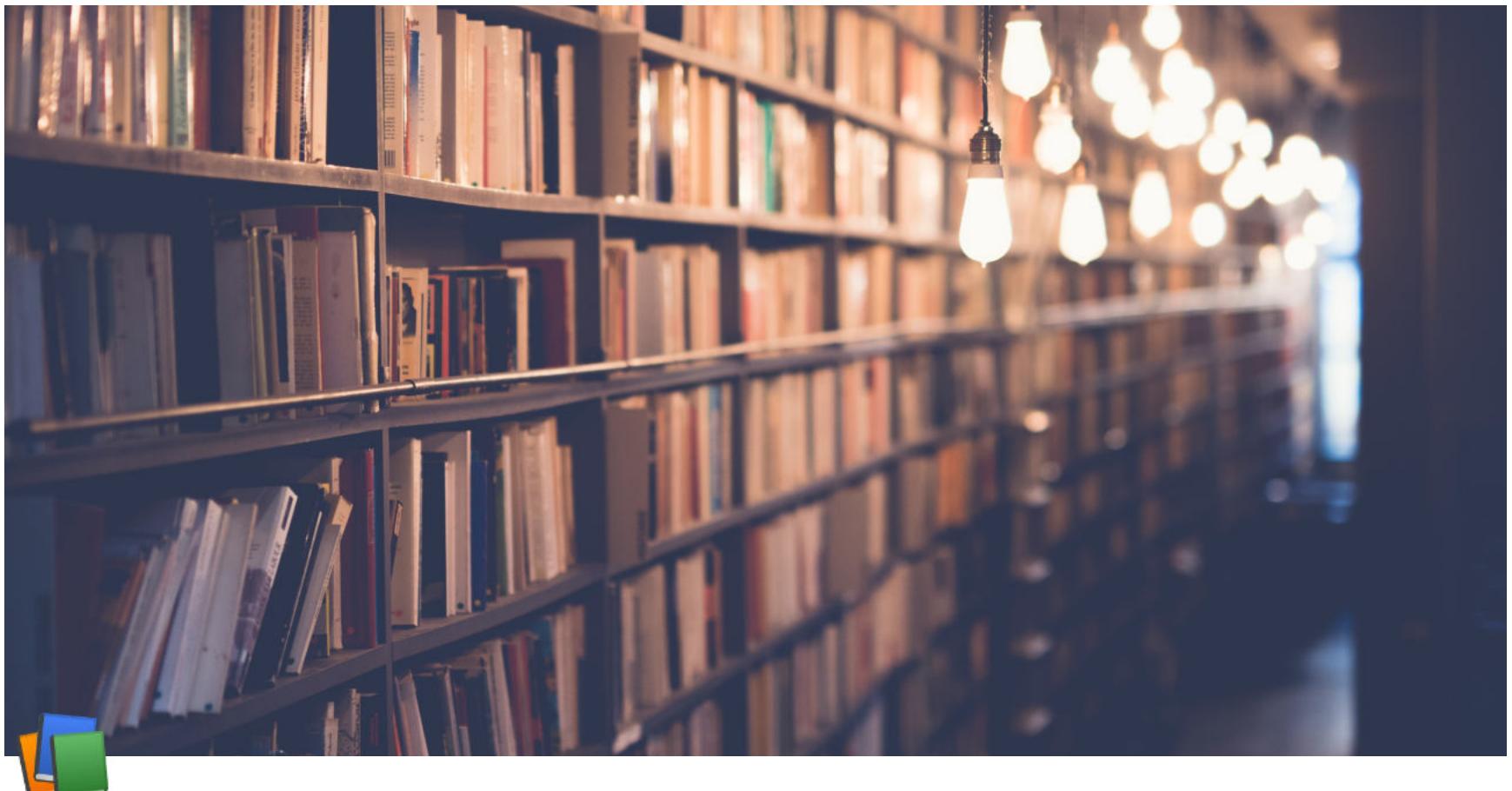
$$JK \rightarrow L$$

This implies that testing for  $JK \rightarrow L$  requires a join

### Comparison of BCNF and 3NF

- It is always possible to decompose a relation into a set of relations that are in 3NF such that:
  - the decomposition is lossless
  - the dependencies are preserved
- It is always possible to decompose a relation into a set of relations that are in BCNF such that:
  - the decomposition is lossless
  - it may not be possible to preserve dependencies

S#	3NF	BCNF
1.	It concentrates on Primary Key	It concentrates on Candidate Key
2.	Redundancy is high as compared to BCNF	0% redundancy
3.	It preserves all the dependencies	It may not preserve the dependencies
4.	A dependency $X \rightarrow Y$ is allowed in 3NF if $X$ is a super key or $Y$ is a part of some key	A dependency $X \rightarrow Y$ is allowed if $X$ is a super key



## Week 6 Lecture 3

Class	BSCCS2001
Created	@October 13, 2021 11:36 AM
Materials	
Module #	28
Type	Lecture
Week #	6

## Relational Database Design (part 8)

### Case Study

#### Library Information System (LIS)

We are asked to design a relational DB schema for a Library Information System (LIS) of an Institute

- The specification document of the LIS has already been shared with you
- We include key points from the Specs
- We carry out the following tasks in the module:
  - Identify the Entity sets with attributes
  - Identify the relationships
  - Build the initial set of relational schema
  - Refine the set of schema with FDs that hold on them
  - Finalize the design of the schema
- The coding of various queries in SQL, based on these schema are left as exercise

#### LIS Specs Excerpts

- An institute library has 200,000+ books and 1,000+ members
- Books are regularly issued by members on loan and returned after a period
- The library needs an LIs to manage the books, the members and the issue-term process

- Every book has
  - title
  - author (in case of multiple authors, only the first author is mentioned)
  - publisher
  - year of publication
  - ISBN number (which is unique for the publication)
  - accession number (which is the unique number of the copy of the book in the library)

There may be multiple copies of the same book in the library

---

There are 4 categories of members of the library:

- Undergraduate students
- Post-graduate students
- Research scholars
- Faculty members

Every student has ...

- Name
- Roll number
- Department
- Gender
- Mobile number
- Date of Birth
- Degree
  - Undergrad
  - Grad
  - Doctoral

Every faculty has ...

- Name
- Employee ID
- Department
- Gender
- Mobile number
- Date of Joining

Library also issues a unique membership number to every member

Every member has a max quota for the number of books he/she can issue for the maximum duration allowed to her/him

Currently, these are set as:

- Each undergraduate student can issue up to 2 books for 1 month duration
- Each postgraduate student can issue up to 4 books for 1 month duration
- Each research scholar can issue up to 6 books for 3 months duration
- Each faculty member can issue up to 10 books for 6 months duration

---

The library has the following rules for issue:

- A book may be issued to a member if it is not already issued to someone else (trivial)
- A book may not be issued to a member if another copy of the same book is already issued to the same member

- No issue will be done to a member if at the time of issue one or more of the books issued by the member has already exceeded its duration of issue
- No issue will be allowed also if the quota is exceeded for the member
- It is assumed that the name of every author or member has two parts
  - First name
  - Last name

## LIS Specs Excerpts: Queries

LIS should support the following operations / queries:

- Add / Remove members, categories of members, books
- Add / Remove / Edit quota for a category of member, duration for a category of member
- Check if the library has a book given its title (part of title should match)
  - If yes, title, author, publisher, year and ISBN should be listed
- Check if the library has a book given its author
  - If yes, title, author, publisher, year and ISBN should be listed
- Check if a copy of a book (given its ISBN) is available with the library for issue
  - All accession numbers should be listed with issued or available information
- Check the available (free) quota of a member
- Issue a book to a member
  - This should check for the rules of the library
- Return a book from a member
- and so on ...

## LIS Entity Sets: books

- Every book has title, author (in case of multiple authors, only the first author is maintained), published, year of publication, ISBN number (which is unique for the publication) and accession number (which is the unique number of the copy of the book in the library)
  - There may be multiple copies of the same book in the library
- Entity set:
  - **books**
- Attributes:
  - title
  - author\_name (composite);
  - publisher
  - year
  - ISBN\_no
  - accession\_no

## LIS Entity Sets: students

- Every student has name, roll number, department, gender, mobile number, date of birth and degree (undergrad, grad, doctoral)
- Entity Set:
  - **students**
- Attributes
  - member\_no - is unique
  - name (composite)

- roll\_no - is unique
- department
- gender
- mobile\_no - may be null
- dob
- degree

### LIS Entity Sets: faculty

- Every faculty has name, employee id, department, gender, mobile number and date of joining
- Entity Set:
  - **faculty**
- Attributes:
  - member\_no - is unique
  - name (composite)
  - id - is unique
  - department
  - gender
  - mobile\_no - may be null
  - doj

### LIS Entity Sets: members

- Library also issues a unique membership number to every member
- There are 4 categories of members of the library:
  - undergraduate students
  - post graduate students
  - research scholars
  - faculty members
- Entity Set:
  - **members**
- Attributes:
  - member\_no
  - member\_type (takes a value in ug, pg, rs or fc)

### LIS Entity Sets: quota

- Every member has a max quota for the number of books she / he can issue for the max duration allowed to her / him
- Currently, these are set as:
  - Each undergraduate student can issue up to 2 books for 1 month duration
  - Each postgraduate student can issue up to 4 books for 1 month duration
  - Each research scholar can issue up to 6 books for 3 months duration
  - Each faculty member can issue up to 10 books for 6 months duration
- Entity Set:
  - **quota**
- Attributes:
  - member\_type
  - max\_books

- max\_duration

## LIS Entity Sets: staff

- Thought not explicitly stated, library would have staffs to manage the LIS
- Entity Set:
  - **staff**
- Attributes: (speculated — to ratify from customer)
  - name (composite)
  - id - is unique
  - gender
  - mobile\_no
  - doj

## LIS Relationships

- Books are regularly issued by members on loan and returned after a period
- The library needs an LIS to manage the books, the members and the issue-return process
- Relationship
  - **book\_issue**
- Involved Entity Sets
  - **students / faculty / members**
    - member\_no
  - **books**
    - accession\_no
- Relationship Attribute
  - doi — date of issue
- Type of relationship
  - Many-to-one from **books**

## LIS Relational Schema

- **books** (title, author\_fname, author\_lname, publisher, year, ISBN\_no, accession\_no)
- **book\_issue** (members, accession\_no, doi)
- **members** (member\_no, member\_type)
- **quota** (member\_type, max\_books, max\_duration)
- **students** (member\_no, student\_fname, student\_lname, roll\_no, department, gender, mobile\_no, dob, degree)
- **faculty** (member\_no, faculty\_fname, faculty\_lname, id, department, gender, mobile\_no, doj)
- **staff** (staff\_fname, staff\_lname, id, gender, mobile\_no, doj)

## LIS Schema Refinement: books

- **books** (title, author\_fname, author\_lname, publisher, year, ISBN\_no, accession\_no)
  - ISBN\_no → title, author\_fname, author\_lname, publisher, year
  - accession\_no → ISBN\_no
  - Key: accession\_no
- Redundancy of book information across copies
- Good to normalize:
  - **book\_catalogue** (title, author\_fname, author\_lname, publisher, year, ISBN\_no)

- ISBN\_no → title, author\_fname, author\_lname, publisher, year
- Key: ISBN\_no
- **book\_copies** (ISBN\_no, accession\_no)
  - accession\_no → ISBN\_no
  - Key: accession\_no
- Both in BCNF
- Decomposition is lossless join and dependency preserving

### LIS Schema Refinement: book\_issue

- book\_issue (member\_no, accession\_no, doi)
  - member\_no, accession\_no → doi
  - Key: members, accession\_no
- In BCNF

### LIS Schema Refinement: quota

- quota (member\_type, max\_books, max\_duration)
  - member\_type → max\_books, max\_duration
  - Key: member\_type
- In BCNF

### LIS Schema Refinement: members

- members (member\_no, member\_type)
  - member\_no → member\_type
  - Key: member\_no
  - Value constraint on member\_type
    - ug, pg or rs: if the member is a student
    - fc: if the member is a faculty
  - In BCNF
  - How to determine the member\_type?

### LIS Schema Refinement: students

- students (member\_no, student\_fname, student\_lname, roll\_no, department, gender, mobile\_no, dob, degree)
  - roll\_no → student\_fname, student\_lname, department, gender, mobile\_no, dob, degree
  - member\_no → roll\_no
  - roll\_no → member\_no
  - 2 Keys: roll\_no | member\_no
- In BCNF
- Issues:
  - member\_no is needed for issue / return queries
    - It is unnecessary to have student's details with that
  - member\_no may also come from faculty relation
  - member\_type is needed for issue / return queries
    - This is implicit in degree — not explicitly given

### LIS Schema Refinement: faculty

- faculty (member\_no, faculty\_fname, faculty\_lname, id, department, gender, mobile\_no, doj)

- id → faculty\_fname, faculty\_lname, department, gender, mobile\_no, doj
- id → member\_no
- member\_no → id
- 2 Keys: id | member\_no
- In BCNF
- Issues:
  - member\_no is needed for the issue / return queries
    - It is unnecessary to have faculty details with that
  - member\_no may also come from **student** relation
  - member\_type is needed for issue / return queries
    - This is implicit by the fact that we are in faculty relation

## LIS Schema Refinement: Query

- Consider a query:
  - Get the name of the member who has issued the book having accession number = 162715
    - If the member is a student

```
SELECT student_fname as First_Name, student_lname as Last_Name
FROM students, book_issue
WHERE accession_no = 162715 AND book_issue.member_no = students.member_no;
```

- If the member is a faculty

```
SELECT faculty_fname as First_Name, faculty_lname as Last_Name
FROM faculty, book_issue
WHERE accession_no = 162715 AND book_issue.member_no = faculty.member_no;
```

- Which query to fire!?

## LIS Schema Refinement: members

There are 4 categories of members: ug students, grad students, research scholars and faculty members

This leads to the following specialization relationships

- Consider the entity set **members** of a library and refine:
  - Attributes:
    - member\_no
    - member\_class — 'student' or 'faculty', used to choose table
    - member\_type — ug, pg, rs, fc, ...
    - roll\_no (if member\_class — 'student', else null)
    - if (if member\_class — 'faculty', else null)
- We can exploit some hidden relationship:
  - student IS A members
  - faculty IS A members
- Types of relationship
  - One-to-one

## LIS Schema Refinement: Query

- Consider the access query again:
  - Get the name of the member who has issued the book having accession number = 162715

```

SELECT
((SELECT faculty_fname as First_Name, faculty_lname as Last_Name
FROM faculty
WHERE member_class = 'faculty' AND members.id = faculty.id)
UNION
(SELECT student_fname as First_Name, student_lname as Last_Name
FROM students
WHERE member_class = 'student' AND members.roll_no = students.roll_no))
FROM members, book_issue
WHERE accession_no = 162715 AND book_issue.member_no = members.member_no;

```

## LIS Schema Refinement: members

- **members** (member\_no, member\_class, member\_type, roll\_no, id)
  - member\_no → member\_type, member\_class, roll\_no, id
  - member\_type → member\_class
  - Key: member\_no

## LIS Schema Refinement: students

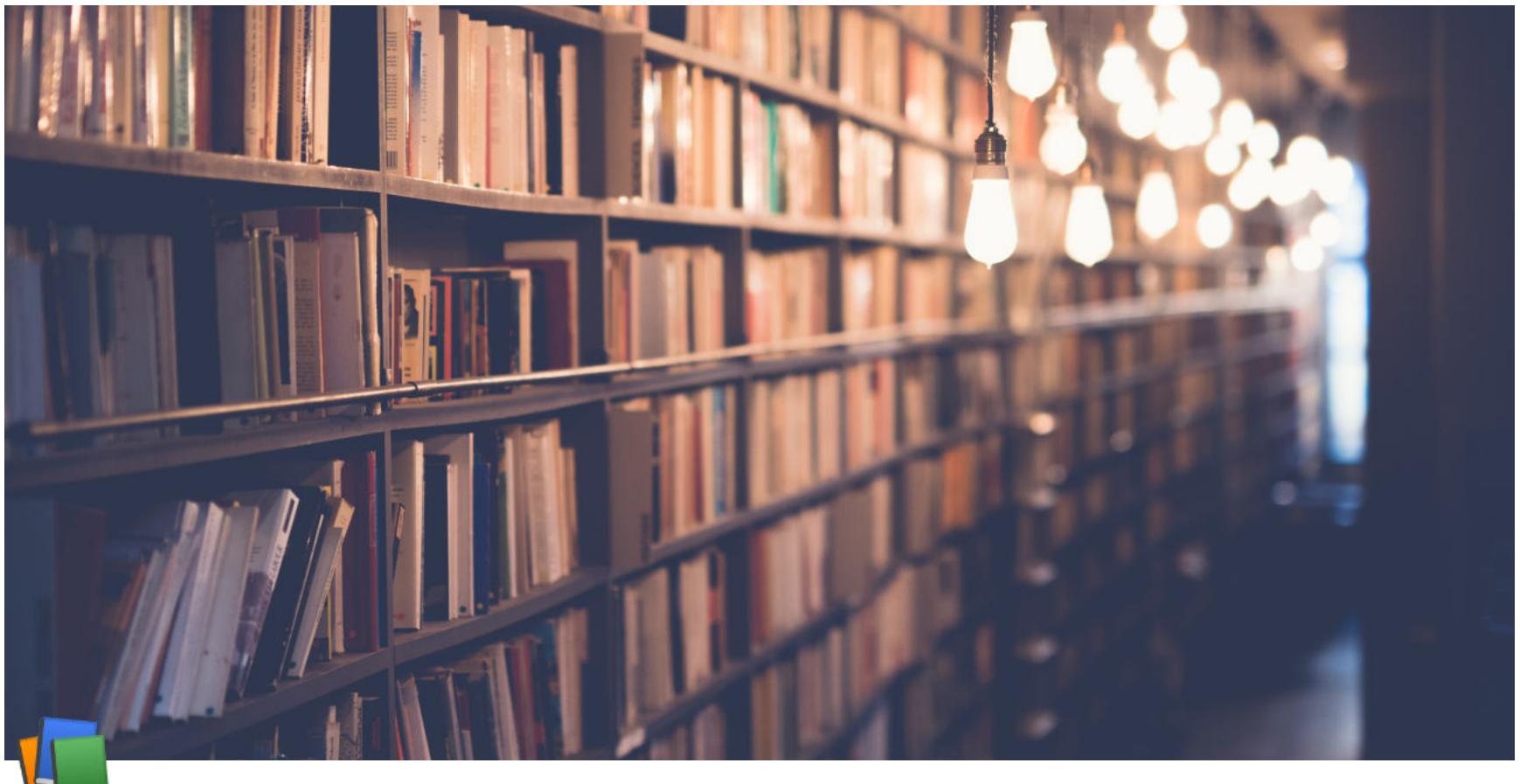
- **students** (student\_fname, student\_lname, roll\_no, department, gender, mobile\_no, dob, degree)
  - roll\_no → student\_fname, student\_lname, department, gender, mobile\_no, dob, degree
  - Keys: roll\_no
  - Note:
    - member\_no is no longer used
    - member\_type and member\_class are set in **members** from degree at the time of creation of a new record

## LIS Schema Refinement: faculty

- **faculty** (faculty\_fname, faculty\_lname, id, department, gender, mobile\_no, doj)
  - id → faculty\_fname, faculty\_lname, department, gender, mobile\_no, doj
  - Keys: id
  - Note:
    - member\_no is no longer used
    - member\_type and member\_class are set in **members** at the time of creation of a new record

## LIS Scheme Refinement: Final

- **book\_catalogue** (title, author\_fname, author\_lname, publisher, year, ISBN\_no)
- **book\_copies** (ISBN\_no, accession\_no)
- **book\_issue** (member\_no, accession\_no, doi)
- **quota** (member\_type, max\_books, max\_duration)
- **members** (member\_no, member\_class, member\_type, roll\_no, id)
- **students** (student\_fname, student\_lname, roll\_no, department, gender, mobile\_no, dob, degree)
- **faculty** (faculty\_fname, faculty\_lname, id, department, gender, mobile\_no, doj)
- **staff** (staff\_fname, staff\_lname, id, gender, mobile\_no, doj)



## Week 6 Lecture 4

Class	BSCCS2001
Created	@October 13, 2021 6:02 PM
Materials	
Module #	29
Type	Lecture
Week #	6

## Relational Database Design (part 9)

### MVD: Multi-valued Dependency

- Persons (Man, Phones, Dog\_Like)

Person :			Meaning of the tuples
Man(M)	Phones(P)	Dogs_Like(D)	
M1	P1/P2	D1/D2	Man M have phones P, and likes the dogs D.
M2	P3	D2	M1 have phones P1 and P2, and likes the dogs D1 and D2.
Key : MPD			

There are no non-trivial FDs because all attributes are combined forming Candidate Key, that is, MDP

In the above relation, 2 multi-valued dependencies exist:

- Man  $\twoheadrightarrow$  Phones
- Man  $\twoheadrightarrow$  Dog\_Like

A man's phone is independent of the phone they like

But, after converting the above relation in Single Valued Attribute, each of a man's phone appears with each of the dogs they like in all combinations

## Post 1NF Normalization

Man(M)	Phones(P)	Dogs_Likes(D)
M1	P1	D1
M1	P2	D2
M2	P3	D2
M1	P1	D2
M1	P2	D1

### MVD

- If two or more independent relations are kept in a single relation, then Multi-valued Dependency is possible
- For example, let there be 2 relations:
  - **Student (SID, Sname) where (SID → Sname)**
  - **Course (CID, Cname) where (CID → Cname)**
- There is no relation defined between Student and Course
- If we kept them in a single relation named **Student\_Course**, then MVD will exist because of m:n Cardinality
- If two or more MVDs exist in a relation, then while converting into SVAs, MVD exists

Student:		Course:		SID	Sname	CID	Cname
SID	Sname	CID	Cname	SID	Sname	CID	Cname
S1	A	C1	C	S1	A	C1	C
S2	B	C2	B	S1	A	C2	B
				S2	B	C1	C
				S2	B	C2	B

**2 MVDs exist:**

1. SID →→ CID
2. SID →→ Cname

- Suppose we record names of the children, and phone numbers for the instructors
  - *inst\_child (ID, child\_name)*
  - *inst\_phone (ID, phone\_number)*
- If we were to combine these schema to get
  - *inst\_info (ID, child\_name, phone\_number)*
  - Example data:
 

(99999, David, 512-555-1234)  
 (99999, David, 512-555-4321)  
 (99999, William, 512-555-1234)  
 (99999, William, 512-555-4321)
- This relation is in BCNF

### MVD: Definition

- Let R be a relation schema and let  $\alpha \subseteq R$  and  $\beta \subseteq R$

- The multi-valued dependency  $\alpha \twoheadrightarrow \beta$  holds on  $R$  if in any legal relation  $r(R)$ , for all pairs of tuples  $t_1$  and  $t_2$  in  $r$  such that  $t_1[\alpha] = t_2[\alpha]$ , there exist tuples  $t_3$  and  $t_4$  in  $r$  such that:

$$t_1[\alpha] = t_2[\alpha] = t_3[\alpha] = t_4[\alpha]$$

$$t_3[\beta] = t_1[\beta]$$

$$t_3[R - \beta] = t_2[R - \beta]$$

$$t_4[\beta] = t_2[\beta]$$

$$t_4[R - \beta] = t_1[R - \beta]$$

**Example:** A relation of university courses, the books recommended for the course, and the lecturers who will be teaching the course:

- $\text{course} \twoheadrightarrow \text{book}$
- $\text{course} \twoheadrightarrow \text{lecturer}$

## Test: $\text{course} \twoheadrightarrow \text{book}$

<u>Course</u>	<u>Book</u>	<u>Lecturer</u>	<u>Tuples</u>
AHA	Silberschatz	John D	t1
AHA	Nederpelt	William M	t2
AHA	Silberschatz	William M	t3
AHA	Nederpelt	John D	t4
AHA	Silberschatz	Christian G	
AHA	Nederpelt	Christian G	
OSO	Silberschatz	John D	
OSO	Silberschatz	William M	

- Let  $R$  be a relation schema with a set of attributes that are partitioned into 3 non-empty subsets  $Y, Z, W$
- We say that  $Y \twoheadrightarrow Z$  ( $Y$  multidetermines  $Z$ ) if and only if for all possible relations  $r(R) < y_1, z_1, w_1 > \in r$  and  $< y_1, z_2, w_2 > \in r$  and  $< y_1, z_1, w_2 > \in r$  and  $< y_1, z_2, w_1 > \in r$
- Note that since the behaviour of  $Z$  and  $W$  are identical it follows that  $Y \twoheadrightarrow Z$  if  $Y \twoheadrightarrow W$

In our example:

- $ID \twoheadrightarrow \text{child\_name}$
- $ID \twoheadrightarrow \text{phone\_number}$

The above formal definition is supposed to formalize the notion that given a particular value of  $Y$ (ID) it has associated with it a set of values of  $Z$  (child\_name) and a set of values of  $W$  (phone\_number) and these two sets are in some sense independent of each other

### NOTE:

- IF  $Y \rightarrow Z$ , then  $Y \twoheadrightarrow Z$
- Indeed we have (in above notation)  $Z_1 = Z_2$

The claim follows

### MVD: Use

- We use multi-valued dependencies in 2 ways:
  - To test relations to determine whether they are legal under a given set of functional and multivalued dependencies
  - To specify the constraints on the set of legal relations
- We shall thus concern ourselves only with the relations that satisfy a given set of functional and multivalued dependencies
- If a relation  $r$  fails to satisfy a given multivalued dependency, we can construct a relation  $r'$  that does satisfy the multivalued dependency by adding tuples to  $r$

## MVD: Theory

	Name	Rule
C-	Complementation	If $X \twoheadrightarrow Y$ , then $X \twoheadrightarrow (R - (X \cup Y))$ .
A-	Augmentation	If $X \twoheadrightarrow Y$ and $W \supseteq Z$ , then $WX \twoheadrightarrow YZ$ .
T-	Transitivity	If $X \twoheadrightarrow Y$ and $Y \twoheadrightarrow Z$ , then $X \twoheadrightarrow (Z - Y)$ .
	Replication	If $X \rightarrow Y$ , then $X \twoheadrightarrow Y$ but the reverse is not true.
	Coalescence	If $X \twoheadrightarrow Y$ and there is a $W$ such that $W \cap Y$ is empty, $W \rightarrow Z$ and $Y \supseteq Z$ , then $X \rightarrow Z$ .

- A MVD  $X \twoheadrightarrow Y$  in  $R$  is called a trivial MVD if
  - $Y$  is a subset of  $X$  ( $X \supseteq Y$ ) or
  - $X \cup Y = R$ 
    - Otherwise, it is a non-trivial MVD and we have to repeat values redundantly in the tuples
- From the definition of multi-valued dependency we can derive the following rule:
  - If  $\alpha \rightarrow \beta$ , then  $\alpha \twoheadrightarrow \beta$

That is, every functional dependency is also a multi-valued dependency
- The closure  $D^+$  of  $D$  is the set of all functional and multi-valued dependencies logically implied by  $D$ 
  - We can compute  $D^+$  from  $D$ , using the formal definitions of functional dependencies and multi-valued dependencies
  - We can manage with such reasoning for very simple multi-valued dependencies, which seem to be most common in practice
  - For complex dependencies, it is better to reason about sets of dependencies using a system of inference rules

## Decomposition of 4NF

### Fourth Normal Form (4NF)

- A relation schema  $R$  is in 4NF w.r.t. a set  $D$  of functional and multi-valued dependencies if for all multi-valued dependencies in  $D^+$  of the form  $\alpha \twoheadrightarrow \beta$ , where  $\alpha \subseteq R$  and  $\beta \subseteq R$ , at least one of the following hold:
  - $\alpha \twoheadrightarrow \beta$  is trivial (that is,  $\beta \subseteq \alpha$  or  $\alpha \cup \beta = R$ )
  - $\alpha$  is a superkey for schema  $R$
- If a relation is in 4NF it is in BCNF

### Restriction of Multivalued Dependencies

- The restriction of  $D$  to  $R_i$  is the set of  $D_i$  consisting of
  - All functional dependencies in  $D^+$  that include only attributes of  $R_i$
  - All multivalued dependencies of the form  

$$\alpha \twoheadrightarrow (\beta \cap R_i)$$

where  $\alpha \subseteq R_i$  and  $\alpha \twoheadrightarrow \beta$  is in  $D^+$

### 4NF Decomposition Algorithm

- For all dependencies  $A \twoheadrightarrow B$  in  $D^+$ , check if A is a superkey
  - By using attribute closure
- if not, then
  - Choose a dependency in  $F^+$  that breaks the 4NF rules, say  $A \twoheadrightarrow B$
  - Create  $R1 = A B$
  - Create  $R2 = (R - (B - A))$
  - Note:  $R1 \cap R2 = A$  and  $A \twoheadrightarrow AB (= R1)$ , so this is lossless decomposition
- Repeat for  $R1$  and  $R2$ 
  - By defining  $D1^+$  to be all dependencies in F that contain only attributes in  $R1$
  - Similarly  $D2^+$

result := {R};

done := false;

compute  $D^+$ ;

Let  $D_i$  denote the restriction of  $D^+$  to  $R_i$

while (not done)

if (there is a schema  $R_i$  in result that is not in 4NF) then

begin

let  $\alpha \twoheadrightarrow \beta$  be a non-trivial multi-valued dependency that holds

on  $R_i$  such that  $\alpha \rightarrow R_i$  is not in  $D_i$  and  $\alpha \cap \beta = \phi$

result := (result -  $R_i$ )  $\cup$  ( $R_i - \beta$ )  $\cup$  ( $\alpha, \beta$ )

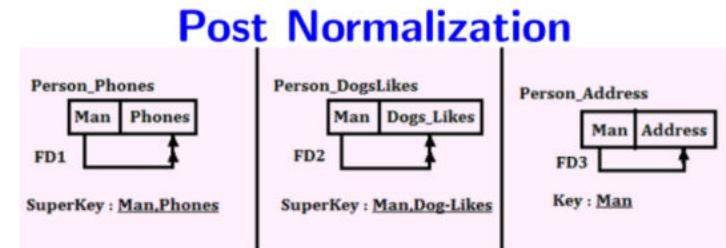
end

else done := true;

NOTE: each  $R_i$  is in 4NF and decomposition is lossless-join

## 4NF Decomposition: Example

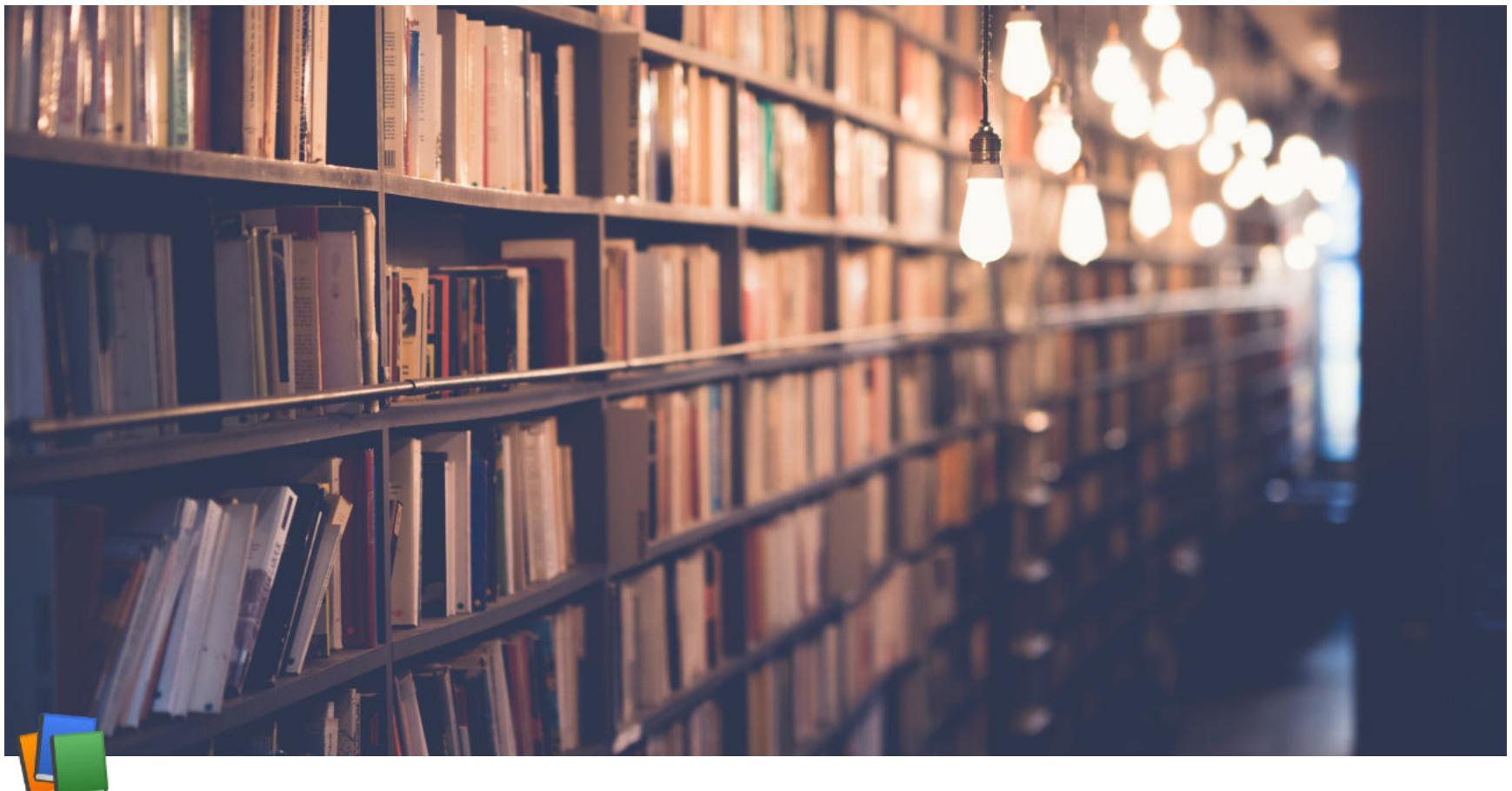
- Example:
- Person\_Modify(Man(M), Phones(P), Dog\_Likes(D), Address(A))
- FDs:
  - ▷ FD1 : Man  $\twoheadrightarrow$  Phones
  - ▷ FD2 : Man  $\twoheadrightarrow$  Dogs\_Like
  - ▷ FD3 : Man  $\rightarrow$  Address
- Key = MPD
- All dependencies violate 4NF



Man(M)	Phones(P)	Dogs_Likes(D)	Address(A)
M1	P1	D1	49-ABC,Bhiwani(HR.)
M1	P2	D2	49-ABC,Bhiwani(HR.)
M2	P3	D2	36-XYZ,Rohtak(HR.)
M1	P1	D2	49-ABC,Bhiwani(HR.)
M1	P2	D1	49-ABC,Bhiwani(HR.)

In the above relations for both the MVD's – '**X**' is **Man**, which is again not the super key, but as **X U Y = R** i.e. (Man & Phones) together make the relation.  
So, the above MVD's are trivial and in FD 3, Address is functionally dependent on Man, where **Man** is the key in **Person\_Address**, hence all the three relations are in 4NF.

- $R = (A, B, C, G, H, I)$   
 $F = A \twoheadrightarrow B$   
 $B \twoheadrightarrow HI$   
 $CG \twoheadrightarrow H$
- $R$  is not in 4NF since  $A \twoheadrightarrow B$  and  $A$  is not a superkey for  $R$
- Decomposition
  - $R_1 = (A, B)$  ( $R_1$  is in 4NF)
  - $R_2 = (A, C, G, H, I)$  ( $R_2$  is not in 4NF, decompose into  $R_3$  and  $R_4$ )
  - $R_3 = (C, G, H)$  ( $R_3$  is in 4NF)
  - $R_4 = (A, C, G, I)$  ( $R_4$  is not in 4NF, decompose into  $R_5$  and  $R_6$ )
    - $A \twoheadrightarrow B$  and  $B \twoheadrightarrow HI \rightarrow A \twoheadrightarrow HI$ , (MVD transitivity), and
    - and hence  $A \twoheadrightarrow I$  (MVD restriction to  $R_4$ )
  - $R_5 = (A, I)$  ( $R_5$  is in 4NF)
  - $R_6 = (A, C, G)$  ( $R_6$  is in 4NF)



## Week 6 Lecture 5

Class	BSCCS2001
Created	@October 14, 2021 12:08 AM
Materials	
Module #	30
Type	Lecture
Week #	6

## Relational Database Design (part 10)

### Database Design Process

#### Design Goals

- Goal for a relational DB design:
  - BCNF / 4NF
  - Lossless join
  - Dependency preservation
- If we cannot achieve this, we accept one of
  - Lack of dependency preservation
  - Redundancy due to use of 3NF
- Interestingly, SQL does not provide a direct way of specifying functional dependencies other than superkeys
- Can specify FDs using assertions, but they are expensive to test (and currently not supported by any of the widely used DB)
- Even if we had a dependency preserving decomposition, using SQL we could not be able to efficiently test a functional dependency whose left hand side is not a key

### Further Normal Forms

- Further NFs:
  - Elementary Key Normal Form (EKNF)

- Essential Tuple Normal Form (ETNF)
- Join Dependencies and Fifth Normal Form (5NF)
- Sixth Normal Form (6NF)
- Domain/Key Normal Form (DKNF)
- Join dependencies generalize multi-valued dependencies
  - Lead to project-join normal form (PJNF) (also called Fifth Normal Form)
- A class of even more general constraints, leads to a normal form called Domain-Key Normal Form
- Problem with these generalized constraints: are hard to reason with, and no set of sound and complete set of inference rules exist
- Hence rarely used

## Overall DB Design Process

- We have assumed schema R is given
  - R could have been generated when converting E-R diagram to a set of tables
  - R could have been a single relation containing all attributes that are of interest (universal relation)
  - Normalization breaks R into smaller relations
  - R could have been the result of some ad hoc design of relations, which we then test/convert to normal form

## ER Model and Normalization

- When an E-R diagram is carefully designed, identifying all entities correctly, the tables generated from the E-R diagram should not need further optimization
- However, in a real (imperfect) design there can be functional dependencies from non-key attributes of an entity to other attributes of the entity
  - Example: an employee entity with attributes  
department\_name and building  
and a functional dependency  
 $department\_name \rightarrow building$
  - Good design would have made department an entity
- Functional dependencies from non-key attributes of a relationship set possible, but rare — most relationships are binary

## Denormalization for Performance

- May want to use non-normalized schema for performance
- For example, displaying prereqs along with course\_id, and title requires join of course with prereq
  - **Course (course\_id, title, ...)**
  - **Prerequisite (course\_id, prereq)**
- **Alternative #1:** Use denormalized relation containing attributes of course as well as prereq with all above attributes:  
**Course (course\_id, title, prereq, ...)**
  - faster lookup
  - extra space and extra execution time for updates
  - extra coding work for programmers and possibility of error in extra code
- **Alternative #2:** Use a materialized view defined as **Course  $\bowtie$  Prerequisite**
  - Benefits and drawbacks same as above, except no extra coding work for programmers and avoids possible errors

## Other Design Issues

- Some aspects of DB design are not caught by normalization
- Examples of bad DB design, to be avoided:

Instead of earnings (company\_id, year, amount), use

- earnings\_2004, earnings\_2005, earnings\_2005, etc. all on the schema (company\_id, earnings)
  - Above are in BCNF, but make querying across years difficult and needs new table each year
- company\_year (company\_id, earnings\_2004, earnings\_2005, earnings\_2006)
  - Also in BCNF, but also makes querying across years difficult and requires new attribute each year
  - is an example of **crosstab**, where values for one attribute become column names
  - Used in spreadsheets, and in data analysis tools

## LIS Example for 4NF

- Consider a different version of relation **book\_catalogue** having the following attributes:
  - *book\_title*
  - *book\_catalogue, author\_lname*: A *book\_title* may be associated with more than one author
- **book\_title** {*book\_title, author\_fname, author\_lname, edition*}

### **book\_catalogue**

Aa book_title	≡ author_fname	≡ author_lname	# edition
DBMS CONCEPTS	BRINDA	RAY	1
DBMS CONCEPTS	AJAY	SHARMA	1
DBMS CONCEPTS	BRINDA	RAY	2
DBMS CONCEPTS	AJAY	SHARMA	2
JAVA PROGRAMMING	ANITHA	RAJ	5
JAVA PROGRAMMING	RIYA	MISRA	5
JAVA PROGRAMMING	ADITI	PANDEY	5
JAVA PROGRAMMING	ANITHA	RAJ	6
JAVA PROGRAMMING	RIYA	MISRA	6
JAVA PROGRAMMING	ADITI	PANDEY	6

- Since, the relation has no FDs, it is already in BCNF
- However, the relation has 2 non-trivial MVDs

*book\_title* → {*author\_fname, author\_lname*} and *book\_title* → *edition*

Thus, it is not in 4NF

- Non-trivial MVDs must be decomposed to convert it into a set of relations in 4NF
- We decompose **book\_catalogue** into **book\_author** and **book\_edition** because:
  - **book\_author** has trivial MVD  
 $\text{book\_title} \rightarrow\!\!\! \rightarrow \{\text{author\_fname, author\_lname}\}$
  - **book\_edition** has trivial MVD  
 $\text{book\_title} \rightarrow\!\!\! \rightarrow \text{edition}$

book_title	author_fname	author_lname
DBMS CONCEPTS	BRINDA	RAY
DBMS CONCEPTS	AJAY	SHARMA
JAVA PROGRAMMING	ANITHA	RAJ
JAVA PROGRAMMING	RIYA	MISRA
JAVA PROGRAMMING	ADITI	PANDEY

Figure: book\_author

book_title	edition
DBMS CONCEPTS	1
DBMS CONCEPTS	2
JAVA PROGRAMMING	5
JAVA PROGRAMMING	6

Figure: book\_edition

## Temporal Databases

- Some data may be inherently historical because they include time-dependent / time-varying data, such as:
  - Medical Records
  - Judicial Records
  - Share prices
  - Exchange rates
  - Interest rates
  - Company profits
  - etc.
- The desire to model such data means that we need to store not only the respective value but also an associated data or a time period for which the value is valid
- Typical queries expressed informally might include:
  - Give me last month's history of the Dollar-Pound Sterling exchange rate
  - Give me the share prices of the NYSE on October 17, 1996
- Temporal DB provides a uniform and systematic way of dealing with historical data

## Temporal Data

- Temporal data have an association time interval during which the data is valid
- A snapshot is the value of the data at a particular point in time
- In practice, DB engineers may add start and end time attributes to relations
- For example, course (course\_id, course\_title) is replaced by  
course (course\_id, course\_title, start, end)

- Constraint: no 2 tuples can have overlapping valid times and are hard to enforce efficiently
- Foreign key references may be to current version of data, or to data at a point in time
  - For example: student transcript should refer to the course information at the time the course was taken

## Temporal Database Theory

- **Model of Temporal Domain:** Single-dimensional linearly ordered which may be ...
  - Discrete or dense
  - Bounded or unbounded
  - Single dimensional or multi-dimensional
  - Linear or non-linear
- **Timestamp Model**
- **Temporal ER model** by adding valid time to
  - Attributes: address of an instructor at different points in time
  - Entities: time duration when a student entity exists
  - Relationships: time during which a student attended a course
  - But no accepted standard
- **Temporal Functional Dependency Theory**
- **Temporal Logic**
- **Temporal Query Language:**
  - TQuel [1987]
  - TSQL2 [1995]
  - SQL/Temporal [1996]
  - SQL/TP [1997]

## Modeling Temporal Data: Uni / Bi Temporal

- There are 2 different aspects of time in temporal DBs
  - **Valid Time:** Time period during which a fact is true in the real world, provided to the system
  - **Transaction Time:** Time period during which a fact is stored in the DB, based on transaction serialization order and is the timestamp generated automatically by the system
- Temporal Relation is one where each tuple has associated time; either valid time or transaction time or both associated with it
  - **Uni-Temporal Relations:** Has one axis of time, either Valid Time or Transaction Time
  - Bi-Temporal Relations: Has both axis of time — Valid time and Transaction time
    - It includes Valid Start Time, Valid End Time, Transaction Start Time, Transaction End Time

## Modeling Temporal Data: Example

- **Example**
  - Let's see an example of a person, John:
    - John was born on April 3, 1992 in Chennai
    - His father registered his birth after 3 days on April 6, 1992
    - John did his entire schooling and college in Chennai
    - He got a job in Mumbai and shifted to Mumbai on June 21, 2015
    - He registered his change of address only on Jan 10, 2016

---

John's Data in Non-Temporal DB

Date	Real world event	Address
April 3, 1992	John is born	
April 6, 1992	John's father registered his birth	Chennai
June 21, 2015	John gets a job	Chennai
Jan 10, 2016	John registers his new address	Mumbai

- In a non-temporal DB, John's address is entered as Chennai from 1992
- When he registers his new address in 2016, the DB gets updated and the address field now shows his Mumbai address
- The previous Chennai address details will not be available
- So, it will be difficult to find out exactly when he was living in Chennai and when he moved to Mumbai

#### Uni-Temporal Relation (Adding Valid Time to John's Data)

Name	City	Valid From	Valid Till
John	Chennai	April 3, 1992	June 20, 2015
John	Mumbai	June 21, 2015	$\infty$

- The valid time temporal DB contents look like this:
 

```
Name, City, Valid From, Valid Till
```
- John's father registers his birth on 6th April 1992, a new DB entry is made:
 

```
Person (John, Chennai, 3-Apr-1992,  $\infty$ )
```
- On January 10, 2016 John reports his new address in Mumbai:
 

```
Person (John, Mumbai, 21-June-2015,  $\infty$ )
```

  - The original entry is updated:
 

```
Person (John, Chennai, 3-Apr-1992, 20-June-2015)
```

#### Bi-Temporal Relation (John's Data Using Both Valid And Transaction Time)

Name	City	Valid From	Valid Till	Entered	Superseded
John	Chennai	April 3, 1992	June 20, 2015	April 6, 1992	Jan 10, 2016
John	Mumbai	June 21, 2015	$\infty$	Jan 10, 2016	$\infty$

- The database contents look like this:
 

```
Name, City, Valid From, Valid Till, Entered, Superseded
```
- John's father registers his birth on 6th April 1992:
 

```
Person (John, Chennai, 3-Apr-1992,  $\infty$ , 6-Apr-1992,  $\infty$ )
```

- On January 10, 2016 John reports his new address in Mumbai:

```
Person(John, Mumbai, 21-June-2015, ∞ , 10-Jan-2016, ∞ )
```

- The original entry is updated as:

```
Person(John, Chennai, 3-Apr-1992, 20-June-2015, 6-Apr-1992 , 10-Jan-2016)
```

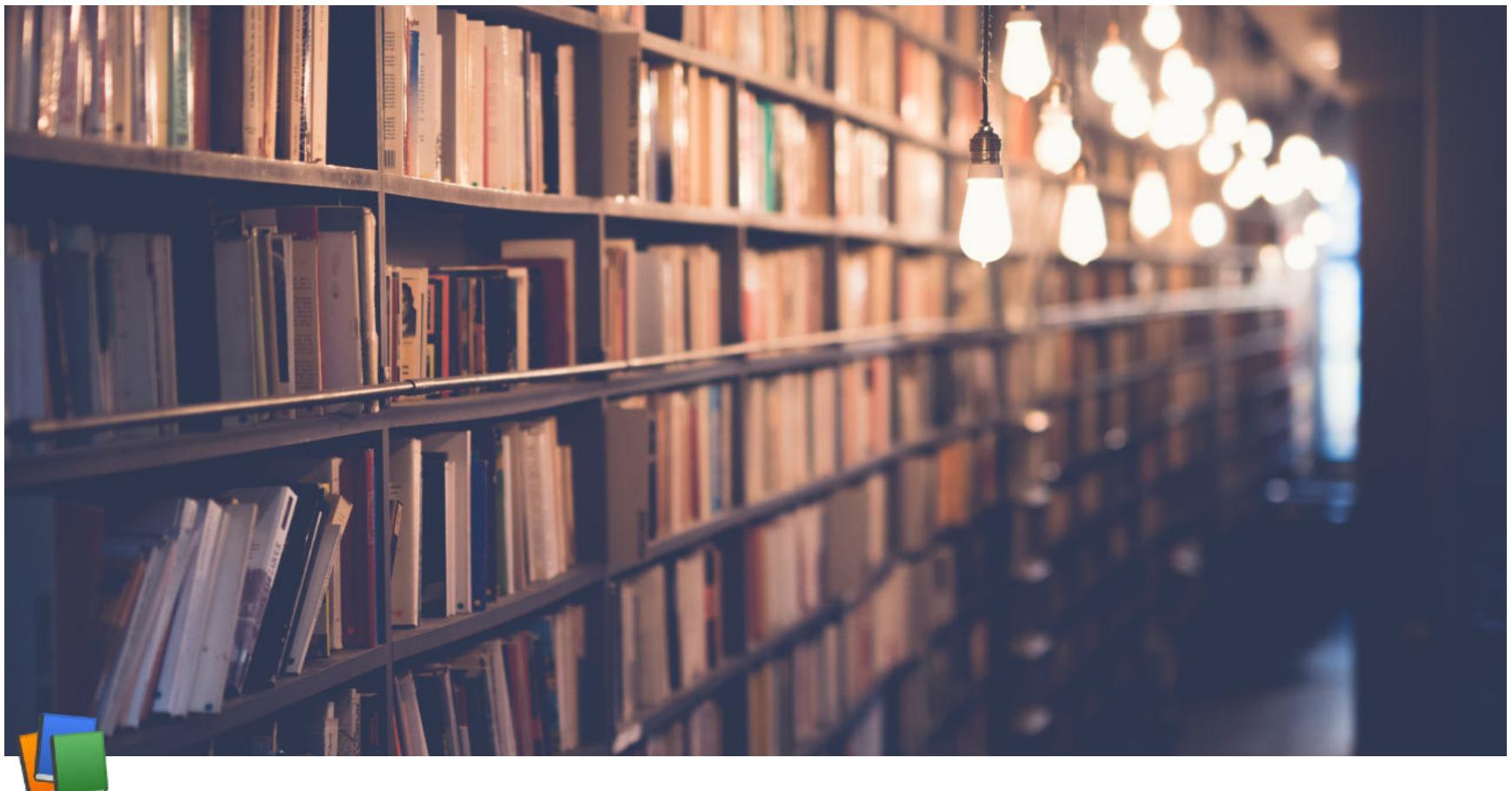
## Modeling Temporal Data: Summary

- **Advantages**

- The main advantages of this bi-temporal relations is that it provides historical and roll back information
  - **Historical information** — Valid time
  - **Rollback information** — Transaction time
- For example, you can get the result of a query on John's history, like: Where did John live in the year 2001?
  - The result for this query can be got with the valid time entry
  - The transaction time entry is important to get the rollback information

- **Disadvantages**

- More storage
- Complex query processing
- Complex maintenance including backup and recovery



## Week 7 Lecture 1

Class	BSCCS2001
Created	@October 19, 2021 1:11 AM
Materials	
Module #	31
Type	Lecture
# Week #	7

## Application Design & Development: Architecture

### Application Programs: Internet/Web or Mobile

- **Financial**
  - **Netbanking** → SBI, PNB, BoB, Canara, HDFC, ICICI
  - **Share Market** → ICICIDirect, Sharekhan, HDFCDirect
  - **Insurance & Investment** → LICI, PolicyBazaar, NSDL, NPS
  - **Payment Gateway** → PayTM, GPay, Bhim UPI, PhonePe
  - **e-Commerce** → Amazon, Flipkart, eBay, BigBazaar, BigBasket
- **Travel & Tourism**
  - **Travel Reservations** → IRCTC, Airlines, MakeMyTrip, Yatra
  - **Accommodation** → Booking, OYO, AirBnB, Fabhotels, Treebo
  - **Transportation** → Uber, Ola Cab, Mega Cab, Meru Cab
  - **Navigation** → Google Maps, MapQuest, Apple Maps
  - **Food & Delivery** → Zomato, Swiggy, UberEats, Dunzo
- **Communication**
  - **Live Interaction** → Zoom, Google Meet, Teams, Webex, Skype
  - **Intermittent Interaction** → WhatsApp, Telegram, Signal, Skype
  - **Mail** → Gmail, Yahoo, Hotmail, Rediffmail, Enterprise Mail

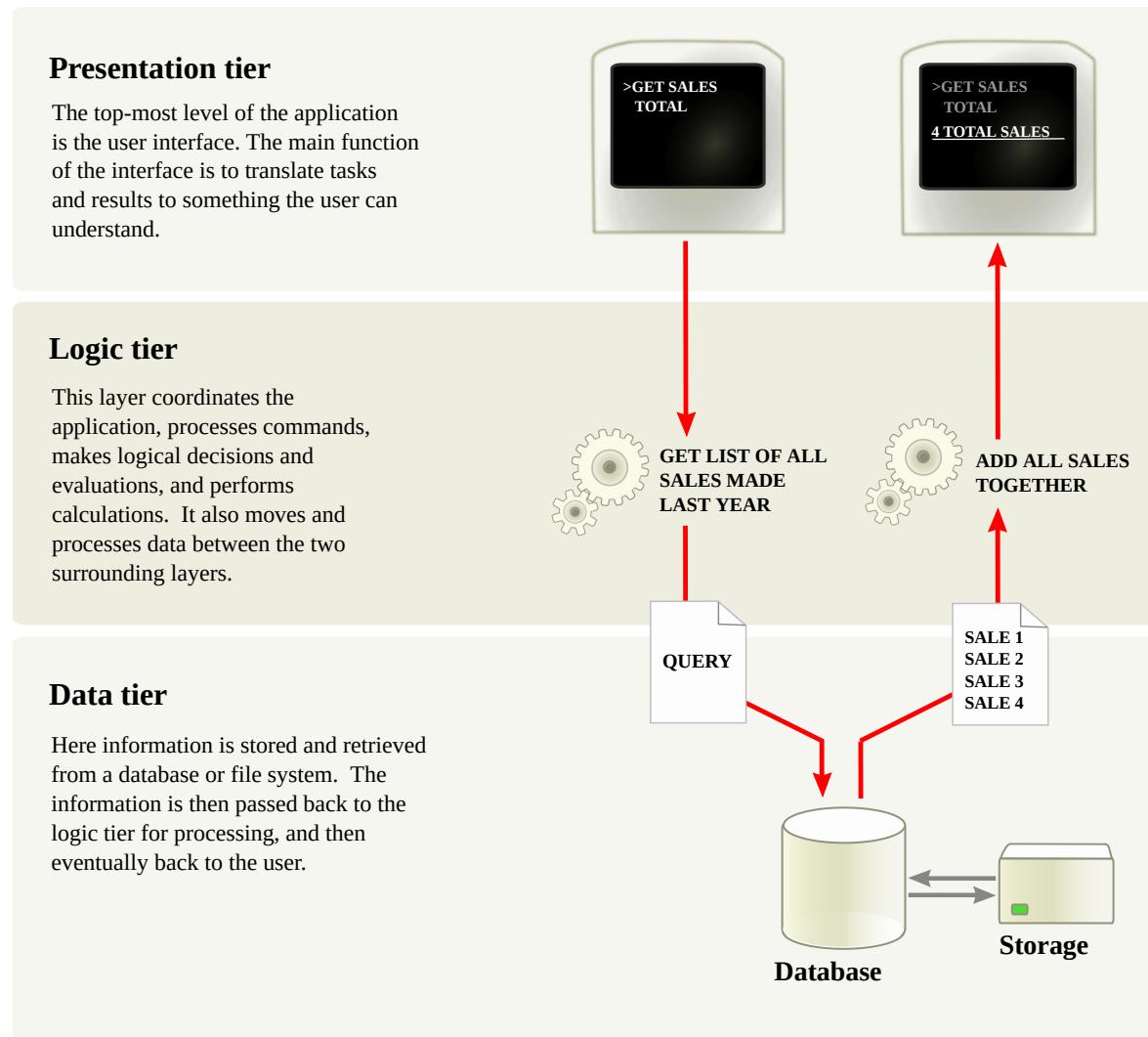
- **Social Media** → Facebook, Instagram, Twitter, YouTube
- **Knowledge Discovery**
  - **Static** → Google, Yahoo, Bing, Wikipedia, [Encyclopedia.com](#)
  - **Q&A** → Quora, ASKfm, Yahoo Answers, Reddit, Digg
- **Sports**
  - **Cricket** → Cricbuzz, CricViz, Cricket-21, Cricket Exchange
  - **Tennis** → ATP, ITF, SwingVision, TennisPAL, Tennis Clash
- **Software Engineering**
  - **Issue Tracking** → Jira, Bugzilla, GitHub, GitLab
  - **VCS** → GitHub, GitLab, Bitbucket, SourceForge
  - **Online IDE** → OnlineGDB, Codechef, Ideone
- **Library**
  - **Digital Library** → National Digital Library of India
  - **Archives** → Internet Archive, arXiv, Nextpoint
- **Education**
  - **eLearning** → BYJU's, IGNOU, NIIT, Edukart
  - **MOOCs** → SWAYAM, edX, Coursera, Udemy
- **Document Processing**
  - **Editing** → Overleaf, Google Docs, Spreadsheet
  - **Website, Blog** → Google sites, WordPress, Weebly
- **Health**
  - **Telemedicine** → MDLIVE, Doctor on Demand
  - **National** → Aarogya Setu, CoWin, NACO App
- **Organizational ERP (Intranet)**
  - **Institutions** → Students, Faculty, Course
  - **Hospital** → Patient, Doctor, OPD, IPD, Pharmacy
  - **Manufacturing** → Suppliers, Inventory, Customers
  - **Bank** → Customers, Accounts, Lockers, Deposits
  - **Courier** → Customers, Parcels, Delivery Agents

## **Characteristics of Application Program**

- **Diversity** → These applications widely differ in their
  - *Domain, functionality, user base, response time, scale, daily hit*, and many more
- **Unity** → Yet, these have a lot in common
  - Most use an RDBMS like Oracle, DB2 MySQL, PostgreSQL, etc. for managing data
  - Applications are functionality split into the *frontend layer, middle layer, backend layer*
    - **Frontend or Presentation Layer/Tier**
      - Interacts with the users → Display/View, Input/Output
      - *Choose item, Add to cart, Checkout, Pay, Track order*
      - Interfaces may be *Browser based, Mobile app or custom*
    - **Middle or Application/Business Logic Layer/Tier**
      - Implements the functionality of the application → Links the frontend & backend
      - *Authentication, Search/Browse logic, Pricing, Cart management Payment handling (gateway), Order management (mail, SMS, internal actions), Delivery management*

- Support functionality based on frontend interface
- **Backend or Data Access Layer/Tier**
  - Manages persistent data, large volume, efficient access, security
  - *User, Cart, Inventory, Order, Vendor DBs*

## Characteristics of Application Programs: Architecture

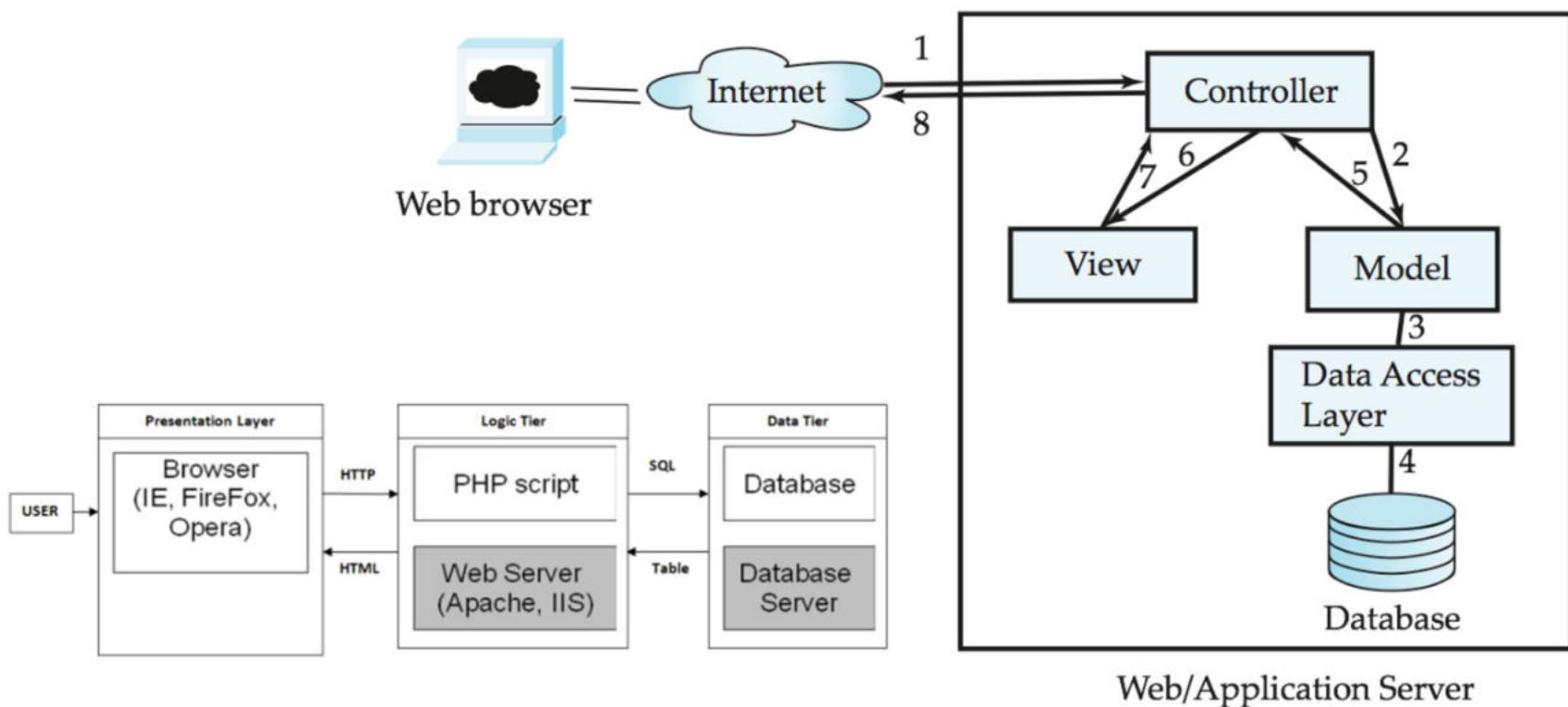


Source: [https://en.wikipedia.org/wiki/Multitier\\_architecture](https://en.wikipedia.org/wiki/Multitier_architecture)

## Application Architectures: Layers

- **Presentation Layer/Tier**
  - **Model-View-Controller (MVC)** architecture
    - **Model** → Business logic
    - **View** → Presentation of data, depends on the display service
    - **Controller** → Receive events, execute actions, and return a view to the user
- **Business Layer/Tier**
  - Provides the high-level view of data and actions on the data
    - Often using an object data model
  - Hides the details of data storage schema
- **Data Access Layer/Tier**
  - Interfaces between business logic layer and the underlying DB
  - Provides mapping from object model of business layer to the relational model of the DB

## Application Architecture: MVC



## Application Architecture: User Interface

- Web browsers have become the de-facto standard user interface to the DBs
  - Enable large number of users to access DBs from anywhere
  - Avoid the need for downloading/installing specialized code, while providing a good Graphical User Interface
    - JavaScript, Flash (dead apparently) and other scripting language runs in the browser, but are downloaded transparently
  - **Examples** → Banks, Airlines and Rental Car reservations, university course registration and grading and so on
- Use in Mobile Devices are getting popular
  - Mobile apps or Browser in Mobile
  - These are similar in architecture and workflow with the web, but have significant differences with their smaller (but wide range of) form factor, and extremely low resources

## Application Architecture: Business Logic Layer

- Provides abstractions of entities
  - For example → students, instructors, courses, etc
- Enforces **business rules** for carrying out actions
  - For example → student can enroll in a class only if she has completed all the prerequisites, and has paid her tuition fee
- Supports **workflows** which define how a task involving multiple participants is to be carried out
  - For example → How to process an application by a student applying to a University
  - Sequence of steps to carry out the task
  - Error handling
    - For example → What to do if the recommendation letters not received on time

## Application Architecture: Object-Relational Mapping

- Allows application code to be written on top of object-oriented data model, while storing data in a traditional relational DB
  - Alternative → implement object-oriented or object-relational DB to store object model
    - It has not been commercially successful
- Schema designer has to provide a mapping between object data and relational schema
  - For example → Java class `Student` mapped to a relation `student`, with corresponding mapping of attributes
  - An object can map to multiple tuples in multiple relations
- Application opens a session, which connects to the DB

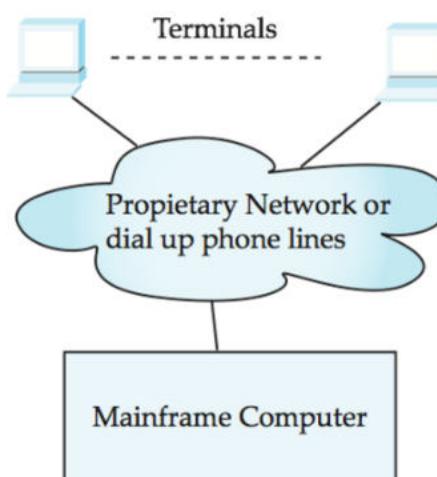
- Objects can be created and saved to the DB using `session.save(object)`
  - Mapping used to create appropriate tuples in the DB
- Query can be run to retrieve objects satisfying specified predicates

## Architecture Classification

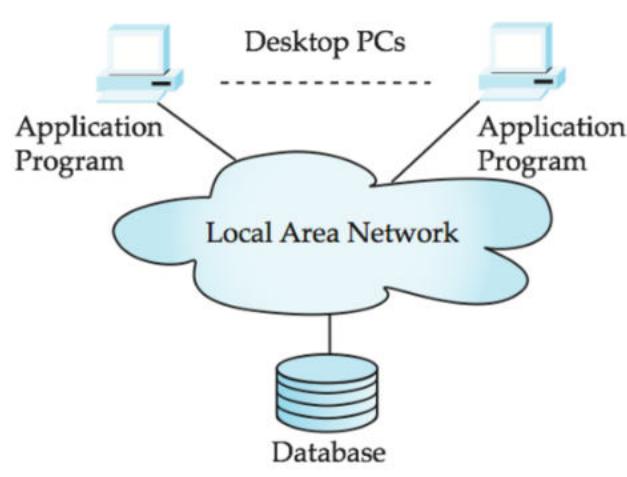
- DB architecture uses programming languages to design a particular type of software for business or organizations
- DB architecture focuses on the design, development, implementation and maintenance of computer programs that store and organize information for businesses, agencies and institutions
- A DB architect develops and implements software to meet the needs of users
- The design of a DBMS depends on its architecture
  - It can be
    - Centralized
    - Decentralized
    - Hierarchical
- The architecture of a DBMS can be seen as either single tier or multi tier:
  - 1-tier architecture
  - 2-tier architecture
  - 3-tier architecture
  - n-tier architecture

## Architecture Evolution

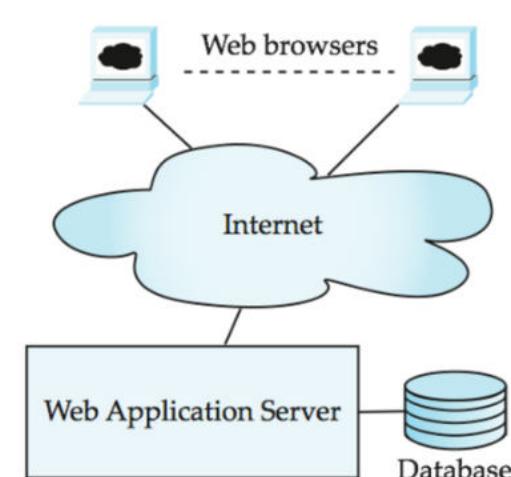
- Three distinct eras of application architecture
  - Mainframe (1960s and 1970s)
  - Personal Computer era (1980s)
  - Web/Mobile era (1990s onwards)



(a) Mainframe Era



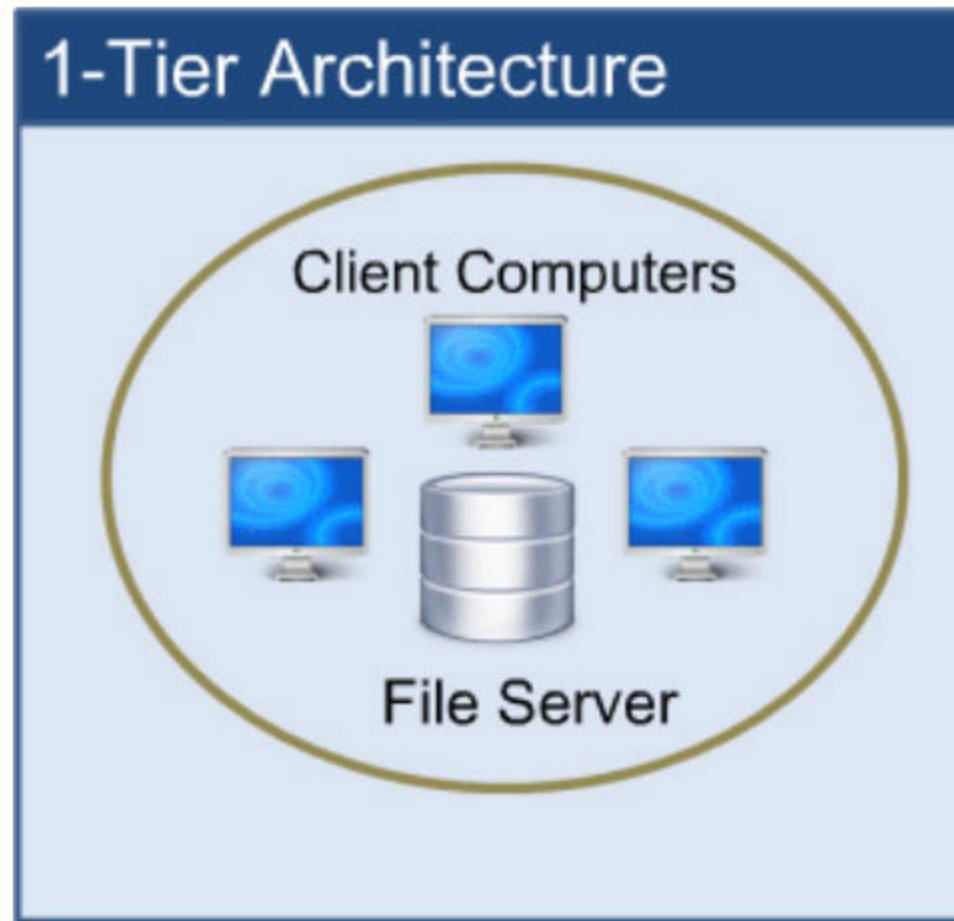
(b) Personal Computer Era



(c) Web era

## 1-tier Architecture

- One-tier architecture involves putting all of the required components for a software application or technology on a single server or platform

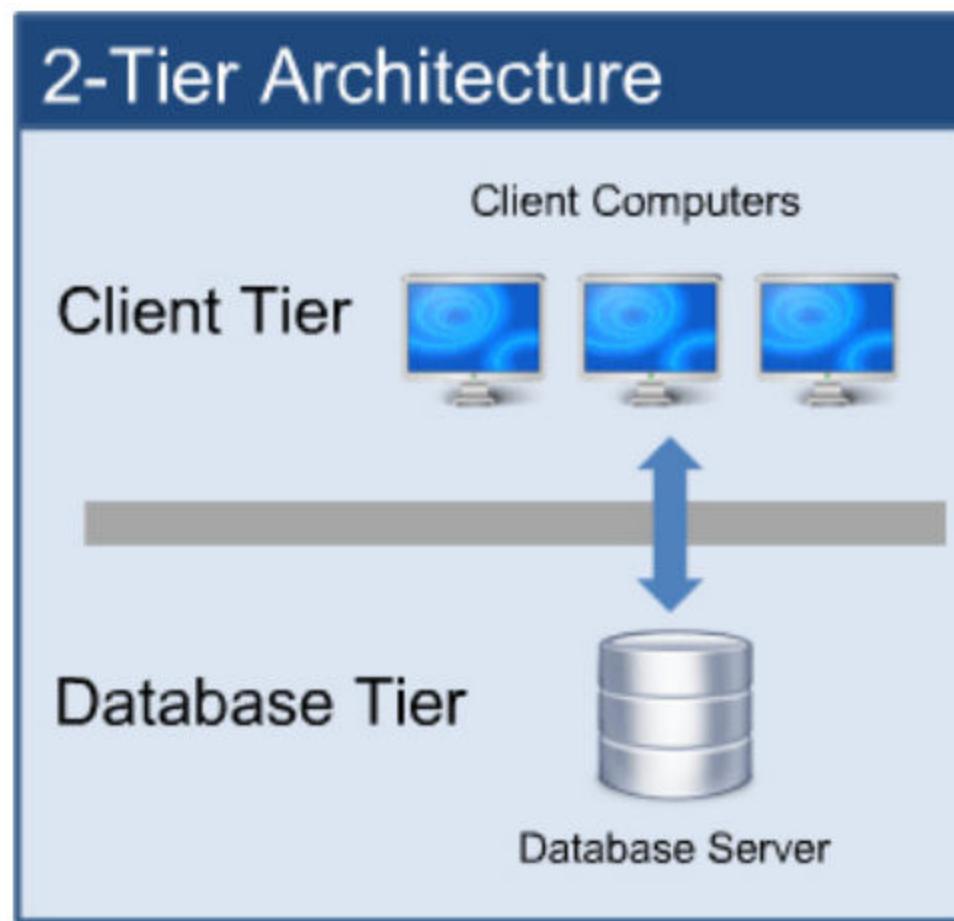


- Basically, a one-tier architecture keeps all of the elements of an application, including the interface, Middleware and back-end data, in one place
- Developers see these types of systems as the simplest and most direct way

Source: <https://medium.com/oceanize-geeks/concepts-of-database-architecture-dfdc558a93e4>

## 2-tier Architecture

- The two-tier architecture is based on Client Server architecture
- It is like client server application



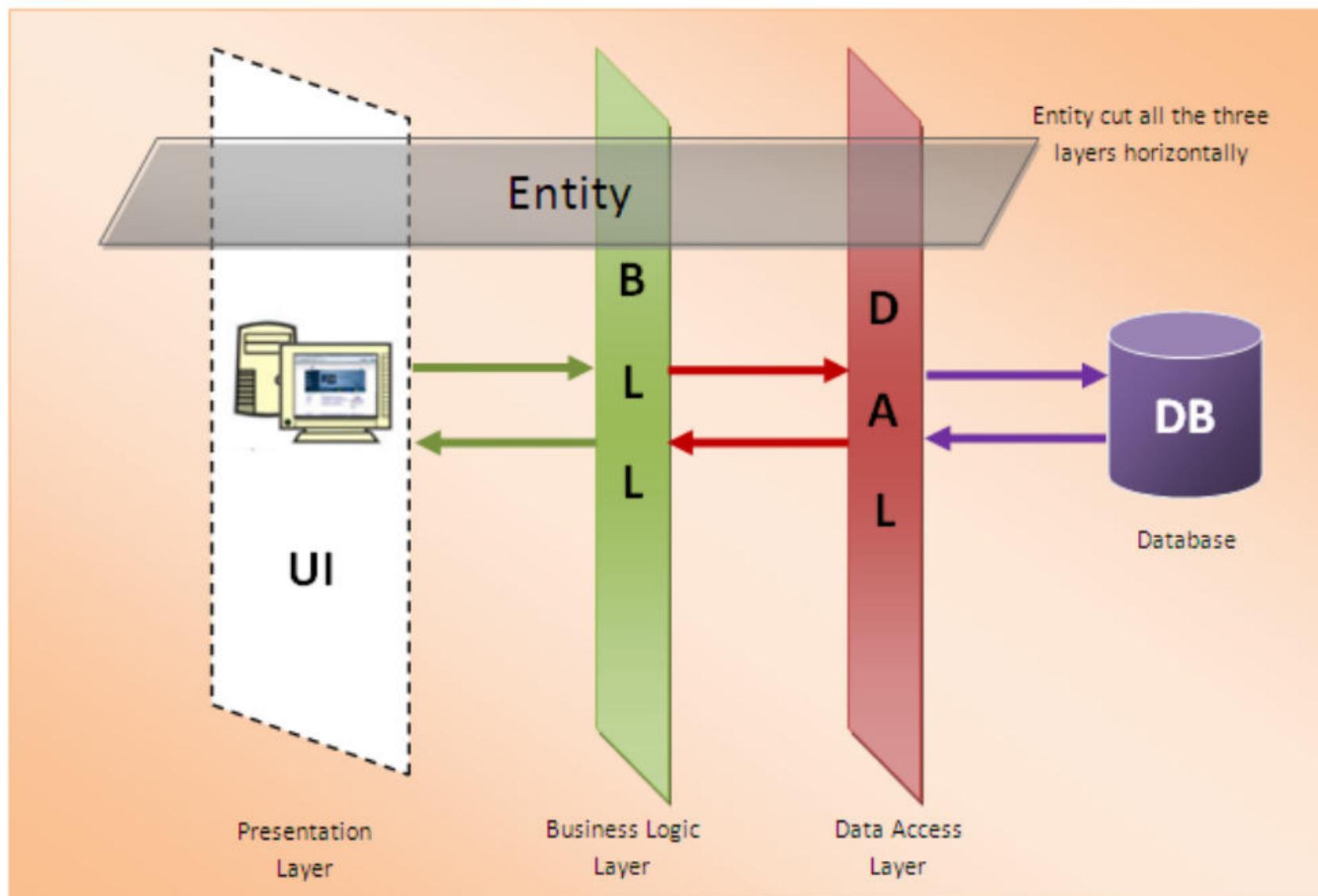
- The direct communication takes place between client and server
- There is no intermediate between the client and the server

Source: <https://medium.com/oceanize-geeks/concepts-of-database-architecture-dfdc558a93e4>

## 3-tier Architecture

- A 3-tier architecture separates its tiers - **Presentation**, **Logic** and **Data Access** from each other based on the complexity of the users and how they use the data present in the DB

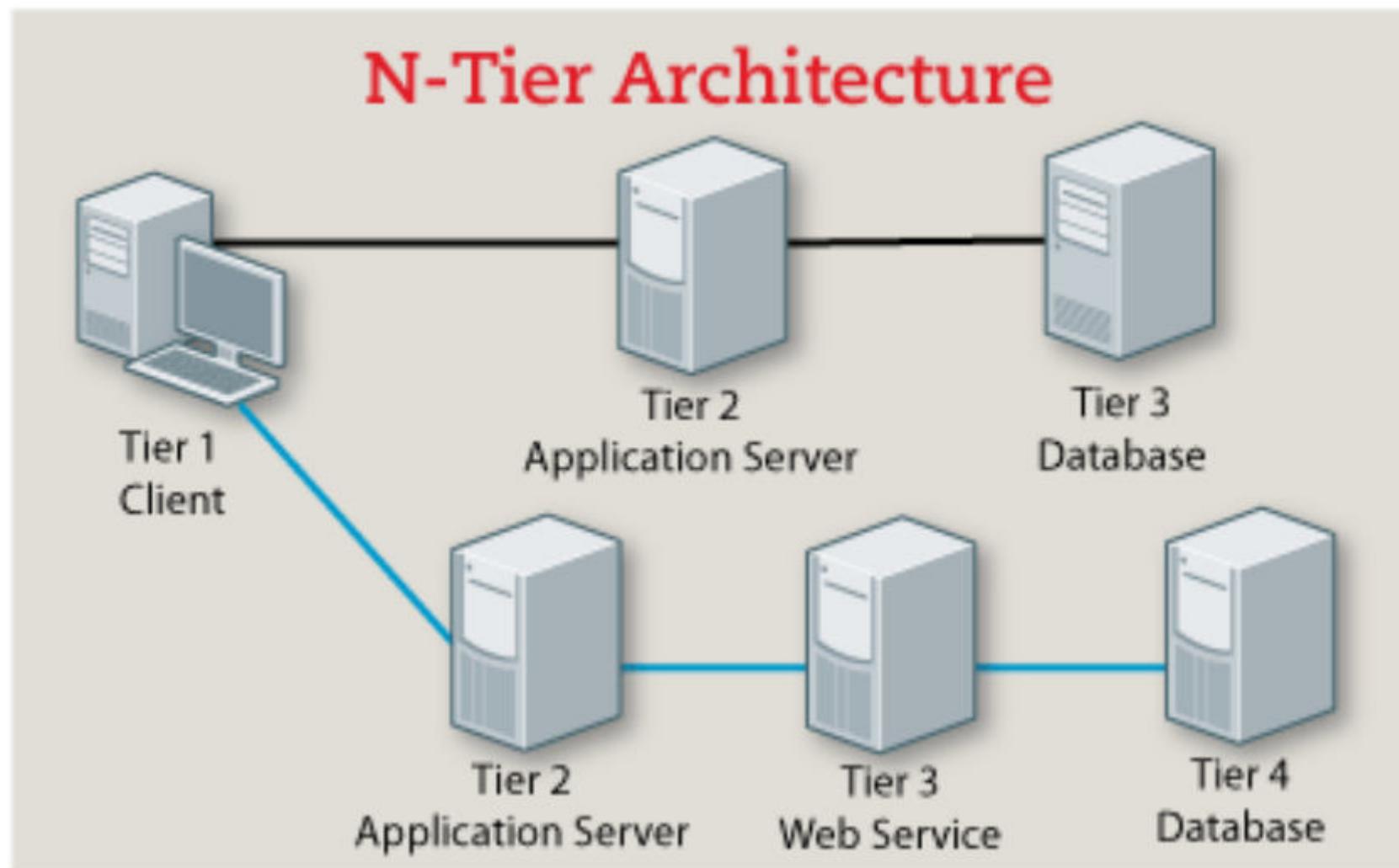
- It is the most widely used architecture to design a DBMS



Source: <https://medium.com/oceanize-geeks/concepts-of-database-architecture-dfdc558a93e4>

### n-tier Architecture

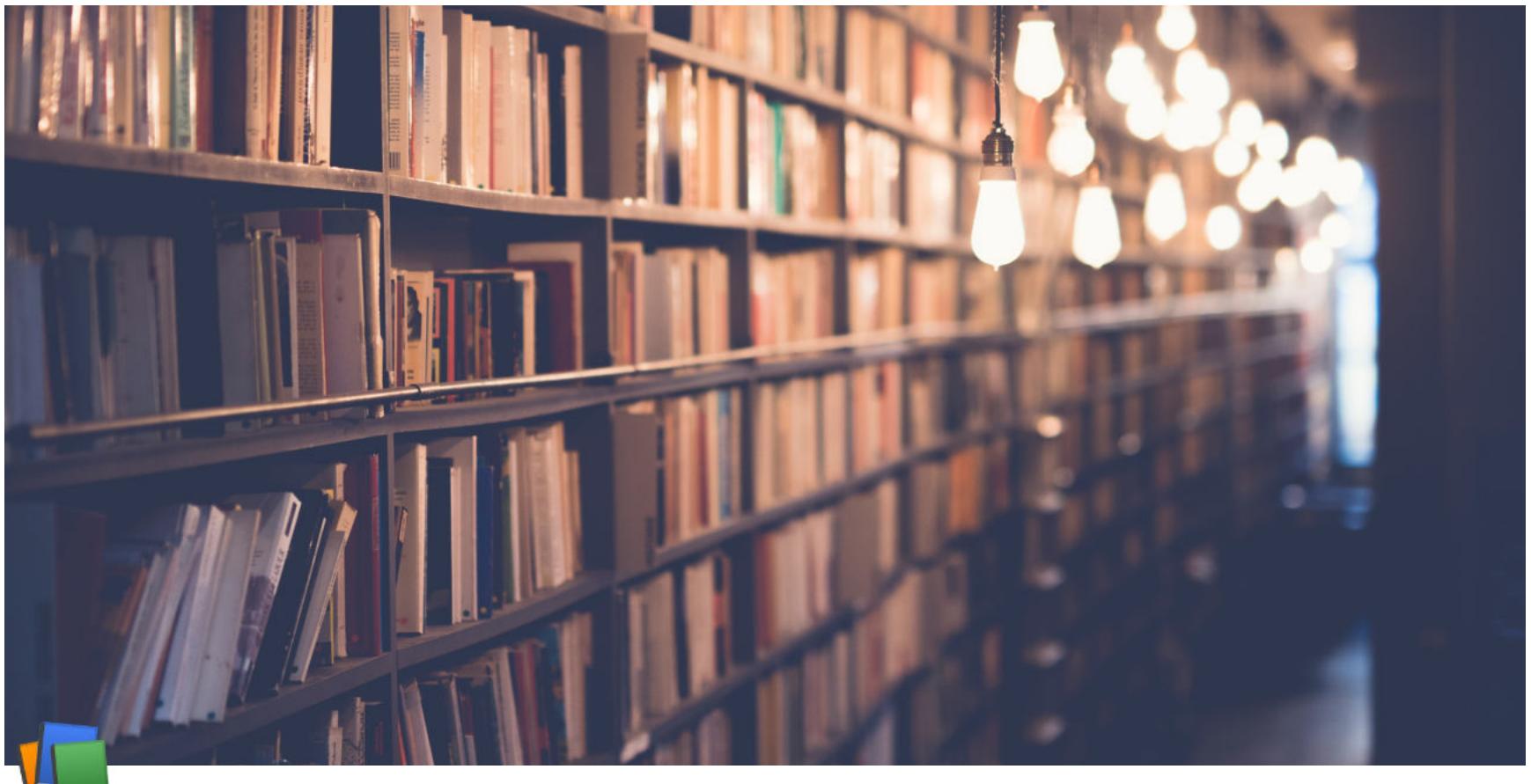
- An n-tier architecture distributes different components of the 3-tiers between different servers and adds interface tiers for interactions and workload balancing



Source: <https://medium.com/oceanize-geeks/concepts-of-database-architecture-dfdc558a93e4>

### Sample Applications in Multiple Tiers

Aa Application	☰ Presentation	☰ Logic	☰ Data	☰ Functionality
<u>Web Mail</u>	<ul style="list-style-type: none"> <li>• Login • Mail List View • Inbox • Sent Items • Outbox • Trash • Mail Composer</li> <li>• Filters</li> </ul>	<ul style="list-style-type: none"> <li>• User Authentication • Connection to Mail Server (SMTP, POP, IMAP) • Encryption/Decryption</li> </ul>	<ul style="list-style-type: none"> <li>• Mail Users • Address Book • Mail items</li> </ul>	<ul style="list-style-type: none"> <li>• Send/Receive Mails • Manage Address Book</li> </ul>
<u>Net Banking</u>	<ul style="list-style-type: none"> <li>• Login • Account View • Add/Delete Account • Add/Delete Beneficiary • Fund Transfer</li> </ul>	<ul style="list-style-type: none"> <li>• User Authentication • Beneficiary Authentication • Transaction Validation • Connection to Banks/Gateways • Encryption/Decryption</li> </ul>	<ul style="list-style-type: none"> <li>• Account Holders • Beneficiaries • Accounts • Debit/Credit Transactions</li> </ul>	<ul style="list-style-type: none"> <li>• Check Balance and Transactions • Transfer Funds</li> </ul>
<u>Timetable</u>	<ul style="list-style-type: none"> <li>• Login • Add/Delete Courses, Teachers, Rooms, Slots • Assignments:</li> <li>• Teachers → Course • Allocations • Course → Room, Slots • Views</li> </ul>	<ul style="list-style-type: none"> <li>• User Authentication • Timetable Assignment Logic • Encryption/Decryption</li> </ul>	<ul style="list-style-type: none"> <li>• Courses • Teachers • Rooms • Slots • Assignments • Allocations</li> </ul>	<ul style="list-style-type: none"> <li>• Manage timetable for multiple courses taken by multiple teachers</li> </ul>



## Week 7 Lecture 2

Class	BSCCS2001
Created	@October 19, 2021 5:12 PM
Materials	
Module #	32
Type	Lecture
# Week #	7

## Application Design & Development: Web Applications

### Web Fundamentals

#### The World Wide Web (WWW)

- The web is a distributed information system based on HyperText
- Most web documents are HyperText documents formatted via the HyperText Markup Language (HTML)
- HTML documents contain
  - Text along with font specifications, and other formatting instructions
  - HyperText links to other documents, which can be associated with regions of the text
  - Forms, enabling users to enter data which can then be sent back to the Web server

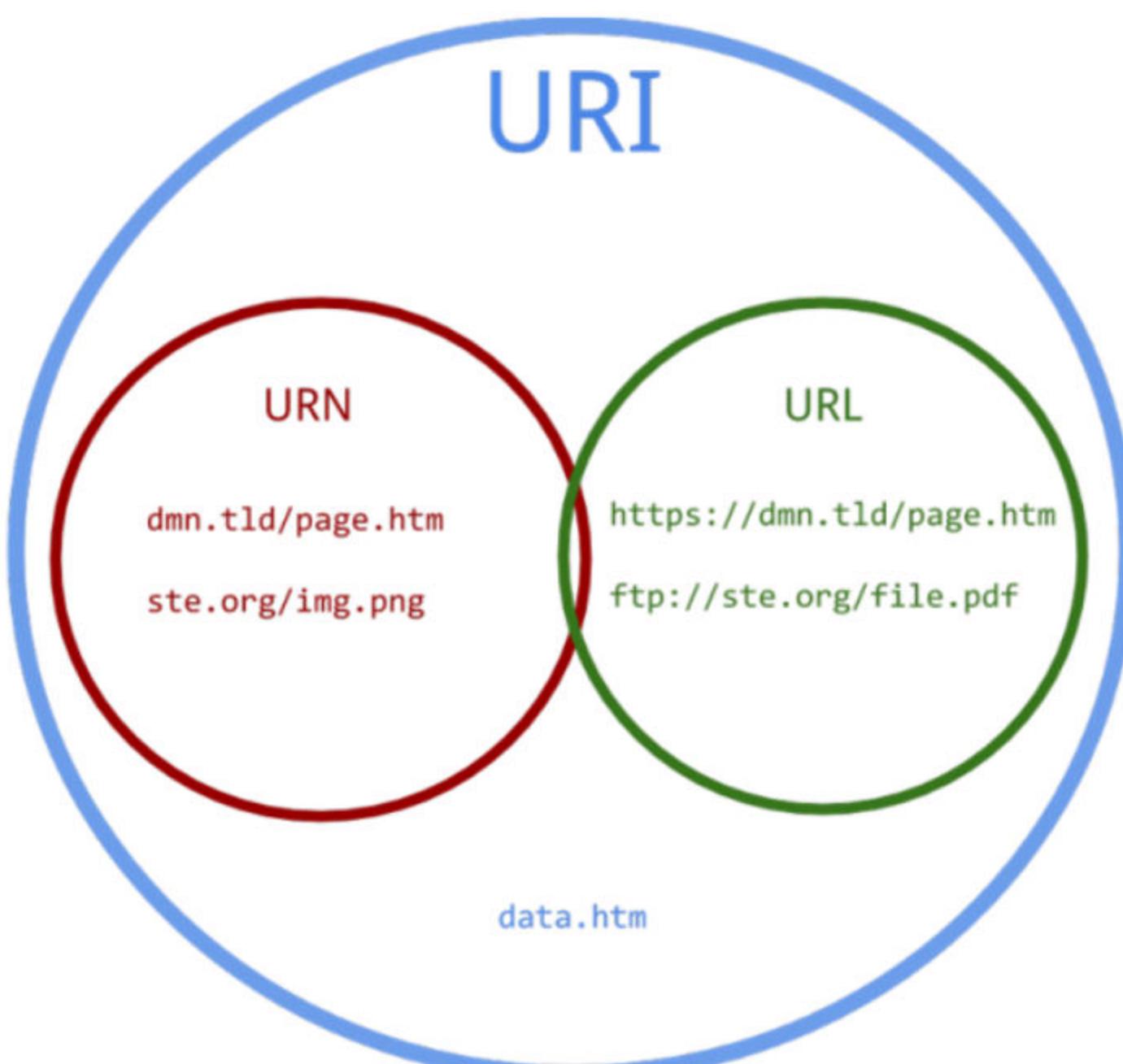
#### Uniform Resource Locators

- On the Web, functionality of pointers is provided by Uniform Resource Locators (URLs)
- URL example: <https://www.acm.org/sigmod>
  - The first part indicates how the document is to be accessed (protocol)
    - "http" indicates that the document is to be accessed using the HyperText Transfer Protocol
  - The second part gives the unique name of a machine on the Internet
  - The rest of the URL identifies the document within the machine
- The local identification can be:

- The path name of a file on the machine:
  - A file at `C:\WINDOWS\media\Alarm01.wav` of the local machine can be accessed as:
    - `file:///C:/WINDOWS/media/Alarm01.wav`
    - `file:///localhost/c:/WINDOWS/media/Alarm01.wav`
- An identifier (path name) of a program, plus arguments to be passed to the program:
  - Searching [google.com](http://www.google.com) with 'silberschatz' has the uri:
    - `http://www.google.com/search?q=silberschatz`

## URI, URL and URN

- Uniform Resource Identifier (URI)
- Uniform Resource Locator (URL)
- Uniform Resource Name (URN)
- Relationships
  - URIs can be classified as locators (URLs), or as names (URNs), or as both
  - URN functions like a person's name
  - URL resembles that person's street address
  - URN defines an item's identity, while the URL provides a method for finding it



## HTML and HTTP

- HTML provides formatting, hypertext link, and image display features
  - including tables, stylesheets (to alter default formatting), etc
- HTML also provides input features

- Select from a set of options
  - Pop-up menus, radio buttons, check lists
- Enter values
  - Text boxes
- Filled in input sent back to the server, to be acted upon by an executable at the server
- HyperText Transfer Protocol (HTTP) used to communicate with the Web Server

## HTTP and Sessions

- The HTTP protocol is **connectionless**
  - That is, once the server replies to a request, the server closes the connection with the client, and forgets all about the request
  - In contrast, Unix logins, and JDBC/ODBC connections stay connected until the client disconnects
    - Retaining user authentication and other information
  - **Motivation** → Reduces the load on the server
    - Operating Systems have tight limits on the number of open connections on a machine
- Information services need session information
  - For example, user authentication should be done only once per session
- Solution → use a **cookie**

## Sessions and Cookies

- A **cookie** is a small piece of text containing identifying information
  - Sent by the server to the browser
    - Sent on first interaction to identify the session
  - Sent by the browser to the server that created the cookie on further interactions
    - part of HTTP
  - Server saves the information about cookies it issued, and can use it when serving a request
    - For example, authentication information and user preferences
- Cookies can be stored permanently or for a limited time

## Web Browser

- A web browser is an application software for accessing the World Wide Web (WWW)
- A web browser's job is to fetch content from the Web and display it on the user's device
- This process begins when the user inputs the URL into the browser address bar, starting with either `http://` or `https://`
- Once a web page has been retrieved, the rendering engine displays it on the user's device
  - A browser or the rendering engine is a core software component for a web browser
  - The primary job of a browser engine is to transform HTML documents and other resources of a web page into an interactive visual representation on a user's device
  - This includes image and video formats supported by the browser
- Web pages usually contain hyperlinks to other pages and resources
  - Each link contains a URL, and when it is clicked or tapped, the browser navigates to the new resource
- Web browsers are used on a range of devices, including desktops, laptops, tablets and smartphones
  - In 2020, an estimated 4.9B people used a browser
  - The most used browser is Google Chrome, with 64% global market share on all devices, followed by Safari with 19%

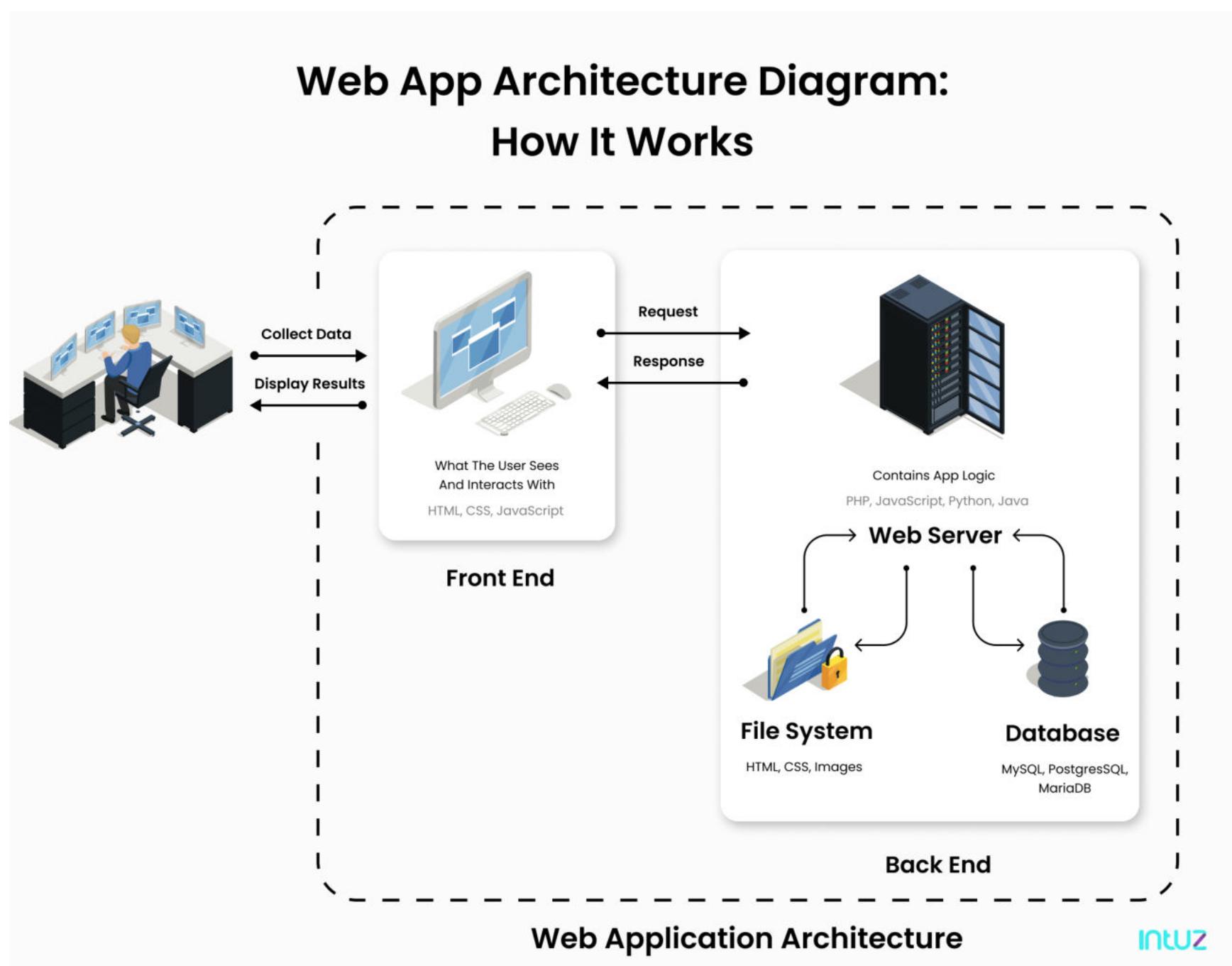
## Web Servers

- A web server is a software and underlying hardware that accepts requests via HTTP or its secure variant HTTPS
- A web browser or crawler, requests for a specific resource using HTTP, and the server responds with the content of that resource or an error message
- The server can also accept and store resources sent from the user agent
- The document name in a URL may identify an executable program, that when run, generates the HTML document
  - When an HTTP server receives a request for such a document, it executes the program and sends back the HTML document that is generated
  - The Web client can pass extra arguments with the name of the document
- To install a new service on the Web, one simply needs to create and install an executable that provides the said service
  - The Web browser provides a GUI to the information service
- Common Gateway Interface (CGI) → a standard interface between web and application server

## Web Services

- Allow data on Web to be accessed using remote procedure call mechanism
- Two approaches are widely used
  - Representational State Transfer (REST) → allows the use of standard HTTP request to a URL to execute a request and return data
    - Returned data is encoded either in XML or in JSON (JavaScript Object Notation)
  - Big Web Services
    - uses XML representation for sending request data, as well as for returning results
    - Standard protocol layer built on top of HTTP

## Web Architecture



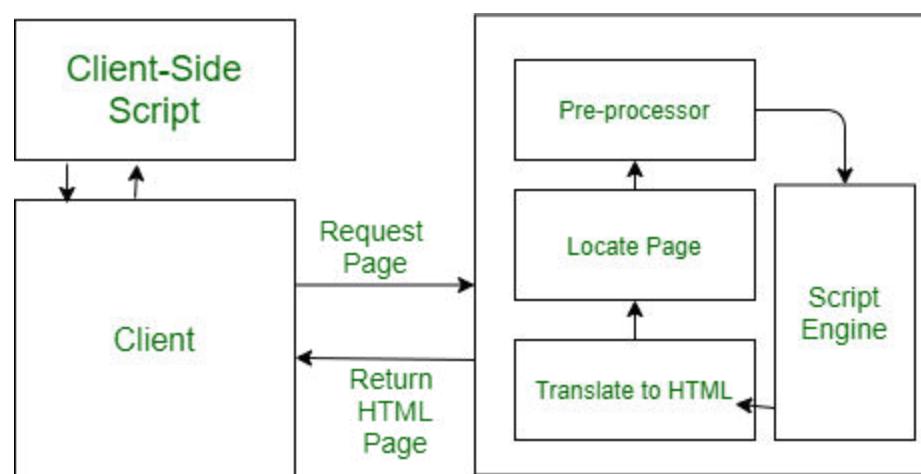
Source: <https://www.intuz.com/guide-on-web-app-architecture>

## Scripting for Web Applications

- A script is a list of (text) commands that are enabled in a web-page or in the server
- They are *interpreted and executed* by a certain program or scripting engine
- Scripts may be written for a variety of purposes such as for automating process on a local-computer or to generate web pages
- The programming languages in which scripts are written are called **scripting language**
- Common scripting languages are VBScript, JavaScript, ASP, PHP, PERL, JSP, etc.

Scripting of 2 types:

- **Client Side** → Client-side scripting is responsible for interaction within a web page
  - The client-side scripts are firstly downloaded at the client-end and then interpreted and executed by the browser
- **Server Side** → Server-side scripting is responsible for the completion or carrying out a task at the server-end and then sending the result to the client-end



Source: <https://www.geeksforgeeks.org/web-scripting-and-its-types/>

## Client Side Scripting

- Browsers can fetch certain scripts (client-side scripts) or programs along with documents, and execute them in "safe mode" at the client side
  - JavaScript
  - Macromedia Flash and Shockwave for animation/games (isn't Flash dead?)
  - VRML
  - Applets (I guess these are dead too?)
- Client-side scripts/programs allow documents to be active
  - For example, animation by executing programs at the local site
  - For example, ensure that values entered by the users satisfy some correctness checks
  - Permit flexible interaction with the user
    - Executing programs at the client site speeds up interaction by avoiding many round trips to the server

## Client Side Scripting: Security

- Security mechanisms needed to ensure that malicious scripts do not cause damage to the client machine
  - Easy for limited capability scripting languages, harder for general purpose programming languages like Java
- For example, Java's security system ensures that the Java applet code does not make any system calls directly
  - Disallows dangerous actions such as file writes
  - Notifies the user about potentially dangerous actions and allows the option to abort the program or to continue execution

## JavaScript

- JavaScript very widely used
  - Forms basis of new generation of Web applications (called Web 2.0 applications) offering rich user interfaces
- JavaScript functions can
  - Check input for validity
  - Modify the displayed web page, by altering the underlying **Document Object Model (DOM)** tree representation of the displayed HTML text
  - Communicate with a web server to fetch data and modify the current page using fetched data, without needing to reload/refresh the page
    - Forms basis of AJAX technology used widely in Web 2.0 applications
    - For example, on selecting a country in the drop-down menu, the list of states in the country is automatically populated in a linked drop-down menu

## JavaScript: Example

```

<html>
<head>
  <script type="text/javascript">
    function validate() {
      var credits = document.getElementById("credits").value;
      if (isNaN(credits) || credits <= 0 || credits >= 16) {
        alert("Credits must be a number greater than 0 and less than 16");
        return false;
      }
    }
  </script>
</head>
<body>
  <form action="createCourse" onsubmit="return validate()">
    Title: <input type="text" id="title" size="20"><br />
    Credits: <input type="text" id="credits" size="2"><br />
    <input type="submit" value="Submit">
  </form>
</body>
</html>

```

## Server Side scripting

- Server-side scripting simplifies the task of connecting a DB to the Web
  - Define an HTML document with embedded executable code/SQL queries
  - Input values from HTML forms can be used directly in the embedded code/SQL queries
  - When the document is requested, the Web server executes the embedded code/SQL queries to generate the actual HTML document
- Numerous server-side scripting languages
  - JSP, PHP
  - General purpose scripting languages like VBScript, Perl, Python

## Servlets

- Java Servlet specification defines an API for communication between the Web/application server and application program running in the server
  - For example, methods to get parameter values from Web forms, and to send HTML text back to the client
- Application program (also called a servlet) is loaded into the server
  - Each request spawns a new thread in the server
    - Thread is closed once the request is serviced

## Servlets: Example

```

import java.io.*;
import javax.servlet.*;
import javax.servlet.http.*;

```

```

public class PersonQueryServlet extends HttpServlet {
    public void doGet(HttpServletRequest request, HttpServletResponse response)
        throws ServletException, IOException {
        response.setContentType("text/html");
        PrintWriter out = response.getWriter();

        out.println("<head><title>Query Result</title></head>");
        out.println("<body>");

        String personotype = request.getParameter("personotype");
        String number = request.getParameter("name");

        if (personotype.equals("student")) {
            . . . code to find students with the specified name . . .
            . . . using JDBC to communicate with the database . . .

            out.println("<table BORDER COLS=3>");
            out.println("<tr> <td>ID</td><td>Name:</td>" + "<td> Department </td> </tr>");

            for(. . . each result . . .) {
                . . . retrieve ID, name and dept name
                . . . into variables ID, name and deptname

                . . . out.println("<tr> <td>" + ID + "</td>" + "<td>" + name
                + "</td>" + "<td>" + deptname + "</td></tr>");
            };

            out.println("</table>");
        }
        else {
            . . . as above, but for instructors . . .
        }
        out.println("</body>");
        out.close();
    }
}

```

## Servlet: Sessions

- Servlet API supports handling of sessions
  - Sets a cookie on first interaction with browser, and uses it to identify session on further interactions
- To check if session is already active:
  - `if (request.getSession(false) == true)`
    - .. then existing session
    - else .. redirect to authentication page
  - authentication page
    - check login/password
    - `request.getSession(true)` : creates new session
- Store/retrieve attribute value pairs for a particular session
  - `session.getAttribute("userid", userid)`
  - `session.getAttribute("userid")`

## Servlet: Support

- Servlets run inside application server such as
  - Apache Tomcat, Glassfish, JBoss
  - BEA Weblogic, IBM WebSphere and Oracle Application Servers
- Application servers support
  - deployment and monitoring of servlets
  - Java 2 Enterprise Edition (J2EE) platform supporting objects, parallel processing across multiple application servers, etc

## Java Server Pages (JSP)

- A JSP page with embedded Java code

```

<html>
<head>
  <title>Hello</title>
</head>
<body>
  <% if (request.getParameter("name") == null)
    { out.println("Hello World"); }
    else { out.println("Hello, " + request.getParameter("name")); }
  %>
</body>
</html>

```

- JSP is compiled into Java + Servlets
- JSP allows new tags to be defined, in tag libraries
  - Such tags are likely library functions, can be used to build rich user interfaces such as paginated display of large datasets

## PHP (Oh Lord, not this)

- PHP is widely used for Web server scripting
- Extensive libraries including for DB access using ODBC

```

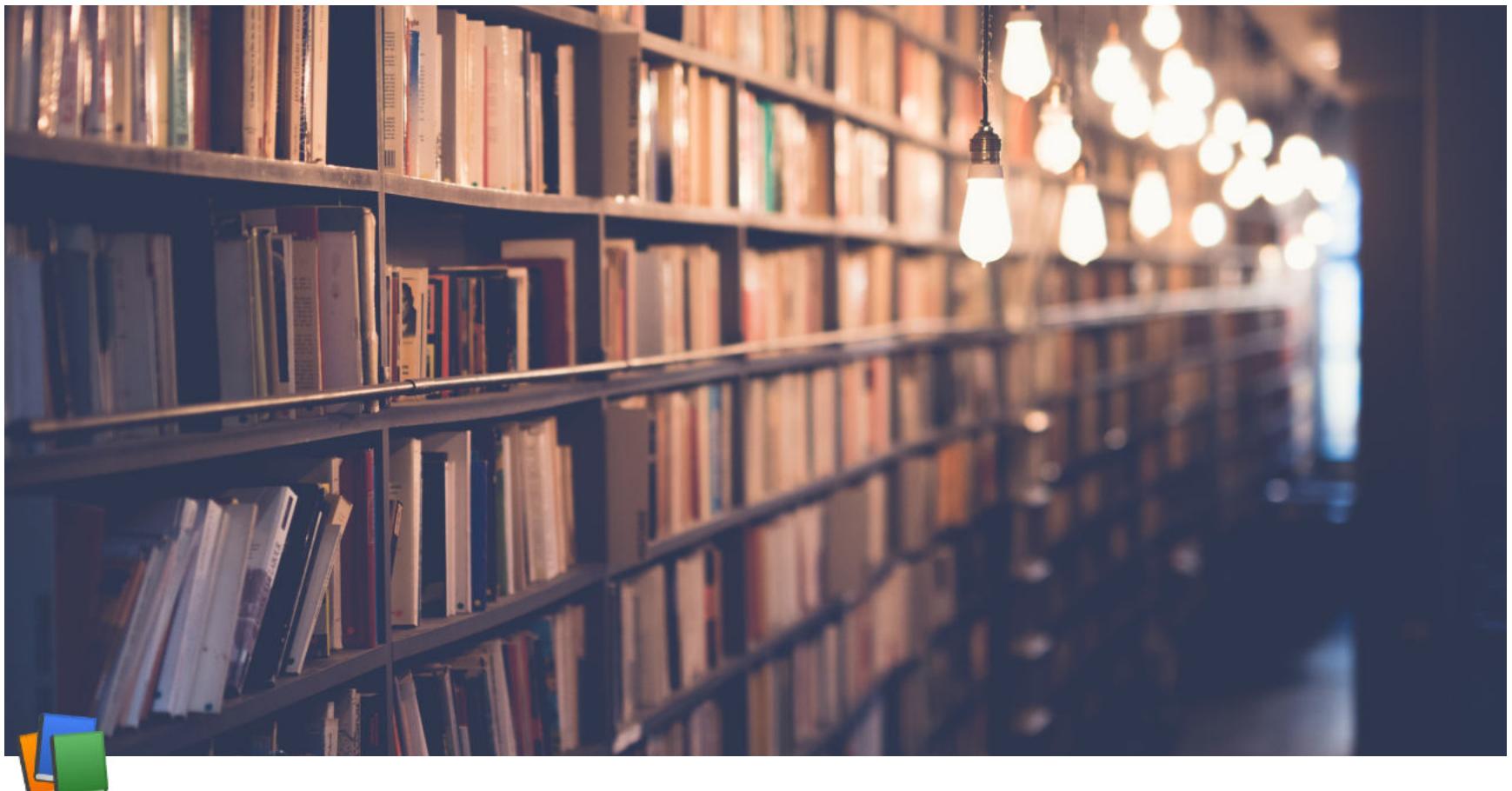
<html>
<head>
  <title>Hello</title>
</head>
<body>
  <? php if (!isset($_REQUEST['name']))
    { echo "Hello World"; }
    else { echo "Hello, " + $_REQUEST['name']; }
  ?>
</body>
</html>

```

## USP (Unique Selling Proposition) of JSP

- **JSP vs Active Server Pages (ASP)**
  - ASP is a similar technology from Microsoft and is proprietary (uses VB)
- 
- ABSOLUTELY PROPRIETARY**
- JSP is platform independent and portable
- **JSP vs Pure Servlets**
  - JSP is a servlet but it is more convenient to write and to modify regular HTML than to have a million `println` statements that generate the HTML
  - The Web page design experts can build the HTML, leaving places for the servlet programmers to insert the dynamic content
- **JSP vs JavaScript**
  - JavaScript can generate HTML dynamically on the client
  - "Client side" → JavaScript code is executed by the browser after the web server sends the HTTP response
    - With the exception of cookies, HTTP and form submission data is not available to JavaScript

- "Server side" → Java Server Pages are executed by the web server before the web server sends the HTTP response
  - It can access server-side resources like DBs, catalogs
- **JSP vs Static HTML**
  - Regular HTML cannot contain dynamic information



## Week 7 Lecture 3

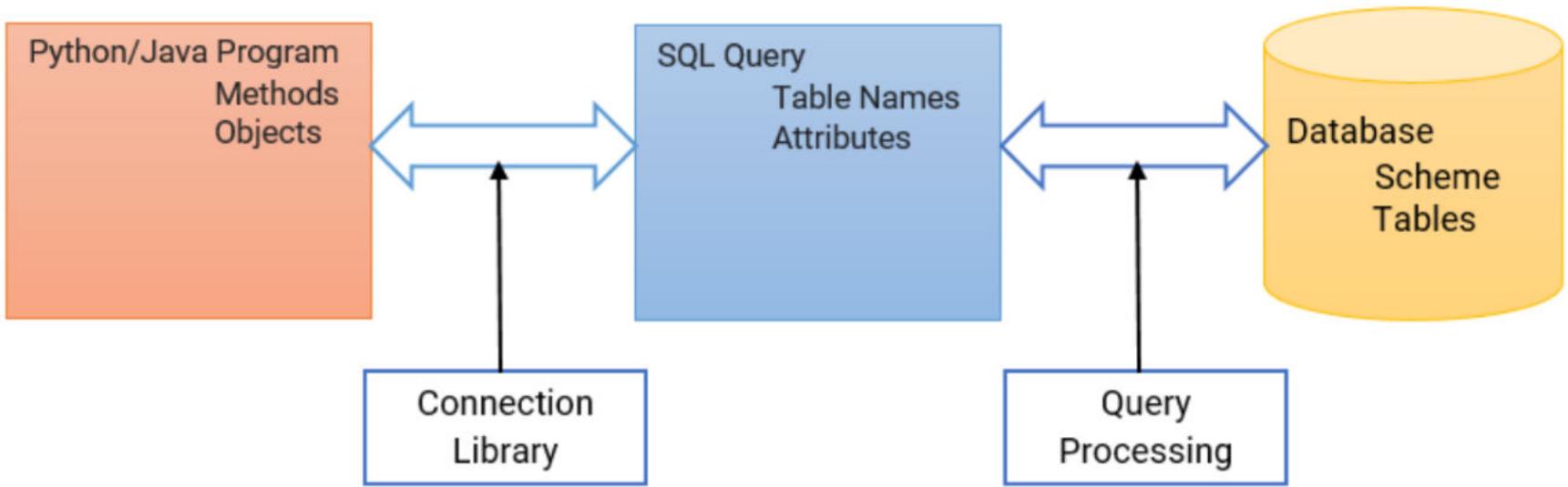
Class	BSCCS2001
Created	@October 20, 2021 1:32 AM
Materials	
Module #	33
Type	Lecture
# Week #	7

## Application Design & Development: SQL and Native Language

### Working with SQL and Native Language

- Applications use **Application Programming Interface (API)** to interact with the DB server
- Applications make calls to
  - Connect with the DB server
  - Send SQL commands to the DB server
  - Fetch tuples of result one-by-one into the program variables
- Frameworks
  - **Connectionist**
    - **Open DB Connectivity (ODBC)** → works with C, C++, C#, Visual Basic and Python
      - Other data APIs include
        - OLEDB
        - ADO.NET
    - **Java DB Connectivity (JDBC)** → works with Java
  - **Embedding**
    - Embedded SQL works with C, C++, C#, Java, COBOL, FORTRAN and Pascal

### Native Language $\iff$ Query Language: Connectionist



## ODBC

- **Open DB Connectivity (ODBC)** is a standard API for accessing DBMS
- It aimed to be independent of DB systems and OS
- An application written using ODBC can be ported to other platforms, both on the client and the server side, with few changes to the data access code
- ODBC is
  - A standard for application program to communicate with a DB server
  - An API to
    - Open a connection with a DB
    - Send queries and updates
    - Get back the results
- Applications such as GUI, Spreadsheets, etc. can use ODBC
- ODBC was originally developed by Microsoft and Simba Technologies during the early 1990s, and became the basis for the Call Level Interface (CLI) standardized by SQL Access Group in the Unix and mainframe field

## ODBC: Python Example

- The code uses a data source names "SQLS" from the `odbc.ini` file to connect and issue a query
- It creates a table, inserts data using literal and parameterized statements and fetches the data

```

import pyodbc

conn = pyodbc.connect('DSN=SQLS;UID=test01;PWD=test01')
cursor = conn.cursor()

cursor.execute("create table rvtest (col1 int, col2 float, col3 varchar(10))")
cursor.execute("insert into rvtest values (1, 10.0, \"ABC\")")
cursor.execute("select * from rvtest")

while True:
    row = cursor.fetchone()

    if not row:
        break

    print(row)

cursor.execute("delete from rvtest")
cursor.execute("insert into rvtest values (?, ?, ?)", 2, 20.0, 'XYZ')
cursor.execute("select * from rvtest")

while True:
    row = cursor.fetchone()

    if not row:
        break

    print(row)

```

Source: <https://dzone.com/articles/tutorial-connecting-to-odbc-data-sources-with-pyth>

## JDBC

- **Java DB Connectivity (JDBC)** is an API for the programming language Java, which defines how a client may access a DB
- It is a Java-based data access technology used for Java DB connectivity
- JDBC supports a variety of features for querying and updating data, and for retrieving query results; metadata retrieval, such as querying about relations present in the DB and the names and the types of relation attributes
- Model for communicating with the DB:
  - Open a connection
  - Create a "statement" object
  - Execute queries using the Statement object to send queries and fetch results
  - Exception mechanism to handle errors
- JDBC, originally released by Sun Microsystems released as part of Java Development Kit (JDK) 1.1 or in 1997, is part of Java Standard Edition platform, from Oracle corporation

## JDBC: Example

- We show a simple example here to connect to SQL server from Java using JDBC to execute DB commands
- In the example, the sample code makes a connection to the sample DB
- Then, using an SQL statement with the `SQLServerStatement` object, it runs the SQL statement and places the data that it returns into a `SQLServerResultSet` object
- Next, the sample code calls the custom `displayRow` method to iterate through the rows of data that are in the result set, and uses the `getString` method to display some of the data
- Complete example can be found at: <https://docs.microsoft.com/en-us/sql/connect/jdbc/retrieving-result-set-data-sample?view=sql-server-ver15>

```

import java.sql.Connection;
import java.sql.DriverManager;
import java.sql.ResultSet;
import java.sql.SQLException;
import java.sql.Statement;

public class RetrieveResultSet {
    public static void main(String[] args) {
        // Create a variable for the connection string.
        String connectionUrl = "jdbc:sqlserver://<server>:<port>;databaseName=AdventureWorks";
        connectionUrl += "user=<user>; password=<password>";

        try (Connection con = DriverManager.getConnection(connectionUrl);
            Statement stmt = con.createStatement()) {
            createTable(stmt);
            String SQL = "SELECT * FROM Production.Product;";
            ResultSet rs = stmt.executeQuery(SQL);
            displayRow("PRODUCTS", rs);
        }

        // Handle any errors that may have occurred.
        catch (SQLException e) {
            e.printStackTrace();
        }
    }

    private static void displayRow(String title, ResultSet rs) throws SQLException {
        System.out.println(title);

        while (rs.next()) {
            // Iterate on Table("ProductID", "Name")
            System.out.println(rs.getString("ProductID") + " : " + rs.getString("Name"));
        }
    }

    private static void createTable(Statement stmt) throws SQLException {
        stmt.execute("if exists (select * from sys.objects where name = 'Product_JDBC_Sample')"
            + "drop table Product_JDBC_Sample");

        String sql = "CREATE TABLE [Product_JDBC_Sample](" // Table Name
            + "[ProductID] [int] IDENTITY(1,1) NOT NULL," // Attribute 1
            + "[Name] [varchar](30) NOT NULL,)"; // Attribute 2

        stmt.execute(sql);
        sql = "INSERT Product_JDBC_Sample VALUES ('Adjustable Time','AR-5381')"; // Add Product 1
        stmt.execute(sql);
        sql = "INSERT Product_JDBC_Sample VALUES ('ML Bottom Bracket','BB-8107')"; // Add Product 2
    }
}

```

```

stmt.execute(sql);
sql = "INSERT Product_JDBC_Sample VALUES ('Mountain-500 Black', 'BK-M18B-44')"; // Add Product 3
stmt.execute(sql);
}
}

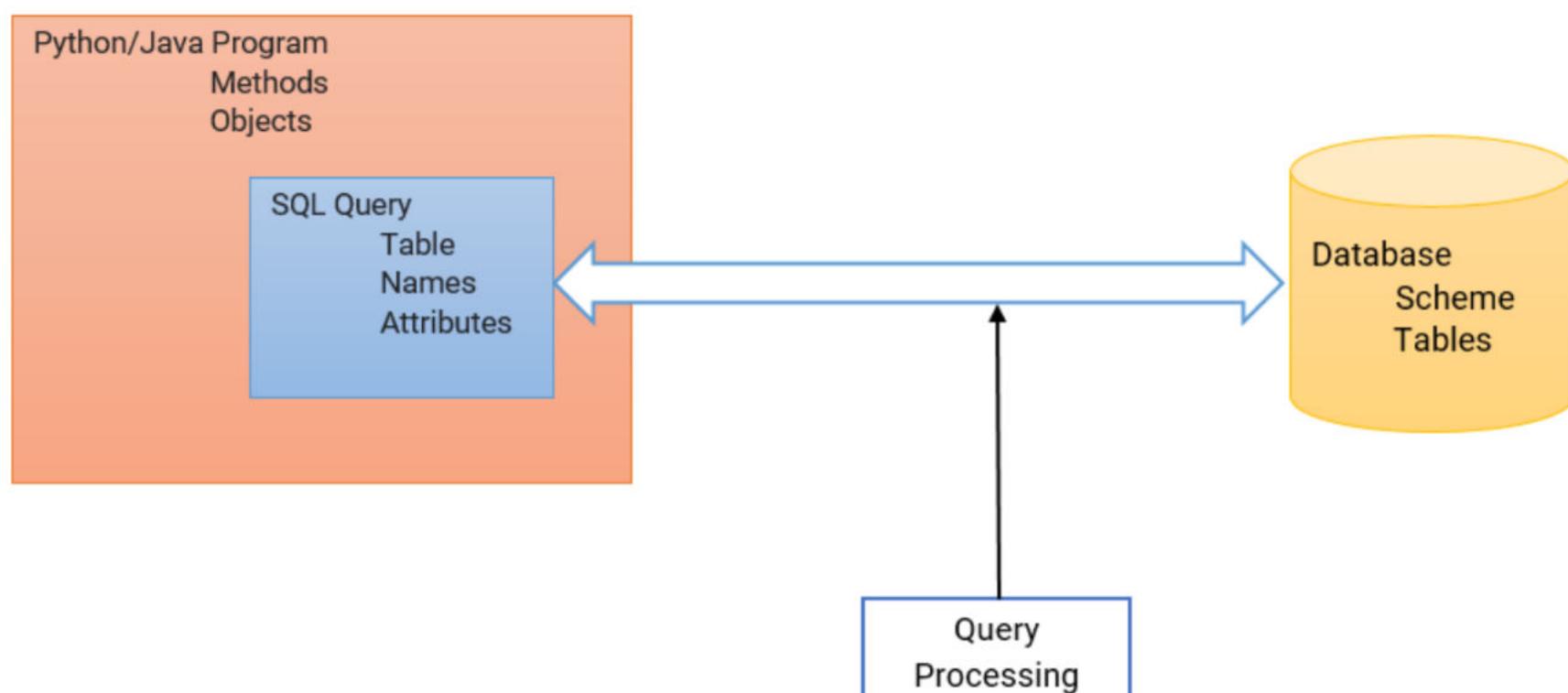
```

## Connectionist Bridge Configurations

A **bridge** is a special kind of driver that uses another driver-based technology

- This driver translates **source function-calls** into **target function-calls**
- Programmers usually use such a bridge when they lack a **source driver** for some DB but have access to a **target driver**
- Common bridges are:
  - **ODBC-to-JDBC (ODBC-JDBC) bridges** → An ODBC-JDBC bridge consists of an ODBC driver which uses the services of a JDBC driver to connect to a database
    - **Example** → OpenLink ODBC-JDBC Bridge, SequeLink ODBC-JDBC Bridge
  - **JDBC-to-ODBC (JDBC-ODBC) bridges** → A JDBC-ODBC bridge consists of a JDBC driver which employs an ODBC driver to connect to a target DB
    - **Example** → OpenLink JDBC-ODBC Bridge, SequeLink JDBC-ODBC Bridge
  - **OLE DB-to-ODBC bridges** → An OLE DB-ODBC bridge consists of an OLE DB Provider which uses the services of an ODBC function calls
    - **Example** → OpenLink OLEDB-ODBC Bridge, SequeLink OLEDB-ODBC Bridge
  - **ADO.NET-to-ODBC bridges** → An ADO.NET-ODBC bridge consists of an ADO.NET Provider which uses the services of an ODBC driver to connect to a target DB
    - **Example** → OpenLink ADO.NET-ODBC Bridge, SequeLink ADO.NET-ODBC Bridge

## Native Language $\iff$ Query Language: Embedded SQL



## Embedded SQL

- The SQL standard defines embedding of SQL in a variety of programming languages such as C, C++, Java, FORTRAN, and PL/1
- A language to which SQL queries are embedded is referred to as a **host language**, and the SQL structures permitted in the host language comprise **embedded SQL**
- The basic form of these languages follow that of the System R embedding of SQL into PL/1
- `EXEC SQL` (or similar alternate like `#sql`) statement is used to identify embedded SQL request to the pre-processor  
`EXEC SQL <embedded SQL statement>;`

**NOTE** → this varies by language:

- In some languages, like COBOL, the semi-colon is replaced with `END-EXEC`
  - In Java embedding uses `# SQL {...};`
- 

- Before executing any SQL statements, the program must first connect to the DB

This is done using:

```
EXEC-SQL connect to server user user-name using password;
```

Here, *server* identifies the server to which a connection is to be established

- Variables of the host language can be used within embedded SQL statements
- They are preceded by a colon (:) to distinguish from SQL variables (for example, `:credit_amount`)
- Variables used as above must be declared within DECLARE section, as illustrated below

The syntax for declaring the variables, however, follows the usual host language syntax

```
EXEC-SQL BEGIN DECLARE SECTION
```

```
    int credit-amount;
```

```
EXEC-SQL END DECLARE SECTION;
```

---

- To write an embedded SQL query, we use the

**declare c cursor for <SQL query>**

- Example

- From within a host language, find the ID and name of the students who have completed more than the number of credits stored in variable `credit_amount` in the host language
- Specify the query in SQL as follows:

```
EXEC SQL
```

```
declare c cursor for
select ID, name
from student
where tot_cred > :credit_amount
```

```
END_EXEC
```

- The variable *c* (used in the cursor definition) is used to identify the query

- 
- The open statement for our examples is as follows:

```
EXEC SQL open c;
```

This statement causes the DB system to execute the query and to save the results within a temporary relation

The query uses the value of the host-language variable *credit-amount* at the time the **open** statement is executed

- The fetch statement causes the values of one tuple in the query result to be placed on host language variables

```
EXEC SQL fetch c into :si, :sn END_EXEC
```

Repeated calls to fetch get successive tuples in the query result

- 
- A variable called SQLSTATE in the SQL communication area (SQLCA) gets set to '02000' to indicate no more data is available

- The **close** statement causes the DB system to delete the temporary relation that holds the result of the query

```
EXEC SQL close c;
```

**NOTE:** Above details vary with language

For example, the Java embedding defines Java iterators to step through result tuples

- 
- Embedded SQL expressions for DB modification (**update**, **insert** and **delete**)

- Can update tuples fetched by the cursor by declaring that the cursor is for update

```
EXEC SQL
```

```
declare c cursor for
```

```

select *
  from instructor
  where dept_name = 'Music'
  for update

```

- We then iterate through the tuples by performing **fetch** operations on the cursor (as illustrated earlier) and after fetching each tuple we execute the following code

```
update instructor
```

```

  set salary = salary + 1000
  where current of c

```

## Embedded SQL: C Example

- Here is an example embedded SQL C program from **DB2: Embedded SQL for C and C++** (by P. Godfrey, Nov. 2002)
- It does not do much, but is instructive
- The app queries a table **sailor** in schema one
- User one has granted select privileges to all on table **sailor**, so the bind step will be legal
- The app takes one argument on the command line, a sailor's SID
  - It then finds the sailor SID's age out of the table ONE.SAILOR and reports it

```

#include <stdio.h>
#include <stdlib.h>
#include <string.h>
#include <sqlenv.h>
#include <sqlcodes.h>
#include <sys/time.h>

#define EXIT 0
#define NOEXIT 1

EXEC SQL INCLUDE SQLCA; // Include DB2's SQL error reporting facility.
EXEC SQL BEGIN DECLARE SECTION; // Declare the SQL interface variables.

short sage, sid; char sname[16];
EXEC SQL END DECLARE SECTION;

// Declare variables to be used in the following C program
char msg[1025]; int rc, errcount;

// This macro prints the message in the SQLCA if the return code is 0 and the SQLCODE is not 0
#define PRINT_MESSAGE() { \
    if (rc == 0 && sqlca.sqlcode != 0) { \
        sqlaintp(msg, 1024, 0, &sqlca); \
        printf("%s\n", msg); \
    } \
}

// The macro prints out all fields in the SQLCA
#define DUMP_SQLCA() { \
    printf("***** DUMP OF SQLCA *****\n"); \
    printf("SQLCAID: %s\n", sqlca.sqlcaid); printf("SQLCABC: %d\n", sqlca.sqlcabc); \
    printf("SQLCODE: %d\n", sqlca.sqlcode); printf("SQLERRML: %d\n", sqlca.sqlerrml); \
    printf("SQLERRD[0]: %d\n", sqlca.sqlerrd[0]); printf("SQLERRD[1]: %d\n", sqlca.sqlerrd[1]); \
    printf("SQLERRD[2]: %d\n", sqlca.sqlerrd[2]); printf("SQLERRD[3]: %d\n", sqlca.sqlerrd[3]); \
    printf("SQLERRD[4]: %d\n", sqlca.sqlerrd[4]); printf("SQLERRD[5]: %d\n", sqlca.sqlerrd[5]); \
    printf("SQLWARN: %s\n", sqlca.sqlwarn); printf("SQLSTATE: %s\n", sqlca.sqlstate); \
    printf("***** END OF SQLCA DUMP *****\n"); \
}

// This macro prints the message in the SQLCA if one exists
// If the return code is not 0 or the SQLCODE is not expected, an error occurred and must be recorded.
#define CHECK_SQL(code,text_string,eExit) { \
    PRINT_MESSAGE(); \
    if (rc != 0 || sqlca.sqlcode != code) { \
        printf("%s\n",text_string); printf("Expected code = %d\n",code); \
        if (rc == 0) DUMP_SQLCA(); \
        else printf("RC: %d\n",rc); \
        errcount += 1; \
        if (eExit == EXIT) goto errorexit; \
    } \
}

```

```

}

main (int argc, char *argv[]) { // The PROGRAM
    // Grab the first command argument. This is the SID
    if (argc > 1) {
        sid = atoi(argv[1]);
        printf("SID requested is %d.\n", sid); // If there is no argument, bail
    } else {
        printf("Which SID?\n");
        exit(0);
    }

    EXEC SQL CONNECT TO C3421M;
    CHECK_SQL(0, "Connect failed", EXIT);

    // Find the name and age of sailor SID
    EXEC SQL SELECT SNAME, AGE into :sname, :sage
    FROM ONE.SAILOR
    WHERE sid = :sid;
    CHECK_SQL(0, "The SELECT query failed.", EXIT);

    // Report the age
    printf("Sailor %s's age is %d.\nExecuted Successfully\nBye\n", sname, sage);
    errorexit:
    EXEC SQL CONNECT RESET;
}

```

- The instance of the table `sailor`:

Aa SNAME	# SID	# RATING	# AGE
yuppy	22	1	20
lubber	31	1	25
guppy	44	2	31
rusty	58	3	47

- If the name of the executable is `sage`, and if you ask:

% sage 44

- The output should be

SID requested is 44

Sailor guppy's age is 31

Executed Successfully

Bye

## Embedded SQL: C Example

- The program prompts the user for an order number, retrieves the customer number, salesperson and status of the order, and displays the retrieved information on the screen

```

int main() {
    EXEC SQL INCLUDE SQLCA;
    EXEC SQL BEGIN DECLARE SECTION;
        int OrderID;          /* Employee ID (from user)      */
        int CustID;           /* Retrieved customer ID       */
        char SalesPerson[10]   /* Retrieved salesperson name  */
        char Status[6];        /* Retrieved order status     */
    EXEC SQL END DECLARE SECTION;

    /* Set up error processing */
    EXEC SQL WHENEVER SQLERROR GOTO query_error;
    EXEC SQL WHENEVER NOT FOUND GOTO bad_number;

    /* Prompt the user for order number */
    printf ("Enter order number: ");
    scanf_s("%d", &OrderID);

    /* Execute the SQL query */
    EXEC SQL SELECT CustID, SalesPerson, Status
    FROM Orders
    WHERE OrderID = :OrderID
    INTO :CustID, :SalesPerson, :Status;

    /* Display the results */
    printf ("Customer number: %d\n", CustID);
    printf ("Salesperson: %s\n", SalesPerson);
    printf ("Status: %s\n", Status);
}

```

```

    exit();

query_error:
    printf ("SQL error: %ld\n", sqlca->sqlcode);
    exit();

bad_number:
    printf ("Invalid order number.\n");
    exit();
}

```

Source: <https://docs.microsoft.com/en-us/sql/odbc/reference/embedded-sql-example?view=sql-server-ver15>

- The statement used to return the data is a singleton `SELECT` statement
  - That is, it returns only a single row of data
  - So, the code example does not declare or use cursors

## Embedded SQL: Java Example

- The following example SQLJ Application, `App.sqlj`, uses static SQL to retrieve and update data from the `EMPLOYEE` table of the sample DB
- Complete example can be found at <https://www.ibm.com/docs/en/i/7.1?topic=essiyja-example-embedding-sql-statements-in-your-java-application>

```

import java.sql.*;
import sqlj.runtime.*;
import sqlj.runtime.ref.*;

#sql iterator App_Cursor1 (String empno, String firstnm) ; // 1
#sql iterator App_Cursor2 (String) ;

class App
{

    *****
    ** Register Driver **
    *****

    static
    {
        try
        {
            Class.forName("com.ibm.db2.jdbc.app.DB2Driver").newInstance();
        }
        catch (Exception e)
        {
            e.printStackTrace();
        }
    }

    *****
    **     Main      **
    *****

    public static void main(String argv[])
    {
        try
        {
            App_Cursor1 cursor1;
            App_Cursor2 cursor2;

            String str1 = null;
            String str2 = null;
            long count1;

            // URL is jdbc:db2:dbname
            String url = "jdbc:db2:sample";

            DefaultContext ctx = DefaultContext.getDefaultContext();
            if (ctx == null)
            {
                try
                {
                    // connect with default id/password
                    Connection con = DriverManager.getConnection(url);
                    con.setAutoCommit(false);
                    ctx = new DefaultContext(con);
                }
                catch (SQLException e)
                {
                    System.out.println("Error: could not get a default context");
                    System.err.println(e);
                }
            }
        }
    }
}

```

```

        System.exit(1);
    }
    DefaultContext.setDefaultCloseOperation(ctx);
}

// retrieve data from the database
System.out.println("Retrieve some data from the database.");
#sql cursor1 = {SELECT empno, firstnme FROM employee}; // 2

// display the result set
// cursor1.next() returns false when there are no more rows
System.out.println("Received results:");
while (cursor1.next()) // 3
{
    str1 = cursor1.empno(); // 4
    str2 = cursor1.firstname();

    System.out.print (" empno= " + str1);
    System.out.print (" firstname= " + str2);
    System.out.println("");
}
cursor1.close(); // 9

// retrieve number of employee from the database
#sql { SELECT count(*) into :count1 FROM employee }; // 5
if (1 == count1)
    System.out.println ("There is 1 row in employee table");
else
    System.out.println ("There are " + count1
                       + " rows in employee table");

// update the database
System.out.println("Update the database.");
#sql { UPDATE employee SET firstnme = 'SHILI' WHERE empno = '000010' };

// retrieve the updated data from the database
System.out.println("Retrieve the updated data from the database.");
str1 = "000010";
#sql cursor2 = {SELECT firstnme FROM employee WHERE empno = :str1}; // 6

// display the result set
// cursor2.next() returns false when there are no more rows
System.out.println("Received results:");
while (true)
{
    #sql { FETCH :cursor2 INTO :str2 }; // 7
    if (cursor2.endFetch()) break; // 8

    System.out.print (" empno= " + str1);
    System.out.print (" firstname= " + str2);
    System.out.println("");
}
cursor2.close(); // 9

// rollback the update
System.out.println("Rollback the update.");
#sql { ROLLBACK work };
System.out.println("Rollback done.");
}

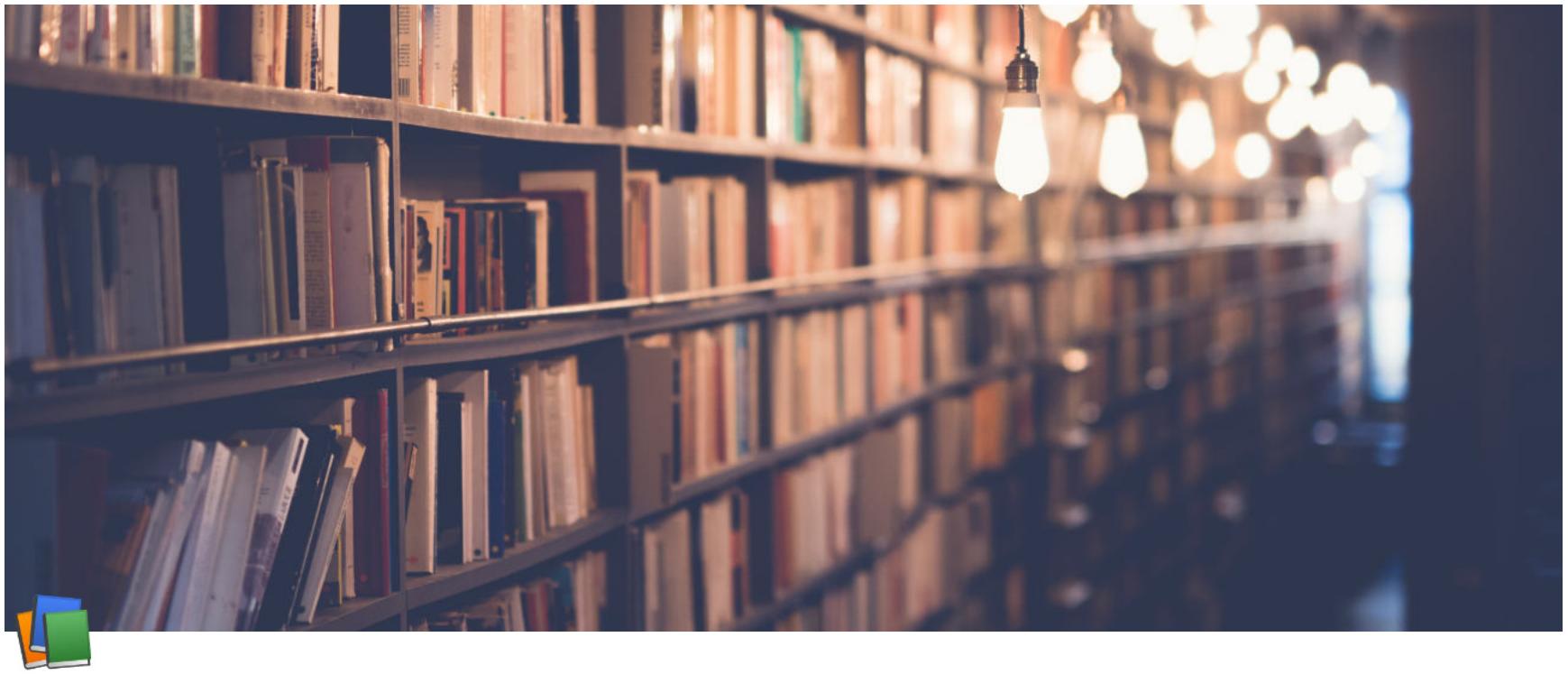
catch( Exception e )
{
    e.printStackTrace();
}
}
}

```

## Embedded SQL: Java Example → Notes

- **Declare iterators** → This section declares two types of iterators
  - **App\_Cursor1** → Declares column data types and names, and returns the values of the columns according to column name (Named binding to columns)
  - **App\_Cursor2** → Declares column data types, and returns the values of the columns by column position (Positional binding to columns)
- **Initialize the iterator** → The iterator object `cursor1` is initialized using the result of a query
  - The query stores the result in `cursor1`
- **Advance the iterator to the new row** → The `cursor1.next()` method returns a Boolean false if there are no more rows to retrieve
- **Move the data** → The named accessor method `empno()` returns the value of the column named `empno` on the current row

- The named accessor method `firstname()` returns the value of the column named `firstname` on the current row
- **SELECT data into a host variable** → The SELECT statement passes the number of rows in the table into the host variable `count1`
- **Close the iterators** → The close() method releases any resources held by the iterators
  - You should explicitly close iterators to ensure that system resources are released in a timely fashion
- **Initialize the iterator** → The iterator object `cursor2` is initialized using the result of a query
  - The query stores the result in `cursor2`
- **Retrieve the data** → The FETCH statement returns the current value of the first column declared in the `ByPos` cursor from the result table into the host variable `str2`
- **Check the success of a FETCH..INTO statement** → The `endFetch()` method returns a Boolean true if the iterator is not positioned on a row, that is, if the last attempt to fetch a row failed
  - The `endFetch()` method returns False if the last attempt to fetch a row was successful
  - DB2 attempts to fetch a row when the `next()` method is called
  - A FETCH..INTO statement implicitly calls the `next()` method
- **Close the iterators** → The close() method releases any resources held by the iterators
  - You should explicitly close iterators to ensure that system resources are released in a timely fashion



## Week 7 Lecture 4

Class	BSCCS2001
Created	@October 20, 2021 3:36 PM
Materials	
Module #	34
Type	Lecture
# Week #	7

## Application Design & Development: Python & PostgreSQL

### Working with PostgreSQL and Python

#### Python modules for PostgreSQL

Following Python modules that can be used to work with a PostgreSQL DB server:

- psycopg2
- pg8000
- py-postgresql
- PyGreSQL
- ocpgdb
- bpgsql
- SQLAlchemy

Source: <https://pynative.com/python-postgresql-tutorial/>

#### Package: `psycopg2`

##### Advantages of psycopg2

- Most popular and stable module to work with PostgreSQL
- Used in most of the Python and Postgres frameworks
- An actively maintained package and supports Python 2.x and 3.x
- Thread-safe and designed for heavily multi-threaded applications

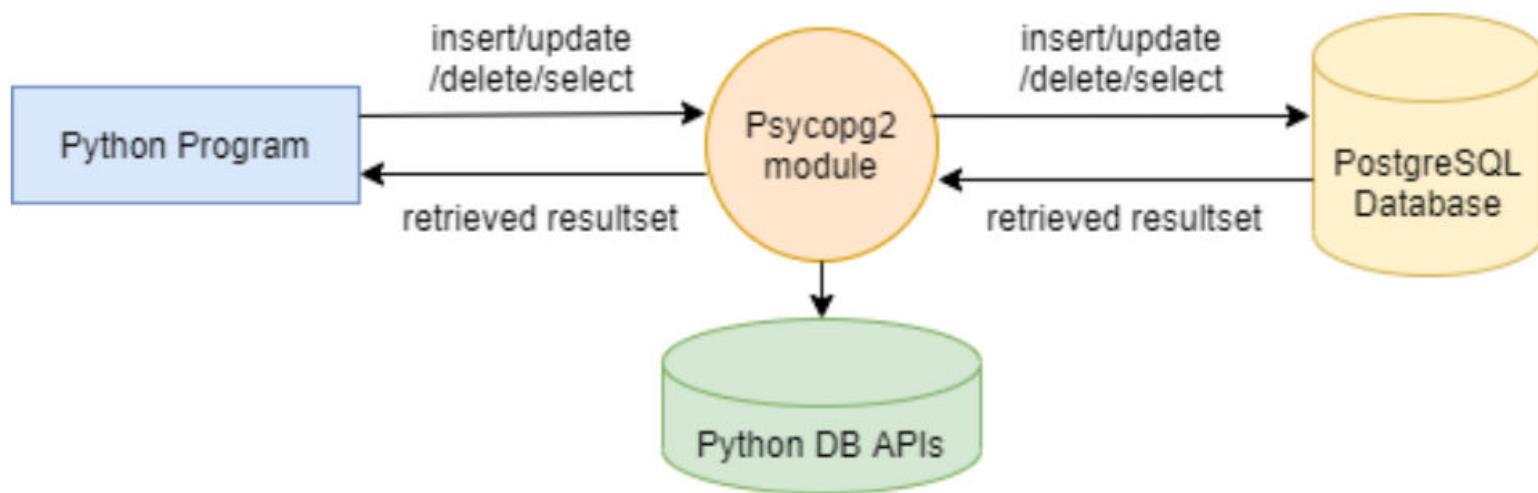
##### Installing Psycopg2 using the `pip` command

- The following `pip` command installs psycopg2 on different OSs including Windows, Mac OS, Linux and Unix  
`pip install psycopg2`
- For installing a specific version, the following command can be used  
`pip install psycopg2==2.8.6`

#### Steps to access PostgreSQL from Python (using psycopg2)

- Create a connection
- Create a cursor
- Execute the query
- Commit/rollback

- Close the cursor
- Close the connection



### Python psycopg2 Module APIs: Connection objects

- `psycopg2.connect(database="mydb", user="myuser", password="mypass", host="127.0.0.1", port="5432")`  
This API opens a connection to the PostgreSQL DB  
If the DB is opened successfully, it returns the connection object
- `connection.close()`  
This method closes the DB connection

Important **psycopg2** module routines for managing cursor object:

- `connection.cursor()`  
This routine creates a cursor which will be used throughout the program
- `cursor.close()`  
This method closes the cursor

### Python psycopg2 Module APIs: insert, delete, update & stored procedures

- `cursor.execute(sql [, optional parameters])`  
This routine executes an SQL statement  
The SQL statement may be parameterized (i.e. placeholders instead of SQL literals)  
The **psycopg2** module supports placeholder using `%s` sign  
For example, `cursor.execute("insert into people values (%s, %s)", (who, age))`
- `cursor.executemany(sql, seq_of_parameters)`  
This routine executes an SQL command against all parameters sequences or mappings found in the sequence SQL
- `cursor.callproc(procname[, parameters])`  
This routine executes a stored database procedure with the given name  
The sequence of parameters must contain one entry for each argument that the procedure expects
- `cursor.rowcount()`  
This is a read-only attribute which returns the total number of DB rows that have been modified, inserted or deleted by the last `execute()`

### Python psycopg2 Module APIs: select

- `cursor.fetchone()`  
This method fetches the next row of a query result set, returning a single sequence, or None when no more data is available
- `cursor.fetchmany([size=cursor.arraysize])`  
This routine fetches the next set of rows of a query result, returning a list  
An empty list is returned when no more rows are available  
The method tries to fetch as many rows as indicated by the size parameter
- `cursor.fetchall()`  
This routine fetches all (remaining) rows of a query result, returning a list  
An empty list is returned when no rows are available

### Python psycopg2 Module APIs: commit & rollback

- `connection.commit()`  
This method commits the current transaction  
If you do not call this method, anything you did since the last call to `commit()` will not be visible to other DB connections
- `connection.rollback()`  
This method rolls back any changes to the DB since the last call to `commit()`

Source: [https://www.tutorialspoint.com/postgresql/postgresql\\_python.htm](https://www.tutorialspoint.com/postgresql/postgresql_python.htm)

## Connect to a PostgreSQL DB server

```
import psycopg2

def connectDb(dbname, username, pwd, address, portnum):
    conn = None

    try:
        # Connect to the PostgreSQL DB
        conn = psycopg2.connect(database = dbname, user = username, password = pwd, host = address, port = portnum)
        print("Database connected successfully")
    except(Exception, psycopg2.DatabaseError) as error:
        print(error)
    finally:
        # Close the connection
        conn.close()

connectDb("mydb", "myuser", "mypass", "127.0.0.1", "5432")
```

### Output

Database connected successfully

`psycopg2.DatabaseError` → Exception raised for errors that are related to the PostgreSQL DB

We assume the following for all the programs in this module

- Database Name → *mydb*
- Username → *myuser*
- Password → *mypass*
- Host name → localhost or 127.0.0.1

## Steps to execute SQL commands

- Use the `psycopg2.connect()` method with the required arguments to connect PostgreSQL
  - It would return a Connection object if the connection is established successfully
- Create a cursor object using the `cursor()` method of the connection object
- The `execute()` methods run the SQL commands and return the result
- Use `cursor.fetchall()` or `fetchone()` or `fetchmany()` to read query result
- Use `commit()` to make the changes in the DB persistent, or use `rollback()` to revert the DB changes
- Use `cursor.close()` and `connection.close()` method to close the cursor and the PostgreSQL connection

## CREATE new PostgreSQL tables

```
import psycopg2

def createTable():
    conn = None

    try:
        conn = psycopg2.connect(database = "mydb", user = "myuser", password = "mypass", host = "127.0.0.1", port = "5432")

        cur = conn.cursor() # Create a new cursor
        cur.execute('''CREATE TABLE EMPLOYEE \
        (emp_num INT PRIMARY KEY NOT NULL, \
        emp_name VARCHAR(40) NOT NULL, \
        department VARCHAR(40) NOT NULL)''' # Execute the CREATE TABLE statement

        conn.commit() # Commit the changes to the DB
        print("Table created successfully")
        cur.close() # close the cursor
    except (Exception, psycopg2.DatabaseError) as error:
        print(error)
    finally:
        if conn is not None:
            conn.close()

    createTable()
```

**Output (if the table EMPLOYEE does not exist)** → Table created successfully

**Output (if the table EMPLOYEE already exists)** → relation "employee" already exists

## Executing INSERT statement from Python

```
import psycopg2

def insertRecord(num, name, dept):
    conn = None

    try:
        # Connect to the PostgreSQL DB
        conn = psycopg2.connect(database = "mydb", user = "myuser", password = "mypass", host = "127.0.0.1", port = "5432")
        cur = conn.cursor() # Create a new cursor

        # Execute the INSERT statement
        cur.execute("INSERT INTO EMPLOYEE (emp_num, emp_name, department) \
        VALUES (%s, %s, %s)", (num, name, dept))
```

```

conn.commit() # Commit the changes to the DB
print ("Total number of rows inserted :", cur.rowcount);
cur.close() # close the cursor
except (Exception, psycopg2.DatabaseError) as error:
    print(error)
finally:
    if conn is not None:
        conn.close()

insertRecord(110, 'Bhaskar', 'HR')

```

**Output** → Total number of rows inserted: 1

**Output (if a row already exists with the emp\_num = 110)** → duplicate key value violates unique constraint "employee\_pkey" DETAIL: Key (emp\_num)=(110) already exists.

## Executing DELETE statement from Python

```

import psycopg2

def deleteRecord(num):
    conn = None

    try:
        # Connect to the PostgreSQL DB
        conn = psycopg2.connect(database = "mydb", user = "myuser", password = "mypass", host = "127.0.0.1", port = "5432")
        cur = conn.cursor() # Create a new cursor

        # Execute the DELETE statement
        cur.execute("DELETE FROM EMPLOYEE WHERE emp_num = %s", (num,))
        conn.commit() # Commit the changes to the DB
        print ("Total number of rows deleted :", cur.rowcount)
        cur.close() # Close the cursor
    except (Exception, psycopg2.DatabaseError) as error:
        print(error)
    finally:
        conn.close() # Close the connection

deleteRecord(110)

```

**Output** → Total number of rows deleted: 1

**Output (If the row does not exist)** → Total number of rows deleted: 0

## Executing UPDATE statement from Python

```

import psycopg2

def updateRecord(num, dept):
    conn = None

    try:
        # Connect to the PostgreSQL DB
        conn = psycopg2.connect(database = "mydb", user = "myuser", password = "mypass", host = "127.0.0.1", port = "5432")
        cur = conn.cursor() # Create a new cursor

        # Execute the UPDATE statement
        cur.execute("UPDATE EMPLOYEE set department = %s where emp_num = %s", (dept, num))
        conn.commit() # Commit the changes to the DB
        print ("Total number of rows updated :", cur.rowcount)
        cur.close() # Close the cursor
    except (Exception, psycopg2.DatabaseError) as error:
        print(error)
    finally:
        conn.close() # Close the connection

updateRecord(110, "Finance")

```

**Output** → Total number of rows updated: 1

**Output (If the row does not exist)** → Total number of rows updated: 0

## Executing SELECT statement from Python

```

import psycopg2

def selectAll():
    conn = None

    try:
        # Connect to the PostgreSQL DB
        conn = psycopg2.connect(database = "mydb", user = "myuser", password = "mypass", host = "127.0.0.1", port = "5432")
        cur = conn.cursor() # Create a new cursor

        # Execute the SELECT statement
        cur.execute("SELECT emp_num, emp_name, department FROM EMPLOYEE")
        rows = cur.fetchall() # Fetches all rows of the query result set

        for row in rows:
            print ("Employee ID = ", row[0], ", NAME = ", row[1], ", DEPARTMENT = ", row[2])

        cur.close() # Close the cursor
    except (Exception, psycopg2.DatabaseError) as error:
        print(error)
    finally:
        conn.close() # Close the connection

selectAll()

```

**Output** →

```
Employee ID = 110, NAME = Bhaskar, DEPARTMENT = HR
Employee ID = 111, NAME = Ishaan, DEPARTMENT = FINANCE
Employee ID = 112, NAME = Jairaj, DEPARTMENT = TECHNOLOGY
Employee ID = 113, NAME = Ananya, DEPARTMENT = TECHNOLOGY
```

## Python frameworks for PostgreSQL

### Web and Internet development using Python

Python offers several frameworks such as **bottle.py**, **Flask**, **CherryPy**, **Pyramid**, **Django** and **web2py** for web development

- Python offers many choices for web development
  - Frameworks such as **Django** and **Pyramid**
  - Micro-frameworks such as **Flask** and **Bottle**
  - Advanced content management systems such as **Plone** and **Django CMS**
- Python's standard library supports many internet protocols
  - HTML and XML
  - JSON
  - E-mail processing
  - Support for FTP, IMAP and other Internet protocols
  - Easy-to-use socket interface
- The package Index has more libraries
  - **Requests** → a powerful HTTP client library
  - **Beautiful Soup** → an HTML parser that can handle all sorts of HTML
  - **Feedparser** → for parsing RSS/Atom feeds
  - **Paramiko** → implementing the SSH2 protocol
  - **Twisted Python** → a framework for asynchronous network programming

Source: <https://www.python.org/about/apps/>

### Flask Web Application Framework

- Flask is a lightweight **WSGI (Web Server Gateway Interface)** web application framework
- It is desired to make getting started quick and easy, with the ability to scale up to complex applications
- It began as a simple wrapper around **Werkzeug (Werkzeug WSGI toolkit)** and **Jinja** (Jinja templating engine) and has since then become one of the most popular Python web application frameworks
- Flask offers suggestions, but does not enforce any dependencies or project layouts
  - It is up to the developer to choose the tools and libraries they want to use
- There are many extensions provided by the community that make adding new functionality easy

#### Installing Flask using the `pip` command

```
pip install -U Flask
```

Source: <https://pypi.org/project/Flask/>

#### A simple example

```
from flask import Flask
app = Flask(__name__)

@app.route('/')
def hello_world():
    return "Hello, World!"

if __name__ == '__main__':
    app.run()
```

- Importing `flask` module in the project is mandatory
  - Our WSGI application is an object of Flask class
- Flask constructor takes the name of the current module `(__name__)` as argument
- The `route()` function of the Flask class is a decorator, which tells the application which URL should call the associated function
  - `app.route(rule, options)`
  - The `rule` parameter represents URL binding with the function
  - The `options` is a list of parameters to be forwarded to the underlying Rule object
- In the above example '/' URL is bound with `hello_world()` function
  - Hence, when the home page of web server is opened in the browser, the output of this function will be rendered
- Finally, the `run()` method of Flask class runs the application on the local development server

Source: [https://www.tutorialspoint.com/flask/flask\\_application.htm](https://www.tutorialspoint.com/flask/flask_application.htm)

```
app.run(host, port, debug, options)
```

- `host` → Hostname to listen on
  - Defaults to `127.0.0.1 (localhost)`
  - Set to `0.0.0.0` to have the server available externally
- `port` → Defaults to 5000
- `debug` → Defaults to `false`
  - If set to `true`, provides a debug information
- `options` → To be forwarded to the underlying Werkzeug server

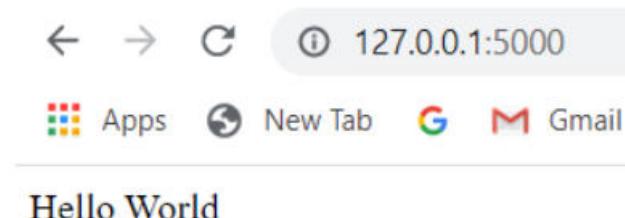
#### Executing the code

- `python hello.py`

#### Output

- \* Running on `http://127.0.0.1:5000/` (Press CTRL+C to quit)

Open the above URL (127.0.0.1:5000) in the browser



#### Python: Flask

- Consider the table **Candidate** (in PostgreSQL) as shown below:

Table "public.candidate"					
Column	Type	Collation	Nullable	Default	
cno	integer			not null	
name	character varying(30)				
email	character varying(30)				
Indexes:					
"candidate_pkey" PRIMARY KEY, btree (cno)					

- Code segment in Python:

```
from flask import Flask, render_template, request
import psycopg2

app = Flask(__name__, template_folder='templates')

if __name__ == '__main__':
    app.run(host='127.0.0.1', debug=True, port=5000)
```

- Source code for `index.html`

```
<!DOCTYPE html>
<html>
<head>
  <title>Candidate Email DB</title>
</head>
<body>
  <h2>Candidate Email DB</h2>
  <a href="/add">Add Email</a><br><br>
  <a href="/viewall">View Email</a>
</body>
</html>
```

- Source code for rendering `index.html` and `add.html` pages

```
@app.route("/")
def index():
    return render_template("index.html")

@app.route("/add")
def add():
    return render_template("add.html")
```

<http://127.0.0.1:5000/>

← → ⌂ ⓘ 127.0.0.1:5000

\_apps New Tab \_G \_M Gmail \_Y

## Candidate Email Database

[Add Email](#)

[View Email](#)

- Source code for `add.html`

```
<!DOCTYPE html>
<html>
<head>
    <title>Add Email</title>
</head>
<body>
    <h2>Email Information</h2>
    <form action = "/savedetails" method="post">
        <table>
            <tr><td>CNO</td><td><input type="text" name="cno" required></td></tr>
            <tr><td>Name</td><td><input type="text" name="name" required></td></tr>
            <tr><td>Email</td><td><input type="text" name="email" required></td></tr>
            <tr><td><input type="submit" value="Submit"></td></tr>
        </table>
    </form>
</body>
</html>
```

- `saveDetails()` function for `add.html`

```
@app.route("/savedetails",methods = ["POST"])
def saveDetails():
    cno = request.form["cno"]
    name = request.form["name"]
    email = request.form["email"]
    conn = None

    try:
        conn = psycopg2.connect(database = "mydb", user = "myuser", password = "mypass", host = "127.0.0.1", port = "5432") # connect to the PostgreSQL database
        cur = conn.cursor() # Create a new cursor

        cur.execute("INSERT INTO Candidate (cno, name, email) VALUES (%s, %s, %s)", (cno, name, email)) # Execute the INSERT statement
        conn.commit() # Commit the changes to the DB
        cur.close() # Close the cursor
    except (Exception, psycopg2.DatabaseError) as error:
        render_template("fail.html")
    finally:
        if conn is not None:
            conn.close() # Close the connection

    return render_template("success.html")
```

<http://127.0.0.1:5000/add>

← → ⌂ ⓘ 127.0.0.1:5000/add

\_apps New Tab \_G \_M Gmail

<http://127.0.0.1:5000/savedetails>

← → ⌂ ⓘ 127.0.0.1:5000/savedetails

\_apps New Tab \_G \_M Gmail \_Y Yo

## Mobile Information

CNO	<input type="text"/>
Name	<input type="text"/>
Email	<input type="text"/>
<input type="button" value="Submit"/>	

## Data Successfully Added

[Go Home](#)

- `viewAll()` function for `viewall.html`

```
@app.route("/viewall")
def viewAll():
    conn = None

    try:
        # Connect to the PostgreSQL DB
```

```

conn = psycopg2.connect(database = "mydb", user = "myuser", password = "mypass", host = "127.0.0.1", port = "5432")
cur = conn.cursor() # Create a new cursor

# Execute the SELECT statement
cur.execute("SELECT cno, name, email FROM Candidate")
results = cur.fetchall() # Fetches all rows of the query result set
cur.close() # Close the cursor
except (Exception, psycopg2.DatabaseError) as error:
    render_template("fail.html")
finally:
    conn.close() # Close the connection

return render_template("viewall.html", rows = results)

```

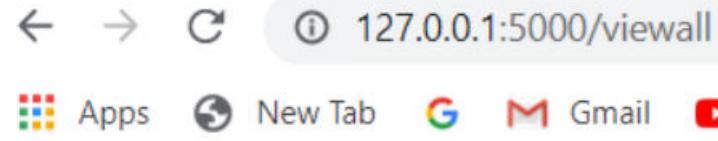
- Source code for [viewall.html](#)

```

<!DOCTYPE html>
<html>
<head>
<title>Email List</title>
</head>
<body>
<h3>Email List</h3>
<table border=5>
<tr>
<th>CNO</th><th>Name</th><th>Email</th>
</tr>
{%
for row in rows %}
<tr>
<td>{{row[0]}}</td><td>{{row[1]}}</td><td>{{row[2]}}</td>
</tr>
{%
endfor %}
</table>
<br><br>
<a href="/">Go Home</a>
</body>
</html>

```

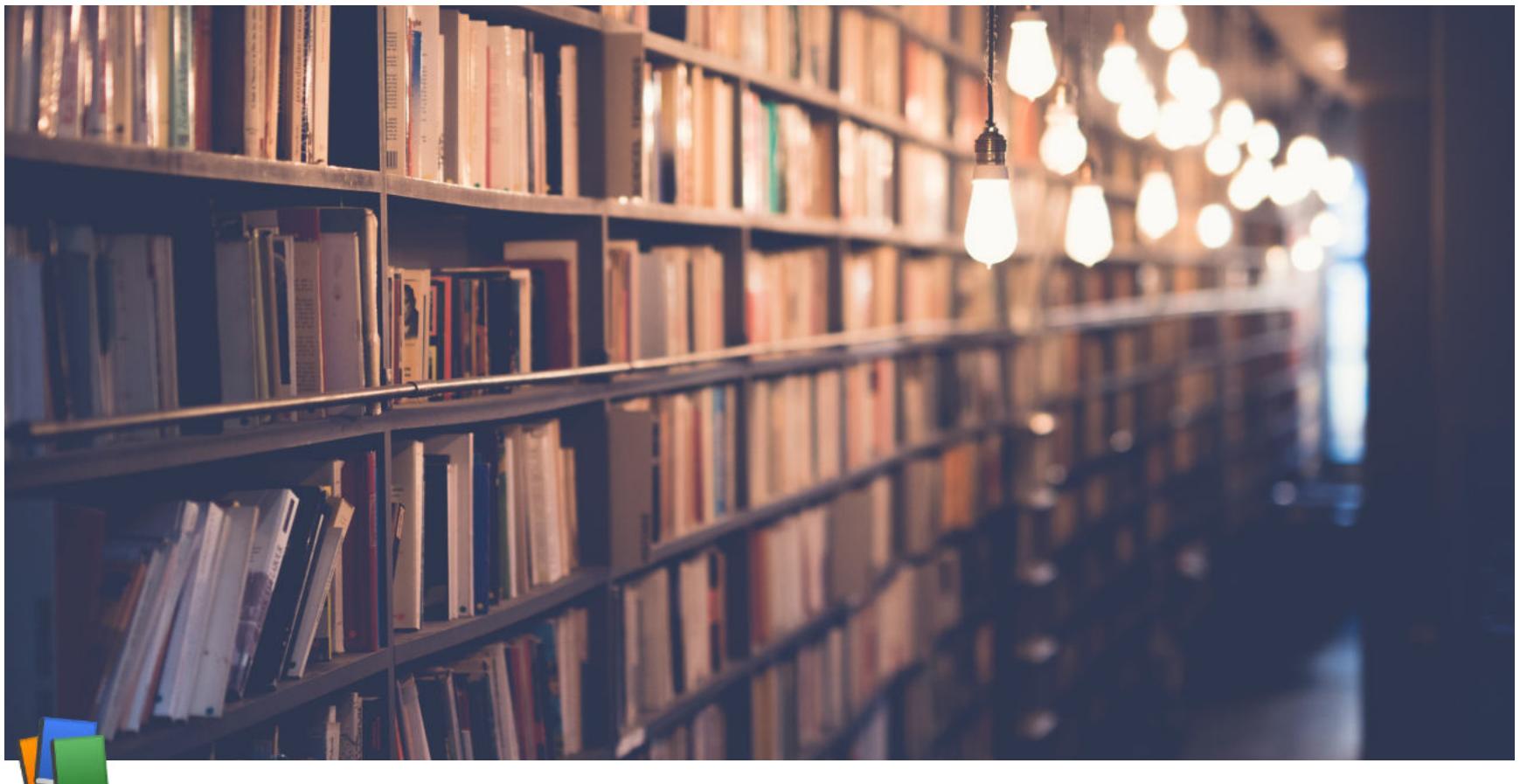
<http://127.0.0.1:5000/viewall>



## Email List

CNO	Name	Mobile
101	Ishaan	ishaan@mymail.com
102	Jairaj	Jairaj@mymail.com
103	Ananya	ananya@mymail.com
104	Barkha	barkha@myemail.com
105	Piyush	piyush@mymail.com

[Go Home](#)



## Week 7 Lecture 5

Class	BSCCS2001
Created	@October 20, 2021 6:56 PM
Materials	
Module #	35
Type	Lecture
# Week #	7

## Application Design & Development: Application Development and Mobile

### Rapid Application Development (RAD)

- A lot of effort is required to develop Web applications interfaces, especially the rich interaction functionality associated with Web 2.0 applications
- Several approaches to speed up application development
  - Function library to generate user-interface elements
  - Drag-and-drop features in an IDE to create user-interface elements
  - Automatically generate code for the user interface from a declarative specification
- Used as part of **Rapid Application Development (RAD)** tools even before Web
- RAD software is an agile model that focuses on fast prototyping and quick feedback in app development to ensure speedier delivery and an efficient result
  - App development has 4 phases → business modeling, data modeling, process modeling and testing & turnover
    - Defining the requirements, Prototyping, Receiving feedback and Finalizing the software
  - With RAD, the time between prototypes and iterations is short, and integration occurs since inception
- Web application development frameworks
  - **Java Server Faces (JSF)**
    - A set of APIs for representing UI components and managing the state, handling the events and input validation, defining page navigation and supporting internationalization and accessibility

- JSP custom tag library for expressing a JSF interface within a JSP page
- **Ruby on Rails**
  - Allows easy creation of simple **CRUD (Create, Read, Update, Delete)** interfaces by code generation from DB schema or object model
- RAD platforms and tools
  - G Suite
  - Google App Engine
  - Microsoft Azure
  - Amazon Elastic Compute Cloud (EC2)
  - AWS Elastic Beanstalk

## ASP.NET and Visual Studio

- ASP.NET provides a variety of controls that are interpreted at server, and generate HTML code
- Visual Studio provides a drag-and-drop development using these controls
  - For example, menus and list boxes can be associated with DataSet object
  - Validator controls (constraints) can be added to form input fields
    - JavaScript to enforce constraints at client, and separately enforced at the server
  - User actions such as selecting a value from a menu can be associated with actions at server
  - DataGrid provides convenient way of displaying SQL query results in a tabular format

## Application Performance and Security

### Application Performance

- Performance is an issue for popular Web sites
  - May be accessed by millions of users every day, thousands of requests per second at peak time
- Caching techniques used to reduce cost of serving pages by exploiting commonalities between requests
  - At the server side
    - Caching of JDBC connections between servlets requests
      - aka connection pooling
    - Caching results of DB queries
      - Cached results must be updated if underlying DB changes
    - Caching of generated HTML
  - At the client side
    - Caching of pages by Web proxy

### Application Security: SQL Injection

- Suppose query is constructed using
  - `"select * from instructor where name = '" + name + "'"`
- Suppose the user, instead of entering a name, enters:
  - `X' or 'Y' = 'Y'`
- The resulting statement becomes
  - `"select * from instructor where name = '" + "X' or 'Y' = 'Y'" + "'"`
  - Which is ...
    - `select * from instructor where name = 'X' or 'Y' = 'Y'`
  - User could have even used

- `X'; update instructor set salary = salary + 10000; --`
- Prepared statement internally uses:  
`"select * from instructor where name = 'X \' or \'YY' = '\'Y'`
- **Always use prepared statements, with user inputs as parameters**

## Application Security: Password Leakage

- Never store password, such as DB passwords, in clear text in scripts that may be accessible to users
  - For example, in files in a directory accessible to a web server
    - Normally, web server will execute, but not provide source of scripts files such as `file.jsp` or `file.php`, but source of editor backup files such as `file.jsp~`, or `.file.jsp.swp` may be served
- Restrict access to DB server from IPs of machine running the application servers
  - Most DBs allow restriction of access by source IP address

## Application Security: Authentication

- Single factor authentication such as passwords are too risky for critical applications
  - Guessing of passwords, sniffing of packets if passwords are not encrypted
  - Passwords re-used by user across sites
  - Spyware which captures password
- Two-factor authentication
  - For example, password plus one-time password sent by SMS
  - For example, password plus one-time password devices
    - Device generates a new pseudo-random number every minute and displays to users
    - User enters the current number as password
    - Application server generates same sequence of pseudo-random number to check that the number is correct

## Application Security: Application-Level Authorization

- Current SQL standard does not allow fine-grained authorization such as "students can see their own grades, but not other's grades"
  - Problem 1 → DB has no idea who are application users
  - Problem 2 → SQL authorization is at the level of tables, or columns of tables, but not to specific rows of a table
- One workaround → use views such as
 

```
CREATE VIEW studentTakes AS
SELECT *
FROM takes
WHERE takes.ID = syscontext.user_id()
```

  - Where `syscontext.user_id()` provides end user identity
    - End user identity must be provided to the DB by the application
    - Having multiple such views is cumbersome
- Currently authorization is done entirely in application
- Entire application code has access to the entire DB
  - Larger surface area, making protection harder
- Alternative → **find-grained (row-level) authorization** schemes
  - Extensions to SQL authorization proposed but not currently implemented
  - Oracle Virtual Private DB (VPD) allows predicates to be added transparently to all the SQL queries, to enforce find-grained authorization
    - For example, add `ID = sys_context.user_id()` to all queries on student relation if user is a student

## **Application Security: Audit Trails**

- Applications must log actions to an audit trail, to detect who carried out an update, or accessed some sensitive data
- Audit trails used after-the-fact to
  - Detect security breaches
  - Repair damage caused by a security breach
  - Trace who carried out the breach
- Audit trails needed at
  - DB level, and at
  - Application level

## **Challenges in Web Application Development**

- User Interface and User Experience
- Scalability
- Performance
- Knowledge of Framework and Platforms
- Security

## **What is a Mobile App?**

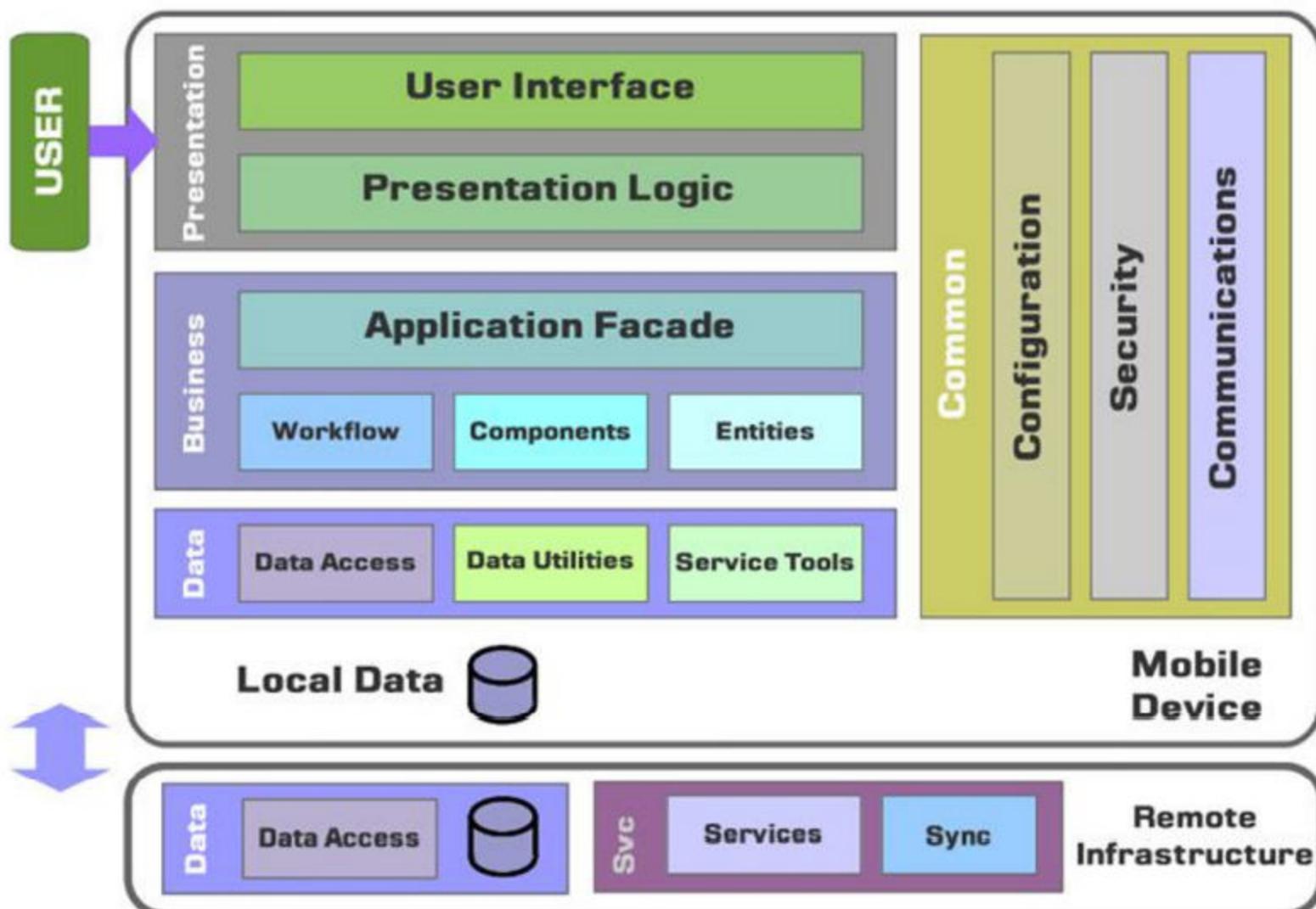
- A type of application software designed to run on a mobile device, such as a smartphone or a tablet computer
- Developed specifically for use on small, wireless computing devices
- Designed with consideration for the demands and constraints of the devices and also to take advantage of any specialized capabilities
  - Cons
    - Form factor — influences display and navigation
    - Limited memory
    - Limited computing power
    - Limited power
    - Limited bandwidth
  - Pros
    - Availability of sensors like accelerometer
    - Availability of touchscreen — Gesture-based navigation

## **Mobile Websites vis-`a-vis Mobile App**

- **Mobile website**
  - Similar to any other website in that it consists of browser-based HTML pages
  - Can display text content, data, images and video
  - Typically accessed over WiFi or 3G or 4G networks
  - Designed for smaller handheld display and touch-screen interface
  - Can also access mobile-specific features such as click-to-call (to dial a number) or location-based mapping
- **Mobile apps**
  - Actual applications that are downloaded and installed on a mobile device
  - Users download apps from device-specific portals such as App Store, Google Play Store
  - The app may
    - Pull content and data from the internet, in a similar fashion to a website or
    - Download the content so that it can be accessed without an internet connection

## Architecture of Mobile App

- Typically 3 tier
  - Presentation
  - Business
  - Data
- Data layer is often split between:
  - Local data
  - Remote data
- Needs customization for platform
  - Android
  - iOS
  - Windows

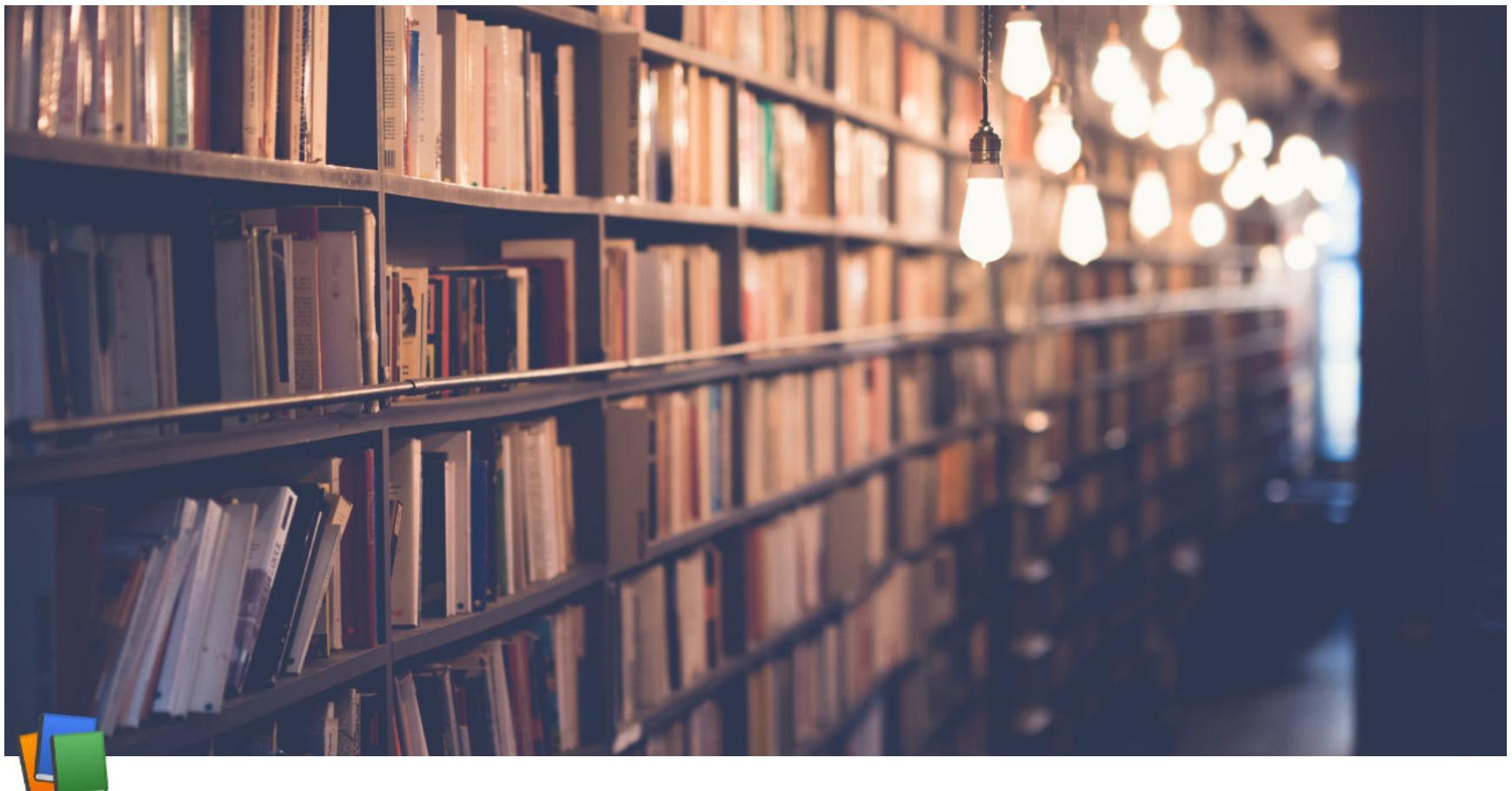


## Types of Mobile Apps

- **Native Apps** → Completely written in the language of the platform
  - iOS → Objective-C
  - Android → Java or C/C++
  - Platform specific (Heavily dependent on the OS)
- **Web Apps** → Run completely inside of a web browser
  - Features interfaces built with HTML or CSS
  - Powered via Web programming languages → Ruby on Rails, JavaScript, PHP or Python
  - Portable across any phone, tablet or computer
- **Hybrid Apps** → Combines attributes of both native and Web Apps
  - Attempts to use redundant, common code that can be used across platforms
  - Tailors required attributes to the native system

## Design Issues

- Determine Device
- Note Device Resources — memory, power, speed
- Consider bandwidth
- Decide on Architecture Layers
- Select Technology
- Define User Interface
- Select Navigation
- Maintain Flow



## Week 8 Lecture 1

Class	BSCCS2001
Created	@October 24, 2021 6:21 PM
Materials	
Module #	36
Type	Lecture
# Week #	8

## Algorithms and Data Structures: Algorithms and Complexity Analysis

### Algorithms and Programs

- **Algorithms**
  - An algorithm is a finite sequence of well-defined, computer-implementable (optional) instructions, typically solves a class of specific problems or to perform a computation
  - Algorithms are always unambiguous and are used as specifications for performing calculations, data processing, automated reasoning and other tasks
  - An algorithm must terminate
- **Program**
  - A computer program is a collection of instructions that can be executed by a computer to perform a specific task
  - A computer program is usually written by a computer programmer in a programming language
  - A program implements an algorithm
  - A program may or may not terminate
    - For example → An Operating System

### Analysis of Algorithms

- **Why?**
  - Set the motivation for algorithm analysis

- Why analyze?
- **What?**
  - Identify what all needs to be analyzed
  - What to analyze?
- **How?**
  - Learn the techniques for analysis
  - How to analyze?
- **Where?**
  - Understand the scenarios for application
  - Where to analyze?
- **When?**
  - Realize your position for seeking the analysis
  - When to analyze?

## Why analyze?

### Practical reasons:

- Resources are scarce
- Greed to do more with less
- Avoid performance bugs

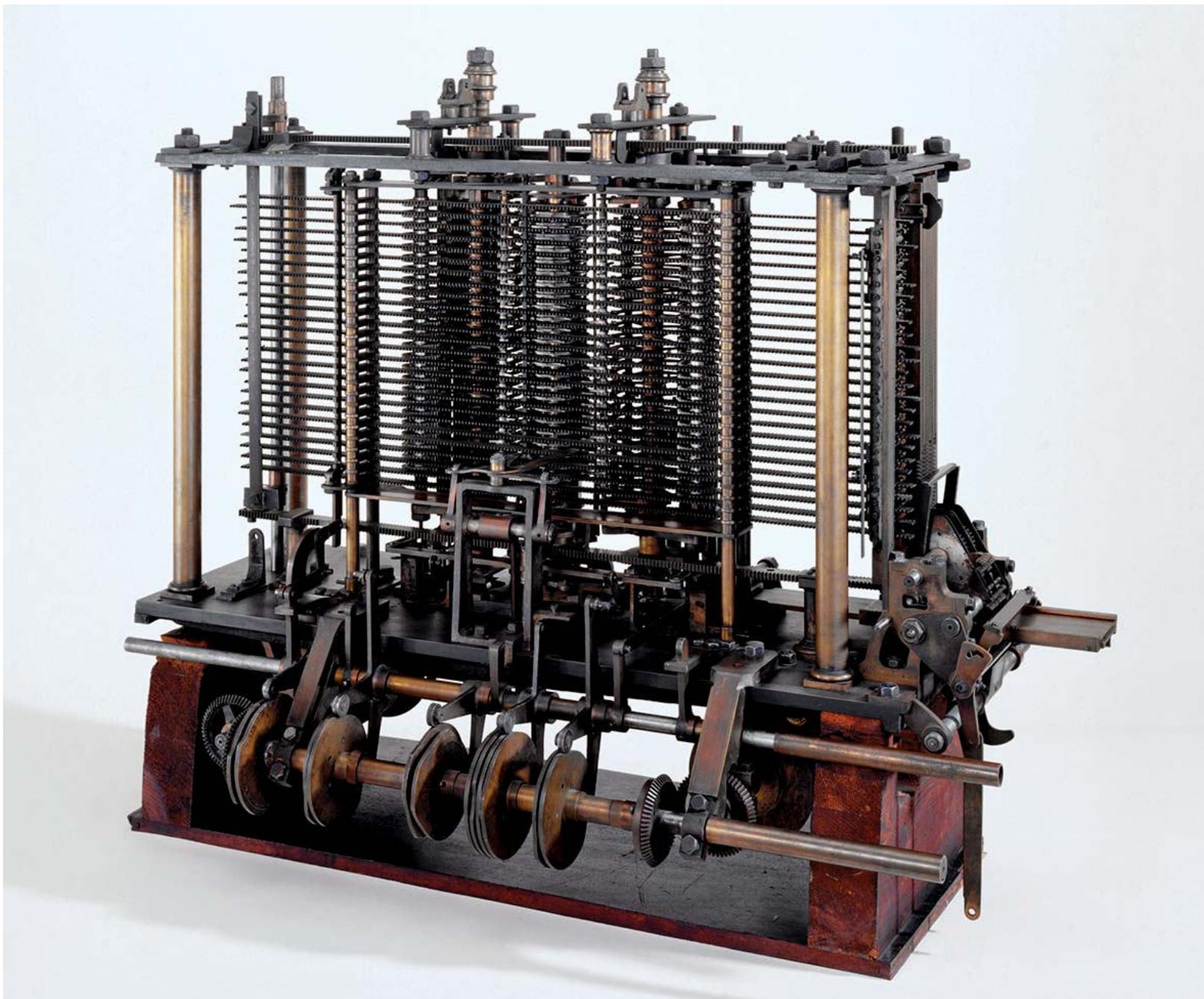
### Core Issues:

- Predict performance
  - How much time does binary search take?
- Compare algorithms
  - How quick is Quicksort? (heh)
- Provide guarantees
  - Size notwithstanding, Red-Black tree inserts in  $O(\log n)$
- Understand theoretical basis
  - Sorting by comparison cannot do better than  $\Omega(n \log n)$

## What to analyze?

**Core Issues** → Cannot control what we cannot measure

- Time
  - Story starts with the Analytical Engine



- Most common analysis factor
- Representative of various related analysis factors like Power, Bandwidth, Processors
- Supported by Complexity Classes
- Space
  - Widely exported
  - Important for hand-held devices
  - Supported by Complexity Classes

## What to analyze?

- Sum of natural numbers

```
int sum(int n)
{
    int s = 0;
    for(; n > 0; --n)
        s = s + n;
    return s;
}
```

- Time  $T(n) = n$  (additions)
- Space  $S(n) = 2$  (n, s)

## What to analyze?

- Find a character in a string

```
int find(char *str, char c)
{
    for(int i = 0; i < strlen(str); ++i)
        if(str[i] == c)
            return i;
```

```

    return 0;
}
n = strlen(str)

```

- Time  $T(n) = n$  (compare) +  $n * T(strlen(str)) \approx n + n^2 \approx n^2$
- Space  $S(n) = 3$  (str, c, i)

## What to analyze?

- Minimum of a sequence of numbers

```

int min(int a[], int n)
{
    for(int i = 0; i < n; ++i)
        cin >> a[i];

    int t = a[--n];
    for(; n > 0; --n)
        if(t < a[--n])
            t = a[n];
    return t;
}

```

- Time  $T(n) = n - 1$  (comparison of value)
- Space  $S(n) = n + 3$  (`a[]`'s, n, i, t)

## How to analyze?

- Counting model
- Asymptotic model
- Generating functions
- Master Theorem

## How to analyze? Counting Models

- **Core Idea** → Total running time = Sum of cost × frequency for all operations
  - Need to analyze program to determine set of operations
  - Cost depends on machine, compiler
  - Frequency depends on the algorithm, input data
- **Machine Model** → Random Access Machine (RAM) Computing Model
  - Input data & size
  - Operations
  - Intermediate Stages
  - Output data & size

## How to analyze? Counting Models

- **Factorial (Recursive)**

```

int fact(int n)
{
    if (n != 0)
        return n * fact(n - 1);
    return 1;
}

```

- Time  $T(n) = n - 1$  (multiplication)
- Space  $S(n) = n + 1$  (n's in recursive calls)

- **Factorial (Iterative)**

```

int fact(int n)
{
    int t = 1;
    for(; n > 0; --n)
        t = t * n;
    return t
}

```

- Time  $T(n) = n$  (multiplication)
- Space  $S(n) = 2 (\textcolor{red}{n}, \textcolor{red}{t})$

## How to analyze? Asymptotic Analysis

### Asymptotic Analysis

- **Core Idea** → Cannot compare actual times; hence, compare Growth or how the time increases with input size
  - Function Approximation (tilde ( $\sim$ ) notation)
  - Common growth functions
    - Big-Oh  $\rightarrow O(\cdot)$
    - Big-Omega  $\rightarrow \Omega(\cdot)$
    - Big-Theta  $\Theta(\cdot)$
  - Solve recurrence with Growth functions

## How to analyze? Asymptotic Analysis

```

int count = 0;
for(int i = 0; i < N; ++i)
    for(int j = i + 1; i < N; ++j)
        if (a[i] + a[j] == 0)
            count++;

```

### Function Approximation (tilde ( $\sim$ ) notation)

Operation	Frequency	Approximation
variable declaration	$N + 2$	$\sim N$
assignment statement	$N + 2$	$\sim N$
less than compare	$\frac{1}{2}(N + 1)(N + 2)$	$\sim \frac{1}{2}N^2$
equal to compare	$\frac{1}{2}N(N - 1)$	$\sim \frac{1}{2}N^2$
array access	$N(N - 1)$	$\sim N^2$
increment	$\frac{1}{2}N(N - 1)$ to $N(N - 1)$	$\sim \frac{1}{2}N^2$ to $\sim N^2$

- Estimate running time (or memory) as a function of input size N
- Ignore lower order terms
  - When N is large, terms are negligible
  - When N is small, we don't care

$f(n) \sim g(n)$  means

$$\lim_{N \rightarrow \infty} \frac{f(n)}{g(n)} = 1$$

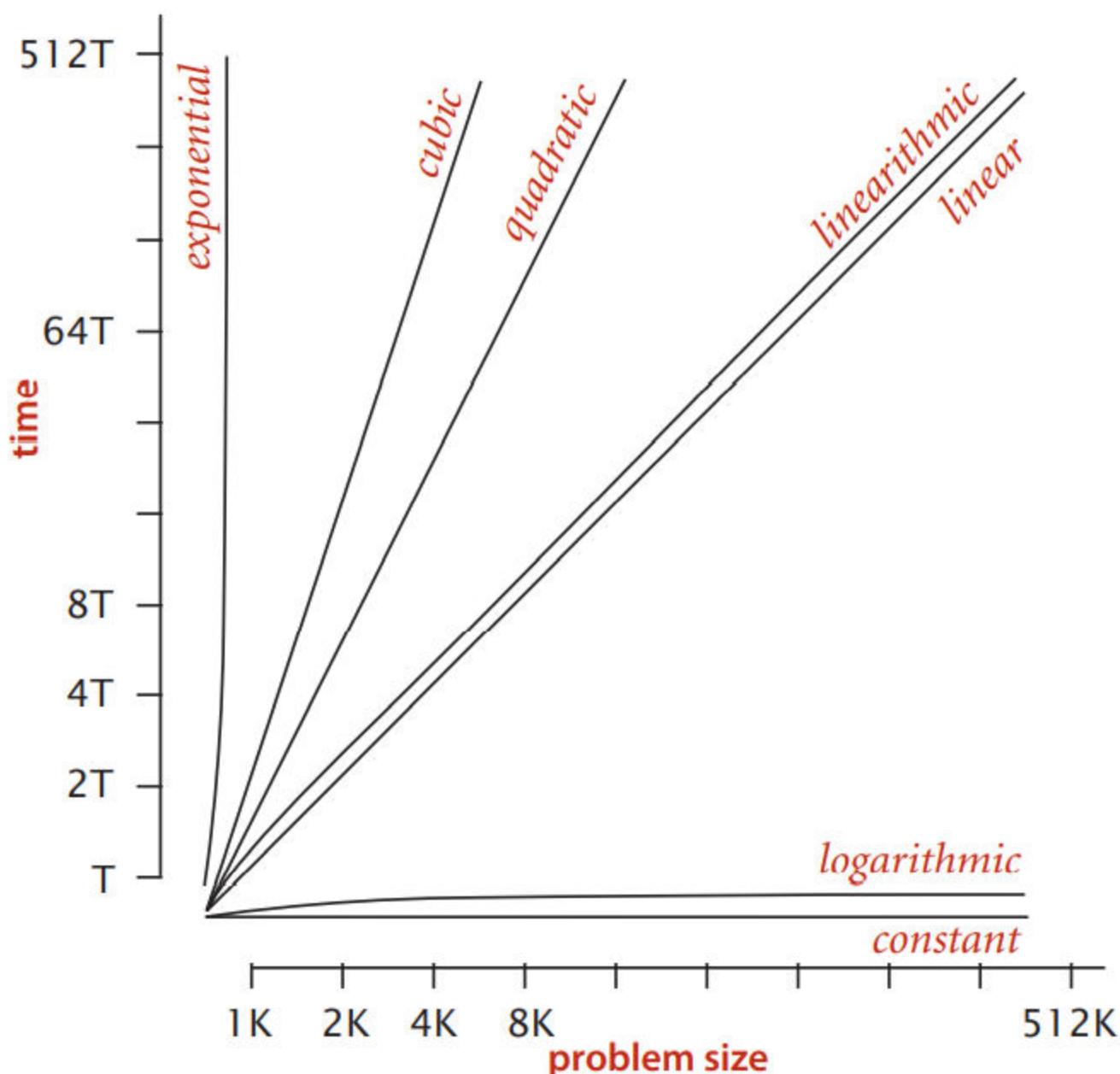
## How to analyze? Asymptotic Analysis

### Common order-of-growth classifications

**Good news.** The set of functions

$1, \log N, N, N \log N, N^2, N^3, \text{ and }, 2^N$  suffices to describe the order of growth of most common algorithms

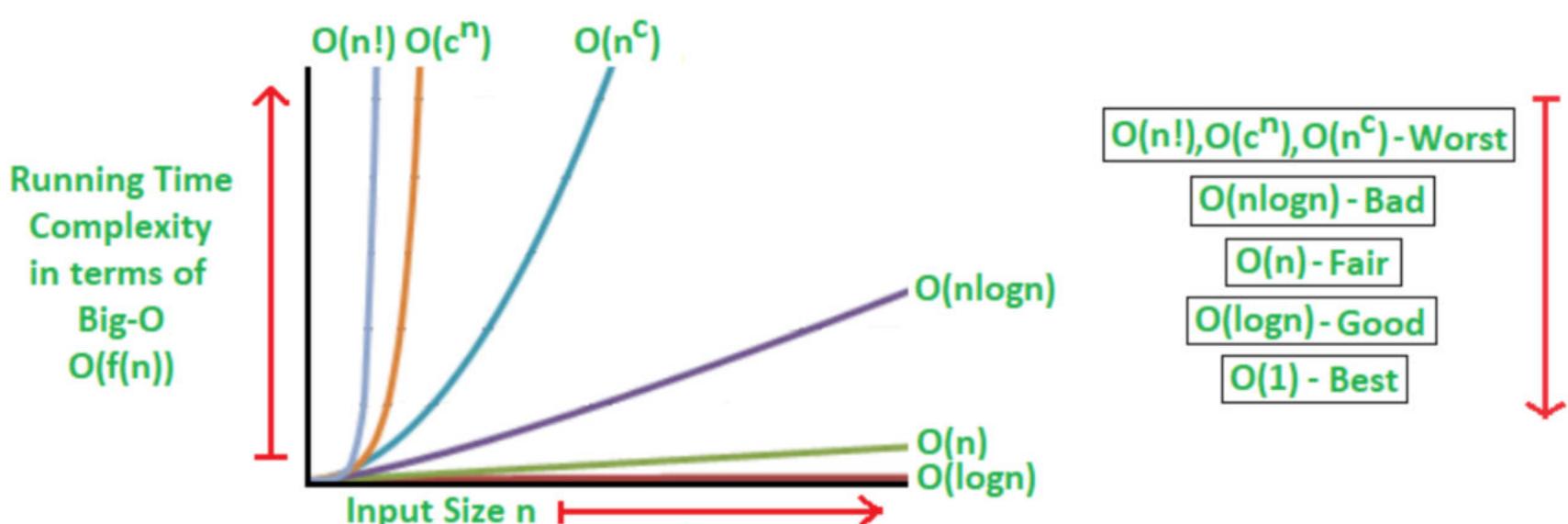
## log-log plot



## Typical orders of growth

Source: Page #188, Chapter 1: Fundamentals, Section 1.4, Algorithms (4th Edition) by Robert Sedgewick & Kevin Wayne

## How to analyze? Asymptotic Analysis



## How to analyze? Asymptotic Analysis

description	order of growth	typical code framework	description	example
<i>constant</i>	1	<code>a = b + c;</code>	<i>statement</i>	<i>add two numbers</i>
<i>logarithmic</i>	$\log N$	[ see page 47 ]	<i>divide in half</i>	<i>binary search</i>
<i>linear</i>	$N$	<pre>double max = a[0]; for (int i = 1; i &lt; N; i++)     if (a[i] &gt; max) max = a[i];</pre>	<i>loop</i>	<i>find the maximum</i>
<i>linearithmic</i>	$N \log N$	[ see ALGORITHM 2.4 ]	<i>divide and conquer</i>	<i>mergesort</i>
<i>quadratic</i>	$N^2$	<pre>for (int i = 0; i &lt; N; i++)     for (int j = i+1; j &lt; N; j++)         if (a[i] + a[j] == 0)             cnt++;</pre>	<i>double loop</i>	<i>check all pairs</i>
<i>cubic</i>	$N^3$	<pre>for (int i = 0; i &lt; N; i++)     for (int j = i+1; j &lt; N; j++)         for (int k = j+1; k &lt; N; k++)             if (a[i] + a[j] + a[k] == 0)                 cnt++;</pre>	<i>triple loop</i>	<i>check all triples</i>
<i>exponential</i>	$2^N$	[ see CHAPTER 6 ]	<i>exhaustive search</i>	<i>check all subsets</i>

### Summary of common order-of-growth hypotheses

Source: Page #187, Chapter 1: Fundamentals, Section 1.4, Algorithms (4th Edition) by Robert Sedgewick & Kevin Wayne

## Asymptotic Notation

For a given function  $g(n)$ , we denote by  $O(g(n))$  the set of functions:

$$O(g(n)) = \{f(n) : \text{there exists positive constants } c \text{ and } n_0 \text{ such that } 0 \leq f(n) \leq cg(n), \text{ for all } n > n_0\}$$

- We use  $O$ -notation to give an upper bound on a function, to within a constant factor
- When we say that the running time of  $A$  is  $O(n^2)$ , we mean that there is a function  $f(n)$  that is  $O(n^2)$  such that for any value of  $n$ , no matter what particular input of size  $n$  is chosen, the running time on that input is bounded from above by the value  $f(n)$
- Equivalently, we mean that the worst-case running time is  $O(n^2)$

## Where to analyze?

### Algorithmic situation

- **Core Idea** → Identify data configurations or scenarios for analysis
  - Best case
    - Minimum running time on an input
  - Worst case
    - Running time guarantees for any input of size  $n$
  - Average case
    - Expected running time for a random input of size  $n$

- Probabilistic case
  - Expected running time of a randomized algorithm
- Amortized case
  - Worst case running time for any sequence of n operations

## Big-O Algorithm Complexity Chart

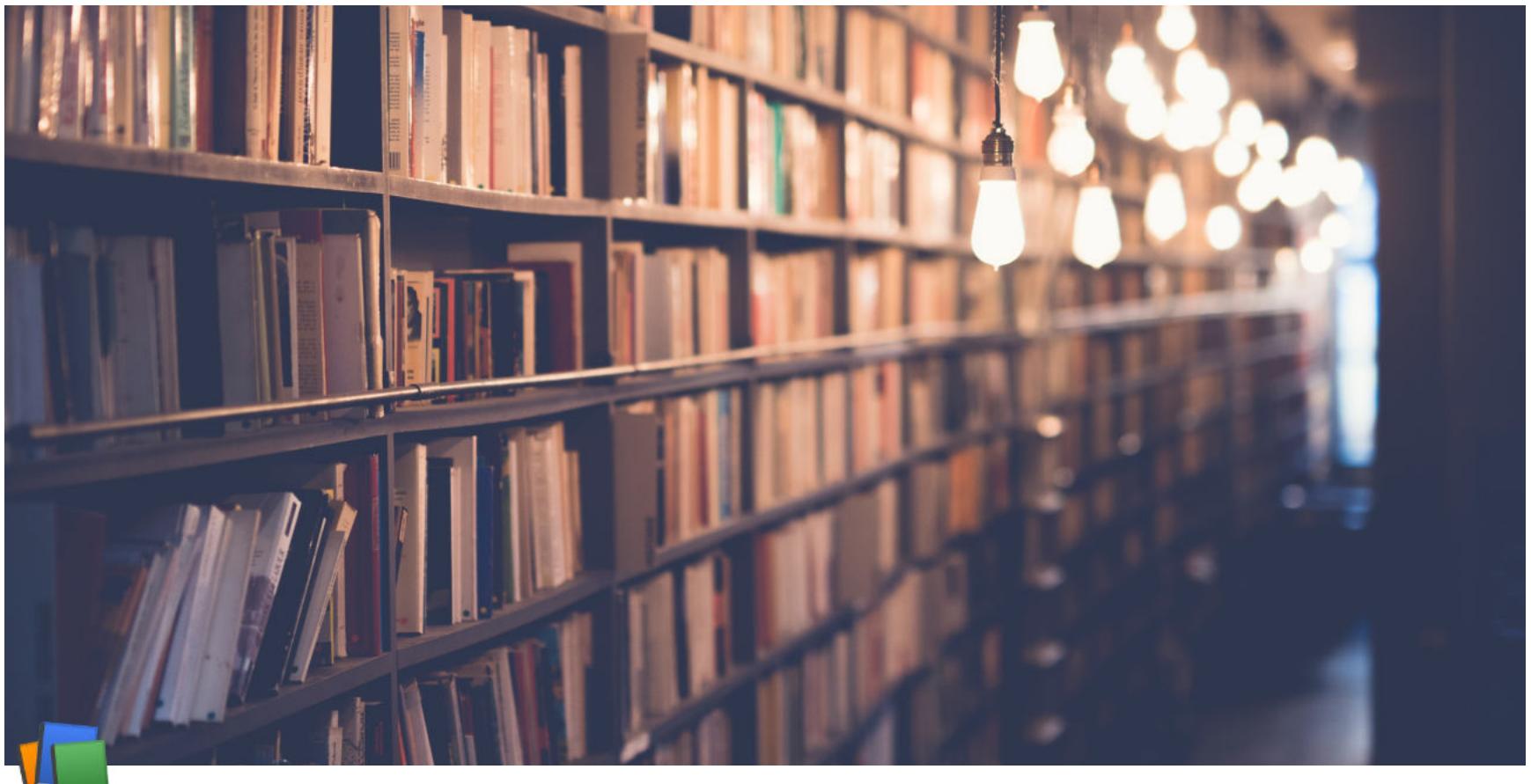
### Common Data Structure Operations

Data Structure	Time Complexity								Space Complexity	
	Average				Worst					
	Access	Search	Insertion	Deletion	Access	Search	Insertion	Deletion		
Array	$\Theta(1)$	$\Theta(n)$	$\Theta(n)$	$\Theta(n)$	$O(1)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	
Stack	$\Theta(n)$	$\Theta(n)$	$\Theta(1)$	$\Theta(1)$	$O(n)$	$O(n)$	$O(1)$	$O(1)$	$O(n)$	
Queue	$\Theta(n)$	$\Theta(n)$	$\Theta(1)$	$\Theta(1)$	$O(n)$	$O(n)$	$O(1)$	$O(1)$	$O(n)$	
Singly-Linked List	$\Theta(n)$	$\Theta(n)$	$\Theta(1)$	$\Theta(1)$	$O(n)$	$O(n)$	$O(1)$	$O(1)$	$O(n)$	
Doubly-Linked List	$\Theta(n)$	$\Theta(n)$	$\Theta(1)$	$\Theta(1)$	$O(n)$	$O(n)$	$O(1)$	$O(1)$	$O(n)$	
Skip List	$\Theta(\log(n))$	$\Theta(\log(n))$	$\Theta(\log(n))$	$\Theta(\log(n))$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n \log(n))$	
Hash Table	N/A	$\Theta(1)$	$\Theta(1)$	$\Theta(1)$	N/A	$O(n)$	$O(n)$	$O(n)$	$O(n)$	
Binary Search Tree	$\Theta(\log(n))$	$\Theta(\log(n))$	$\Theta(\log(n))$	$\Theta(\log(n))$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	
Cartesian Tree	N/A	$\Theta(\log(n))$	$\Theta(\log(n))$	$\Theta(\log(n))$	N/A	$O(n)$	$O(n)$	$O(n)$	$O(n)$	
B-Tree	$\Theta(\log(n))$	$\Theta(\log(n))$	$\Theta(\log(n))$	$\Theta(\log(n))$	$O(\log(n))$	$O(\log(n))$	$O(\log(n))$	$O(\log(n))$	$O(n)$	
Red-Black Tree	$\Theta(\log(n))$	$\Theta(\log(n))$	$\Theta(\log(n))$	$\Theta(\log(n))$	$O(\log(n))$	$O(\log(n))$	$O(\log(n))$	$O(\log(n))$	$O(n)$	
Splay Tree	N/A	$\Theta(\log(n))$	$\Theta(\log(n))$	$\Theta(\log(n))$	N/A	$O(\log(n))$	$O(\log(n))$	$O(\log(n))$	$O(n)$	
AVL Tree	$\Theta(\log(n))$	$\Theta(\log(n))$	$\Theta(\log(n))$	$\Theta(\log(n))$	$O(\log(n))$	$O(\log(n))$	$O(\log(n))$	$O(\log(n))$	$O(n)$	
KD Tree	$\Theta(\log(n))$	$\Theta(\log(n))$	$\Theta(\log(n))$	$\Theta(\log(n))$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	$O(n)$	

### Array Sorting Algorithms

Algorithm	Time Complexity			Space Complexity
	Best	Average	Worst	
Quicksort	$\Omega(n \log(n))$	$\Theta(n \log(n))$	$\Theta(n^2)$	$O(\log(n))$
Mergesort	$\Omega(n \log(n))$	$\Theta(n \log(n))$	$\Theta(n \log(n))$	$O(n)$
Timsort	$\Omega(n)$	$\Theta(n \log(n))$	$\Theta(n \log(n))$	$O(n)$
Heapsort	$\Omega(n \log(n))$	$\Theta(n \log(n))$	$\Theta(n \log(n))$	$O(1)$
Bubble Sort	$\Omega(n)$	$\Theta(n^2)$	$\Theta(n^2)$	$O(1)$
Insertion Sort	$\Omega(n)$	$\Theta(n^2)$	$\Theta(n^2)$	$O(1)$
Selection Sort	$\Omega(n^2)$	$\Theta(n^2)$	$\Theta(n^2)$	$O(1)$
Tree Sort	$\Omega(n \log(n))$	$\Theta(n \log(n))$	$\Theta(n \log(n))$	$O(n)$
Shell Sort	$\Omega(n \log(n))$	$\Theta(n(\log(n))^2)$	$\Theta(n(\log(n))^2)$	$O(1)$
Bucket Sort	$\Omega(n+k)$	$\Theta(n+k)$	$\Theta(n^2)$	$O(n)$
Radix Sort	$\Omega(nk)$	$\Theta(nk)$	$\Theta(nk)$	$O(n+k)$
Counting Sort	$\Omega(n+k)$	$\Theta(n+k)$	$\Theta(n+k)$	$O(k)$
Cubesort	$\Omega(n)$	$\Theta(n \log(n))$	$\Theta(n \log(n))$	$O(n)$

Source: <https://www.bigocheatsheet.com>



## Week 8 Lecture 2

Class	BSCCS2001
Created	@October 25, 2021 12:10 AM
Materials	
Module #	37
Type	Lecture
# Week #	8

## Algorithms and Data Structures: Data Structures

### Data Structure

- A data structure specifies the way of organizing and storing in-memory data that enables efficient access and modification of the data
  - Linear Data Structures
  - Non-linear Data Structures
- Most data structure has a container for the data and typical operations that it needs to perform
- For applications relating to data management, the key operations are:
  - Create
  - Insert
  - Delete
  - Find/Search
  - Close
- Efficiency is measured in terms of time and space taken for these operations

### Linear Data Structures

- A linear data structure has data elements arranged in linear or sequential manner such that each member element is connected to its previous and next element
- Since data elements are sequentially connected, each element is traversable through a single run

- Examples of linear data structures are Array, Linked List, Queue, Stack, etc

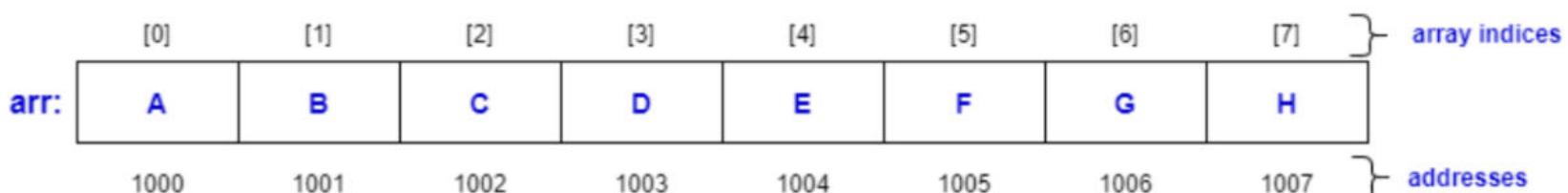


Different examples of linear data structures:

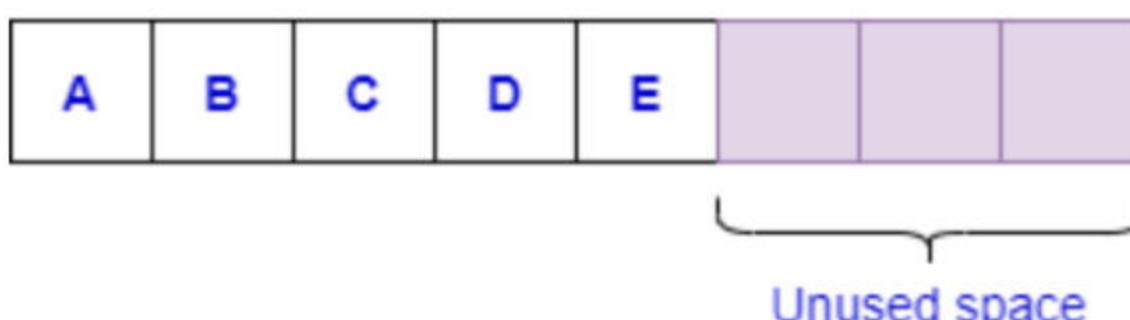
- **Array** → The data elements are stored at contiguous locations in the memory
- **Linked List** → The data elements are not required to be stored in contiguous locations in memory
  - Rather, each element stores a link (a pointer to a reference) to the location of the next element
- **Queue** → It is a FIFO (First In, First Out) data structure
  - The element that has been inserted first in the queue would be removed first
  - Thus, insert and removal of the elements in this take place in the same order
- **Stack** → It is a LIFO (Last In, First Out) data structure
  - The element that has been inserted last in the stack would be removed first
  - Thus, insert and removal of the elements in this take place in the reverse order

## Linear Data Structure: Array

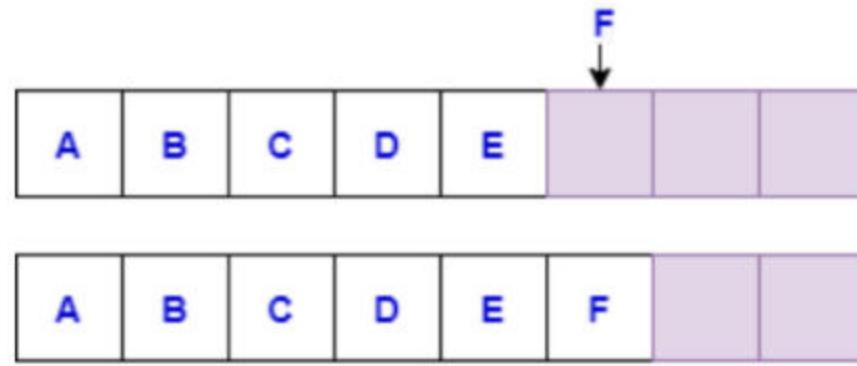
- The elements are stored in contiguous memory locations



- Simple access using indices
  - For example → let the array name be `arr`, we can access the element at index 5 as `arr[5]`
- Arrays allow random access using its index which is fast (cost of  $O(1)$ )
  - Useful for operations like sorting, searching
- **Have fixed size, not flexible** → Since we do not know the number of elements to be stored in runtime, If we create it too large then it can be a waste of memory, if we create it too small then some elements may not be accommodated in the array
  - For example → Suppose we create an array to store 8 elements
    - However, during the execution of the program only 5 elements are available, which results in the wastage of the memory space



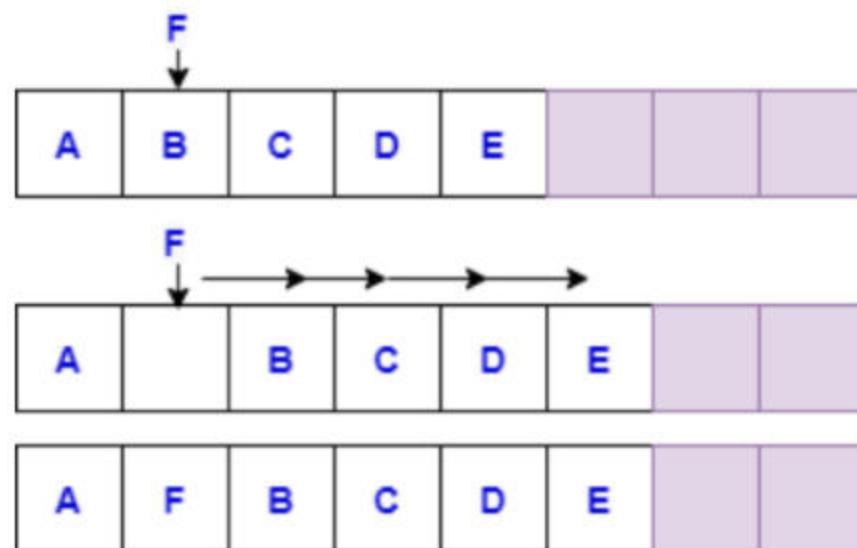
- Insertion and removal of elements from an array are costlier since the memory locations have to be consecutive
  - Insertion or removal of an element from the end of an array is easy
    - Insert at the end:



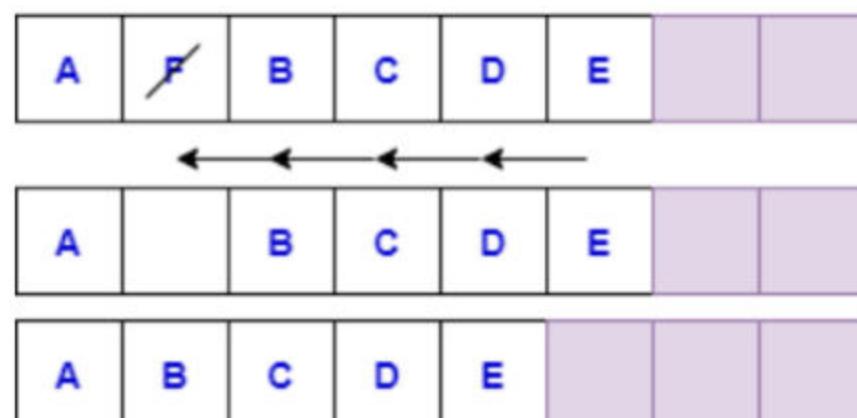
- Remove from the end:



- Insert and remove elements at any arbitrary position is costly (cost of  $O(n)$ )
  - Insert at any arbitrary position

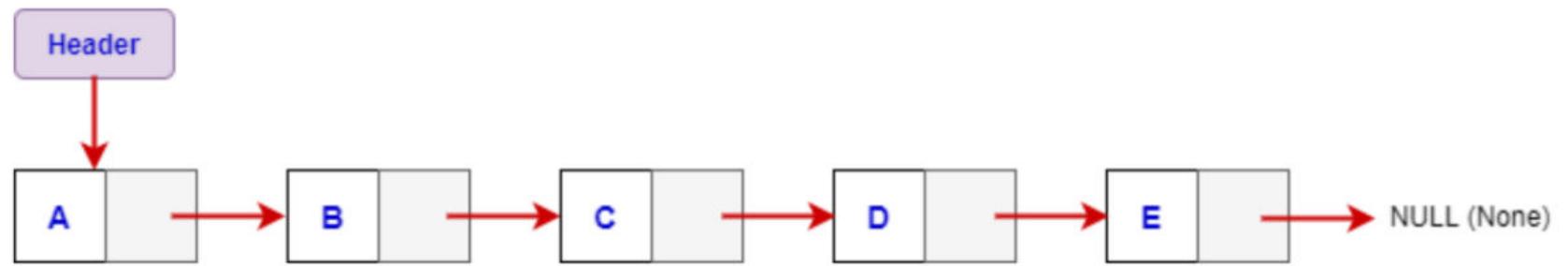


- Remove from any arbitrary position



## Linear Data Structure: Linked List

- Elements are not required to be stored at contiguous memory locations
  - A new element can be stored anywhere in the memory where free space is available
  - Thus, it provides better memory usage than arrays
- For each new element allocated, a link (a pointer or a reference) is created for the new element using which the element can be added to the linked list

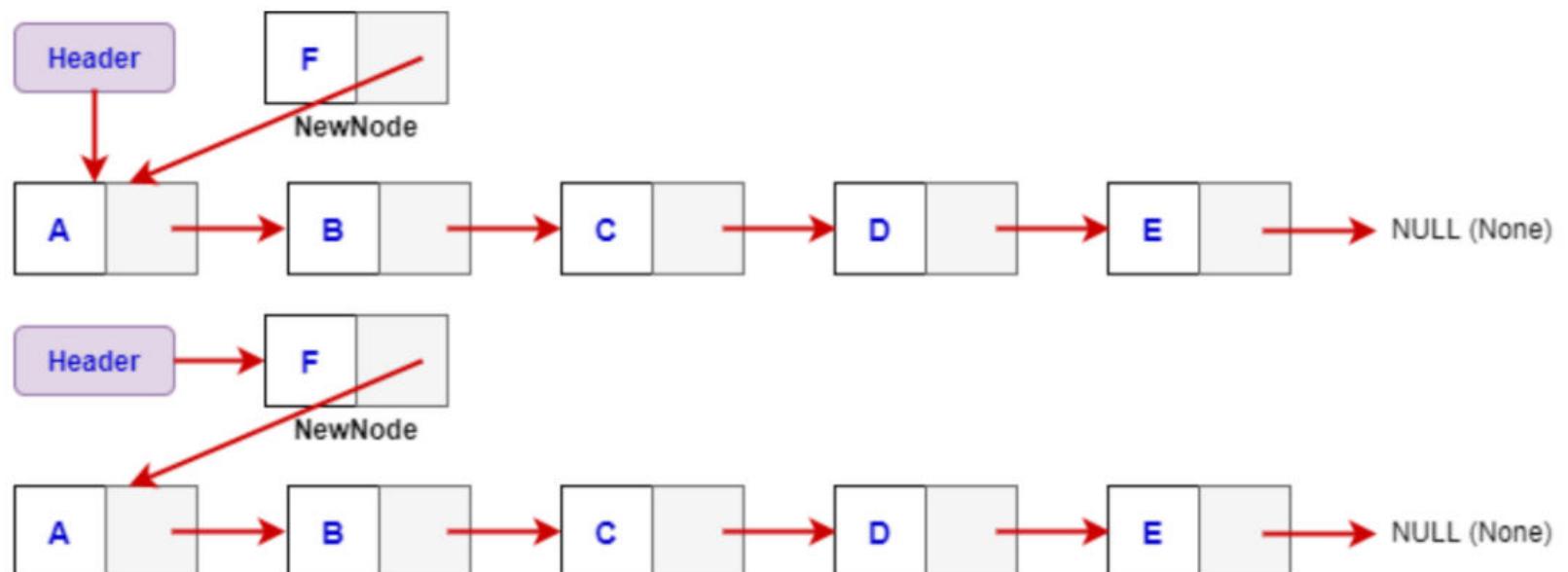


Each element is stored in a node

A node has 2 parts

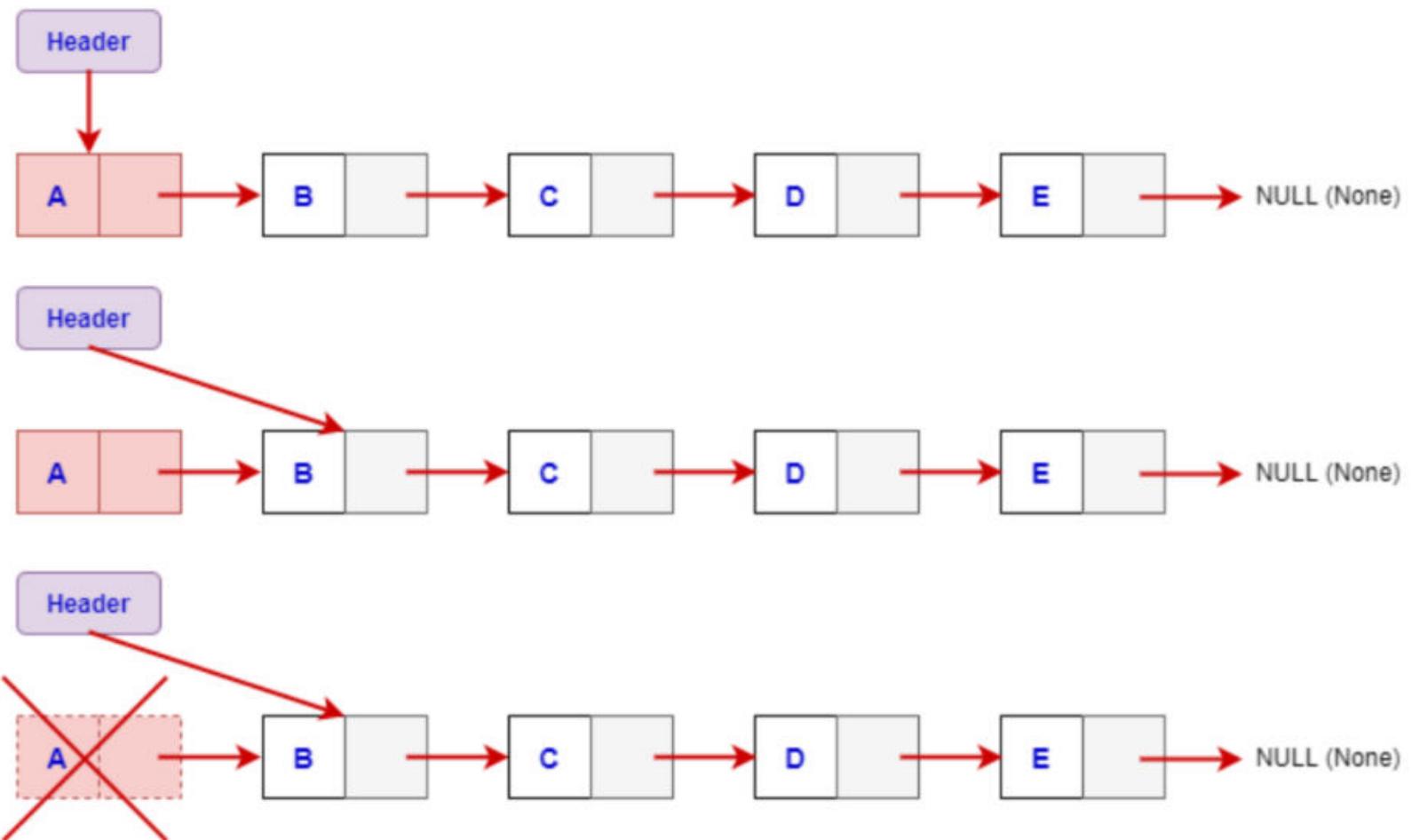
- **Info** → stores the element
- **Link** → stores the location of the next node
- Header is a link to the first node of the linked list
- **Flexible in size**
  - Size of a linked list grows or shrinks as and when new elements are inserted or deleted
- Random access is not possible in linked lists
  - The elements will have to be accessed sequentially
- Insertion or Removal of an element at/from any arbitrary position is efficient as none of the elements are required to be moved to new locations
  - Insertion at front

1. `NewNode.Link = Header`
2. `Header = NewNode`



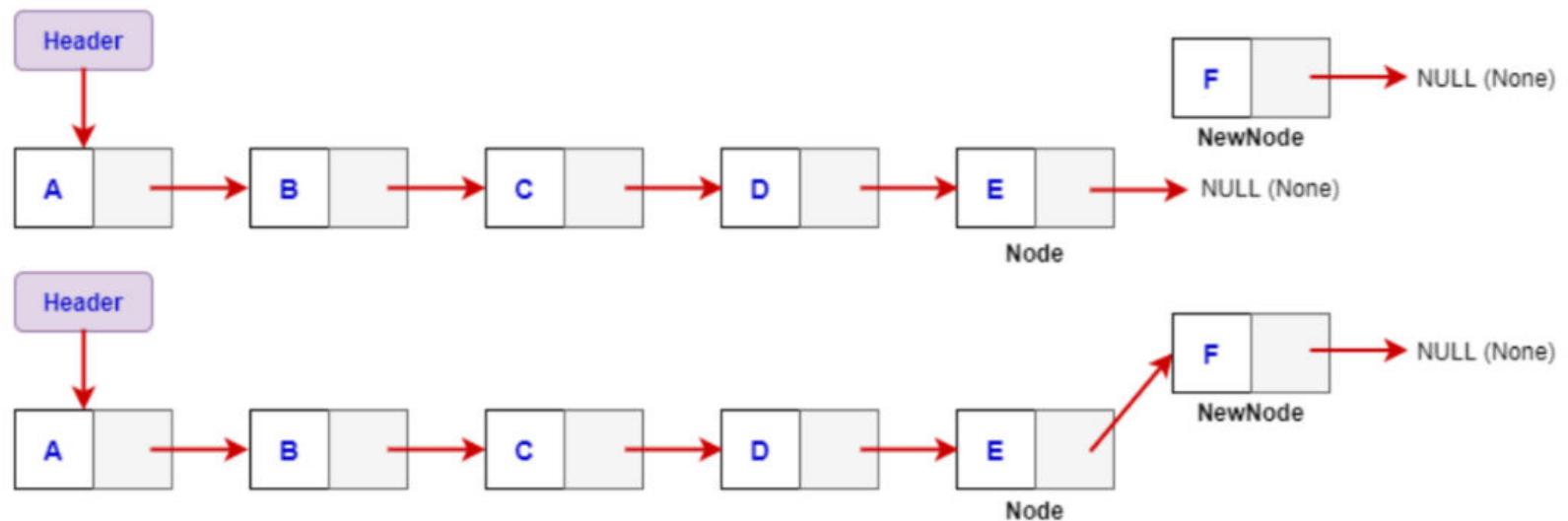
- Remove from the front

1. Temp = Header
2. Header = Header.Link
3. Delete(Temp)



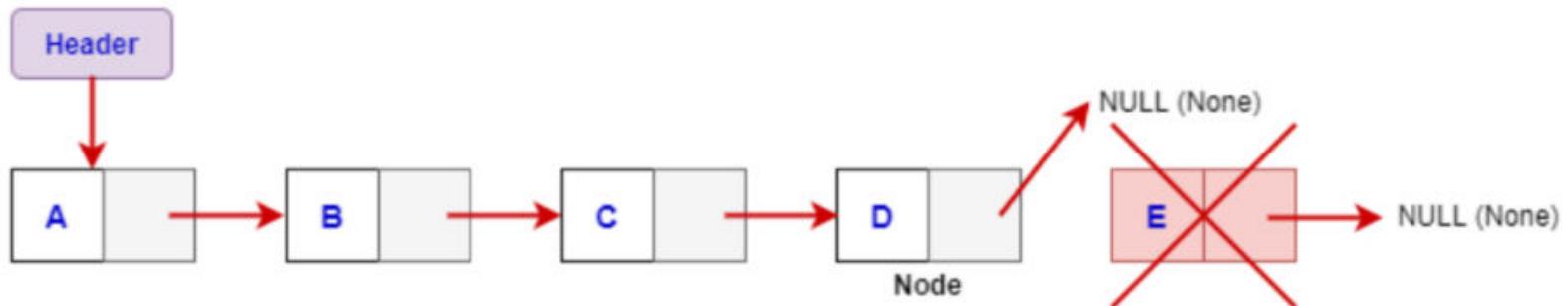
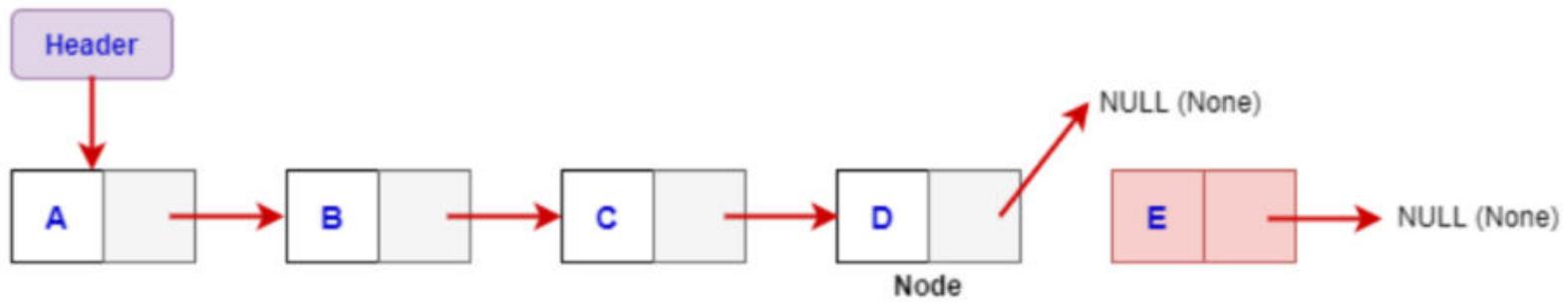
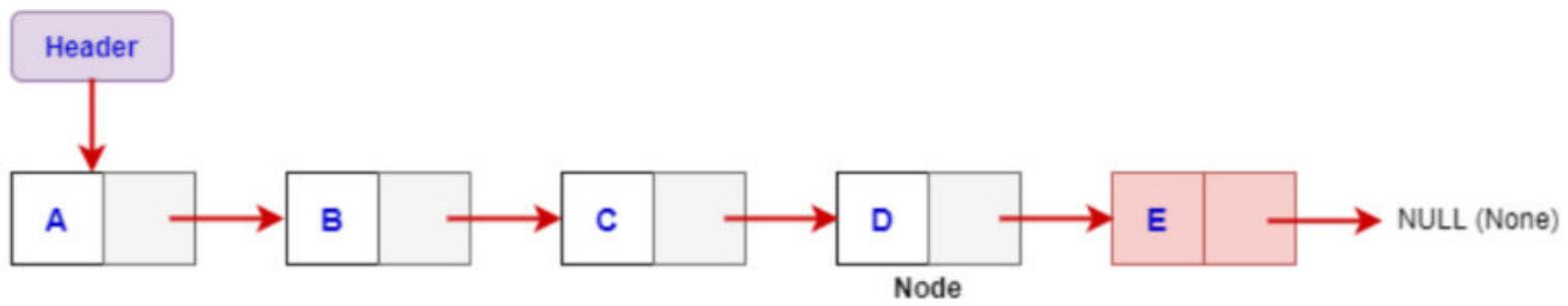
- Insertion at end

## 1. Node.Link = NewNode



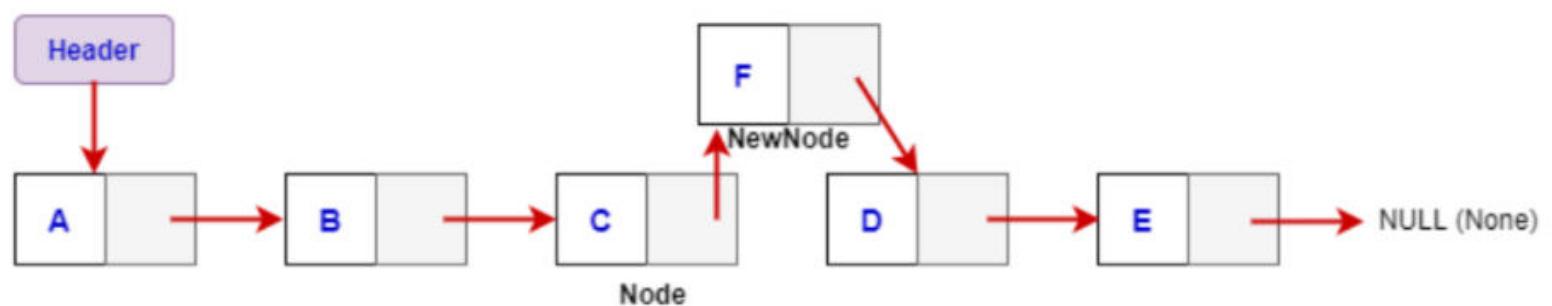
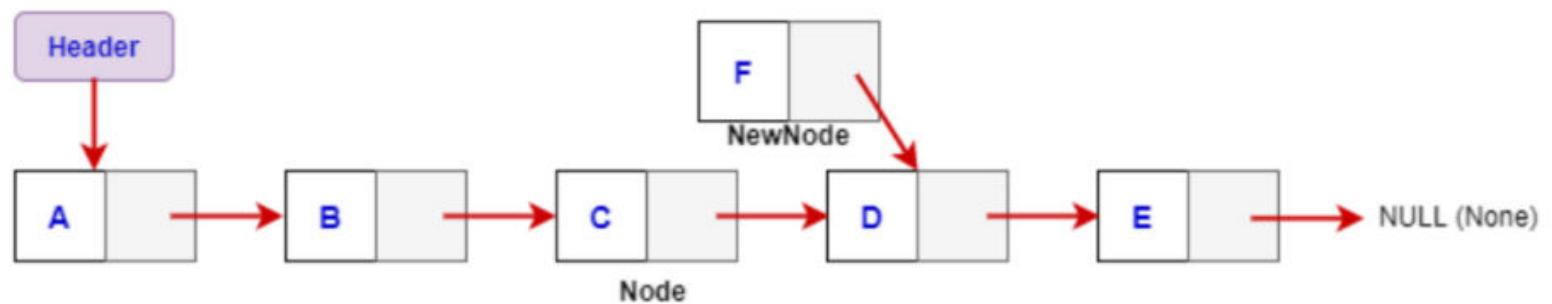
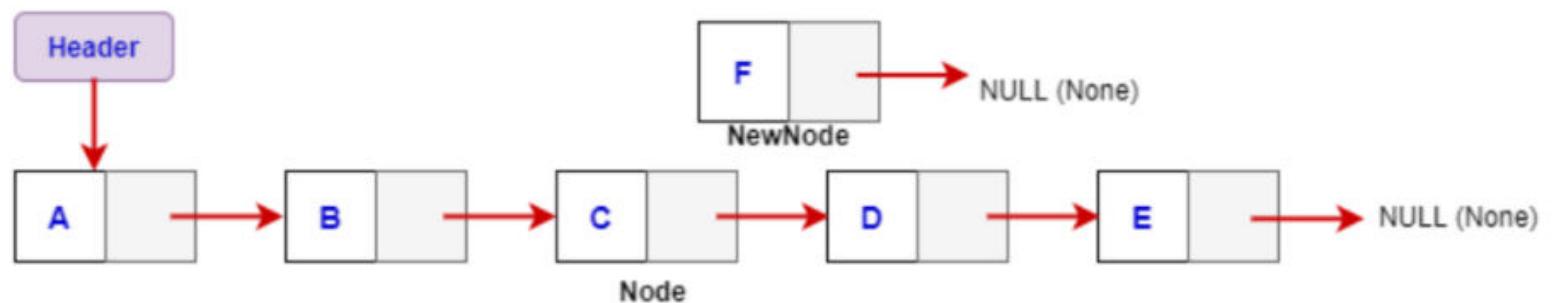
- Remove from end

1. Temp = Node.Link
2. Node.Link = NULL
3. Delete(Temp)



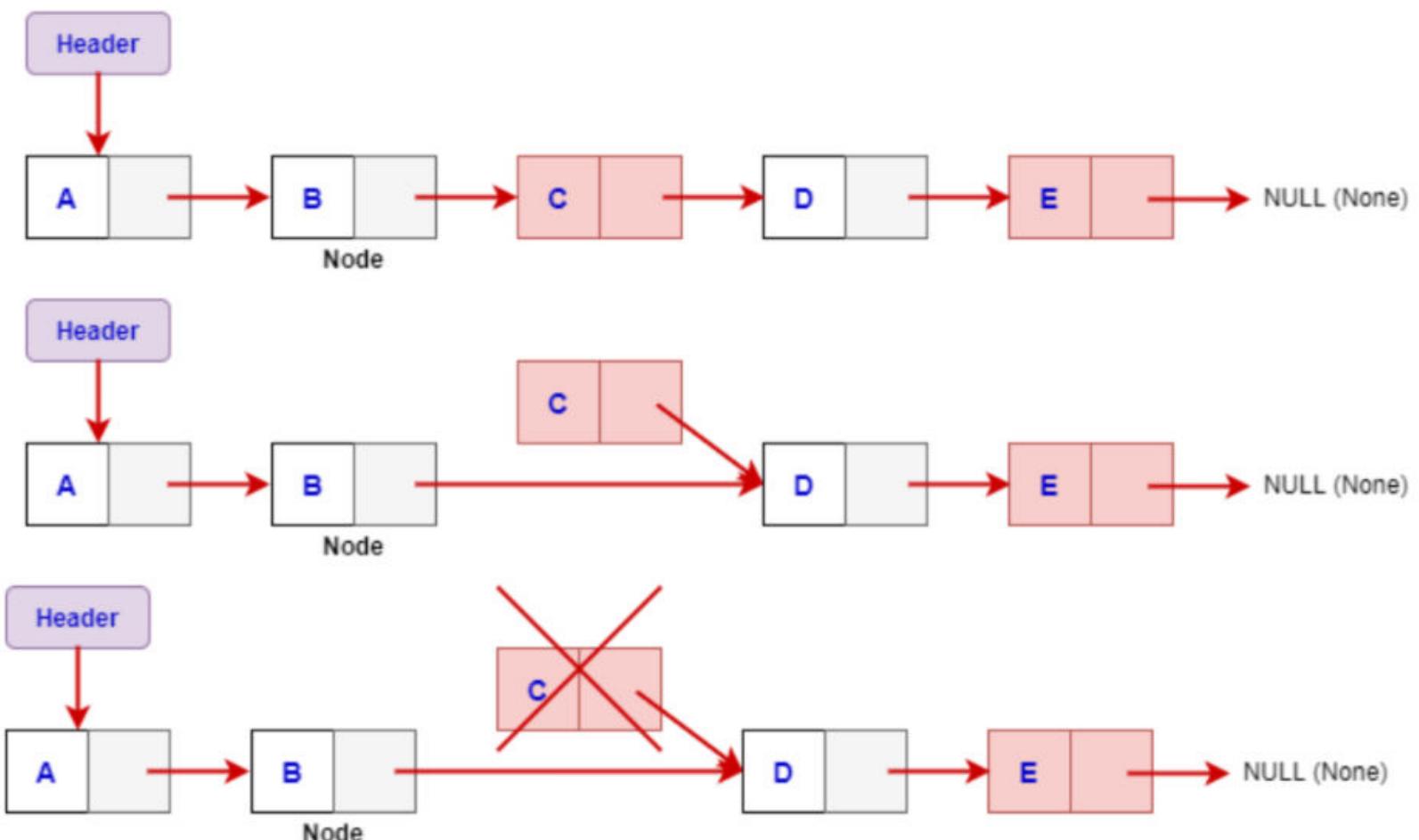
- Insertion at any intermediate position

1. NewNode.Link = Node.Link
2. Node.Link = NewNode



- Remove from any intermediate position

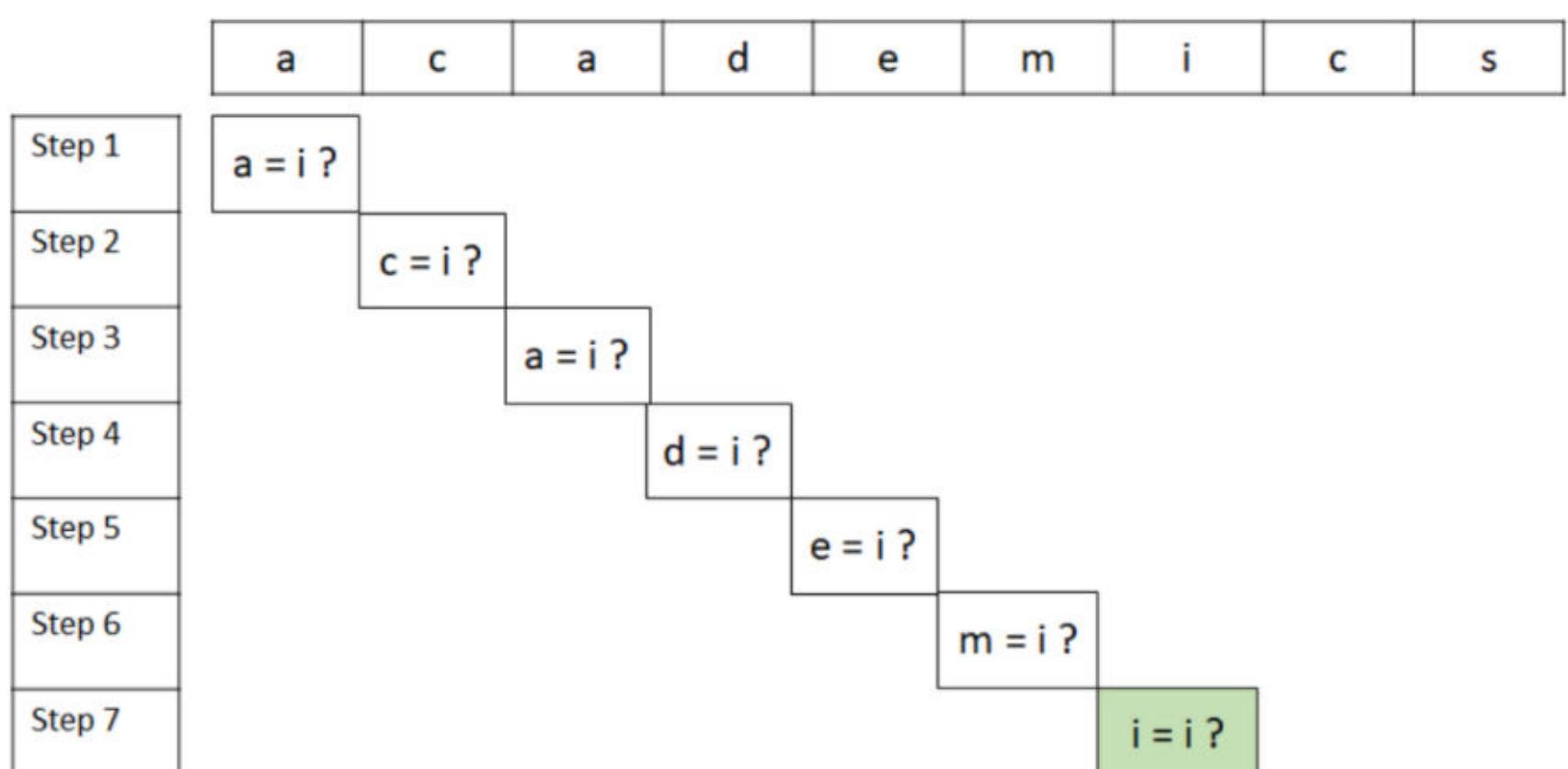
1. Temp = Node.Link
2. Node.Link = Node.Link.Link
3. Delete(Temp)



## Linear Search

- The algorithm starts with the first element, compares with the given key value and returns yes if a match is found
- If it does not match, then it proceeds sequentially comparing each element of the list with the given key until a match has been found or the full list is traversed

Let the given input list be `inputArr = ['a', 'c', 'a', 'd', 'e', 'm', 'i', 'c', 's']` and the search key be `'i'`



```
def linear_search(input_array, k):
    for i in range(len(input_array)):
        if input_array[i] == k:
            return i
    return -1

inputArr = ['a', 'c', 'a', 'd', 'e', 'm', 'i', 'c', 's']
k = 'i'
```

```

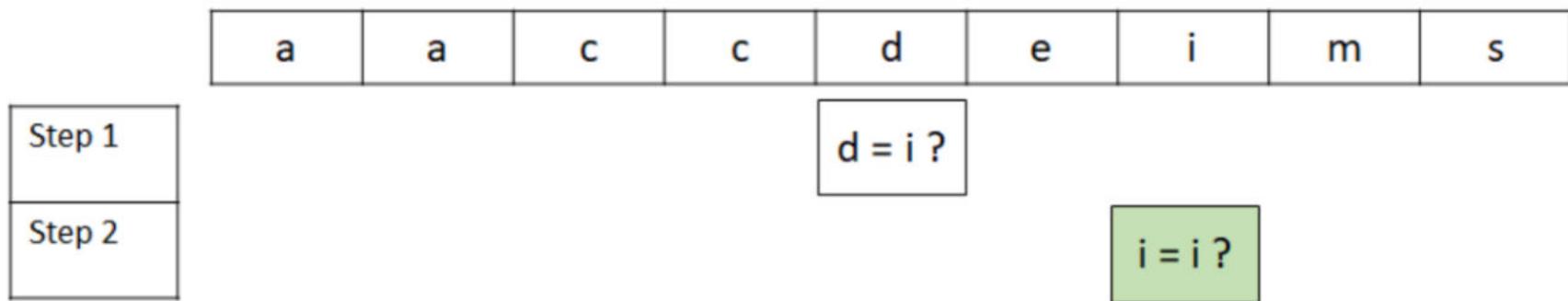
index = linear_search(inputArr, k)
if index != -1:
    print("Element found at " + index)

```

## Binary Search

- The input for the algorithm is always a sorted list
- The algorithm compares the key  $k$  with the middle element in the list
- If the key matches, then it returns the index
- If the key does not match and is greater than the middle element, then the new list is the list to the right of the middle element
- If the key does not match and is less than the middle elements, then the new list is the list to the left of the middle element

Let the given input list be `inputArr = ['a', 'a', 'c', 'c', 'd', 'e', 'i', 'm', 's']` and the search key be `'i'`



```

def binary_search(arr, k):
    low = 0
    high = len(arr) - 1
    mid = 0

    while low <= high:
        mid = (low + high) // 2

        if arr[mid] < k:
            low = mid + 1
        elif arr[mid] > k:
            high = mid - 1
        else:
            return mid

    return -1

inputArr = ['a', 'a', 'c', 'c', 'd', 'e', 'i', 'm', 's']
k = 'i'
index = binary_search(inputArr, k)

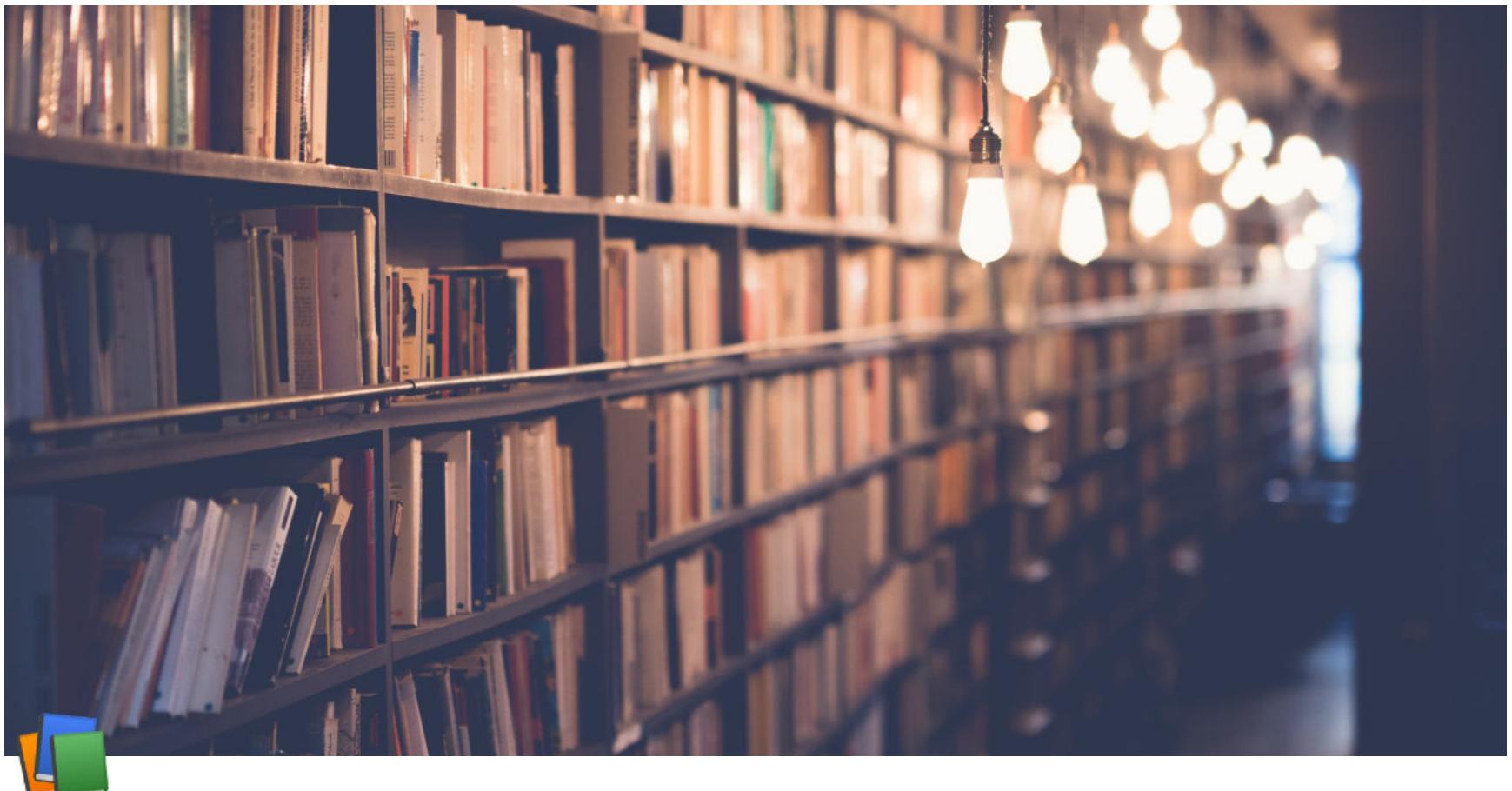
if index != -1:
    print("Element found at " + index)

```

## Common Data Structure operations

Data Structure	Time Complexity								Space Complexity	
	Average				Worst					
	Access	Search	Insertion	Deletion	Access	Search	Insertion	Deletion		
<b>Linear Data Structures</b>	Array	<span>O(1)</span>	<span>O(n)</span>	<span>O(n)</span>	<span>O(n)</span>	<span>O(1)</span>	<span>O(n)</span>	<span>O(n)</span>	<span>O(n)</span>	
	Stack	<span>O(n)</span>	<span>O(n)</span>	<span>O(1)</span>	<span>O(1)</span>	<span>O(n)</span>	<span>O(n)</span>	<span>O(1)</span>	<span>O(n)</span>	
	Queue	<span>O(n)</span>	<span>O(n)</span>	<span>O(1)</span>	<span>O(1)</span>	<span>O(n)</span>	<span>O(n)</span>	<span>O(1)</span>	<span>O(n)</span>	
	Singly-Linked List	<span>O(n)</span>	<span>O(n)</span>	<span>O(1)</span>	<span>O(1)</span>	<span>O(n)</span>	<span>O(n)</span>	<span>O(1)</span>	<span>O(n)</span>	
	Doubly-Linked List	<span>O(n)</span>	<span>O(n)</span>	<span>O(1)</span>	<span>O(1)</span>	<span>O(n)</span>	<span>O(n)</span>	<span>O(1)</span>	<span>O(n)</span>	
<b>Non-Linear Data Structures</b>	Skip List	<span>O(log(n))</span>	<span>O(log(n))</span>	<span>O(log(n))</span>	<span>O(log(n))</span>	<span>O(n)</span>	<span>O(n)</span>	<span>O(n)</span>	<span>O(n log(n))</span>	
	Hash Table	<span>N/A</span>	<span>O(1)</span>	<span>O(1)</span>	<span>O(1)</span>	<span>N/A</span>	<span>O(n)</span>	<span>O(n)</span>	<span>O(n)</span>	
	Binary Search Tree	<span>O(log(n))</span>	<span>O(log(n))</span>	<span>O(log(n))</span>	<span>O(log(n))</span>	<span>O(n)</span>	<span>O(n)</span>	<span>O(n)</span>	<span>O(n)</span>	
	Cartesian Tree	<span>N/A</span>	<span>O(log(n))</span>	<span>O(log(n))</span>	<span>O(log(n))</span>	<span>N/A</span>	<span>O(n)</span>	<span>O(n)</span>	<span>O(n)</span>	
	B-Tree	<span>O(log(n))</span>	<span>O(n)</span>							
	Red-Black Tree	<span>O(log(n))</span>	<span>O(n)</span>							
	Splay Tree	<span>N/A</span>	<span>O(log(n))</span>	<span>O(log(n))</span>	<span>O(log(n))</span>	<span>N/A</span>	<span>O(log(n))</span>	<span>O(log(n))</span>	<span>O(n)</span>	
	AVL Tree	<span>O(log(n))</span>	<span>O(n)</span>							
	KD Tree	<span>O(log(n))</span>	<span>O(log(n))</span>	<span>O(log(n))</span>	<span>O(log(n))</span>	<span>O(n)</span>	<span>O(n)</span>	<span>O(n)</span>	<span>O(n)</span>	

Source: <https://www.bigocheatsheet.com>



## Week 8 Lecture 3

Class	BSCCS2001
Created	@October 25, 2021 11:26 AM
Materials	
Module #	38
Type	Lecture
# Week #	8

## Algorithms and Data Structures: Data Structures

### Non-linear data structures

#### Non-linear data structures: Why?

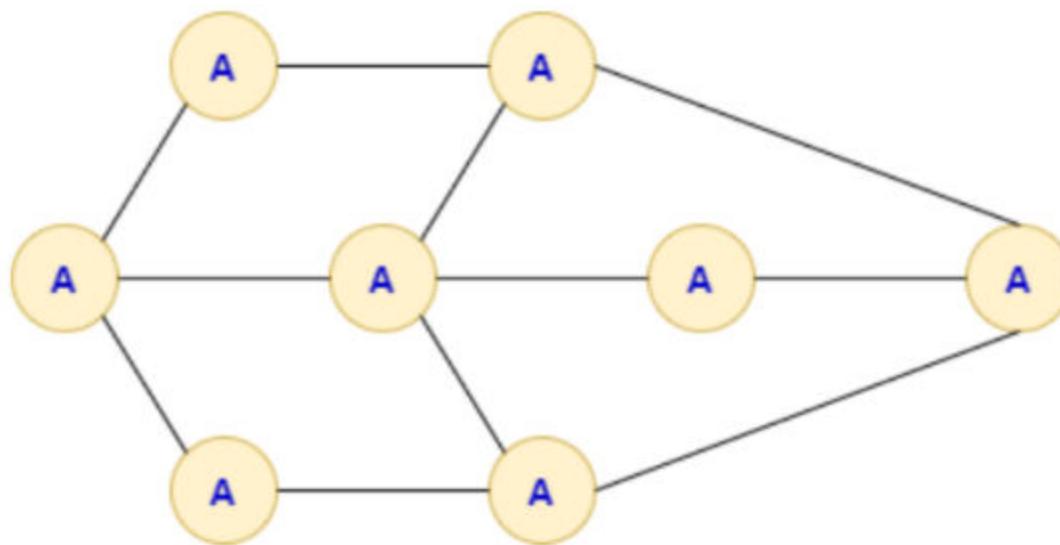
- From the study of Linear Data Structures in the previous module, we can make the following summary observations:
  - All of them have the space complexity  $O(n)$ , which is optimal
    - However, the actual used space may be lower in array while linked list has an overhead of 100% (double)
  - All of them have complexities that are identical for Worst as well as Average case
  - All of them offer satisfactory complexity for some operations while being unsatisfactory on the others

	Array		Linked List	
	Unordered	Ordered	Unordered	Ordered
Access	$O(1)$	$O(1)$	$O(n)$	$O(n)$
Insert	$O(n)$	$O(n)$	$O(1)$	$O(1)$
Delete	$O(n)$	$O(n)$	$O(1)$	$O(1)$
Search	$O(n)$	$O(\lg n)$	$O(n)$	$O(n)$

- Non-linear data structures can be used to trade-off between extremes and achieve a balanced good performance for all
- Non-linear data structures are those data structures in which data items are not arranged in a sequence and each element may have multiple paths to connect to other elements
- Unlike linear data structures, in which each element is directly connected with utmost 2 neighbouring elements (previous and next elements), non-linear data structures may be connected with more than 2 elements
- The elements don't have a single path to connect to the other elements but have multiple parts
  - Traversing through the elements is not possible in one run as the data is non-linearly arranged
- Common Non-linear data structures include:
  - **Graph** → Undirected or Directed, Unweighted or Weighted and variants
  - **Tree** → Rooted or Unrooted, Binary or n-ary, Balance or Unbalanced and variants
  - **Hash Table** → Array with lists (coalesced chains) and one or more hash functions
  - **Skip List** → Multi-layered interconnected linked lists
  - and so on ...

## Graph

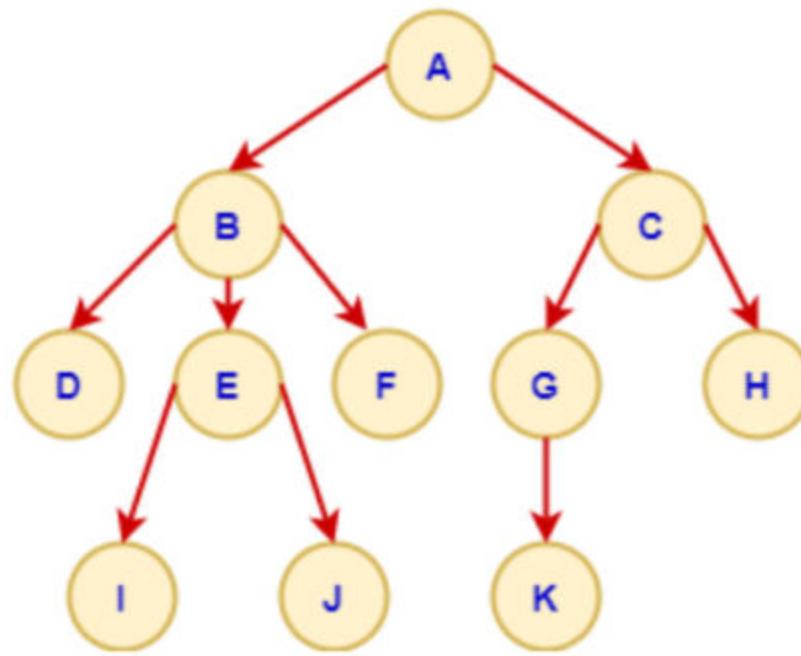
- **Graph** → Graph  $G$  is a collection of vertices  $V$  (store the elements) and connecting edges (links)  $E$  between the vertices:
- $$G = \langle V, E \rangle \text{ where } E \subseteq V \times V$$



- A graph may be:
  - Undirected or Directed
  - Unweighted or Weighted
  - Cyclic or Acyclic
  - Disconnected or Connected
  - and so on ...
- Examples of a graph include
  - ER Diagram
  - Network: Electrical, Water
  - Friendships in Facebook
  - Knowledge Graph

## Tree

- **Tree** → Is a connected acyclic graph representing hierarchical relationship



- A tree may be:

- Rooted or Unrooted
- Binary or n-ary
- Balance or Unbalanced
- Disconnected (forest) or Connected
- and so on ...

- Examples of tree include:

- Composite Attributes
- Family Genealogy
- Search Trees
- and so on ...

- **Root** → The node at the top of the tree is called the root

- There is only one root per tree and one path from the root node to any node
- **A** is the root node in the given tree

- **Parent** → The node which is a predecessor of any node is called the parent node

- In the given tree, **B** is the parent of **E**
- Every node, except the root node, has a unique parent

- **Child** → A node which is the descendant of a node

- **D, E** and **F** are the child nodes of **B**

- **Leaf** → A node which does not have any child node

- **I, J** and **K** are leaf nodes

- **Internal Nodes** → The node which has at least one child is called the Internal Node

- **Sub-tree** → Sub-tree represents the tree rooted at that node

- **Path** → Path refers to the sequence of nodes along the edges of a tree

- **Siblings** → Nodes having the same parent

- **D, E** and **F** are siblings

- **Arity** → Number of children of a node

- **B** has arity 3, **E** has arity 2, **G** has arity 1 and **D** has arity 0 (Leaf)

Maximum arity of a node is defined as the arity of the tree

- **Levels** → The root node is said to be at level 0 and the children of the root node are at level 1 and the children of the nodes which are at level 1 will be at level 2 and so on ...

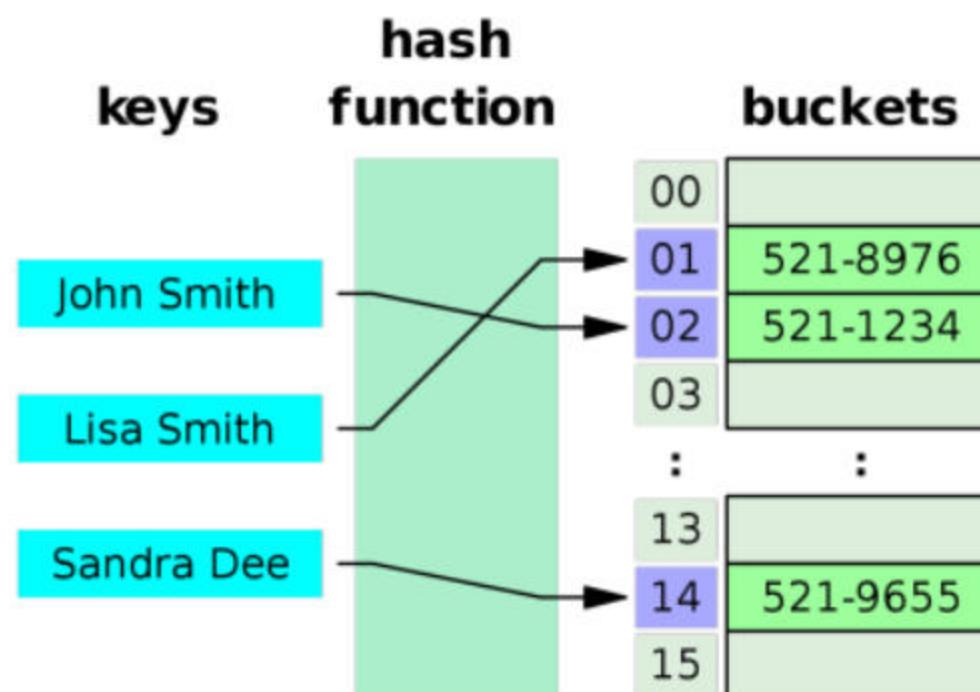
Level is the length of the path (number of links) or distance of a node from the root node

So, level of **A** is 0, level of **C** is 1, level of **G** is 2 and the level of **J** is 3

- **Height** → Max level in a tree
- **Binary Tree** → It is a tree, where each node can have at most 2 children
  - It has arity 2
- **Fact 1** → A tree with  $n$  nodes has  $n - 1$  edges
- **Fact 2** → The maximum number of nodes at level  $l$  of a binary tree is  $2^l$
- **Fact 3** → If  $h$  is the height of a binary tree of  $n$  nodes, then:
  - $h + 1 \leq n \leq 2^{h+1} - 1$
  - $\lceil \lg(n+1) \rceil - 1 \leq h \leq n - 1$
  - $O(\lg n) \leq h \leq O(n)$
  - For a  $k$ -ary tree,  $O(\lg_k n) \leq h \leq O(n)$

## Hash Table

- **Hash Table (or Hash Map)** → Implements an associative array abstract data type, a structure that can map keys to values by using a hash function to compute an index (hash code), into an array of buckets or slots, from which the desired value can be found



- A hash table may be using:
  - Static or Dynamic Schemes
  - Open Addressing
  - 2-Choice Hashing
  - and so on ...
- Examples of Hash Tables include:
  - Associative arrays
  - Database indexing
  - Caches
  - and so on ...

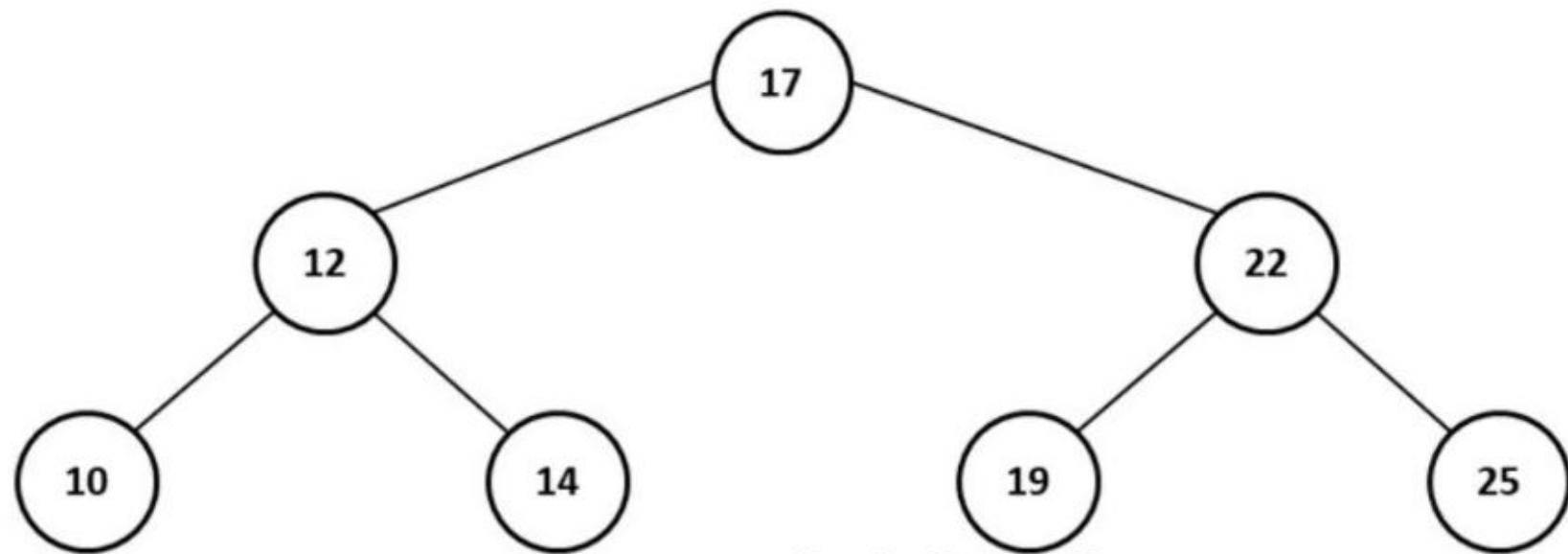
## Binary Search Tree

- During the study of linear data structure, we observed that
  - Binary search is efficient in the search of a key:  $O(\log n)$ 
    - It needs to be performed on a sorted array

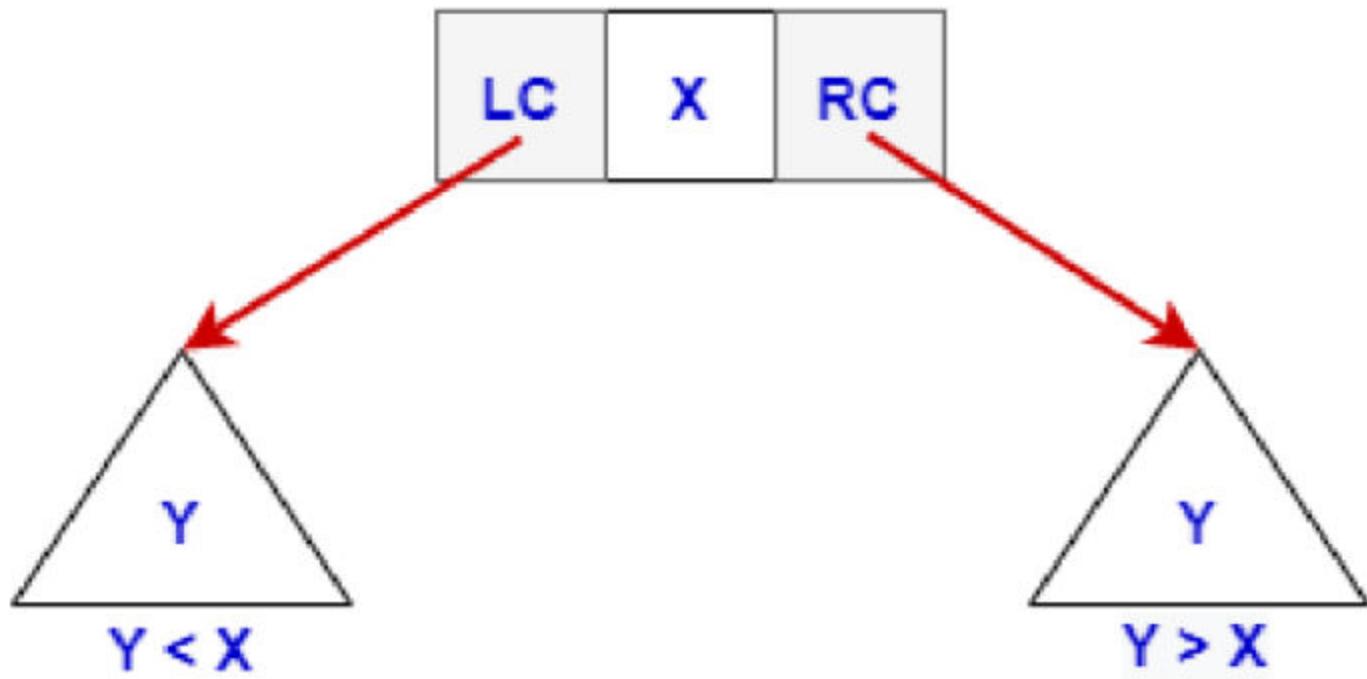
- The array makes insertion and deletion expensive at  $O(n)$
  - The linked list, on the other hand, is efficient in insertion and deletion at  $O(1)$ , while it makes the search expensive at  $O(n)$ 
    - $O(1)$  insert/delete is possible because we just need to manipulate the pointers and not physically move the data
  - Using the non-linearity, specifically (binary) trees, we can combine the benefits of both
  - Note that once an array is sorted, we know the order in which its elements may be checked (for any key) during a search
  - As the binary search splits the array, we can conceptually consider the **Middle Element** to be the **Root** of a tree and **left (right) sub-array** to be its **left (right) sub-tree**
  - Progressing recursively, we have a **Binary Search Tree (BST)**
- 
- Consider the data set:

10	12	14	17	19	22	25
LL	L	LR	M	RL	R	RR

- Search order is:
  - First → M
  - Second → L or R
  - Third:
    - For L → LL or LR
    - For R → RL or RR
  - Recursive ...
- Put as a tree



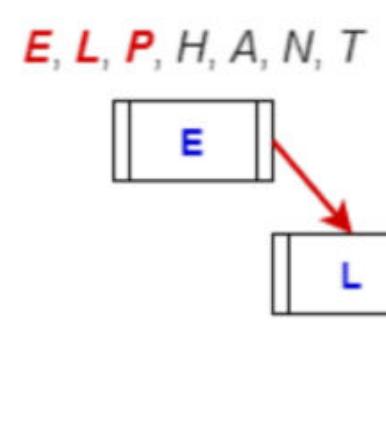
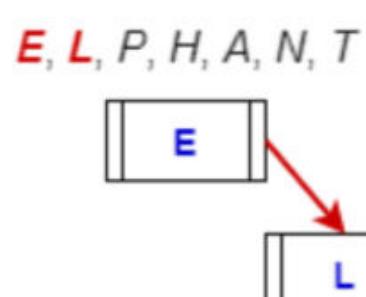
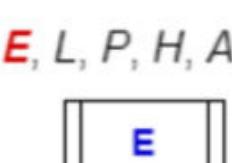
- 
- **Binary Search Tree (BST)** → It is a tree in which all the nodes hold the following:
    - The value of each node in the left subtree is less than the value of its root
    - The value of each node in the right subtree is greater than the value of its root



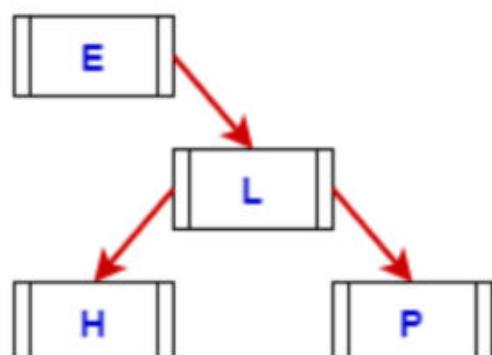
- **Structure of BST node** → Each node consists of an element (**X**), and a link to the left child or the left subtree (**LC**), and a link to the right child or the right subtree (**RC**)

- **Example** → Obtain the BST by inserting the following values:

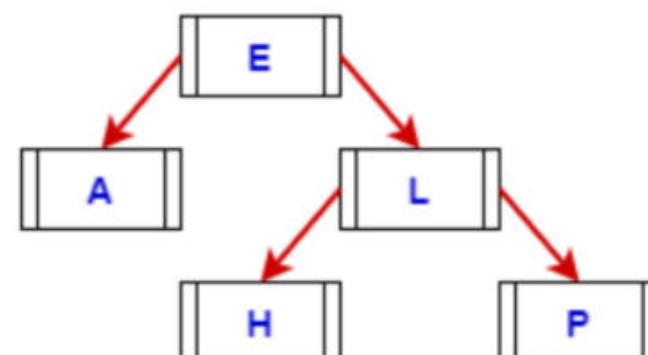
**E, L, P, H, A, N, T**



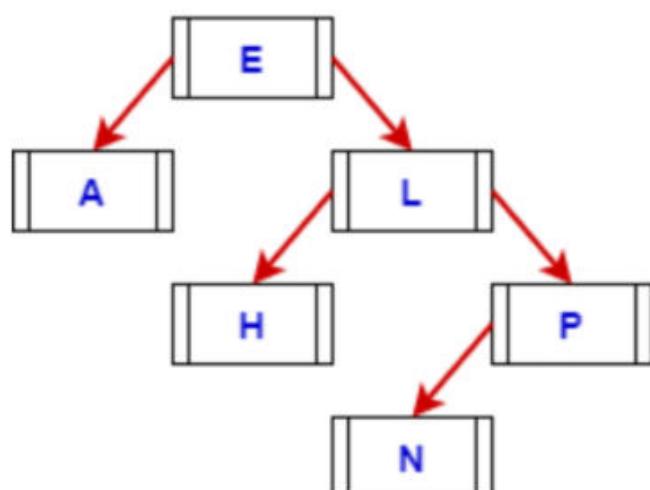
**E, L, P, H, A, N, T**



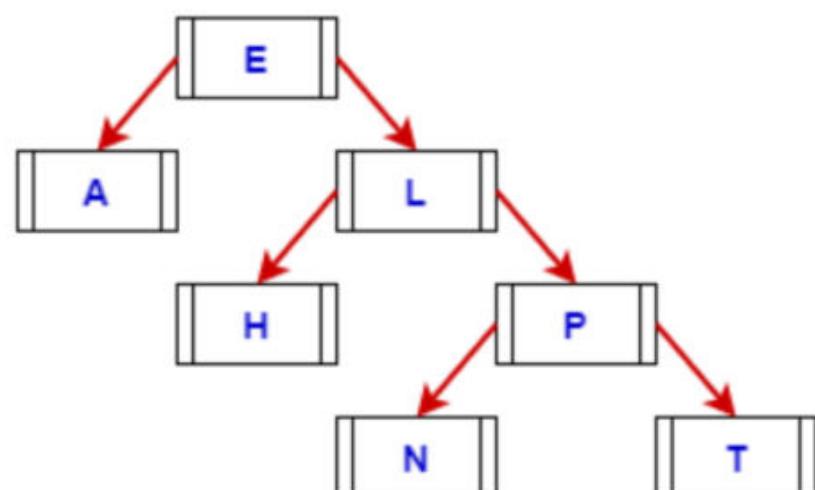
**E, L, P, H, A, N, T**



**E, L, P, H, A, N, T**



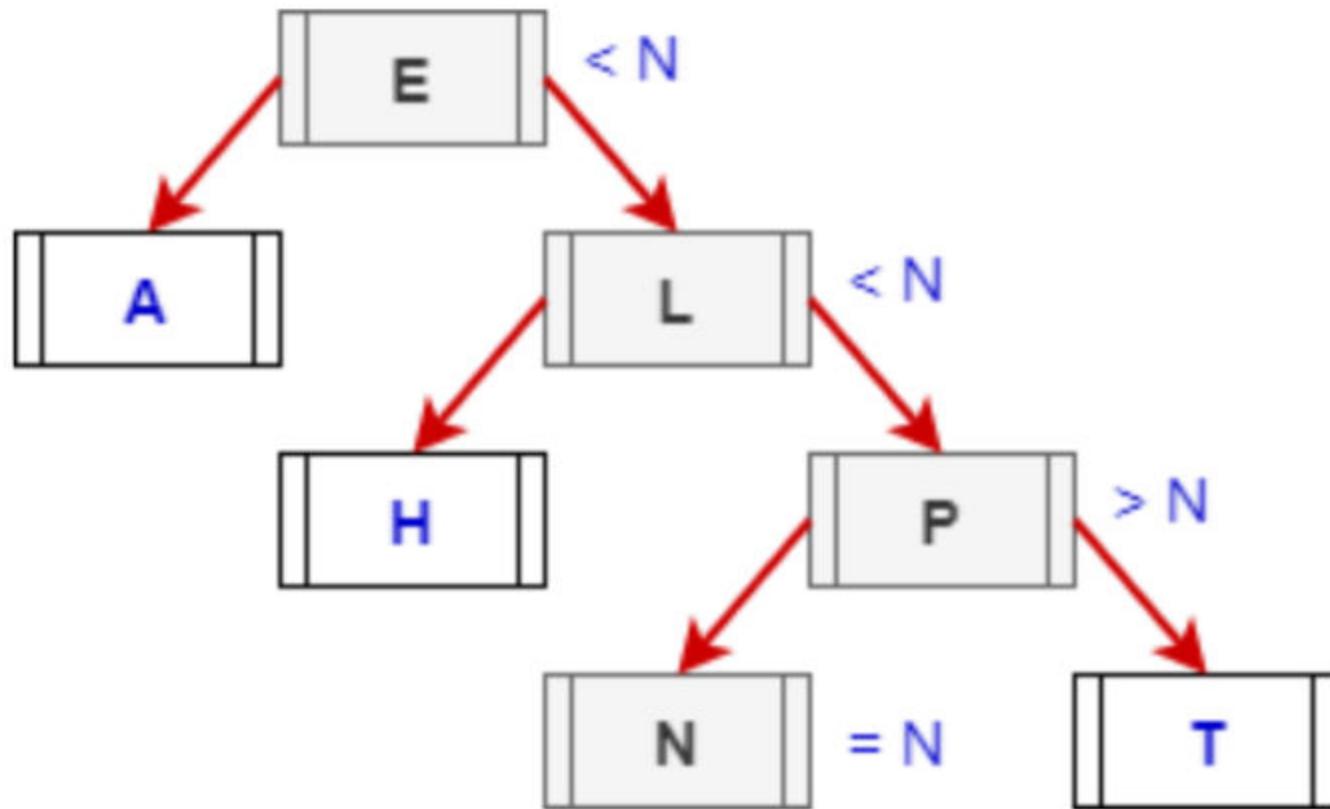
**E, L, P, H, A, N, T**



## Searching a key in the BST

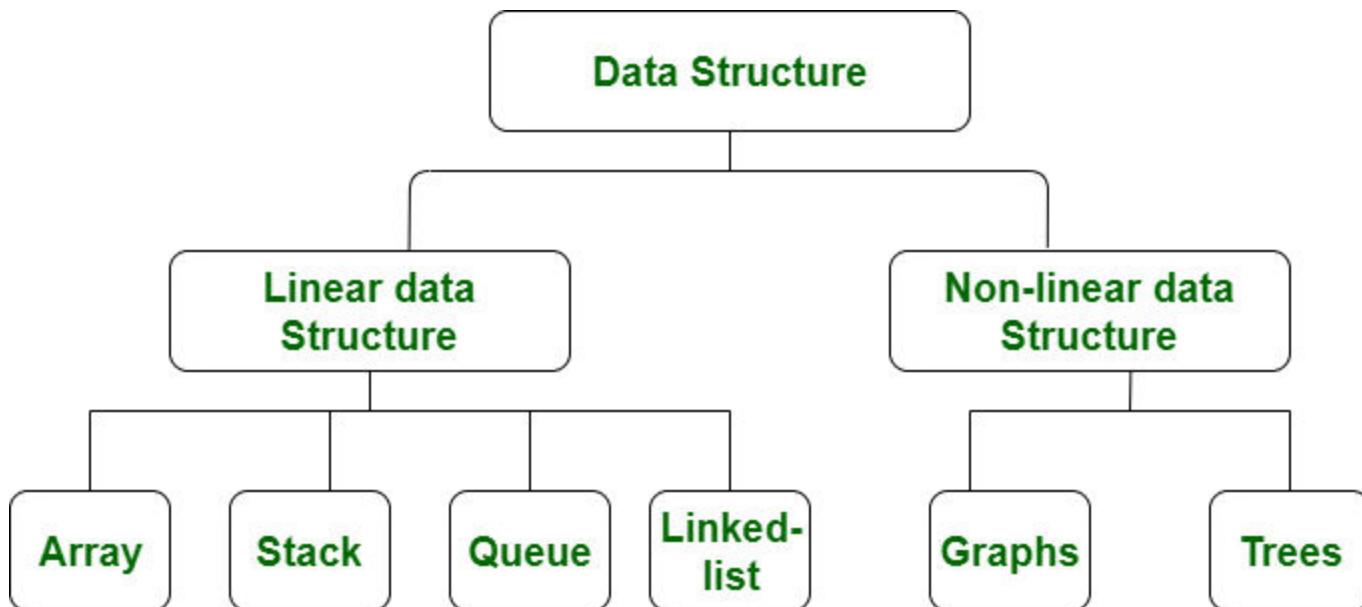
`search(root, key)`

1. Compare the key with the element at root
  - a. If the key is equal to root's element then
    - i. Element found and return
  - b. else if they key is lesser than the root's element
    - i. `search(root.lc)` # Search on the left subtree
  - c. else: `(the key is greater than the root's element)`
    - i. `search(root.rc)` # Search on the right subtree



- Searching a key in the BST is  $O(h)$ , where  $h$  is the height of the key
- **Worst Case**
  - The BST is skewed binary search tree (all the nodes except the leaf would have one child)
  - This can happen if they keys are inserted in sorted order
  - Height ( $h$ ) of the BST having  $n$  elements becomes  $n - 1$
  - Time complexity of search in BST becomes  $O(n)$
- **Best Case**
  - The BST is balanced binary search tree
  - This is possible if
    - If the keys are inserted in purely randomized order
    - If the tree is explicitly balanced after every insertion
  - Height ( $h$ ) of the binary search tree becomes  $\log n$
  - Time complexity of search in BST becomes  $O(\log n)$

## Linear and non-Linear Data Structures



Source: <https://www.geeksforgeeks.org/difference-between-linear-and-non-linear-data-structures/>

#### Linear Data Structure

In a linear data structure, data elements are arranged in a linear order where each and every elements are attached to its previous and next adjacent.

In linear data structure, single level is involved.

Its implementation is easy in comparison to non-linear data structure.

In linear data structure, data elements can be traversed in a single run only.

In a linear data structure, memory is not utilized in an efficient way.

Its examples are: array, stack, queue, linked list, etc.

Applications of linear data structures are mainly in application software development.

#### Non-linear Data Structure

In a non-linear data structure, data elements are attached in hierarchically manner.

Whereas in non-linear data structure, multiple levels are involved.

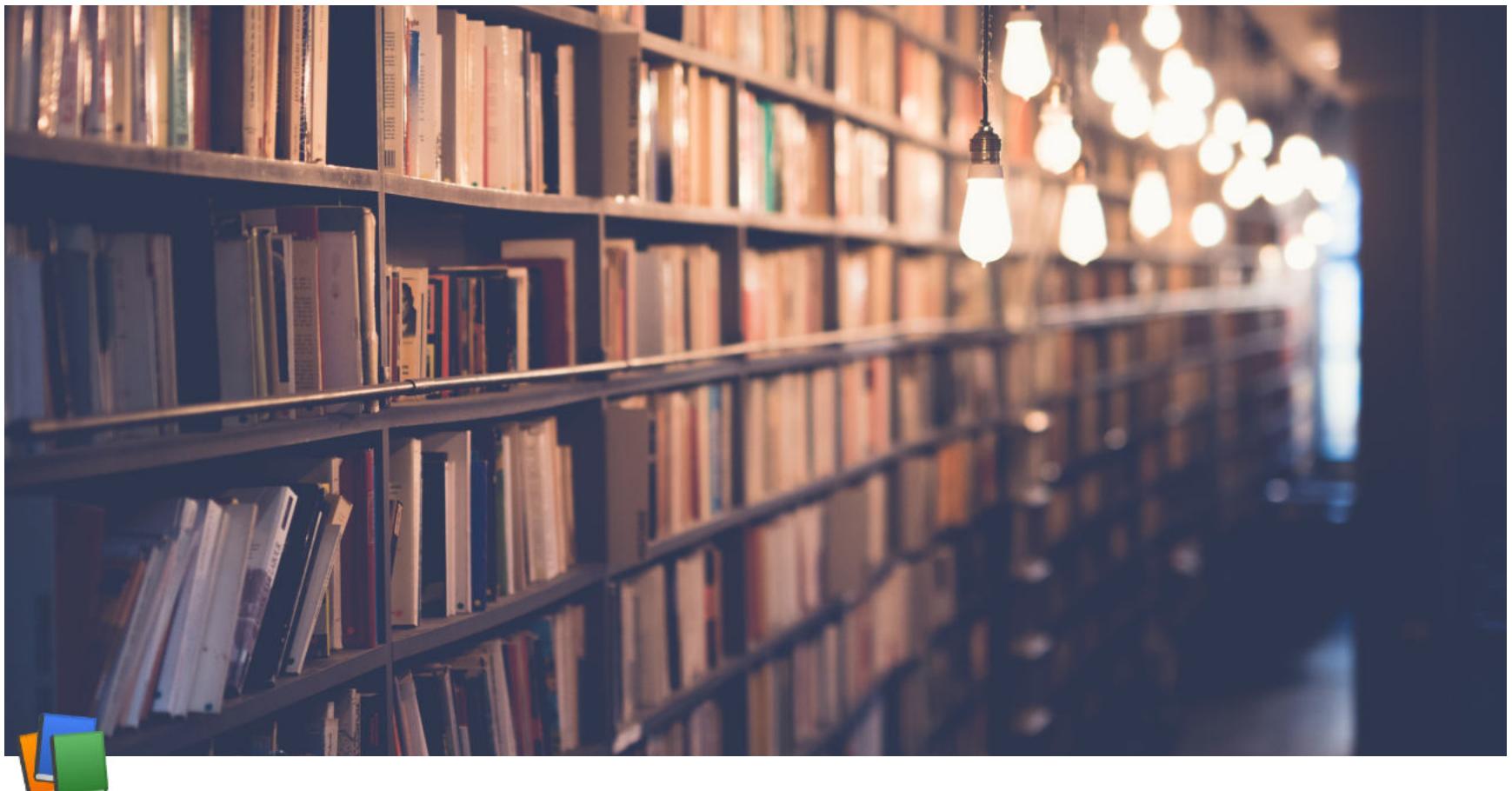
While its implementation is complex in comparison to linear data structure.

While in non-linear data structure, data elements can't be traversed in a single run only.

While in a non-linear data structure, memory is utilized in an efficient way.

While its examples are: trees and graphs.

Applications of non-linear data structures are in Artificial Intelligence and image processing.



## Week 8 Lecture 4

Class	BSCCS2001
Created	@October 25, 2021 1:02 PM
Materials	
Module #	39
Type	Lecture
# Week #	8

## Storage and File Structure: Physical Storage

### Classification of Physical Storage Media

- Speed with which data can be accessed
- Cost per unit of data
- Reliability
  - Data loss on power failure or system crash
  - Physical failure of the storage device
- Can differentiate storage into:
  - **Volatile storage** → Loses content when power is switched off
  - **Non-volatile storage** →
    - Content persists even when the power is off
    - Includes secondary and tertiary storage, as well as battery backed-up main memory

### Physical Storage Media

- **Cache**
  - Fastest and most costly form of storage
  - Volatile
  - Managed by the computer system hardware
- **Main memory**

- Fast access (10's to 100's of nanoseconds (ns))
  - $1 \text{ ns} = 10^{-9} \text{ seconds}$
- Generally too small (or too expensive) to store the entire DB
  - Capacities of up to a few gigabytes widely used currently
  - Capacities have gone up and per-byte costs have decreased steadily and rapidly (roughly factor of 2 every 2-3 years)
- **Volatile**
  - Contents of the main memory are usually lost if a power failure or system crash occurs

## Physical Storage Media: Flash Memory

- Data survives power failure
- Data can be written at a location only once, but location can be erased and written to again
  - Can support only a limited number ( $10K - 1M$ ) of write/erase cycles
  - Erasing of memory has to be done to an entire bank of memory
- Reads are roughly as fast as main memory
- But writes are slow (few microseconds), erase is slower
- Widely used in embedded devices such as digital cameras, phones and USB keys

## Physical Storage Media: Magnetic Disk

- Data is stored on spinning disk, and read/write magnetically
- Primary medium for the long-term storage of data
  - Typically stores the entire DB
- Data must be moved from the disk to main memory for access, and written back for storage — much slower access than the main memory
- Direct-access
  - Possible to read data on the disk in any order, unlike magnetic tape
- Capacities range up to roughly 16-32TB
  - Much larger capacity and much lower cost/byte than the main memory/flash memory
  - Growing constantly and rapidly with technology improvements (factor of 2 to 3 every 2 years)
- Survives power failures and system crashes
  - Disk failure can destroy data, but is rare

## Physical Storage Media: Optical Storage

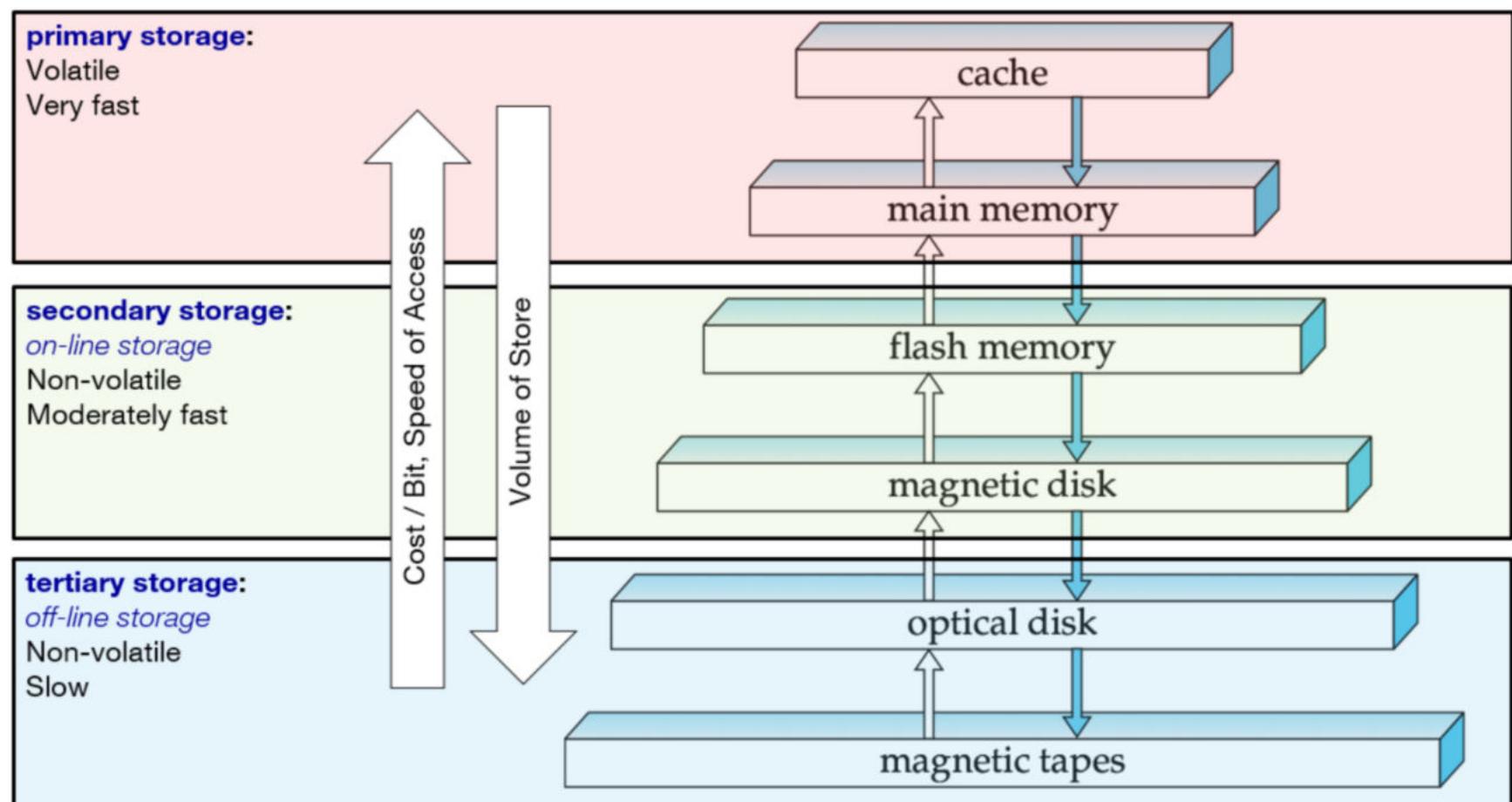
- Non-volatile, data is read optically from a spinning disk using a LASER
- CD-ROM (640MB) and DVD(4.7 to 17GB) most popular forms
- Blu-ray disks: 27GB to 54GB
- Write-one, Read-many (WORM) optical disks used for archival storage (CD-R, DVD-R, DVD+R)
- Multiple write versions also available (CD-RW, DVD-RW, DVD+RW and DVD-RAM)
- Reads and Writes are slower than with magnetic disks
- **Juke-box** systems, with large number of removable disks, a few drives and a mechanism for automatic loading/unloading of disks available for storing large volumes of data

## Physical Storage Media: Tape Storage

- Non-volatile, used primarily for backup (to recover from a disk failure) and for archival data
- **Sequential-access**
  - Much slower than a disk

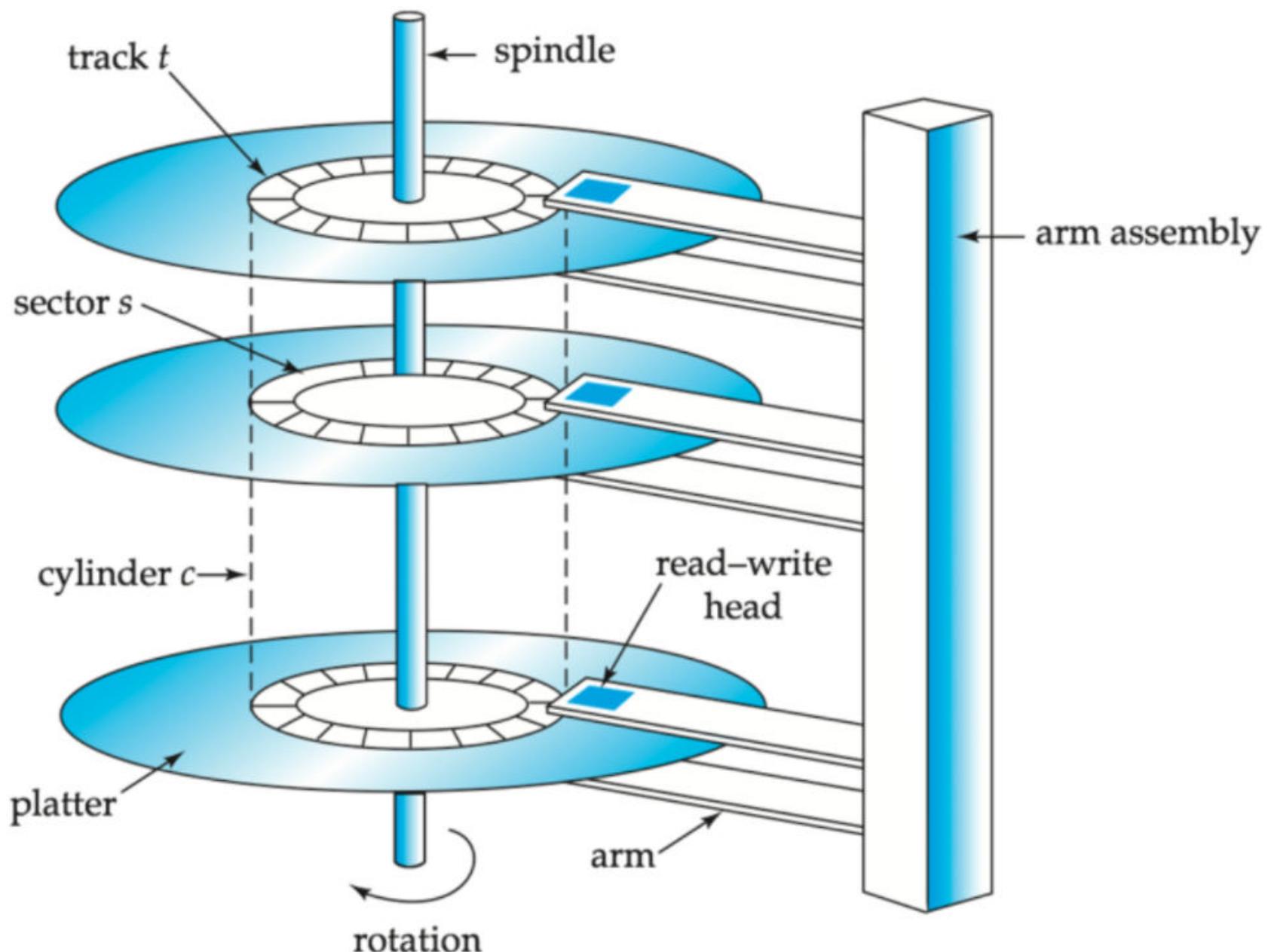
- Very high capacity (40-300TB tapes available)
- Tape can be removed from drive storage costs much cheaper than the disk, but drives are expensive
- Tape jukeboxes available for storing massive amounts of data
  - Hundreds of terabytes (TB) ( $1TB = 10^{12}$  bytes) to even multiple petabytes (PB) ( $1PB = 10^{15}$  bytes)

## Storage hierarchy



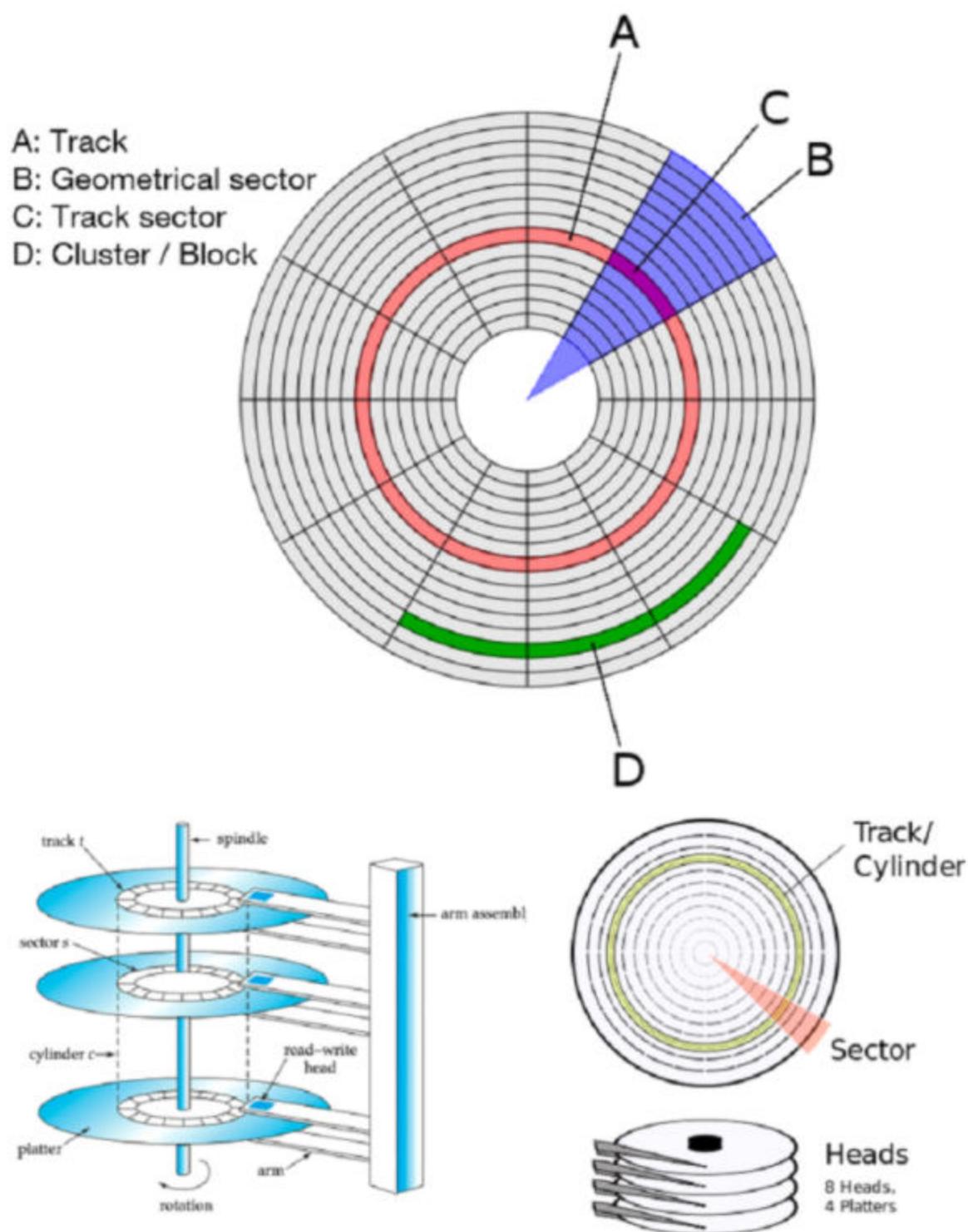
## Magnetic Disk

### Magnetic Disk: Mechanism



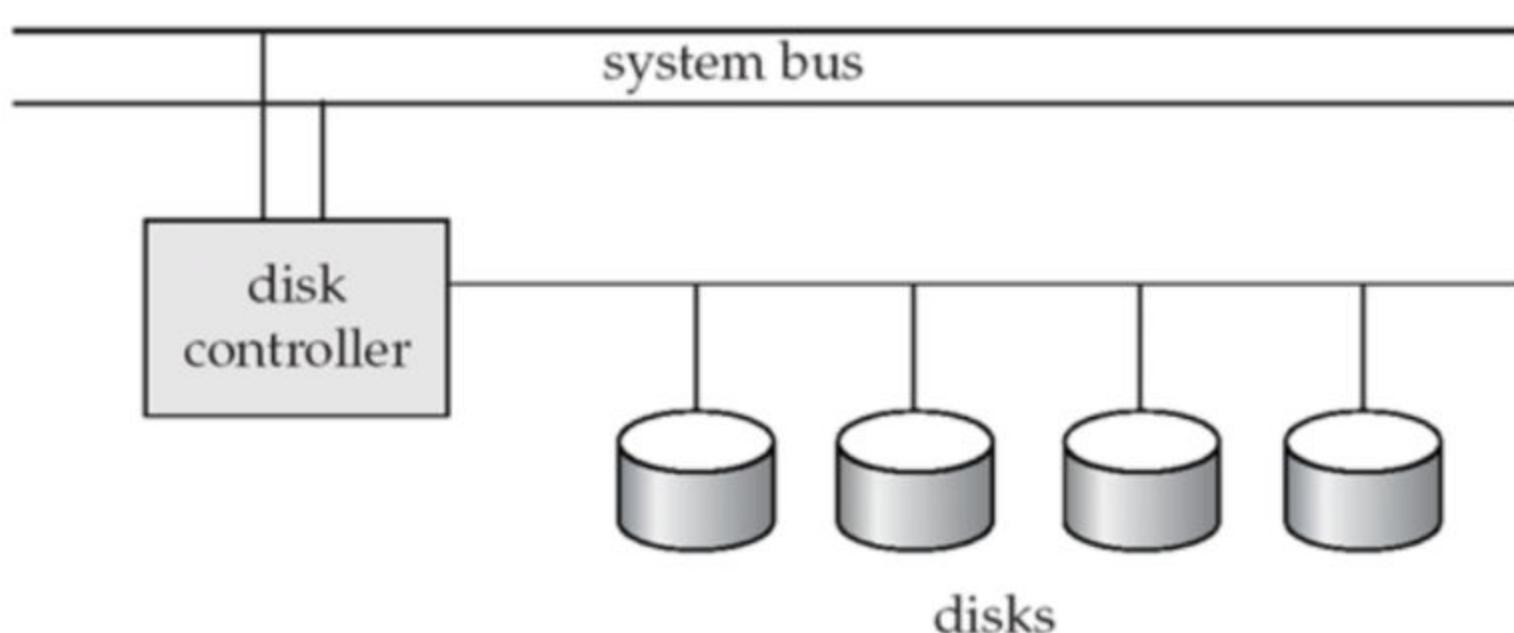
**NOTE: Diagram is schematic, and simplifies the structure of actual disk drives**

- Read-write head
  - Positioned very close to the platter surface
- Surface of the platter is divided into circular **tracks**
  - Over 50K-100K tracks per platter on typical hard disks
- Each track is divided into **sectors**
  - A sector is the smallest unit of data read or written
  - Sector size typically 512 bytes
  - Sectors / track → 500 to 1K (inner) to 1K to 2K (outer)
- To read/write a sector
  - Disk arm swings to position head on right track
  - Platter spins → Read/Write as sector passes under the head
- Head-disk assemblies
  - Multiple disk platters on a single spindle (1 to 5 usually)
  - One head per platter, mounted on a common arm
- Cylinder  $i$  consists of  $i^{th}$  track of all the platters



## Magnetic Disk: Disk Controller, Subsystems and Interfaces

- **Disk Controller** → Interfaces between the computer system and the disk drive hardware
  - Accepts high-level commands to read or write a sector
  - Initiates actions moving the disk arm to the right track, reading or writing the data
  - Computes and attaches checksums to each sector to verify that correct read back
  - Ensures successful writing by reading back sector after writing it
  - Performs remapping of bad sectors
- **Disk Subsystem**



- **Disk Interface Standards Families** → ATA, SATA, SCSI, SAS and several variants
- **Storage Area Networks (SAN)** → Connects disks by a high-speed network to a number of servers
- **Network Attached Storage (NAS)** → Provides a file system interface using networked file system protocol

## Magnetic Disk: Performance Measures

- **Access Time** → Time from a read or write request issue to start of data transfer
  - **Seek Time** → Time to reposition the arm over the correct track
    - Avg. seek time is 1/2 the worst case seek time; 1/3 if all the tracks have same number of sectors
    - 4 to 10 milliseconds on typical disks
  - **Rotational Latency** → Time for the sector to be accessed to appear under the head
    - Average latency is 1/2 of the worst case latency
    - 4 to 11 milliseconds on typical disks (5400 to 15000 RPM)
- **Data-transfer rate** → The rate at which data can be retrieved from or stored to the disk
  - 25 to 100MB per second max rate, lower for inner tracks
  - Multiple disks may share a controller, so rate that controller can handle is also important
- **Mean Time to Failure (MTTF)** → Avg. time the disk is expected to run continuously without any failure
  - Typically 3 to 5 years
  - Probability of failure of new disks is quite low, corresponding to a theoretical MTTF of 500,000 to 1,200,000 hours for a new disk
    - For example → an MTTF of 1,200,000 hours for a new disk means that given 1000 relatively new disks, on average one will fail every 1200 hours
  - MTTF decreases as the disk ages

## Magnetic Tapes

- Hold large volumes of data and provide high transfer rates
  - Tape formats
    - Few GB for DAT (Digital Audio Tape) format
    - 10 - 40GB with DLT (Digital Linear Tape) format
    - 100GB+ with Ultrium format
    - 330GB with Ampex helical scan format
  - Transfer rates from a few to 10's of MB/s
- Tapes are cheap, but the cost of drives is very high
- Very slow access time in comparison to magnetic and optical disks
  - Limited to sequential access
  - Some formats (Accelis) provide faster seek (10's of seconds) at cost of lower capacity
- Used mainly for backup, for storage of infrequently used information and as an offline medium for transferring information from one system to another
- Tape jukeboxes used for very large capacity storage
  - Multiple petabytes ( $10^{15}$  bytes)

## Cloud Storage

- Cloud storage is purchased from a 3rd party cloud vendor who owns and operates the data storage capacity and delivers it over the internet in a pay-as-you-go model
- The cloud storage vendors manage capacity, security and durability to make data accessible to applications all around the world
- Applications access cloud storage through traditional storage protocols or directly via an API

- Many vendors offer complementary services designed to help collect, manage, secure and analyze data at a massive scale
  - Various available options for cloud storage are:
    - Google Drive
    - Amazon Drive
    - Microsoft OneDrive
    - Evernote
    - Dropbox
    - and so on ...

## Cloud storage v/s Traditional Storage

Parameters	Cloud Storage	Traditional Storage
Cost	Cloud storage is cheaper per GB than using external drives.	The hardware and infrastructure costs are high and adding on more space and upgrading only adds extra costs.
Reliability	Cloud storage is highly reliable as it takes less time to get under functioning	Traditional storage requires high initial effort and is less reliable.
File Sharing	Cloud storage supports file sharing dynamically as it can be shared anywhere with network access	Traditional storage requires physical drives to share data and a network is to be established between both
Accessibility	Cloud storage gives you access to your files from anywhere	Restricted to local access
Backup/ Recovery	Very safe from on site disaster. In case of a hard drive failure or other hardware malfunction, you can access your files on the cloud, which acts as a backup solution for your local storage on physical drives	Data that is stored locally is much more susceptible to unexpected events and local storage and local backups could be easily lost

## Other storage

### Optical Disks

- Compact disk-read only memory (CD-ROM)
  - Removable disks, 640MB per disk
  - Seek time about 100 msec (optical read is heavier and slower)
  - Higher latency (3000 RPM) and lower data-transfer rates (3 - 6MB/s) compared to magnetic disks
- Digital Video Disk (DVD)
  - DVD-5 holds 4.7GB and DVD-9 holds 8.5GB
  - DVD-10 and DVD-18 are double sided formats with capacities of 9.4GB and 17GB
  - Blu-ray DVD → 27GB (54GB for double sided disk)
  - Slow seek time, for same reasons as CD-ROM
- Record once versions (CD-R and DVD-R) are popular
  - Data can only be written once and cannot be erased
  - High capacity and long lifetime; used for archival storage
  - Multi-write versions (CD-RW, DVD-RW, DVD+RW and DVD-RAM) also available

### Flash drives

- Flash drives are often referred to as pen drives, thumb drives or jump drives
  - They have completely replaced floppy drives for portable storage

- Considering how large and inexpensive they have become, they have also replaced CDs and DVDs for data storage purposes
- USB flash drives are removable and re-writable storage devices that, as the name suggests, require a USB port for connection and utilizes non-volatile flash memory technology
- The storage space in USB is quite large with sizes ranging from 128MB to 2TB
- The USB standard a flash drive is built around will determine the number of things about its potential performance, including maximum transfer rate

## Secure Digital Cards (SD Cards)

- A Secure Digital (SD) card is a type of removable memory card used to read and write large quantities of data
- Due to their relatively small size, SD cards are widely used in mobile electronics, cameras, smart devices, video game consoles and more
- There are several types of SD cards sold and used today:

Card Type	Year of Debut	Capacity	Supported Devices
SD	1996	128MB to 2GB	All host devices that support SD, SDHC, SDXC
SDHC	2006	4GB to 32GB	All host devices that support SDHC, SDXC
SDXC	2009	64GB to 2TB	All host devices that support SDXC

Card Type	Capacity	File System	Remarks
SD	128MB to 2GB	FAT16	FAT16 supports 16 MB to 2 GB
SDHC	4GB to 32GB	FAT32	FAT32 can be support up to 16 TB
SDXC	64GB to 2TB	exFAT	exFAT is non-standard, supports file up to 4 GB

Source: <https://integralmemory.com/faq/what-are-differences-between-fat16-fat32-and-exfat-file-systems>

## Flash storage

- NOR Flash vs NAND Flash
- NAND Flash
  - Used widely for storage, since it is much cheaper than NOR Flash
  - Requires page-at-a-time read (page: 515 bytes to 4KB)
  - Transfer rate around 20MB/s
  - **Solid State Disks** → Use multiple flash storage devices to provide higher transfer rate of 200MB/s or higher
  - Erase is very slow (1 to 2ms)
    - Erase block contains multiple pages
    - Remapping of logical page addresses to physical page addresses avoids waiting for erase
      - Translation table tracks mapping
      - Also stored in a label field of flash page
      - Remapping carried out by flash translation layer
    - After 100,000 to 1,000,000 erases, erase block becomes unreliable and cannot be used
      - Wear leveling

## Solid State Drives (SSDs)

- SSDs replace traditional mechanical hard disks by using flash-based memory, which is significantly faster
- SSDs speed up computers significantly due to their low read-access time and fast throughput
- The idea of SSDs was introduced in 1978
  - It was implemented using semiconductors

- It stores the data in the persistent state even when no power is supplied
- The speed of SSD much larger than that of HDD as it reads/writes data at a higher input-output per second
- Unlike HDDs, SSDs do not include any moving parts
  - SSDs resists vibrations and high temperatures

## SSD v/s HDD

Parameters	SSD	HDD
Technology	Integrated circuit using Flash memory	Mechanical Parts, including spinning disks or platters
Access Time	0.1 ms	5.5-8.0 ms
Average Seek Time	0.08-0.16 ms	< 10 ms
Speed (SATA II)	80-250 MB/sec	65-85 MB/sec
Random I/O Performance	6000 io/s	400 io/s
Backup rates	6 hours	20- 24 hours
Reliability	The failure rate of less than 0.5%	Failure rate fluctuates between 2-5%
Energy Consumption	2 to 5 watts	6 to 15 watts

## Future of Storage

### DNA Digital Storage

Oooooooh, we going Cyberpunk

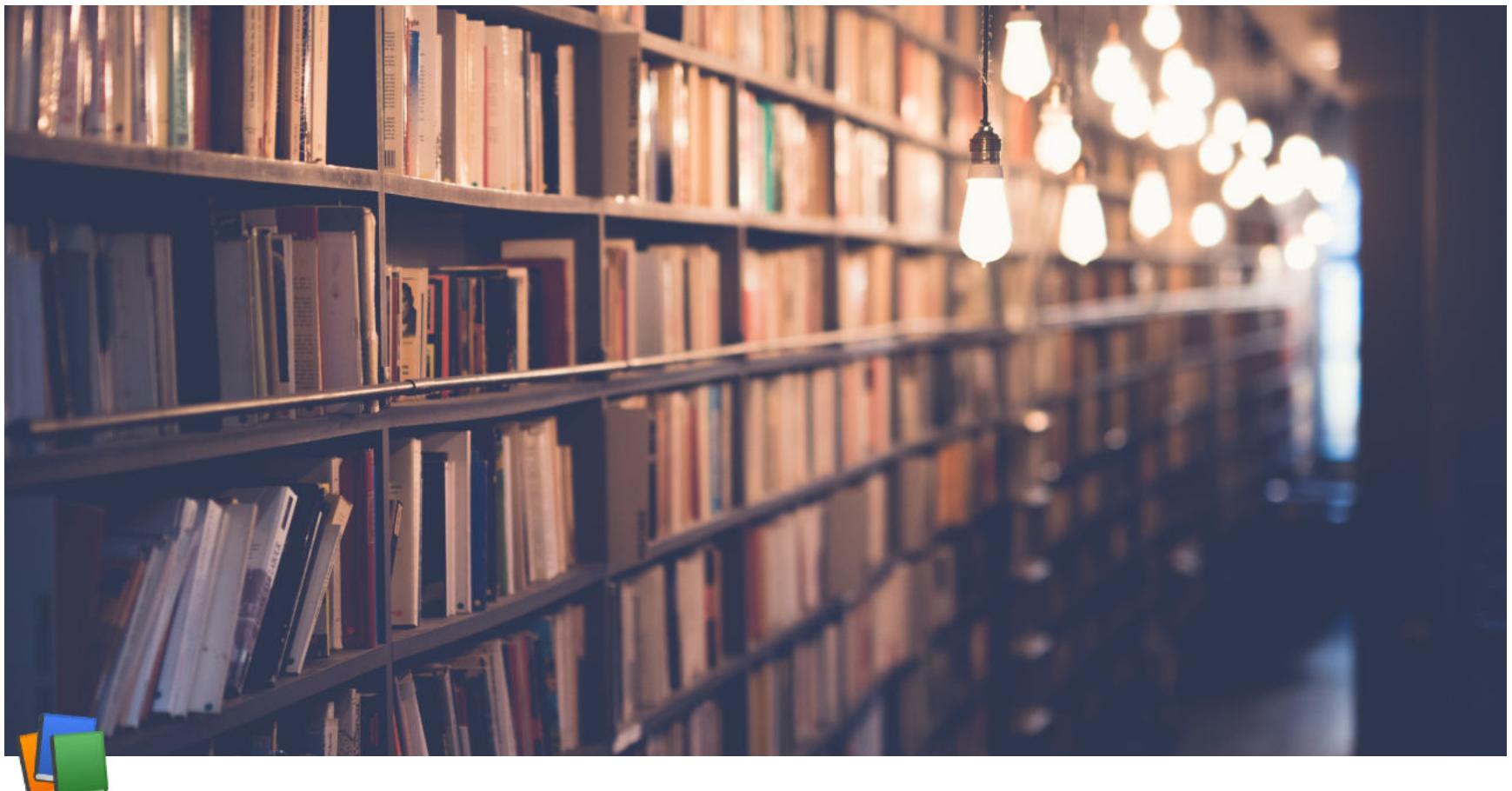


- DNA digital data storage is the process of encoding and decoding binary data to and from synthesized strands of DNA
- While DNA as a storage medium has enormous potential because of its high storage density, its practical use is currently severely limited because of its high cost and very slow read and write times
- Digital storage systems encode the text, photos, videos or any kind of information as a series of 0s and 1s
  - This same information can be encoded in DNA using the 4 nucleotides that make up the genetic code: A, T, G and C
  - For example → G and C could be used to represent 0 while A and T represent 1
- DNA has several other features that makes it desirable as a storage medium; it is extremely stable and is fairly easy (but expensive) to synthesize and sequence
- Also, because of its high density — each nucleotide, equivalent to up to 2 bits, is about 1 cubic nanometer - an exabyte ( $10^{18}$  bytes) of data stored as DNA could fit in the palm of our hands
- DNA synthesis → A DNA synthesizer machine builds synthetic DNA strands matching the sequence of digital code

### Quantum Memory

- Quantum Memory is the quantum-mechanical version of ordinary computer memory
- Whereas ordinary memory stores information as binary states (represented by 1's and 0's)
  - Quantum memory stores a quantum state for later retrieval
- These states hold useful computation information known as **qubits**
- Quantum memory is essential for the development of many devices in quantum information processing applications such as quantum network, quantum repeater, linear optical quantum computation or long-distance quantum communication

- Unlike the classical memory of everyday computers, the states stored in quantum memory can be in a quantum superposition, giving much more practical flexibility in quantum algorithms than classical information storage



## Week 8 Lecture 5

▼ Class	BSCCS2001
⌚ Created	@October 25, 2021 2:53 PM
📎 Materials	
☰ Module #	40
▼ Type	Lecture
# Week #	8

## Storage and File Structure: File Structure

### File Organization

- A Database is
  - A collection of files
  - A file is
    - A sequence of records
    - A record is
      - A sequence of fields
- One approach:
  - Assume record size is fixed
  - Each file has records of one particular type only
  - Different files are used for different relations
  - This case is easiest to implement; will consider variable length records later
- A Database file is partitioned into fixed-length storage units called blocks
  - Blocks are units of both storage allocation and data transfer

### Fixed-Length Records

- Simple approach
  - Store record  $i$  starting from byte  $n * (i - 1)$ , where  $n$  is the size of each record

- Record access is simple but records may cross blocks
  - Modification → Do not allow records to cross block boundaries
- Deletion of record  $i \rightarrow$  Alternatives
  - Move records  $i + 1, \dots, n$  to  $i, \dots, n - 1$
  - Move record  $n$  to  $i$
  - Do not move records, but link all the free records on a free list

record 0	10101	Srinivasan	Comp. Sci.	65000
record 1	12121	Wu	Finance	90000
record 2	15151	Mozart	Music	40000
record 3	22222	Einstein	Physics	95000
record 4	32343	El Said	History	60000
record 5	33456	Gold	Physics	87000
record 6	45565	Katz	Comp. Sci.	75000
record 7	58583	Califieri	History	62000
record 8	76543	Singh	Finance	80000
record 9	76766	Crick	Biology	72000
record 10	83821	Brandt	Comp. Sci.	92000
record 11	98345	Kim	Elec. Eng.	80000

### Deleting Record 3 with Comparison

Before deletion				After deletion & Compaction				
record 0	10101	Srinivasan	Comp. Sci.	65000	10101	Srinivasan	Comp. Sci.	65000
record 1	12121	Wu	Finance	90000	12121	Wu	Finance	90000
record 2	15151	Mozart	Music	40000	15151	Mozart	Music	40000
record 3	22222	Einstein	Physics	95000	32343	El Said	History	60000
record 4	32343	El Said	History	60000	33456	Gold	Physics	87000
record 5	33456	Gold	Physics	87000	45565	Katz	Comp. Sci.	75000
record 6	45565	Katz	Comp. Sci.	75000	58583	Califieri	History	62000
record 7	58583	Califieri	History	62000	76543	Singh	Finance	80000
record 8	76543	Singh	Finance	80000	76766	Crick	Biology	72000
record 9	76766	Crick	Biology	72000	83821	Brandt	Comp. Sci.	92000
record 10	83821	Brandt	Comp. Sci.	92000	98345	Kim	Elec. Eng.	80000
record 11	98345	Kim	Elec. Eng.	80000				

### Deleting Record 3 with Moving last record

Before deletion				After deletion & Movement				
record 0	10101	Srinivasan	Comp. Sci.	65000	10101	Srinivasan	Comp. Sci.	65000
record 1	12121	Wu	Finance	90000	12121	Wu	Finance	90000
record 2	15151	Mozart	Music	40000	15151	Mozart	Music	40000
record 3	22222	Einstein	Physics	95000	98345	Kim	Elec. Eng.	80000
record 4	32343	El Said	History	60000	32343	El Said	History	60000
record 5	33456	Gold	Physics	87000	33456	Gold	Physics	87000
record 6	45565	Katz	Comp. Sci.	75000	45565	Katz	Comp. Sci.	75000
record 7	58583	Califieri	History	62000	58583	Califieri	History	62000
record 8	76543	Singh	Finance	80000	76543	Singh	Finance	80000
record 9	76766	Crick	Biology	72000	76766	Crick	Biology	72000
record 10	83821	Brandt	Comp. Sci.	92000	83821	Brandt	Comp. Sci.	92000
record 11	98345	Kim	Elec. Eng.	80000				

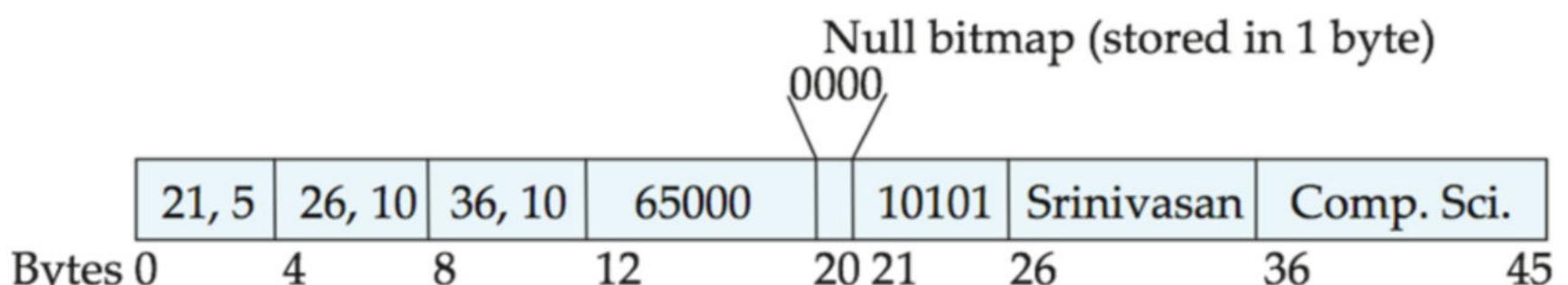
## Free Lists

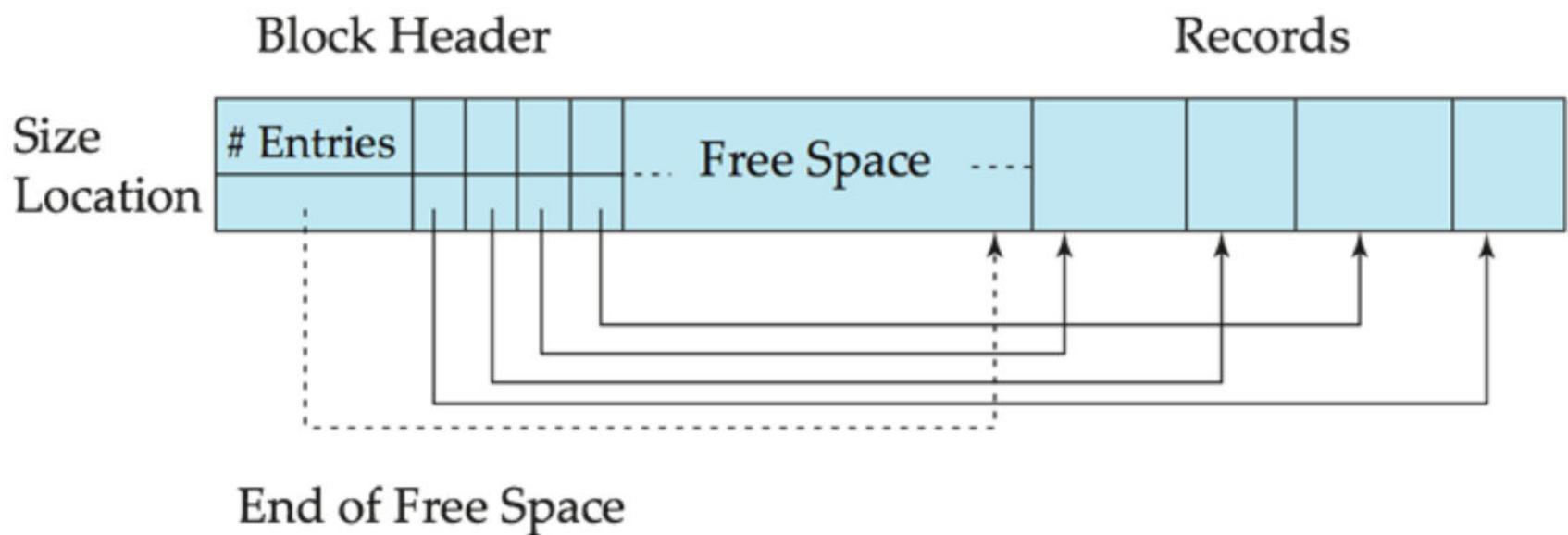
- Store the address of the first deleted record in the file header
- Use this first record to store the address of the second deleted record, and so on ...
- Consider these stored addresses as pointers since they point to the location of the record
- More space efficient representation → Re-use space for normal attributes of free records to store pointers (No pointers stored in in-use records)

header				
record 0	10101	Srinivasan	Comp. Sci.	65000
record 1				
record 2	15151	Mozart	Music	40000
record 3	22222	Einstein	Physics	95000
record 4				
record 5	33456	Gold	Physics	87000
record 6				
record 7	58583	Califieri	History	62000
record 8	76543	Singh	Finance	80000
record 9	76766	Crick	Biology	72000
record 10	83821	Brandt	Comp. Sci.	92000
record 11	98345	Kim	Elec. Eng.	80000

## Variable-Length Records

- Variable-length records arise in DB systems in several ways:
  - Storage of multiple record types in a file
  - Record types that allow variable lengths for one or more fields such as strings (varchar)
  - Record types that allow repeating fields (used in some older data models)
- Attributes are stored in order
- Variable length attributes represented by fixed size (offset, length) with actual data stored after all fixed length attributes
- Null values represented by null-value bitmap





- Slotted page header contains:
  - Number of record entries
  - End of free space in the block
  - Location and size of each record
- Records can be moved around within a page to keep them contiguous with no empty space between them; entry in the header must be updated
- Pointers should not point directly to record — instead they should point to the entry for the record in the header

### Organization of records in Files

- **Heap** → A record can be placed anywhere in the file where there is space
- **Sequential** → Store records in sequential order, based on the value of the search key of each record
- **Hashing** → A hash function computed on some attributes of each record; the result specifies in which block of the file the record should be placed
- Records of each relation may be stored in a separate file
  - In a ***multitable clustering file organization*** records of several different relations can be stored in the same file
    - Motivation → Store related records on the same block to minimize I/O

### Sequential File Organization

- Suitable for applications that require sequential processing of the entire file
- The records in the file are ordered by a **search-key**

10101	Srinivasan	Comp. Sci.	65000	
12121	Wu	Finance	90000	
15151	Mozart	Music	40000	
22222	Einstein	Physics	95000	
32343	El Said	History	60000	
33456	Gold	Physics	87000	
45565	Katz	Comp. Sci.	75000	
58583	Califieri	History	62000	
76543	Singh	Finance	80000	
76766	Crick	Biology	72000	
83821	Brandt	Comp. Sci.	92000	
98345	Kim	Elec. Eng.	80000	

- Deletion → use pointer chains
- Insertion → Locate the pointer where the record is to be inserted
  - if there is free space, insert there
  - if no free space, insert the record in an **overflow block**
  - In either case, pointer must chain must be updated
- Need to re-organize the file from time to time to restore sequential order

10101	Srinivasan	Comp. Sci.	65000	
12121	Wu	Finance	90000	
15151	Mozart	Music	40000	
22222	Einstein	Physics	95000	
32343	El Said	History	60000	
33456	Gold	Physics	87000	
45565	Katz	Comp. Sci.	75000	
58583	Califieri	History	62000	
76543	Singh	Finance	80000	
76766	Crick	Biology	72000	
83821	Brandt	Comp. Sci.	92000	
98345	Kim	Elec. Eng.	80000	

32222	Verdi	Music	48000	
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## Multitable Clustering File Organization

Store several relations in one file using a ***multitable clustering file organization***

	<i>dept_name</i>	<i>building</i>	<i>budget</i>	
<i>department</i>	Comp. Sci. Physics	Taylor Watson	100000 70000	
<i>instructor</i>	<i>ID</i>	<i>name</i>	<i>dept_name</i>	<i>salary</i>
	10101 33456 45565 83821	Srinivasan Gold Katz Brandt	Comp. Sci. Physics Comp. Sci. Comp. Sci.	65000 87000 75000 92000
multitable clustering of department and instructor				
	Comp. Sci. 45564 10101 83821 Physics 33456	Taylor Katz Srinivasan Brandt Watson Gold	100000 75000 65000 92000 70000 87000	

- Good for queries involving  $department \bowtie instructor$  and for queries involving one single department and its instructors
- Bad for queries involving only  $department$
- Results in variable size records
- Can add pointers chains to link records of a particular relation

Comp. Sci.	Taylor	100000	
45564	Katz	75000	
10101	Srinivasan	65000	
83821	Brandt	92000	
Physics	Watson	70000	
33456	Gold	87000	

The diagram shows a pointer chain starting from the last record of the first relation (Physics, Watson, 70000) and ending at the first record of the second relation (Comp. Sci., Taylor, 100000). An arrow points from the end of the first relation's row to the start of the second relation's row.

## Data Dictionary Storage

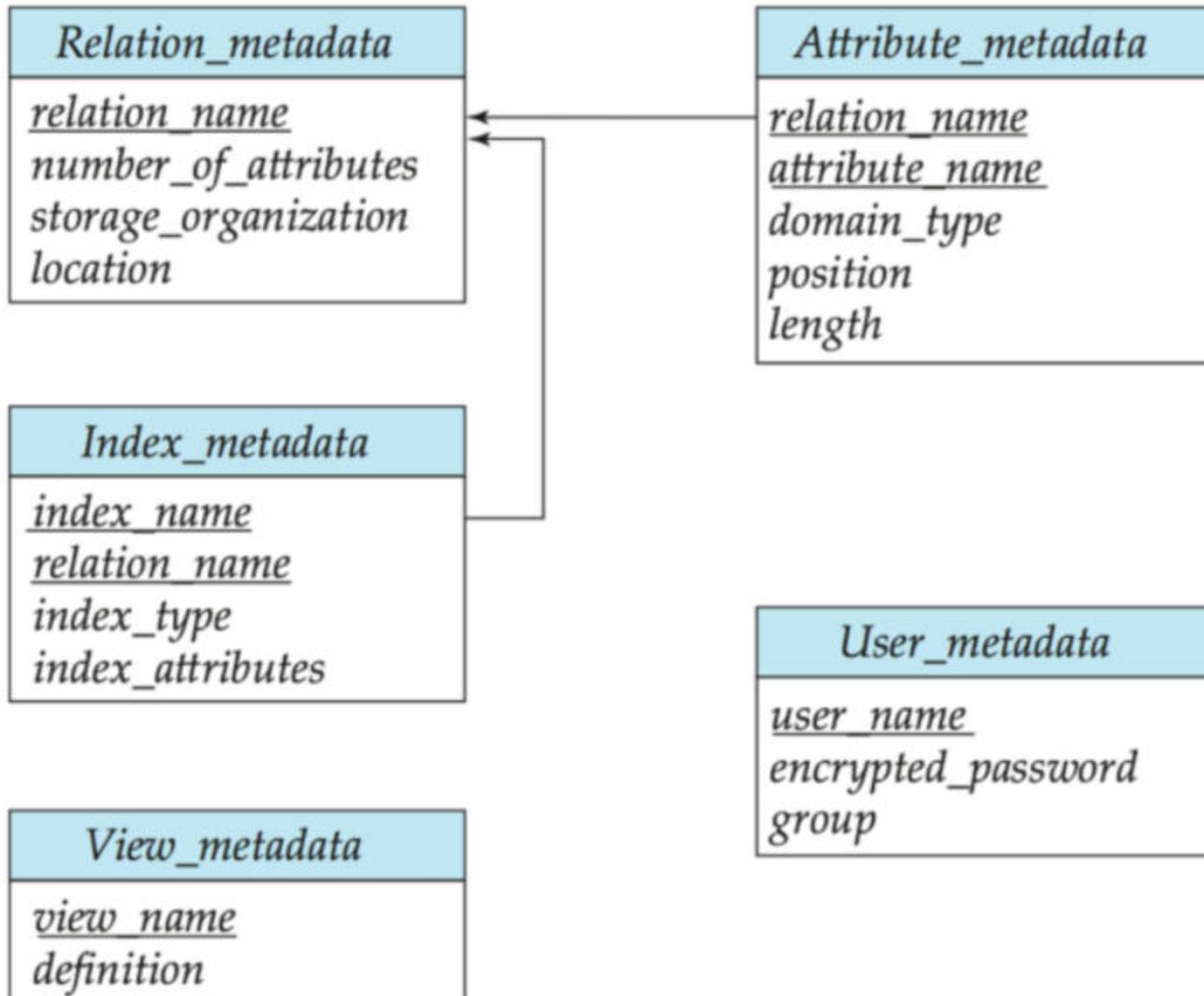
**Data Dictionary** (also, **System Catalog**) stores ***metadata*** (data about data) such as:

- Information about relations
  - names of relations
  - names, types and lengths of attributes of each relation
  - names and definition of views
  - integrity constraints
- User and accounting information, including password
- Statistical and descriptive data
  - Number of tuples in each relation
- Physical file organization information
  - How relation is stored (sequential/hash/...)
  - Physical location of relation

- Information about indices

## Relational Representation of System metadata

- Relational representation on disk
- Specialized data structures designed for efficient access, in memory



## Storage Access

- A database file is partitioned into fixed-length storage units called **blocks**
  - Blocks are units of both storage allocation and data transfer
- Database system seeks to minimize the number of block transfers between the disk and the memory
  - We can reduce the number of disk accesses by keeping as many blocks as possible in the main memory
- **Buffer** → Portion of the main memory available to store copies of disk blocks
- **Buffer Manager** → Subsystem responsible for allocating buffer space in the main memory

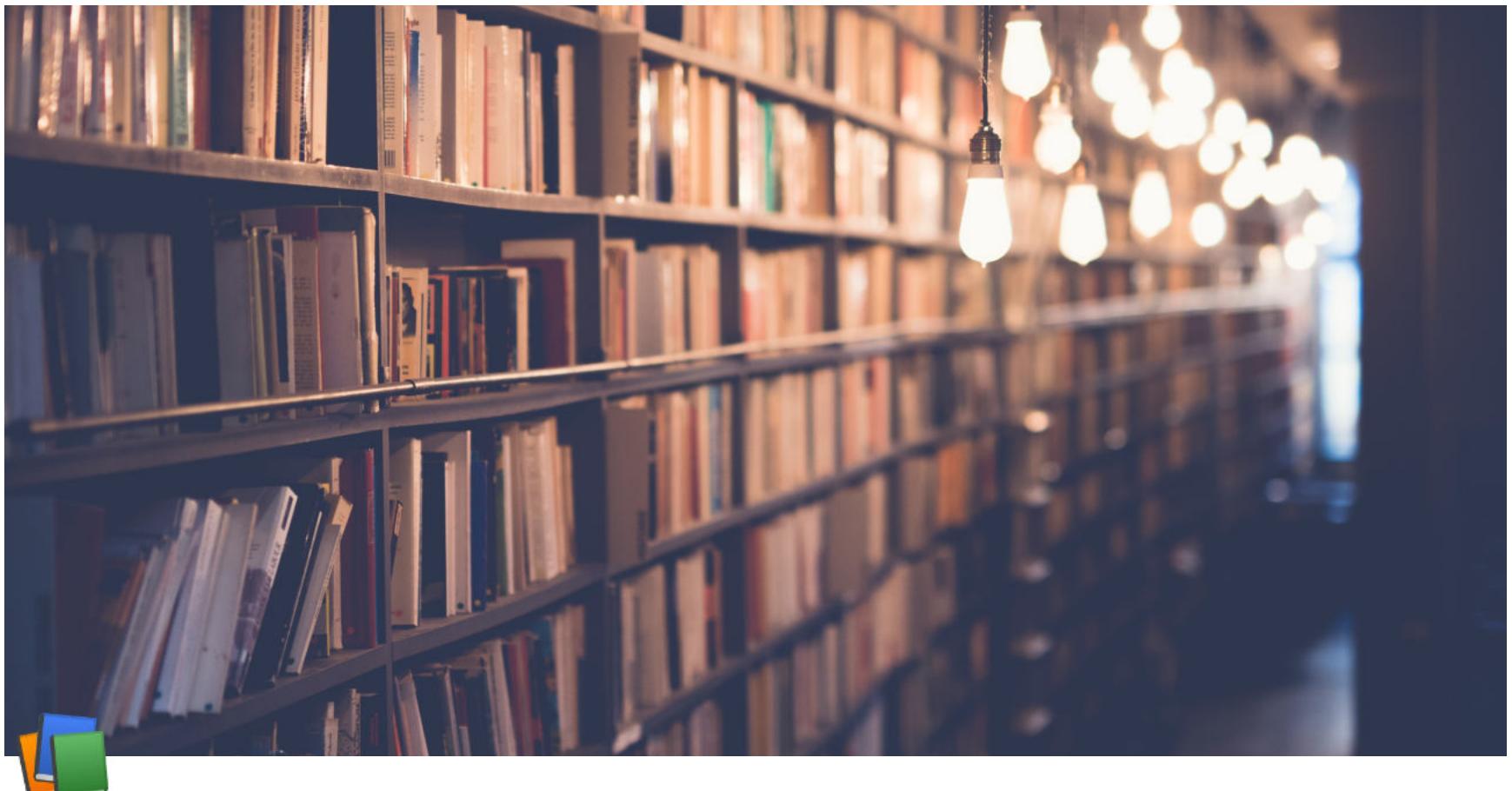
## Buffer Manager

- Programs call on the buffer manager when they need a block from the disk
  - If the block is already in the buffer, buffer manager returns the address of the block in the main memory
  - If the block is not in the buffer, the buffer manager
    - Allocates space in the buffer of the block
      - Replacing (throwing out) some other block, if required, to make space for the new block
      - Replaced block written back to disk only if it was modified since the most recent time that it was written to / fetched from the disk
    - Reads the block from the disk to the buffer, and returns the address of the block in the main memory to the requester

## Buffer Replacement Policies

- Most Operating Systems replace the block **least recently used (LRU strategy)**
- Idea behind LRU — Use past pattern of block references as a predictor of future references

- Queries have well-defined access patterns (such as sequential scans) and a database system can use the information in a user's query to predict future references
  - LRU may be a bad strategy for certain access patterns involving repeated scans of data
    - For example → When computing the join of 2 relations  $r$  and  $s$  by a nested loop
      - for each tuple  $tr$  of  $r$  do
      - for each tuple  $ts$  of  $s$  do
        - if the tuples  $tr$  and  $ts$  match ...
  - Mixed strategy with hints on replacement strategy provided by the query optimizer is preferable
- **Pinned block** → Memory block that is not allowed to be written back to the disk
- **Toss-immediate strategy** → Frees the space occupied by a block as soon as the final tuple of that block has been processed
- **Most recently used (MRU) strategy** → System must pin the block currently being processed
  - After the final tuple of that block has been processed, the block is unpinned and it becomes the most recently used block
- Buffer manager can use statistical information regarding the probability that a request will reference a particular relation
  - For example → the data dictionary is frequently accessed
    - Heuristic → keep data-dictionary blocks in the main memory buffer
- Buffer managers also support forced output of blocks for the purpose of recovery



## Week 9 Lecture 1

Class	BSCCS2001
Created	@November 2, 2021 2:40 PM
Materials	
Module #	41
Type	Lecture
# Week #	9

## Indexing and Hashing → Indexing (part 1)

### Concepts of Indexing

#### Search Records

- Consider a table → Faculty (Name, Phone)

Index on "Name"		Table "Faculty"			Index on "Phone"	
Name	Pointer	Rec #	Name	Phone	Pointer	Phone
Anupam Basu	2	1	Partha Pratim Das	81998	6	81664
Pabitra Mitra	6	2	Anupam Basu	82404	1	81998
Partha Pratim Das	1	3	Ranjan Sen	84624	2	82404
Prabir Kumar Biswas	7	4	Sudeshna Sarkar	82432	4	82432
Rajib Mall	5	5	Rajib Mall	83668	5	83668
Ranjan Sen	3	6	Pabitra Mitra	81664	3	84624
Sudeshna Sarkar	4	7	Prabir Kumar Biswas	84772	7	84772

- How to search on Name?
  - Get the phone number for 'Pabitra Mitra'
  - Use "Name" Index — sorted on 'Name', search 'Pabitra Mitra' and navigate on pointer (red #)
- How to search on Phone?
  - Get the name of the faculty having phone number = 84772

- Use "Phone" Index — sorted on 'Phone', search '84772' and navigate on pointer (rec #)
- We can keep the records sorted on 'Name' or on 'Phone' (called the primary index), but not on both

## Basic Concepts

- Indexing mechanisms used to speed up access to desired data
  - For example →
    - Name in a faculty table
    - Author catalog in a library
- **Search Key** → Attribute or set of attributes used to look up records in a file
- An **index file** consists of records (called **index entries**) of the form



- Index files are typically much smaller than the original file
- Two basic kinds of indices →
  - **Ordered indices** → search keys are stored in sorted order
  - **Hash indices** → search keys are distributed uniformly across **buckets** using a **hash function**

## Index Evaluation Metrics

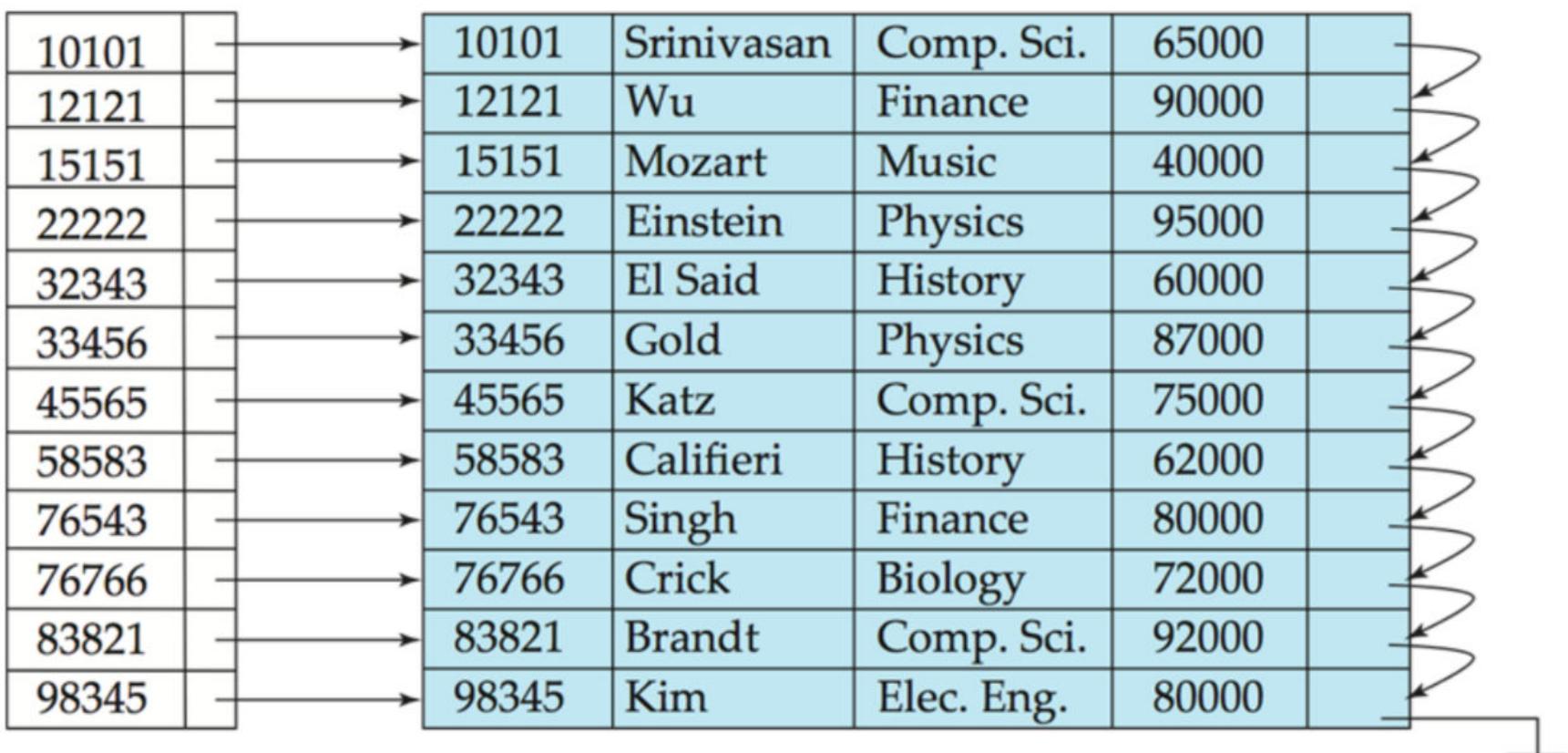
- Access types supported efficiently
  - For example →
    - records with a specified value in the attribute
    - records with an attribute value falling in a specified range of values
- Access time
- Insertion time
- Deletion time
- Space overhead

## Ordered Indices

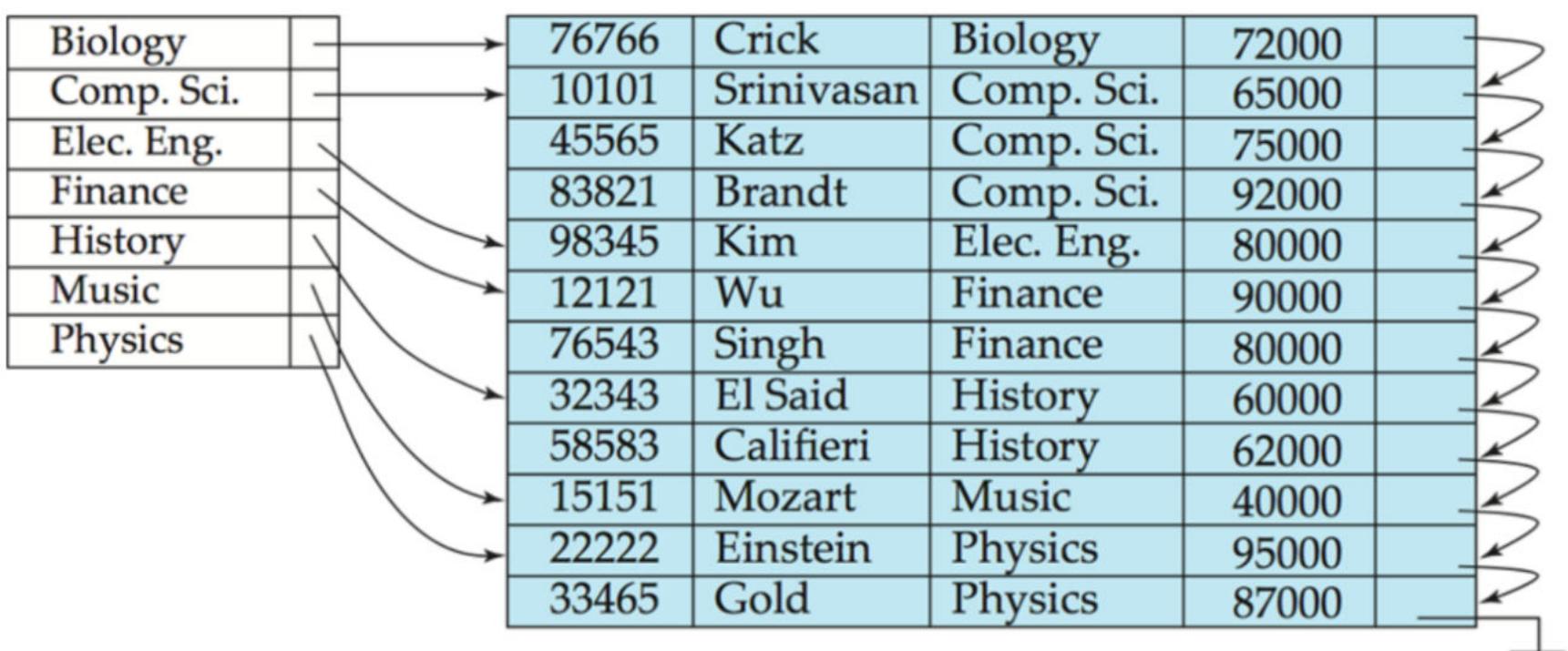
- In an **ordered index**, index entries are stored sorted on the search key value
  - For example → author catalog in library
- **Primary index** → In a sequentially ordered file, the index whose search key specifies the sequential order of the file
  - Also called the **clustering index**
  - The search key of a primary index is usually but not necessarily the primary key
- **Secondary index** → An index whose search key specifies an order different from the sequential order of the file
  - Also called the **non-clustering index**
- **Index-sequential file** → ordered sequential file with a primary index

## Dense Index Files

- **Dense Index** → Index record appears for every search-key value in the file
- For example → index on *ID* attribute of *instructor* relation

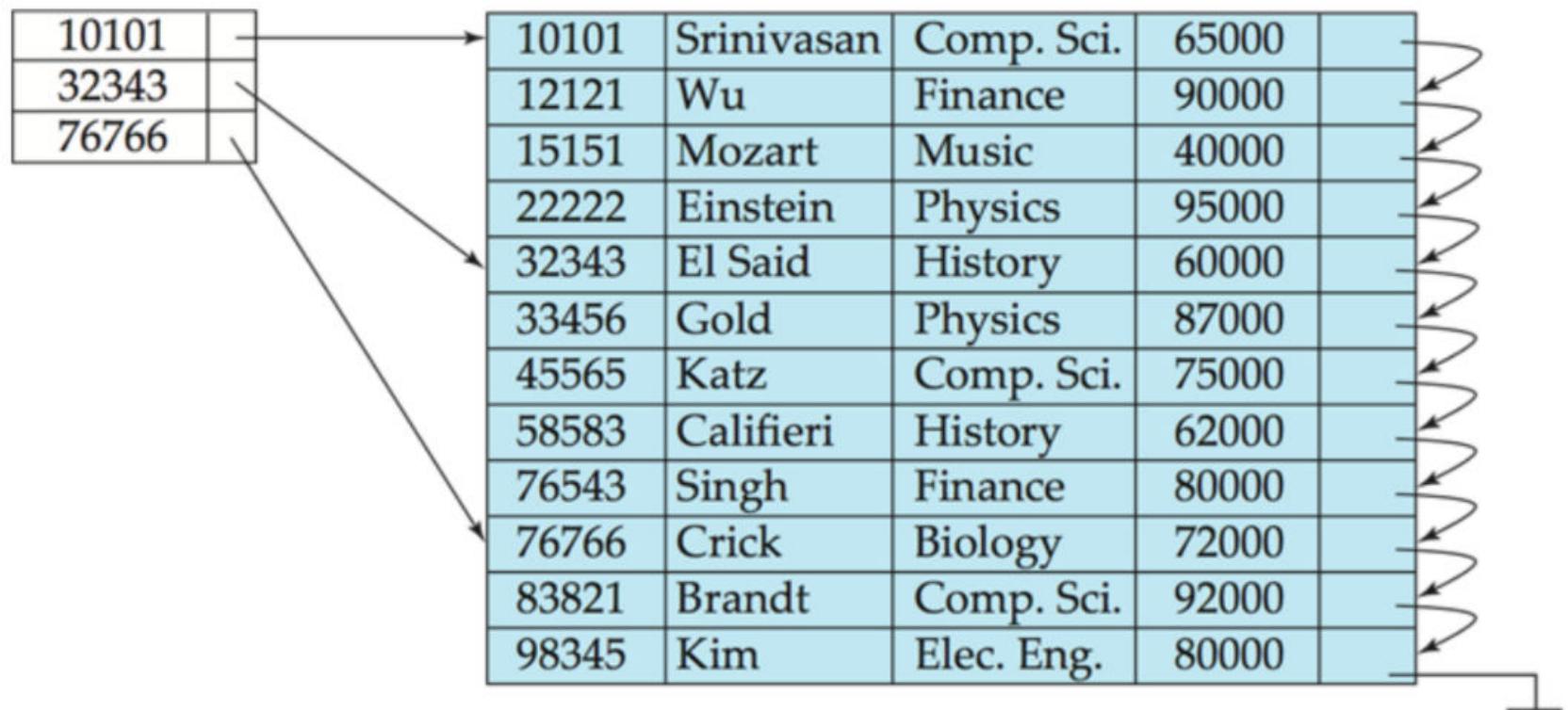


- Dense index on *dept\_name*, with *instructor* file stored on *dept\_name*

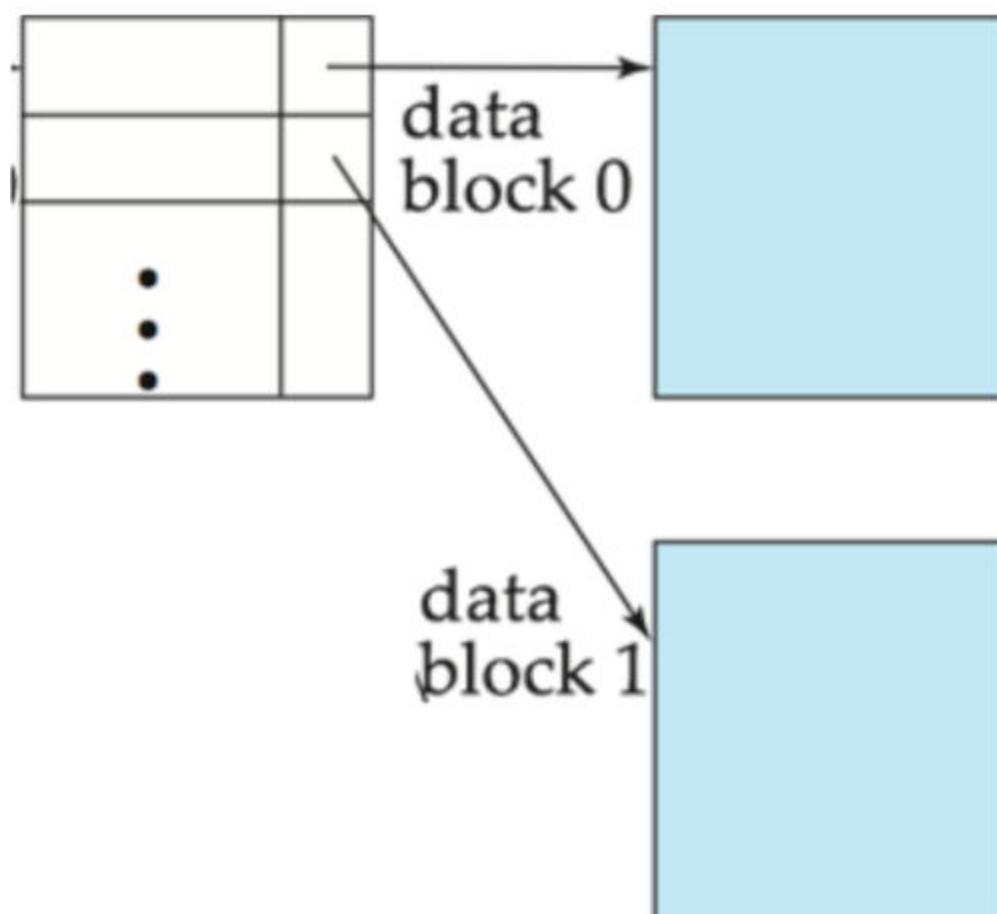


## Sparse Index Files

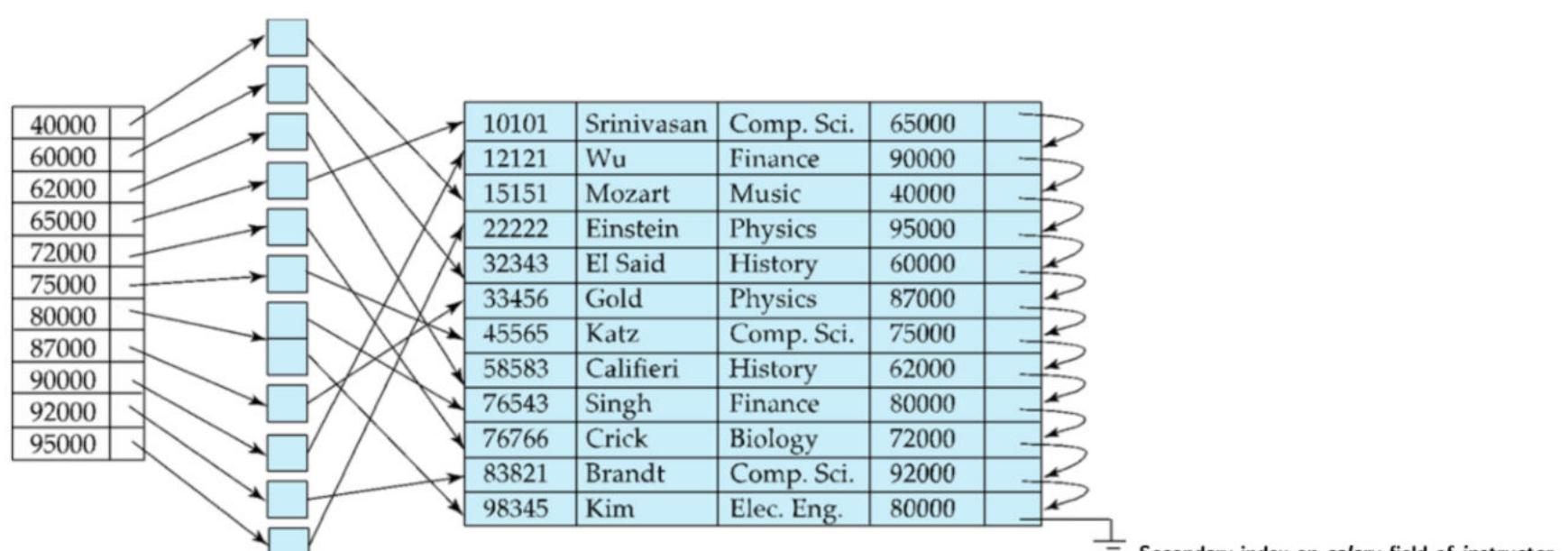
- Sparse Index** → Contains index records for only some search-key values
  - Applicable when records are sequentially ordered on search-key
- To locate a record with search-key value  $K$  we →
  - Find index record with largest search-key value  $< K$
  - Search file sequentially starting at the record to which the index record points



- Compared to dense indices →
  - Less space and less maintenance overhead for insertions and deletions
  - Generally slower than dense index for locating records
- Good tradeoff** → Sparse index with an index entry for every block in file, corresponding to least search-key value in the block



### Secondary Indices Example



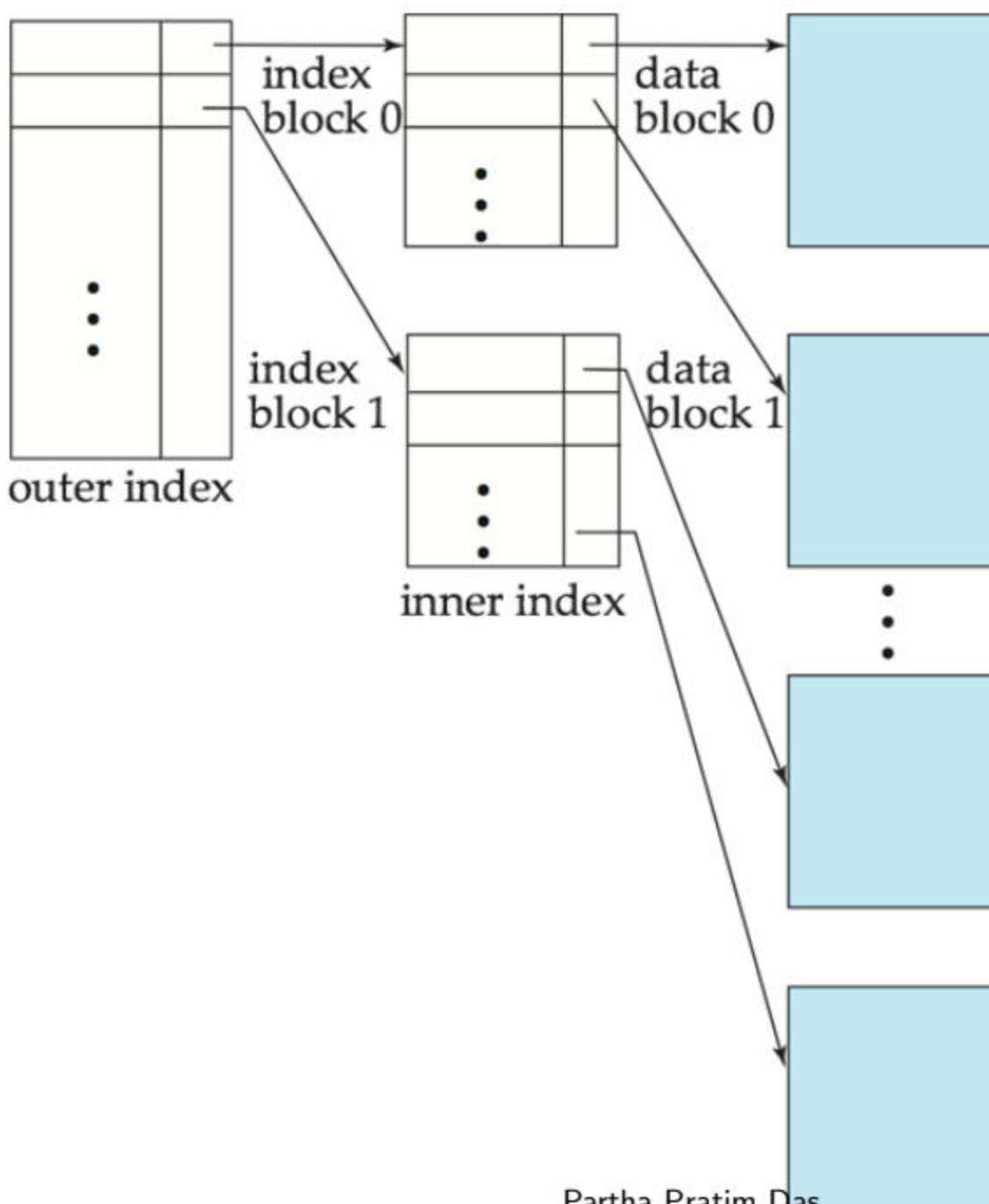
- Index record points to a bucket that contains pointers to all the actual records with that particular search-key value
- Secondary indices have to be dense

## Primary and Secondary Indices

- Indices offer substantial benefits when searching for records
- BUT → Updating indices imposes overhead on database modification — when a file is modified, every index on the file must be updated
- Sequential scan using primary index is efficient, but a sequential scan using a secondary index is expensive
  - Each record access may fetch a new block from the disk
  - Block fetch requires about 5 to 10 milliseconds, versus about 100 nanoseconds for memory access

## Multilevel Index

- If primary index does not fit in memory, access becomes expensive
- **Solution** → treat primary index kept on disk as a sequential file and construct a sparse index on it
  - outer index → a sparse index of primary index
  - inner index → the primary index file
- If even outer index is too large to fit in the main memory, yet another level of index can be created and so on
- Indices at all levels must be updated on insertion or deletion from the file



## Index Update → Deletion

- If deleted record was the only record in the file with its particular search-key value, the search-key is deleted from the index also
- **Single-level index entry deletion** →
  - **Dense indices** → deletion of search-key is similar to file record deletion

- **Sparse indices** —

- If an entry for the search key exists in the index, it is deleted by replacing the entry in the index with the next search-key value in the file (in search-key order)
- If the next search-key value already has an index entry, the entry is deleted instead of being replaced

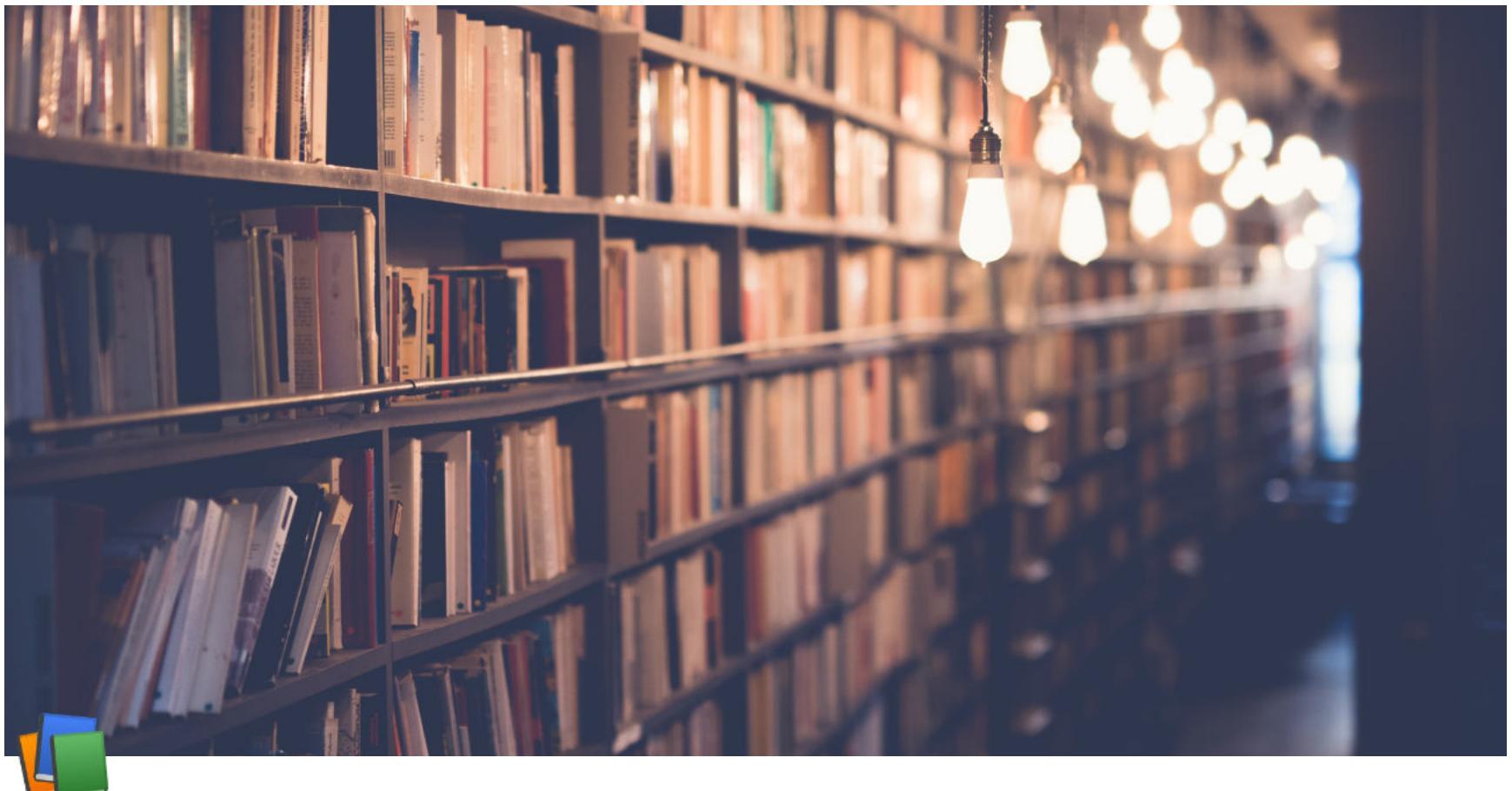
- **Single-level index insertion** →

- Perform a lookup using the search-key value appearing in the record to be inserted
- **Dense indices** → if the search-key value does not appear in the index, insert it
- **Sparse indices** → if index stores an entry for each block of the file, no change needs to be made to the index unless a new block is created
  - If a new block is created, the first search-key value appearing in the new block is inserted into the index

- **Multilevel insertion and deletion** → algorithms are simple extensions of the single-level algorithms

## Secondary Indices

- Frequently, one wants to find all the records whose values in a certain field (which is not the search-key of the primary index) satisfy some condition
  - Example 1 → In the instructor relation stored sequentially by the ID, we may want to find all instructors in a particular department
  - Example 2 → as above, but where we want to find all instructions with a specified salary or with salary in a specific range of values
- We can have a secondary index with an index record for each search-key value



## Week 9 Lecture 2

Class	BSCCS2001
Created	@November 2, 2021 4:46 PM
Materials	
Module #	42
Type	Lecture
# Week #	9

## Indexing and Hashing → Indexing (part 2)

### Balanced Binary Search Trees

#### Search Data Structures

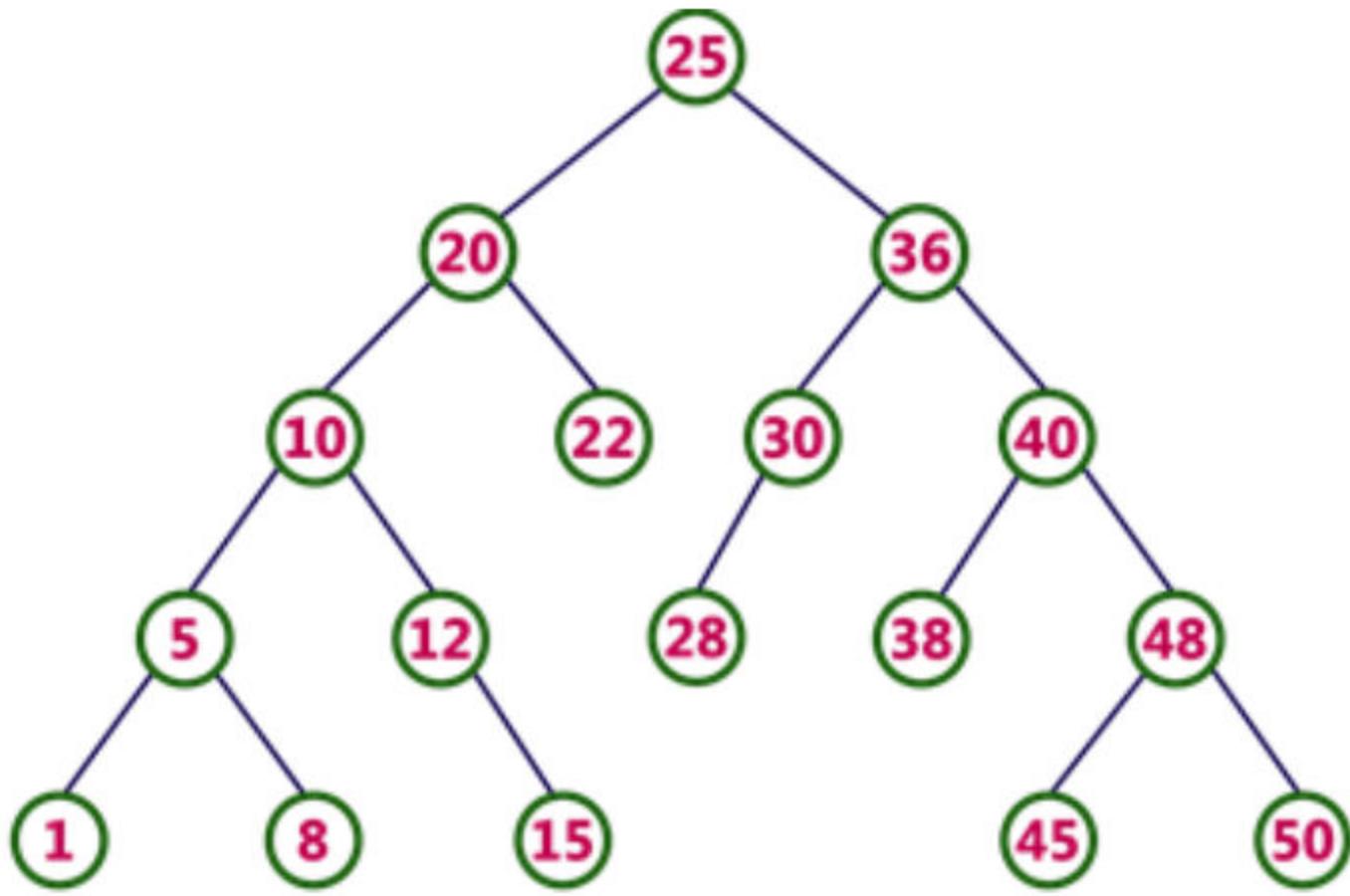
- How to search a key in a list of  $n$  data items?
  - Linear search:  $O(n)$  → Find 28  $\implies$  16 comparisons
    - Unordered items in an array — search sequentially
    - Unordered/Ordered items in a list — search sequentially

22	50	20	36	40	15	08	01	45	48	30	10	38	12	25	28	05	END
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----

- Binary search:  $O(\log n)$  → Find 28  $\implies$  4 comparisons — 25, 36, 30, 28
  - Ordered items in an array — search by divide-and-conquer

01	05	08	10	12	15	20	22	25	28	30	36	38	40	45	48	50	END
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----

- Binary Search Tree — recursively on left/right



- Worst case time ( $n$  data items in the data structure)

Data Structure	Search	Insert	Delete	Remarks
Unordered Array	$O(n)$	$O(1)$	$O(1)$	
Ordered Array	$O(\log n)$	$O(n)$	$O(n)$	
Unordered List	$O(n)$	$O(1)$	$O(1)$	
Ordered List	$O(n)$	$O(1)$	$O(1)$	
Binary Search Tree	$O(h)$	$O(1)$	$O(1)$	The time to Insert / Delete an item is the time after the location of the item has been ascertained by Search.

- Between an array and a list, there is a trade-off between search and insert/delete complexity
- For a BST of  $n$  nodes,  $\log n \leq h < n$ , where  $h$  is the height of the tree
- A BST is balanced if  $h \sim O(\log n) \rightarrow$  that is what we desire

## Search Data Structures → BST

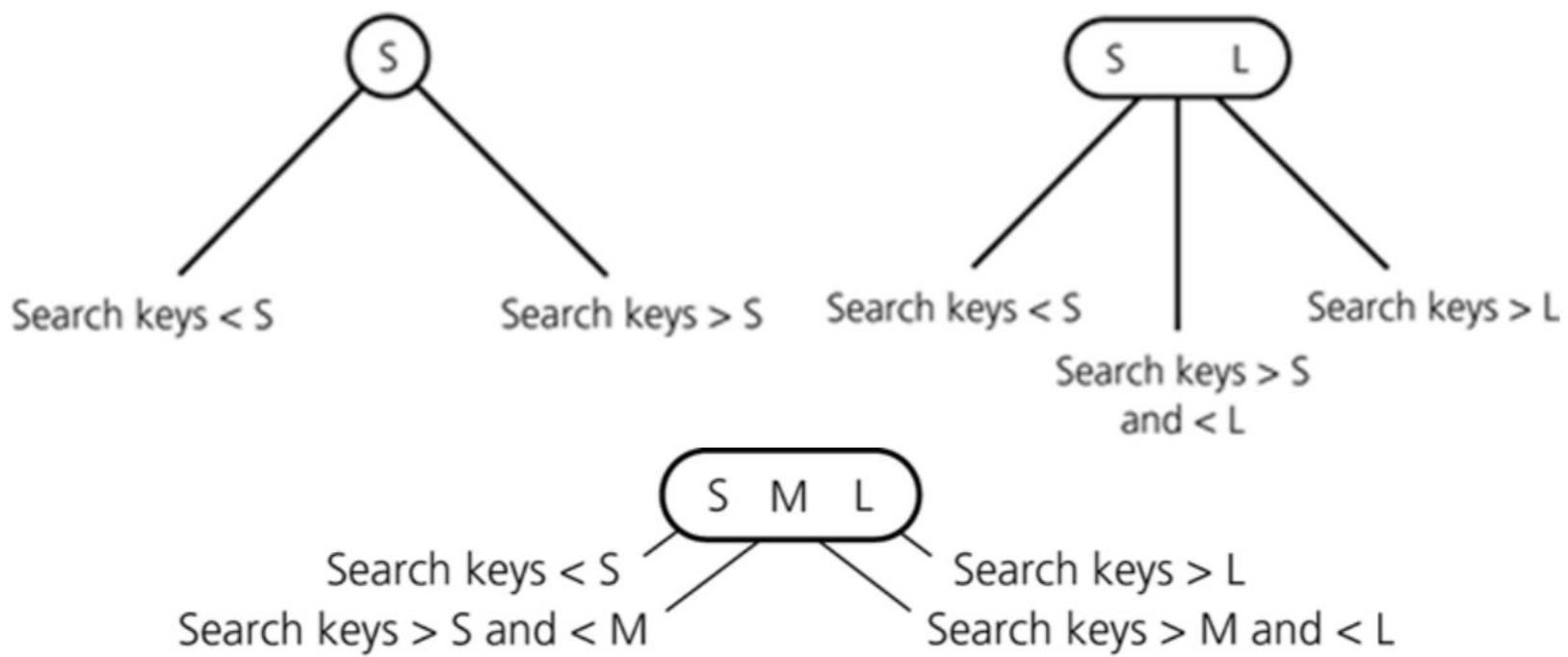
- In the worst case, searching a key in a BST is  $O(h)$ , where  $h$  is the height of the tree
- **Bad Tree**  $\rightarrow h \sim O(n)$ 
  - The BST is a skewed binary search tree (all the nodes except the leaf would have only one child)
  - This can happen if keys are inserted in sorted order
  - Height ( $h$ ) of the BST having  $n$  elements becomes  $n - 1$
  - Time complexity of search in BST becomes  $O(n)$
- **Good Tree**  $\rightarrow h \sim O(\log n)$ 
  - The BST is a balanced binary search tree
  - This is possible if
    - If keys are inserted in purely randomized order, Or
    - If the tree is explicitly balanced after every insertion
  - Height ( $h$ ) of the binary search tree becomes  $\log n$
  - Time complexity of search in BST becomes  $O(\log n)$

## Balanced Binary Search Trees

- A BST is balanced if  $h \sim O(\log n)$
- Balancing guarantees may be of various types →
  - Worst-case
    - AVL Tree: Self-balancing BST
      - Named after inventors Adelson-Velsky-Landis
      - Heights of the two child subtrees of any node differ by at most one:  $|h_L - h_R| \leq 1$
      - If they differ by more than one, rebalancing is done by rotation
    - Randomized
      - Randomized BST
        - A BST of  $n$  keys is random if either it is empty ( $n = 0$ ) or the probability that a given key is at the root is  $\frac{1}{n}$  and the left and the right subtrees are random
      - Skip List
        - A skip list is built (probabbilistically) in layers of ordered linked lists
    - Amortized
      - Splay
        - A BST where recently accessed elements are quick to access again
  - These data structures have the optimal complexity for the required operations →
    - Search:  $O(\log n)$
    - Insert: Search +  $O(1) \rightarrow O(\log n)$
    - Delete: Search +  $O(1) \rightarrow O(\log n)$
  - And they are →
    - Good for in-memory operations
    - Work well for small volume of data
    - Has complex rotation and/or similar operations
    - Do not scale for external data structures

## 2-3-4 Trees

- All leaves are at the same depth
  - Height,  $h$ , of all leaf nodes are the same
    - $h \sim O(\log n)$
    - Complexity of search, insert and delete  $\rightarrow O(h) \sim O(\log n)$
- All data is kept in sorted order
- Every node (leaf or internal) is a 2-node, 3-node or a 4-node (based on the number of links or children) and holds one, two or three data elements, respectively
- Generalizes easily to larger nodes
- Extends to external data structures
- Uses 3 kinds of nodes satisfying key relationships as shown below:
  - A 2-node must contain a single data item (S) and two links
  - A 3-node must contain two data items (S, L) and three links
  - A 4-node must contain three data items (S, M, L) and four links
  - A leaf may contain either one, two or three data items

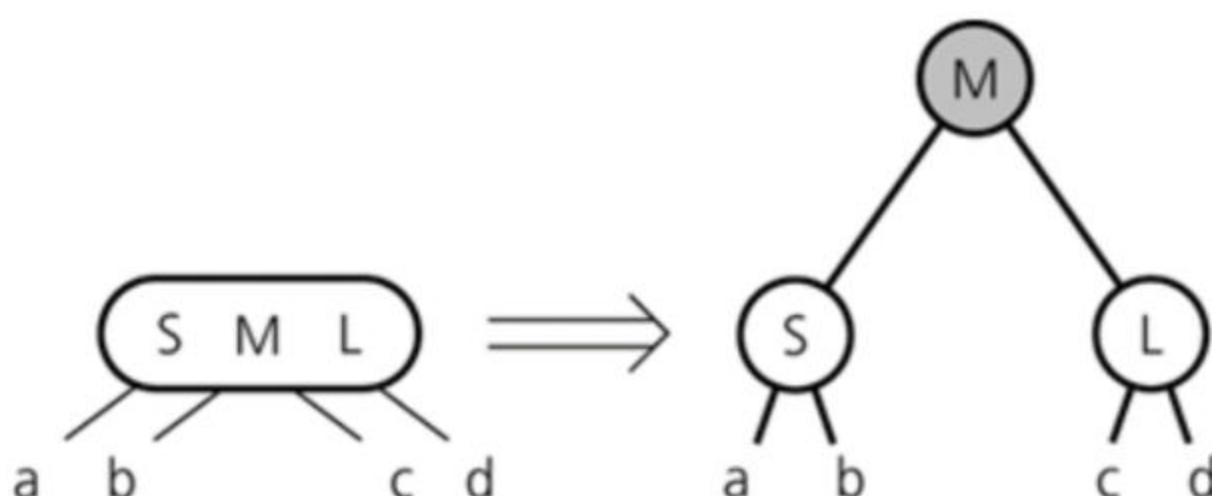


## 2-3-4 Trees → Search

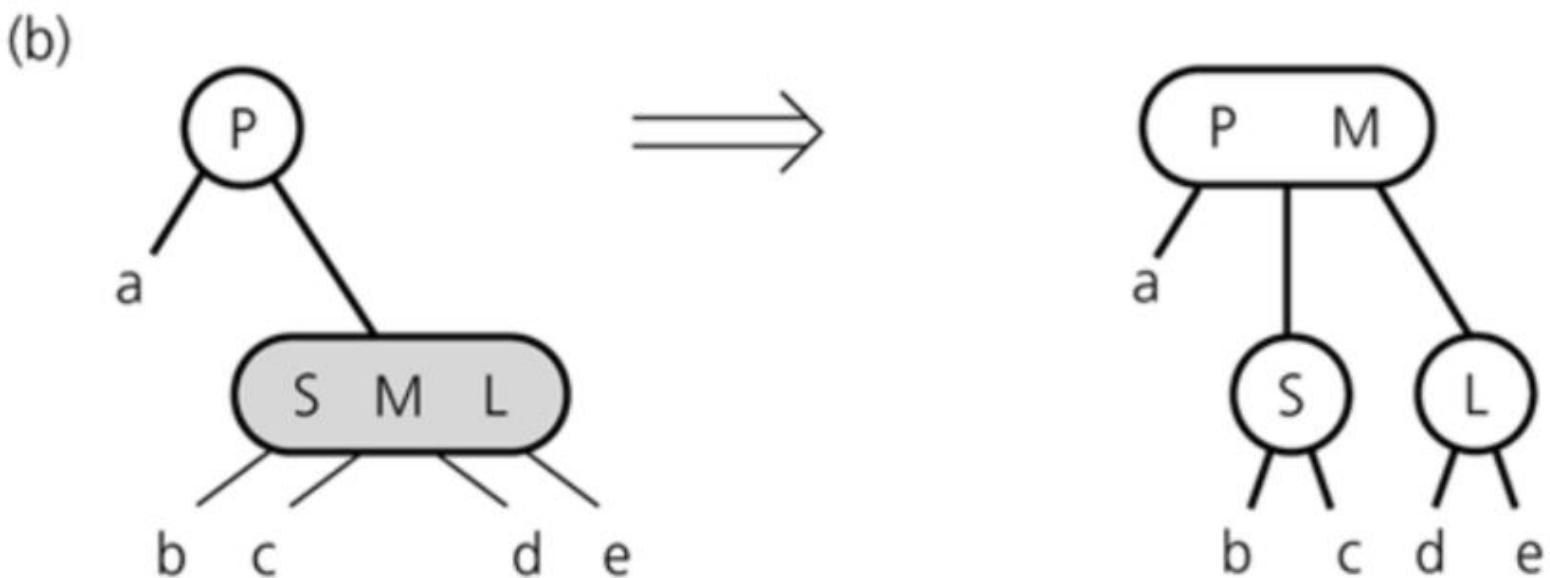
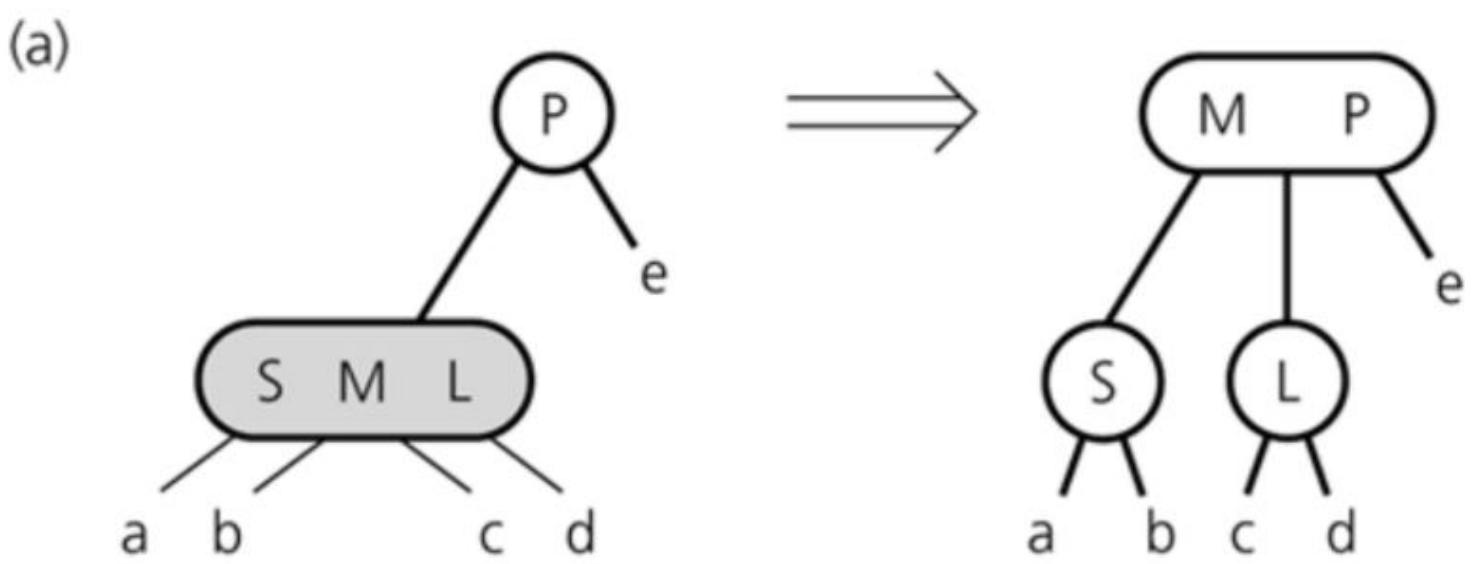
- Search
  - Simple and natural extension of search in BST

## 2-3-4 Trees → Insert

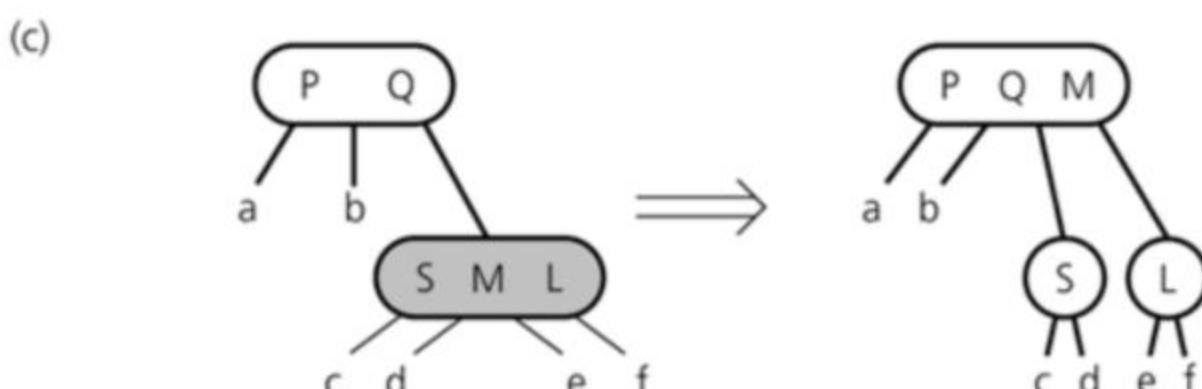
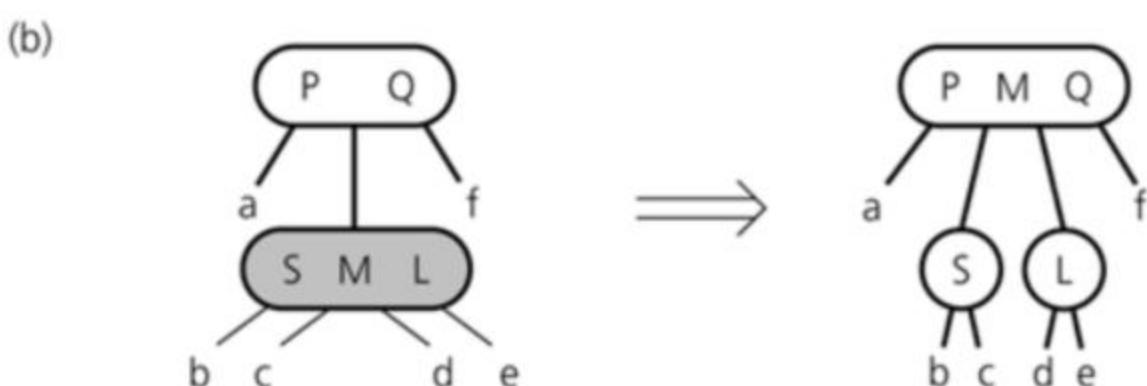
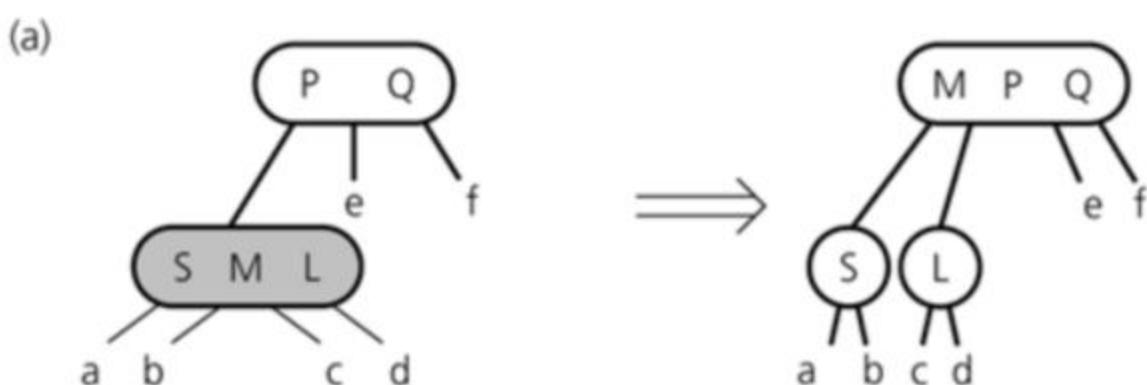
- Insert
  - Search to find the expected location
    - If it is a 2 node, change to 3 node and insert
    - If it is a 3 node, change to 4 node and insert
    - If it is a 4 node, split the node by moving the middle item to parent node and then insert
  - Node splitting
    - A 4-node is split as soon as it is encountered during a search from the root to a leaf
    - The 4-node that is split will
      - Be the root
      - Have a 2-node parent
      - Have a 3-node parent
- Splitting at Root



- Splitting with 2 Node parent



- Splitting with 3 Node parent

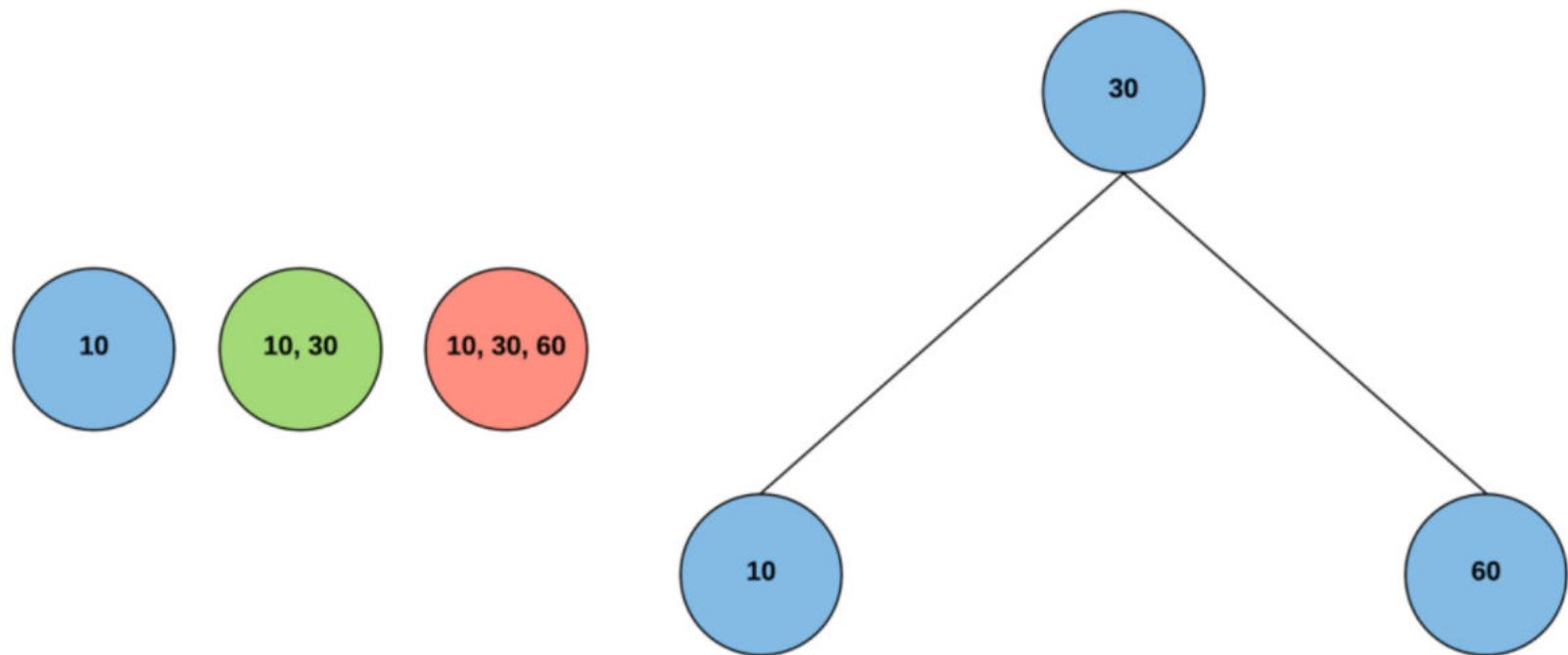


- Node Splitting: There are two strategies:
  - Early: Split a 4-node as soon as you cross on in traversal

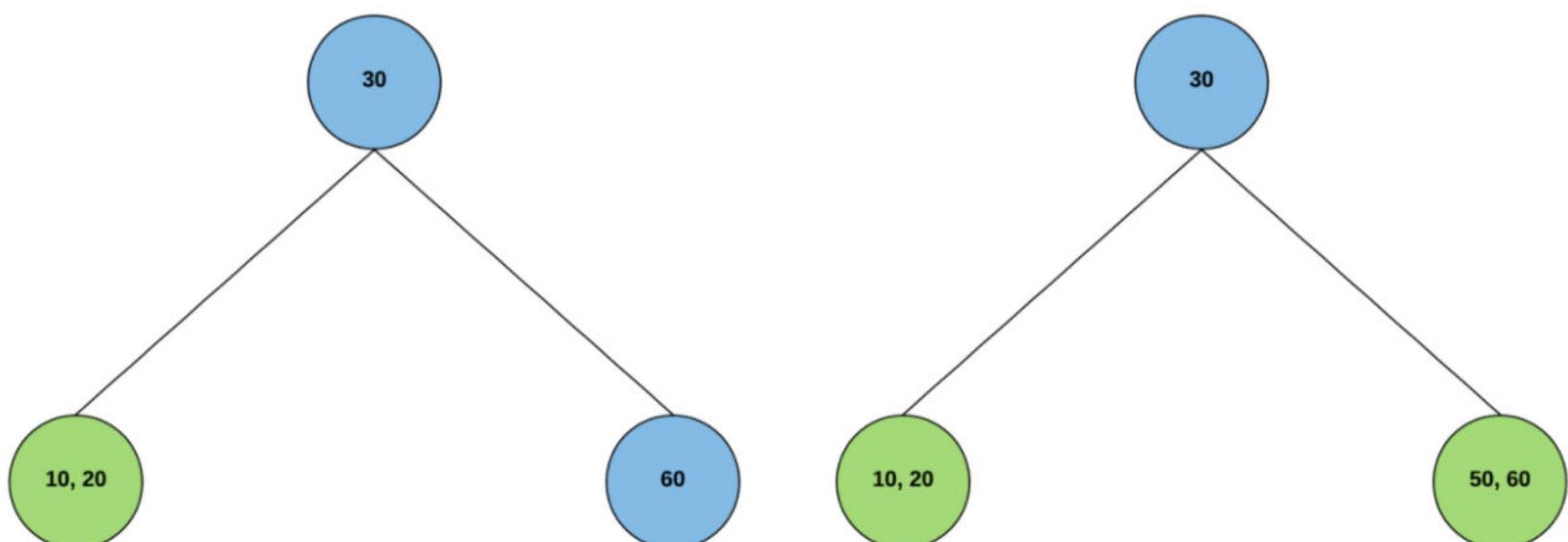
- It ensures that the tree does not have a path with multiple 4-nodes at any point
  - Late: Split a 4-node only when you need to insert an item in it
    - This might lead to cases where for one insert we may need to perform  $O(h)$  splits going till up to the root
- Both are valid and has the same complexity  $O(h)$ 
  - However, they lead to different results
  - Different texts and sites follow different strategies
- Here, we are following early strategy

### 2-3-4 Trees: Insert → Example

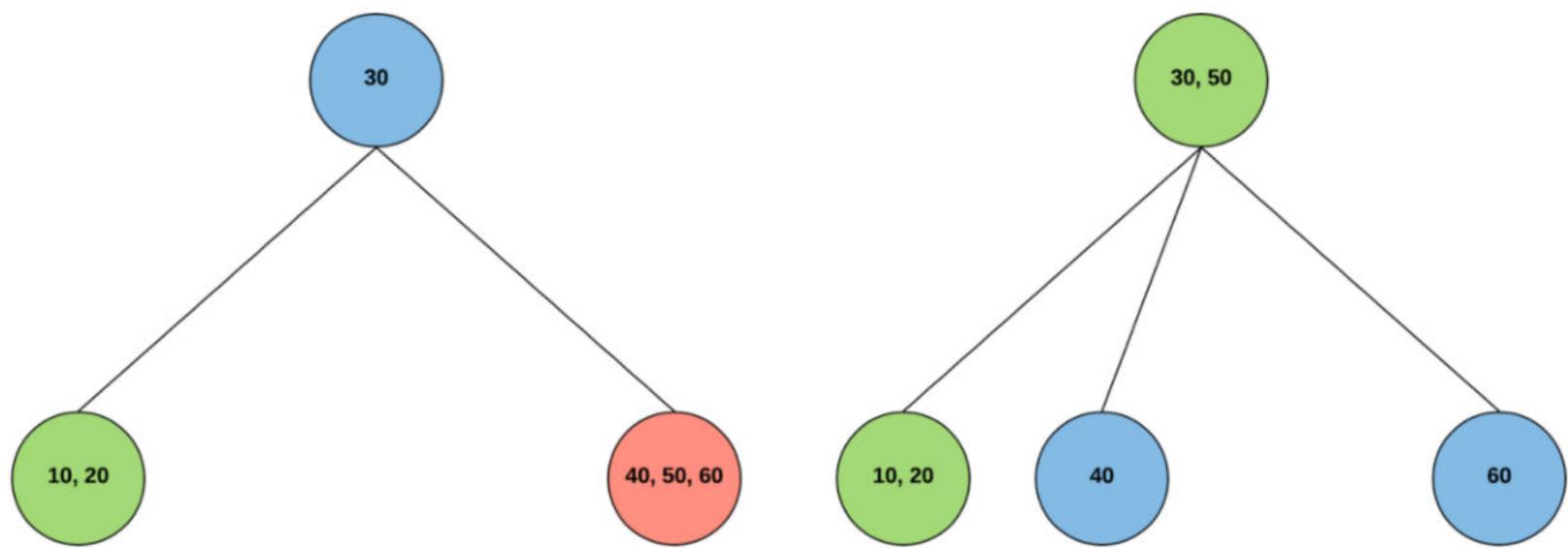
- Insert 10, 30, 60, 20, 50, 40, 70, 80, 15, 90, 100
- 10
- 10, 30
- 10, 30, 60
- Split for 20



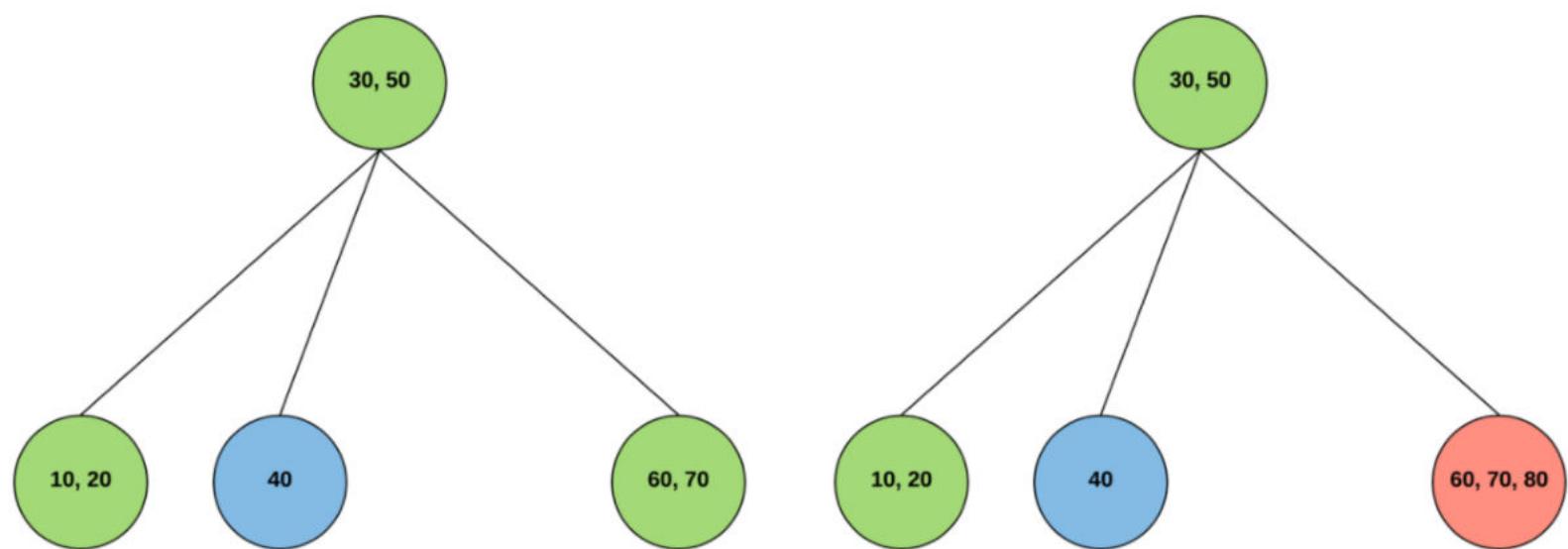
- 10, 30, 60, 20
- 10, 30, 60, 20, 50



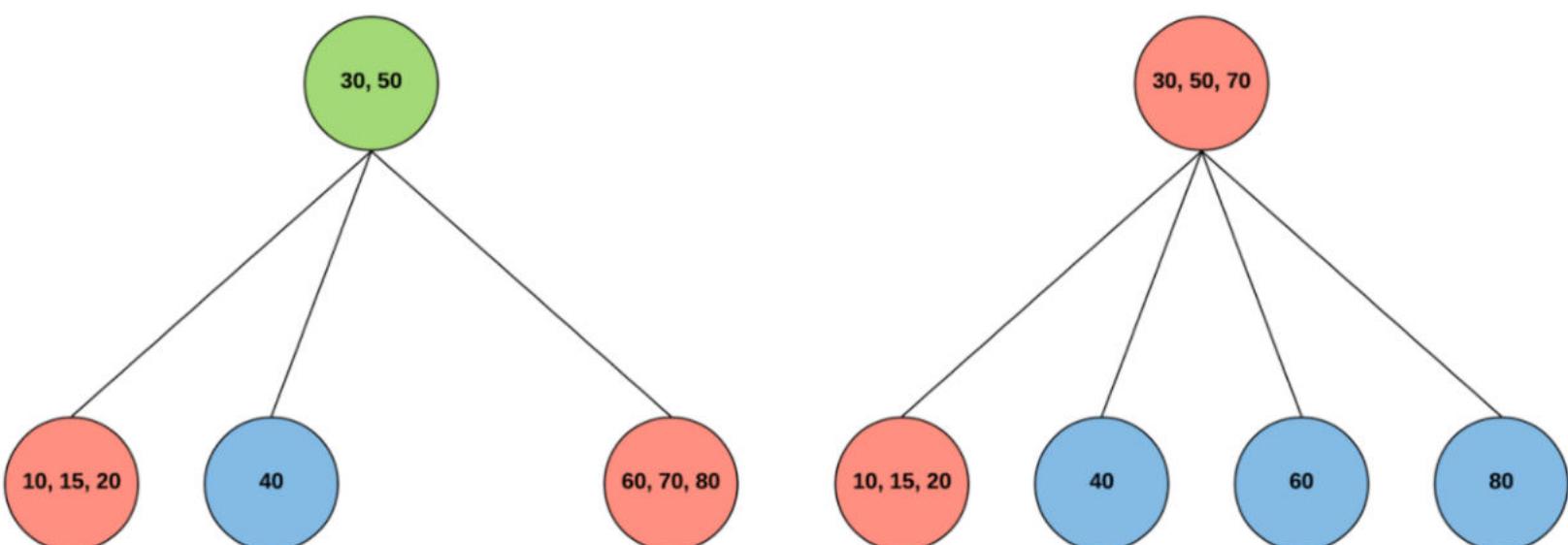
- 10, 30, 60, 20, 50, 40
- Split for 70



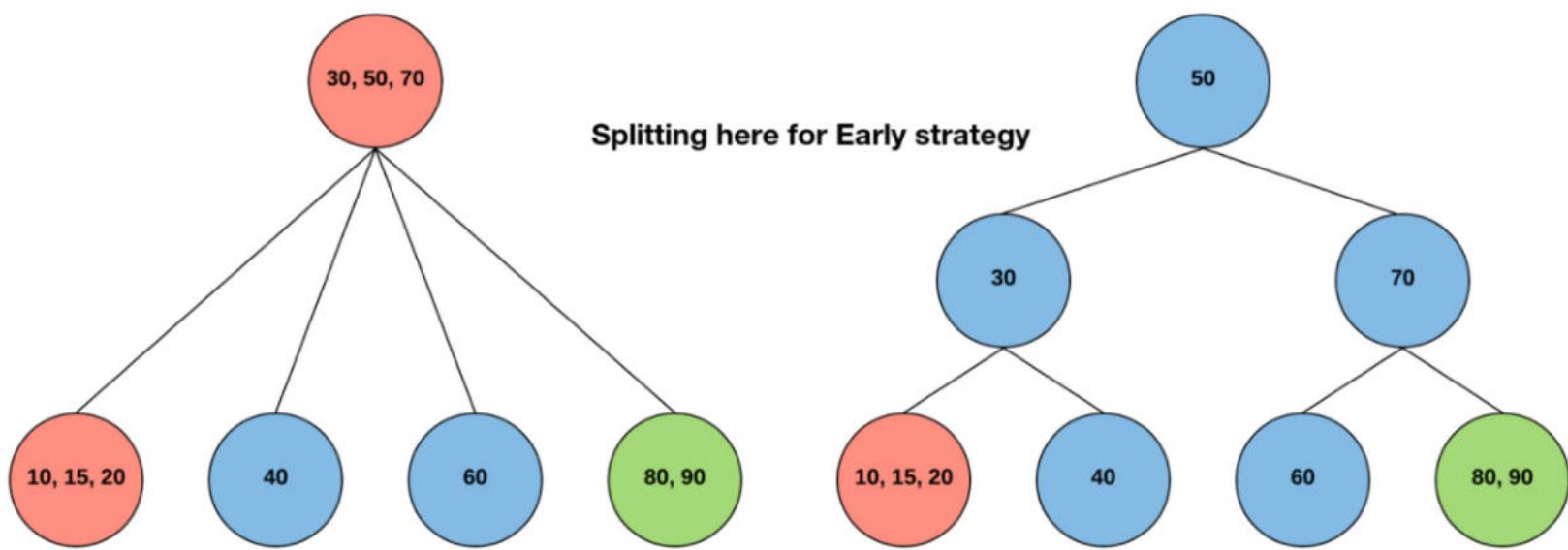
- 10, 30, 60, 20, 50, 40, 70
- 10, 30, 60, 20, 50, 40, 70, 80



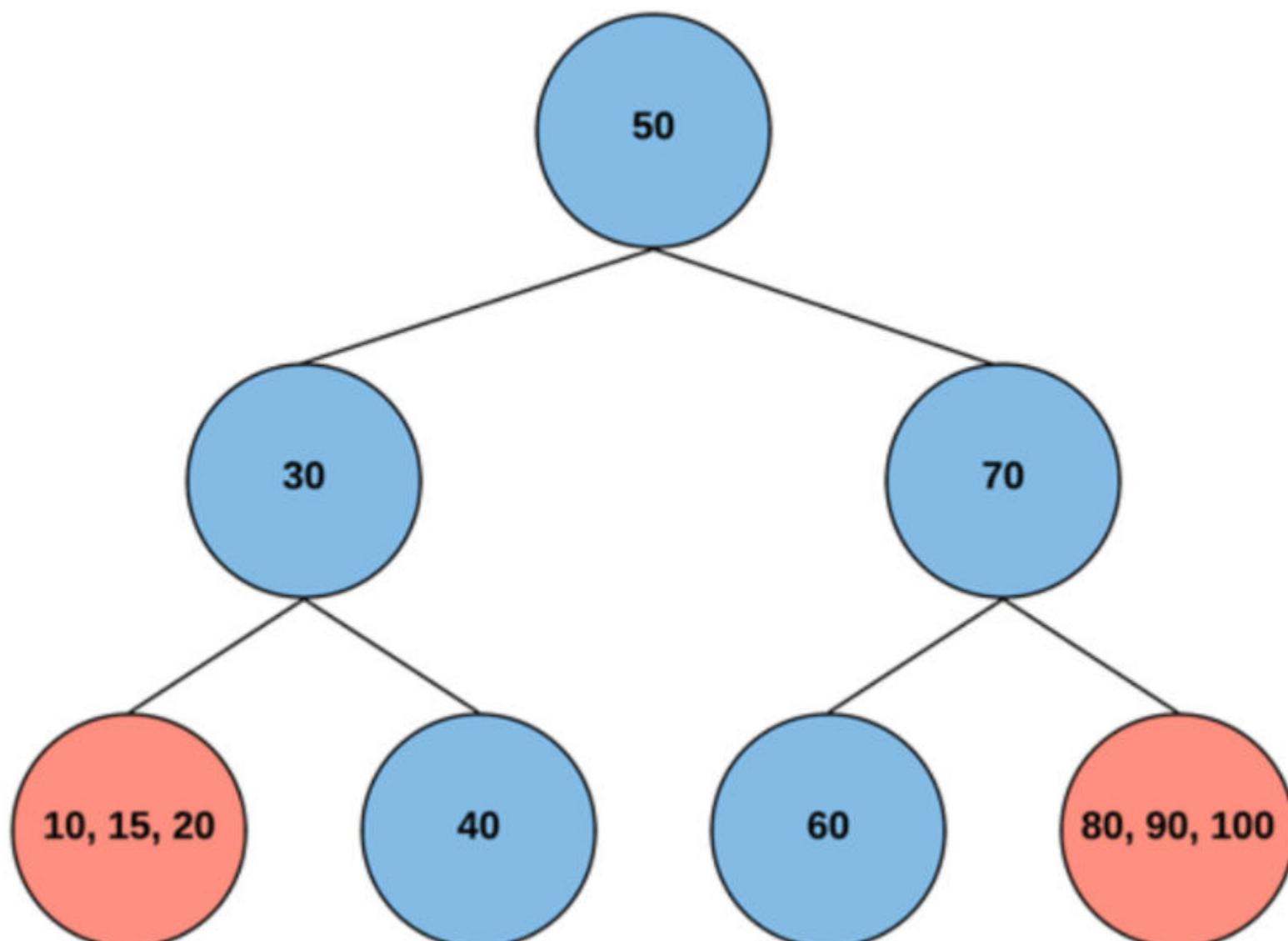
- 10, 30, 60, 20, 50, 40, 70, 80, 15
- Split for 90



- 10, 30, 60, 20, 50, 40, 70, 80, 15, 90
- Split for 100



- 10, 30, 60, 20, 50, 40, 70, 80, 15, 90, 100



## 2-3-4 Trees: Delete

- Delete
  - Locate the node  $n$  that contains the item `theItem`
  - Find `theItem`'s inorder successor and swap it with `theItem` (deletion will always be at the leaf)
  - If that leaf is a 3-node or a 4-node, remove `theItem`
  - To ensure that `theItem` does not occur in a 2-node
    - Transform each 2-node encountered into a 3-node or a 4-node
    - Reverse different cases illustrated for splitting

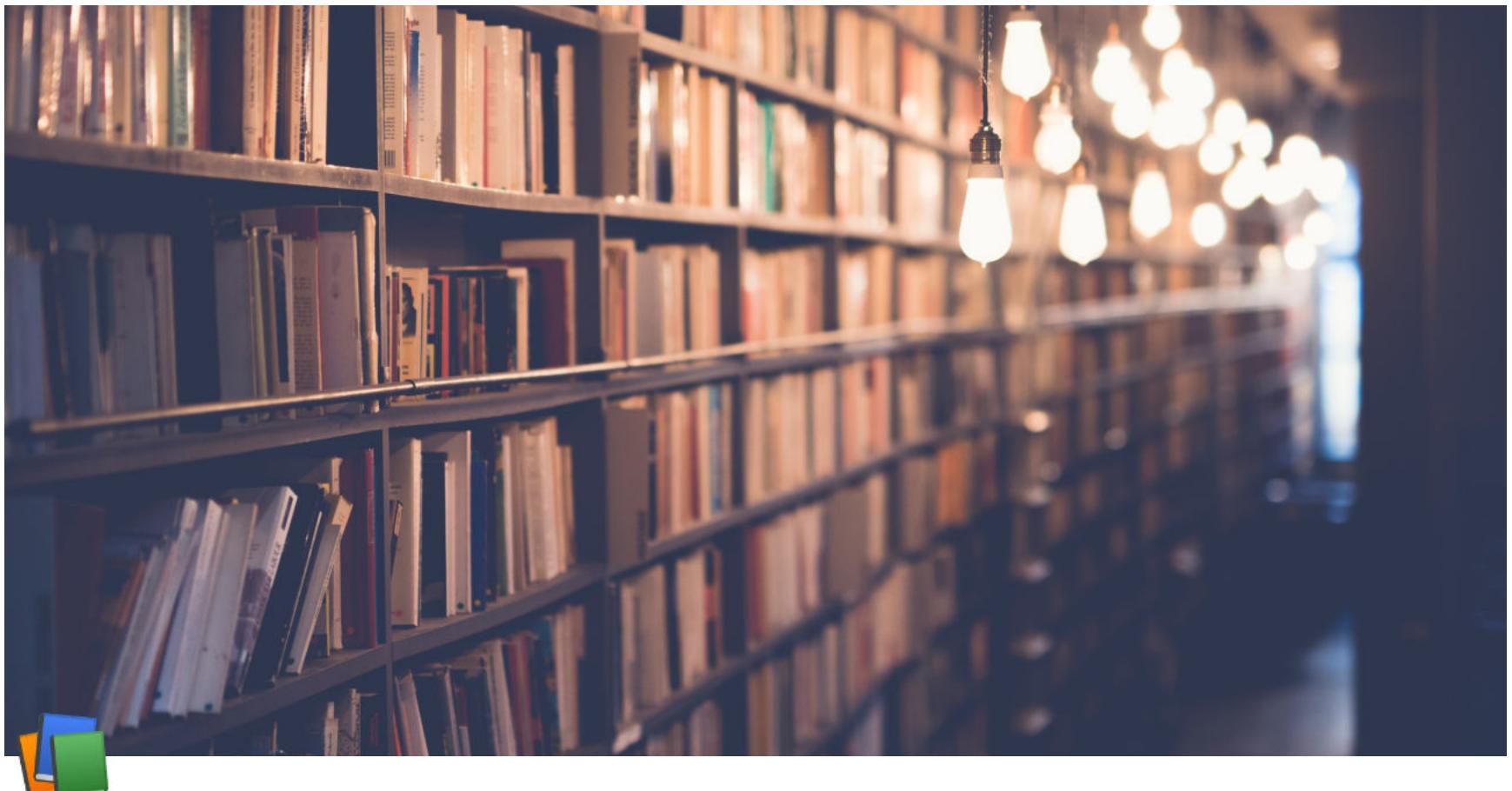
## 2-3-4 Tree

- Advantages
  - All leaves are at the same depth: Height,  $h \sim O(\log n)$
  - Complexity of search, insert and delete:  $O(h) \sim O(\log n)$

- All data is kept in sorted order
- Generalizes easily to larger nodes
- Extends to external data structures
- Disadvantages
  - Uses variety of node types — need to destruct and construct multiple nodes for converting a 2 Node to 3 Node, a 3 Node to a 4 Node, for splitting, etc

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- Consider only one node type with space for 3 items and 4 links
  - Internal node (non-root) has 2 to 4 children (links)
  - Leaf node has 1 to 3 items
  - Wastes some space, but has several advantages for external data structures
- Generalizes easily to larger nodes
  - All paths from root to leaf are of the same length
  - Each node that is not a root or a leaf has between  $\lceil \frac{n}{2} \rceil$  and  $n$  children
  - A leaf node has between  $\lceil \frac{(n-1)}{2} \rceil$  and  $n - 1$  values
  - Special cases
    - If the root is not a leaf, it has at least 2 children
    - If the root is a leaf, it can have between 0 and  $(n - 1)$  values
- Extends to external data structures
  - B-Tree
  - 2-3-4 Tree is a B-Tree when  $n = 4$



## Week 9 Lecture 3

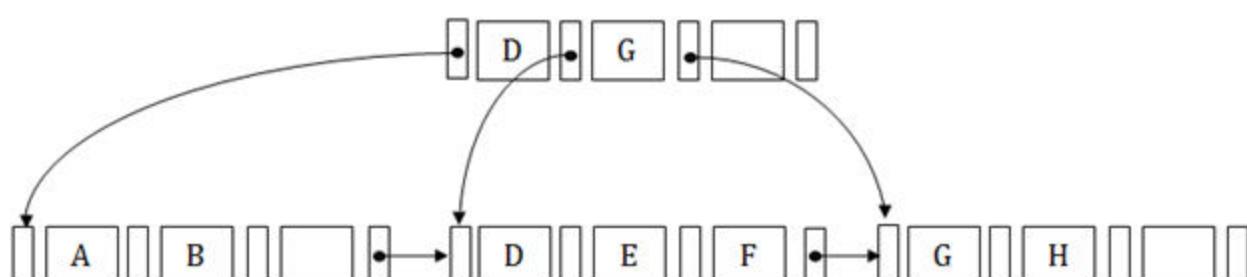
Class	BSCCS2001
Created	@November 2, 2021 5:49 PM
Materials	
Module #	43
Type	Lecture
# Week #	9

## Indexing and Hashing → Indexing (part 3)

### B<sup>+</sup> Tree Index Files

#### B<sup>+</sup> Tree

- It is a ***balanced binary search tree***
  - It follows a multi-level index format like 2-3-4 Tree
- It has the leaf nodes denoting actual data pointers
- Ensures that all leaf nodes remain at the same height (like 2-3-4 Tree)
- It has the leaf nodes that are linked using a linked list
  - It can support random access as well as sequential access
- Example

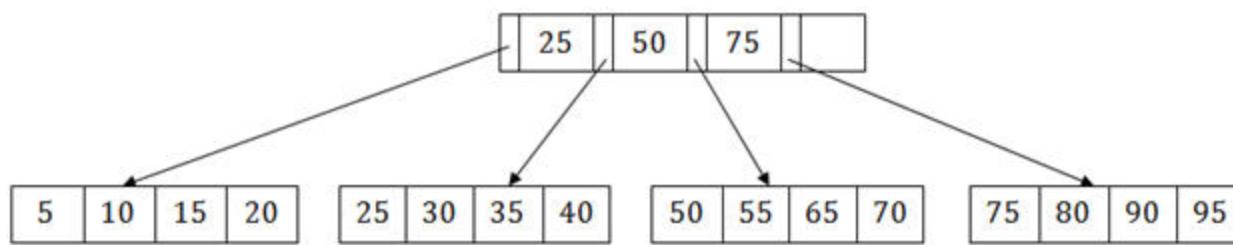


- Internal node contains
  - At least  $\frac{n}{2}$  child pointers, except the root node

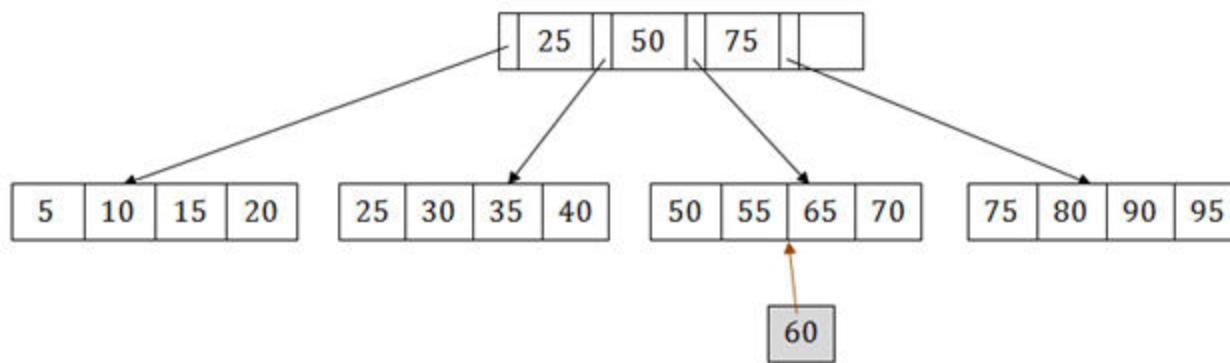
- At most  $n$  pointers
- Leaf node contains
  - At least  $\frac{n}{2}$  record pointers and  $\frac{n}{2}$  key values
  - At most  $n$  record pointers and  $n$  key values
  - One block pointer  $P$  to point to next leaf node

## B<sup>+</sup> Tree: Search

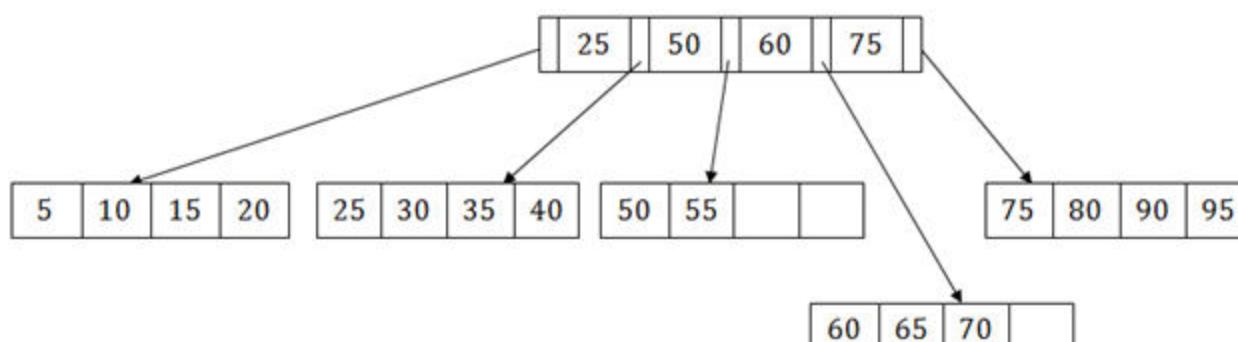
- Suppose we have to search 55 in the B<sup>+</sup> tree below
  - First, we will fetch for the intermediary node which will direct to the leaf node that can contain a record for 55
- So, in the intermediary node, we will find a branch between 50 and 75 nodes
  - Then at the end, we will be redirected to the third leaf node
  - Here DBMS will perform a sequential search to find 55



## B<sup>+</sup> Tree: Insert

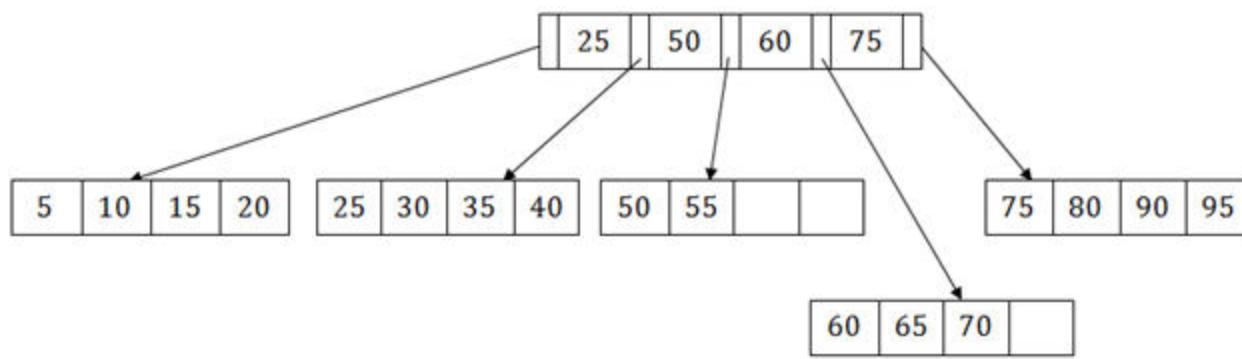


- Suppose we want to insert a record 60 that goes to the 3<sup>rd</sup> leaf node after 55
- The leaf node of this tree is already full, so we cannot insert 60 there
- So we have to split the leaf node, so that it can be inserted into tree without affecting the fill factor, balance and order
- The 3<sup>rd</sup> leaf node has the values (50, 55, 60, 65, 70) and its current root node is 50
- We will split the leaf node of the tree in the middle so that its balance is not altered

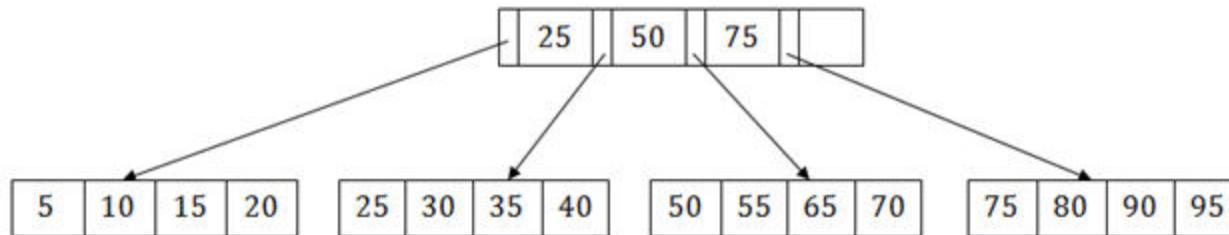


- So we can group (50, 55) and (60, 65, 70) into 2 leaf nodes
- If these two has to be leaf nodes, the intermediate node cannot branch from 50
- It should have 60 added to it, and then we can have pointers to a new leaf node
- This is how we can insert an entry when there is an overflow
  - In a normal scenario, it is very easy to find the node where it fits and then place it in that leaf node

## B<sup>+</sup> Tree: Delete



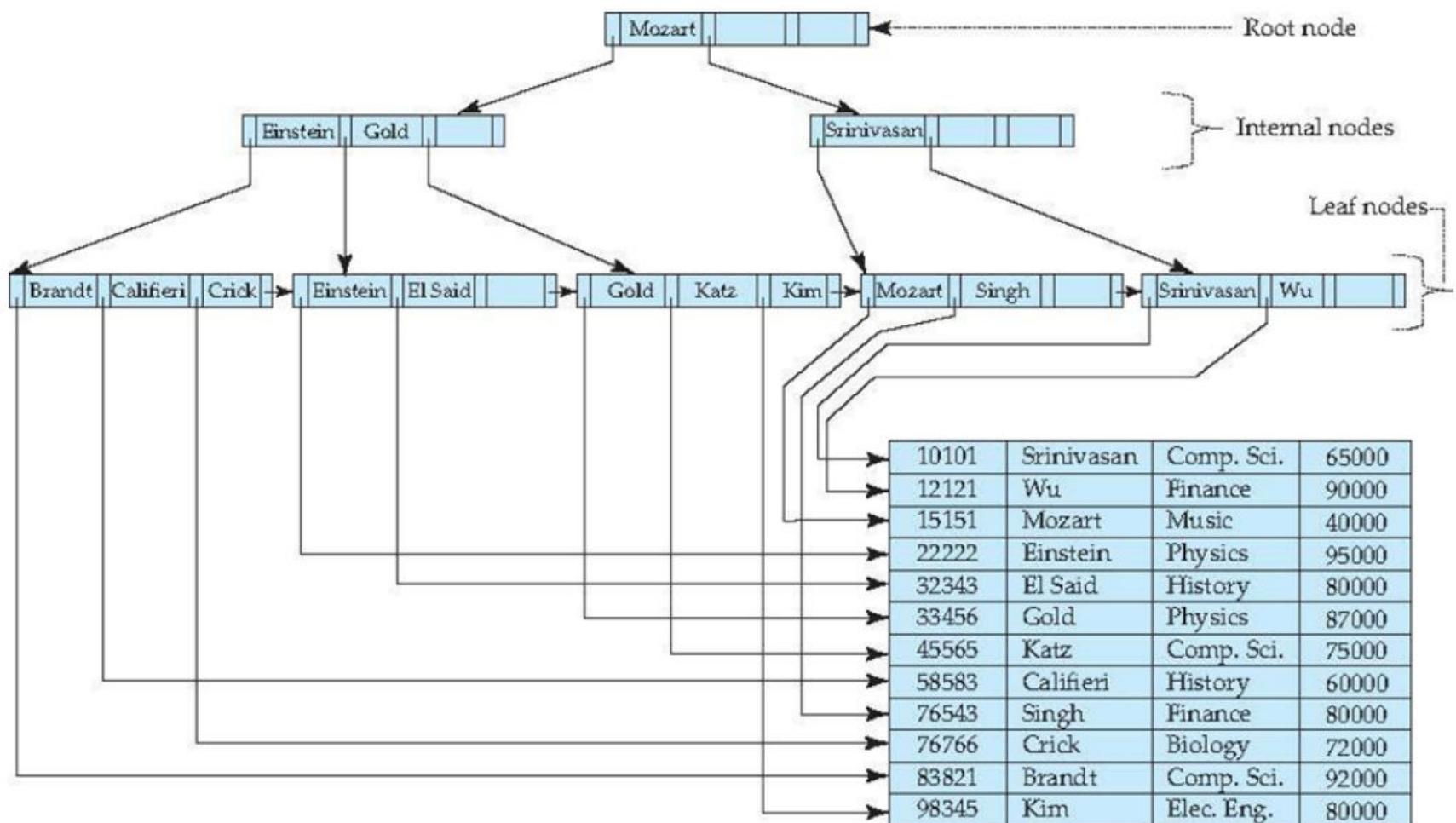
- To delete 60, we have to remove 60 from intermediate node as well as 4<sup>th</sup> leaf node
- If we remove it from the intermediate node, then the tree will not remain a B<sup>+</sup> tree
- So, with deleting 60 we rearrange the nodes



## B<sup>+</sup> Tree Index Files

- B<sup>+</sup> tree indices are an alternative to indexed-sequential files
- ***Disadvantages of ISAM files***
  - Performance degrades as file grows, since many overflow blocks get created
  - Periodic re-organization of entire file is required
- ***Advantages of B<sup>+</sup> tree index files***
  - Automatically re-organizes itself with small, local, changes in the face of insertions and deletions
  - Re-organization of entire file is not required to maintain performance
- **Minor disadvantage of B<sup>+</sup> trees:**
  - Extra insertion and deletion overhead, space overhead
- **Advantages of B<sup>+</sup> trees outweigh disadvantages**
  - B<sup>+</sup> trees are used extensively

## B<sup>+</sup> Tree Index Files: Example



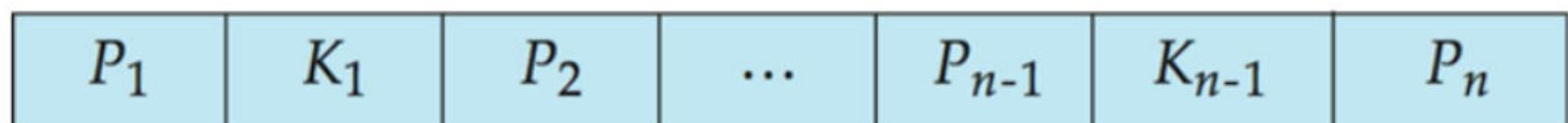
## B<sup>+</sup> Tree Index Files: Structure

A B<sup>+</sup> tree is a rooted tree satisfying the following properties:

- All paths from the root to leaf are the same of the same length
- Each node that is not a root node or a leaf node has between  $\lceil \frac{n}{2} \rceil$  and  $n$  children
- A leaf node has between  $\lceil \frac{n-1}{2} \rceil$  and  $n - 1$  values
- Special cases:
  - If the root is not a leaf, it has at least 2 children
  - If the root is a leaf (that is, there are no other nodes in the tree) it can have between 0 and  $(n - 1)$  values

## B<sup>+</sup> Tree Index Files: Node Structure

- Typical node



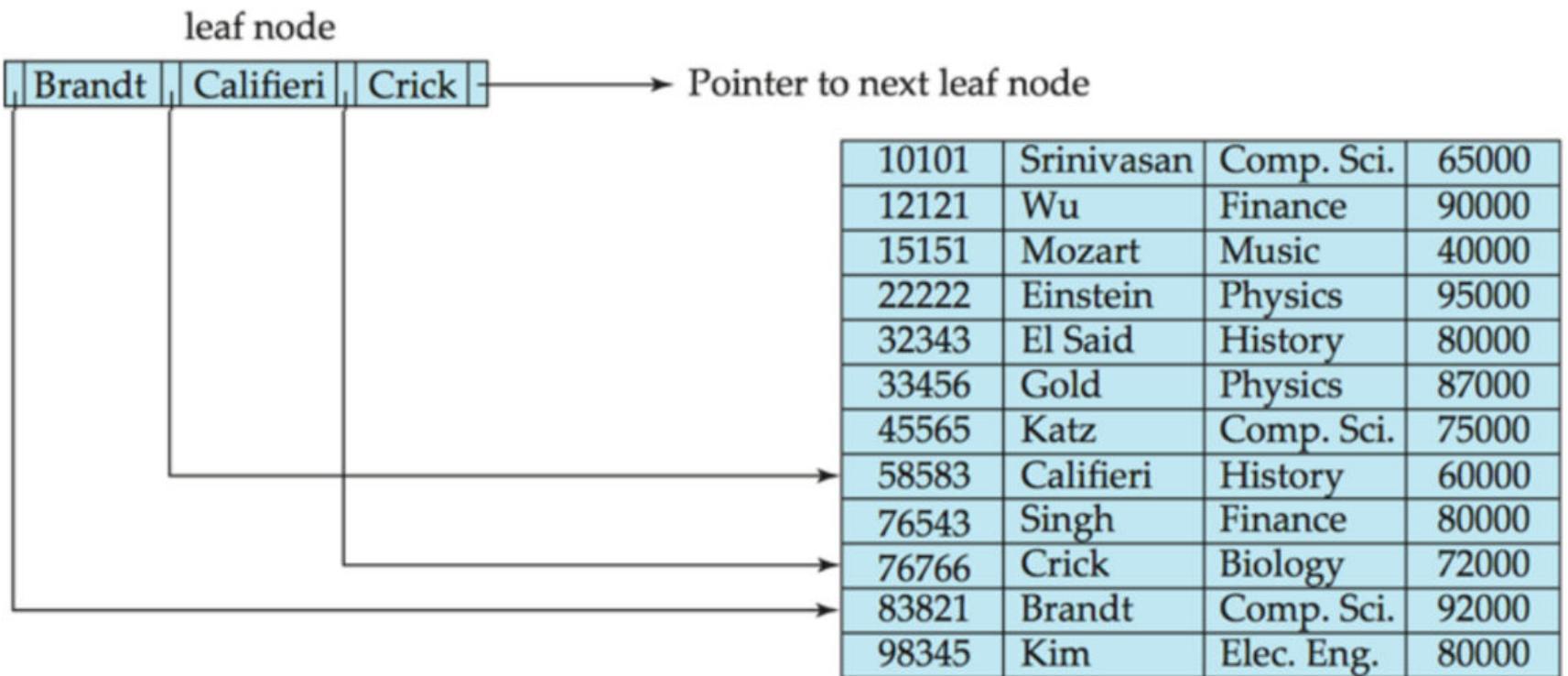
- $K_i$  are the search-key values
- $P_i$  are the pointers to children (for non-leaf nodes) or pointers to records or buckets of records (for leaf nodes)
- The search-keys in a node are ordered  

$$K_1 < K_2 < K_3 < \dots < K_{n-1}$$

(initially, assume no duplicate keys, address duplicates later)

## B<sup>+</sup> Tree Index Files: Leaf Nodes

- For  $i = 1, 2, \dots, n - 1$ , pointer  $P_i$  points to a file record with search-key value  $K_i$
- If  $L_i, L_j$  are leaf nodes and  $i < j$ ,  $L_i$ 's search-key values are less than or equal to  $L_j$ 's search-key values
- $P_n$  points to next leaf node in search-key order

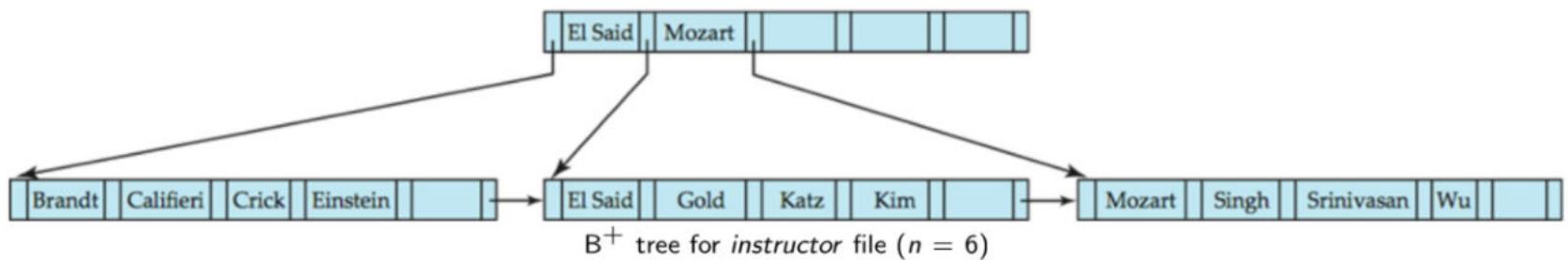


### B<sup>+</sup> Tree Index Files: Non-Leaf Nodes

- Non-leaf nodes form a multi-level sparse index on the leaf nodes
- For a non-leaf node with  $m$  pointers
  - All the search-keys in the sub-tree to which  $P_1$  points are less than  $K_1$
  - For  $2 \leq i \leq n - 1$ , all the search-keys in the sub-tree to which  $P_i$  points have values greater than or equal to  $K_{i-1}$  and less than  $K_i$
  - All the search-keys in the sub-tree to which  $P_n$  points have values greater than or equal to  $K_{n-1}$

$P_1$	$K_1$	$P_2$	...	$P_{n-1}$	$K_{n-1}$	$P_n$
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### B<sup>+</sup> Tree Index Files: Examples



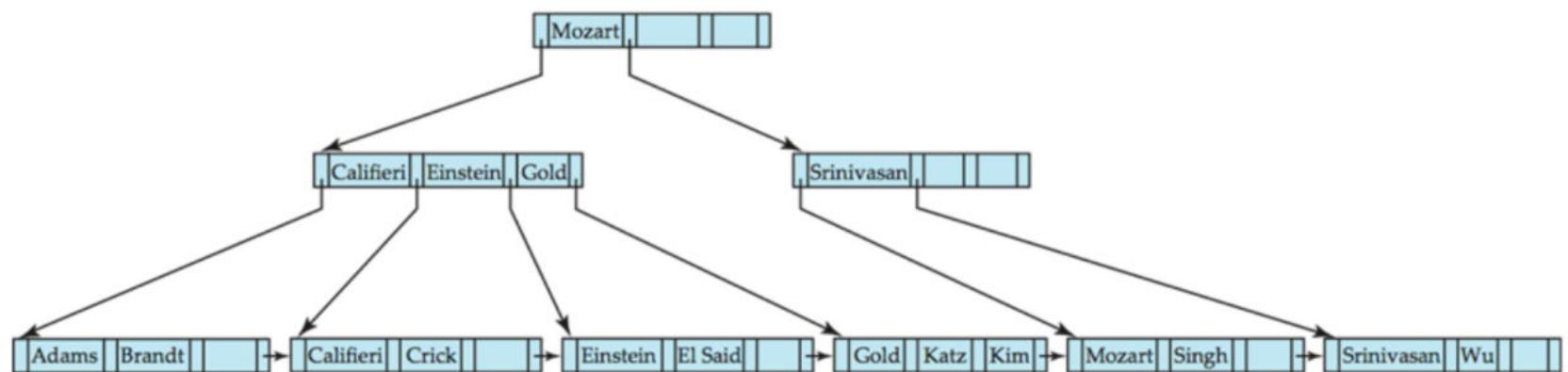
- Leaf nodes must have between 3 and 5 values:  $\lceil \frac{n-1}{2} \rceil$  and  $n - 1$ , with  $n = 6$
- Non-leaf nodes other than root must have between 3 and 6 children:  $\lceil \frac{n}{2} \rceil$  and  $n$  with  $n = 6$
- Root must have at least 2 children

### B<sup>+</sup> Tree Index Files: Observations

- Since the inter-node connections are done by pointers, logically close blocks need not be physically close
- The non-leaf levels of the B<sup>+</sup> tree form a hierarchy of sparse indices
- The B<sup>+</sup> tree contains a relatively small number of levels
  - Level below root has at least  $2 * \lceil \frac{n}{2} \rceil$
  - Next level has at least  $2 * \lceil \frac{n}{2} \rceil * \lceil \frac{n}{2} \rceil$  values
  - ... etc.
  - If there are K search-key values in the file, the tree height is no more than  $\lceil \log_{\lceil \frac{n}{2} \rceil}(K) \rceil$
  - thus searches can be conducted efficiently
- Insertions and deletions to the main file can be handled efficiently, as the index can be restructured in logarithmic time

## B<sup>+</sup> Tree Index Files: Queries

- Find record with search-key value V
  - C = root
  - While C is not a leaf node
    - Let i be least value such that  $V \leq K_i$
    - If no such exists, set C = last non-null pointer in C
    - Else {if ( $V = K_i$ ) Set  $C = P_{i+1}$  else set  $C = P_i$ }
  - Let i be least value s.t.  $K_i = V$
  - If there is such a value i, follow pointer  $P_i$  to the desired record
  - Else no record with search-key value k exists



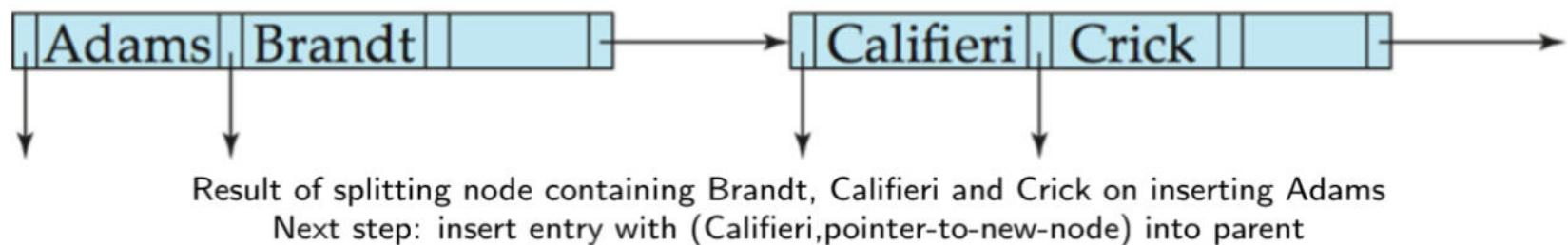
- If there are K search-key values in the file, the height of the tree is no more than  $\lceil \log_{\lceil \frac{n}{2} \rceil}(K) \rceil$
- A node is generally the same size as a disk block, typically 4 kilobytes
  - and n is typically around 100 (40 bytes per index entry)
- With 1 million search key values and n = 100
  - at most  $\log_{50}(1,000,000) = 4$  nodes are accessed in a lookup
- Contrast this with a balanced binary tree with 1 million search key values — around 20 nodes are accessed with a lookup
  - above difference is significant since every node access may need a disk I/O, costing around 20 milliseconds

## B<sup>+</sup> Tree Index Files: Handling Duplicates

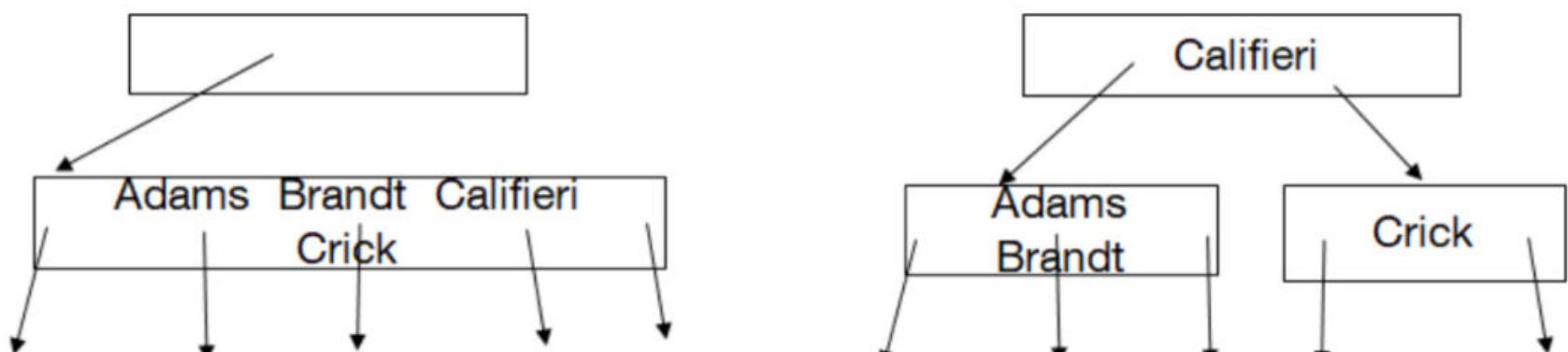
- With duplicate search keys
  - In both leaf and internal nodes
    - we cannot guarantee that  $K_1 < K_2 < K_3 < \dots < K_{n-1}$
    - but can guarantee  $K_1 \leq K_2 \leq K_3 \leq \dots \leq K_{n-1}$
  - Search-keys in the sub-tree to which  $P_i$  points
    - are  $\leq K_i$ , but not necessarily  $< K_i$
    - to see why, suppose same search-key value V is present in two leaf node  $L_i$  and  $L_{i+1}$ 
      - Then in parent node  $K_i$  must be equal to V
- We modify the procedures as follows
  - traverse  $P_i$  even if  $V = K_i$
  - As soon as we reach a leaf node C check if C has only search key values less than V
    - if so set C = right sibling of C before checking whether C contains V
- Procedure `printAll`
  - uses modified find procedure to find the first occurrence of V
  - traverse through consecutive leaves to find all occurrences of V

## Updates on B<sup>+</sup> Trees: Insertion

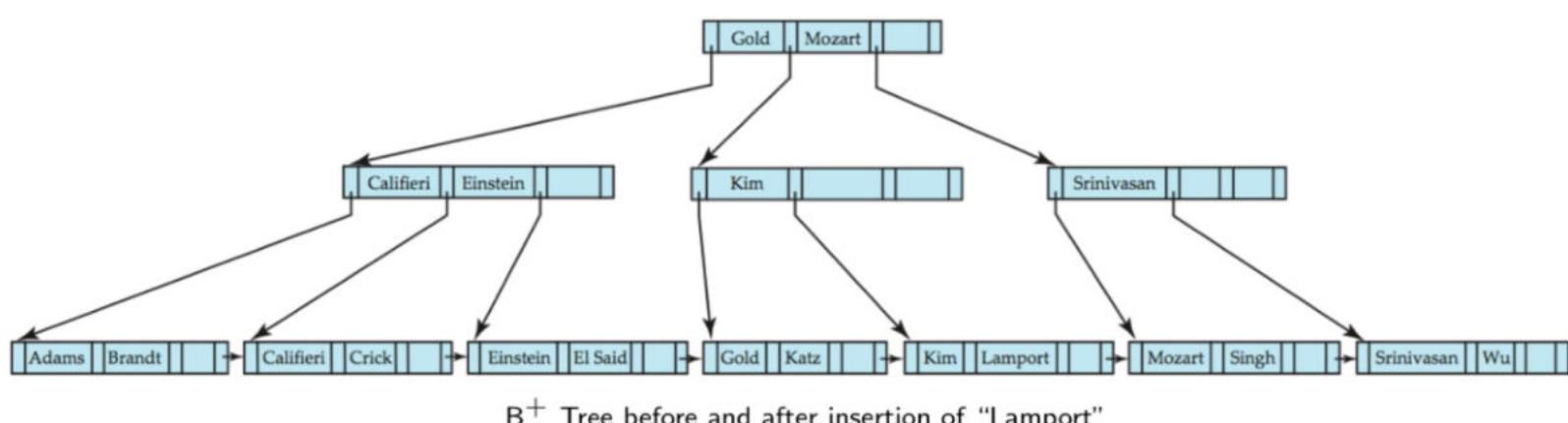
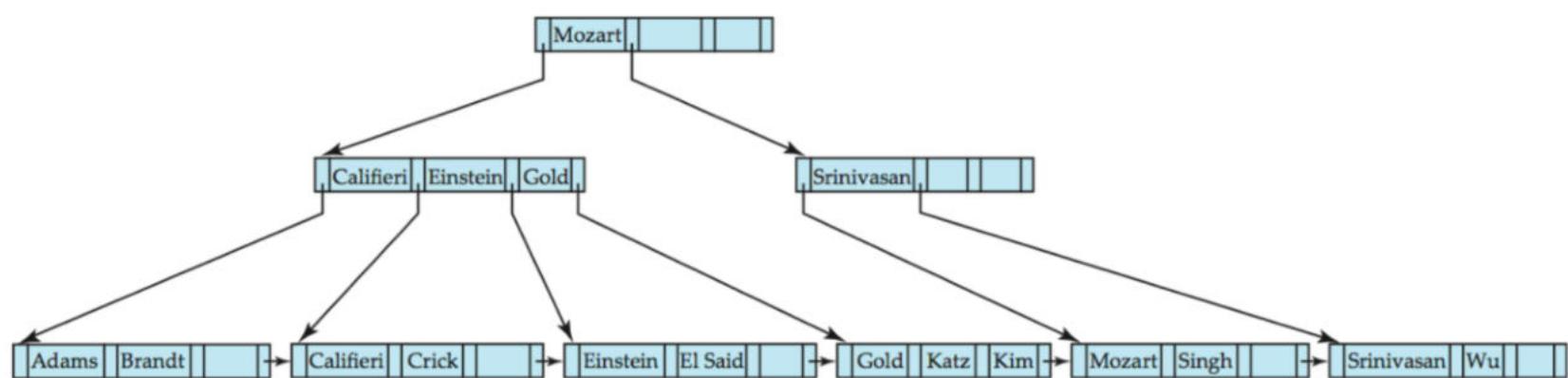
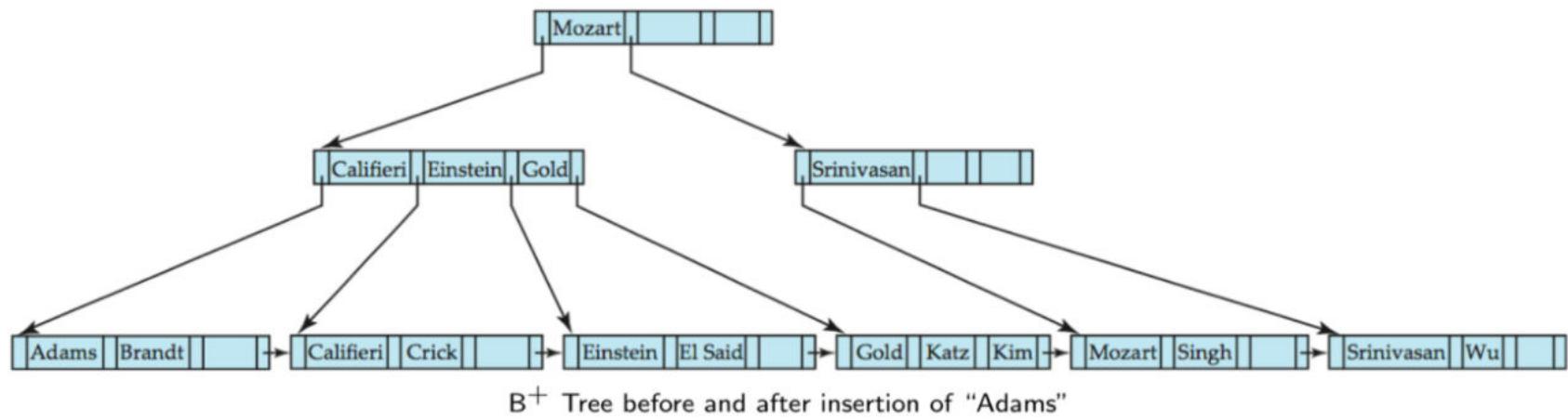
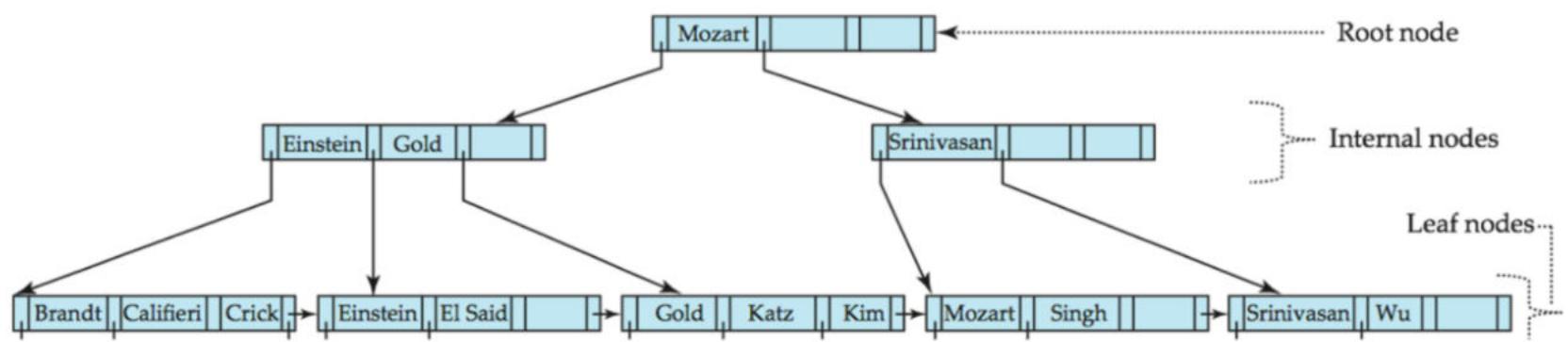
- Find the leaf node in which the search-key value would appear
- If the search-key value is already present in the leaf node
  - Add record to the file
  - If necessary, add a pointer to the bucket
- If the search-key value is not present, then
  - Add the record to the main file (and create a bucket if necessary)
  - If there is room in leaf node, insert (key-value, pointer) pair in the leaf node
  - Otherwise, split the node (along with the new (key-value, pointer) entry)
- Splitting a leaf node:
  - take the  $n$  (search-key value, pointer) pairs (including the one being inserted) in sorted order
    - Place the first  $\lceil \frac{n}{2} \rceil$  in the original node, and the rest in a new node
  - let the new node be  $p$  and let  $k$  be the least key value in  $p$ 
    - Insert  $(k, p)$  in the parent of the node being split
  - if the parent is full, split it and **propagate** the split further up
- Splitting of nodes proceeds upwards till a node that is not full is found
  - in the worst case, the root node may be split increasing the height of the tree by 1



- Splitting a non-leaf node → when inserting  $(k, p)$  into an already full internal node  $N$ 
  - Copy  $N$  to an in-memory area  $M$  with space for  $n + 1$  pointers and  $n$  keys
  - Insert  $(k, p)$  into  $M$
  - Copy  $P_1, K_1, \dots, K_{\lceil \frac{n}{2} \rceil - 1}, \dots, P_{\lceil \frac{n}{2} \rceil}$  from  $M$  back into node  $N$
  - Copy  $P_{\lceil \frac{n}{2} \rceil + 1}, K_{\lceil \frac{n}{2} \rceil + 1}, \dots, K_n, P_{n+1}$  from  $M$  into newly allocated node  $N'$
  - Insert  $(K_{\lceil \frac{n}{2} \rceil}, N')$  into parent  $N$



## Updates on B<sup>+</sup> Trees: Insertion Example

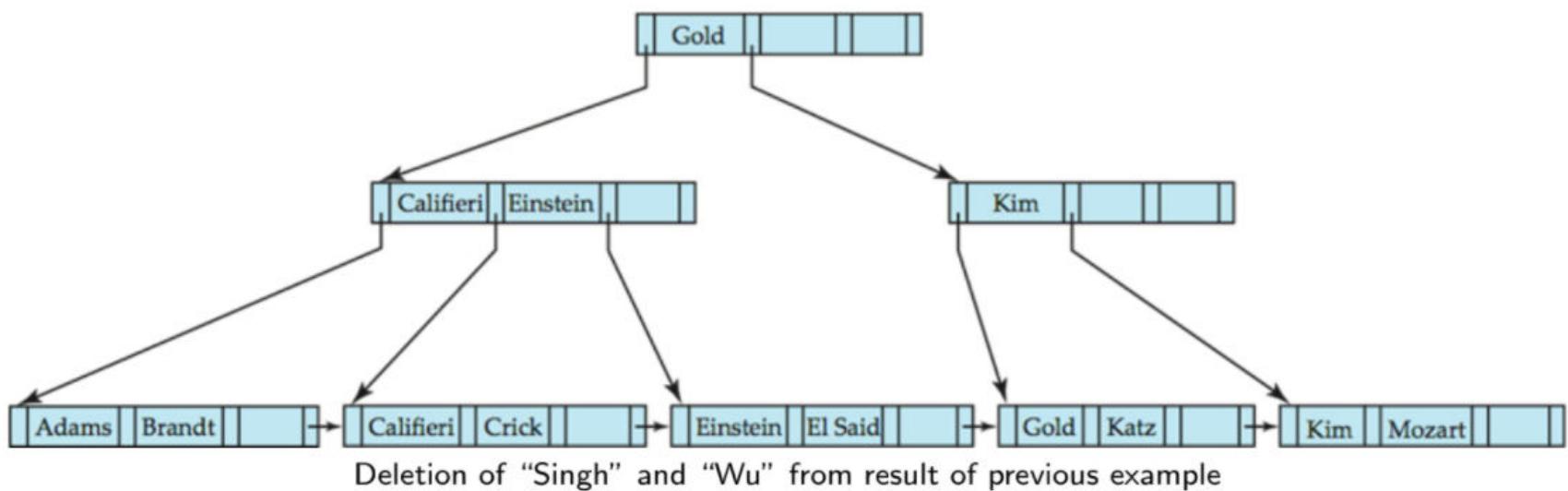
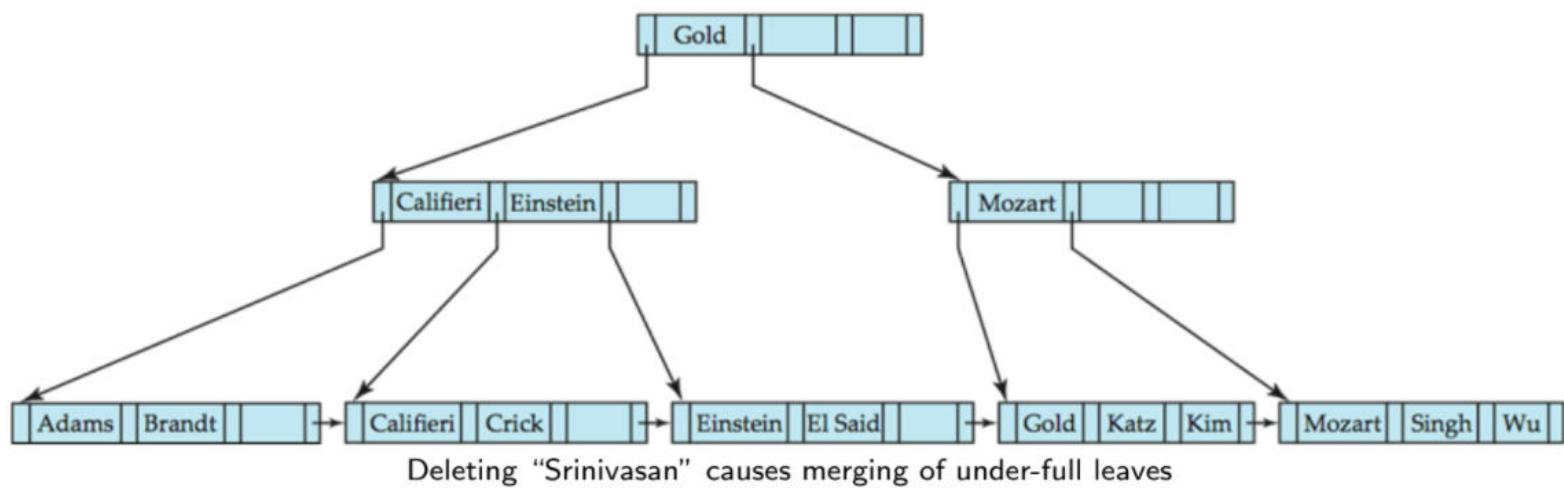
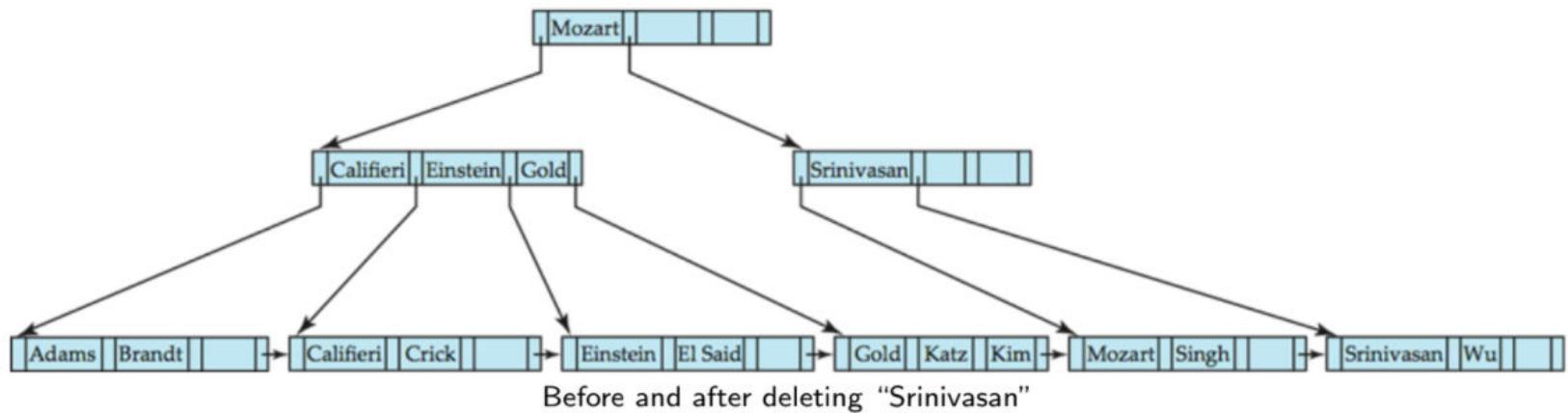


## Updates on B<sup>+</sup> Trees: Deletion

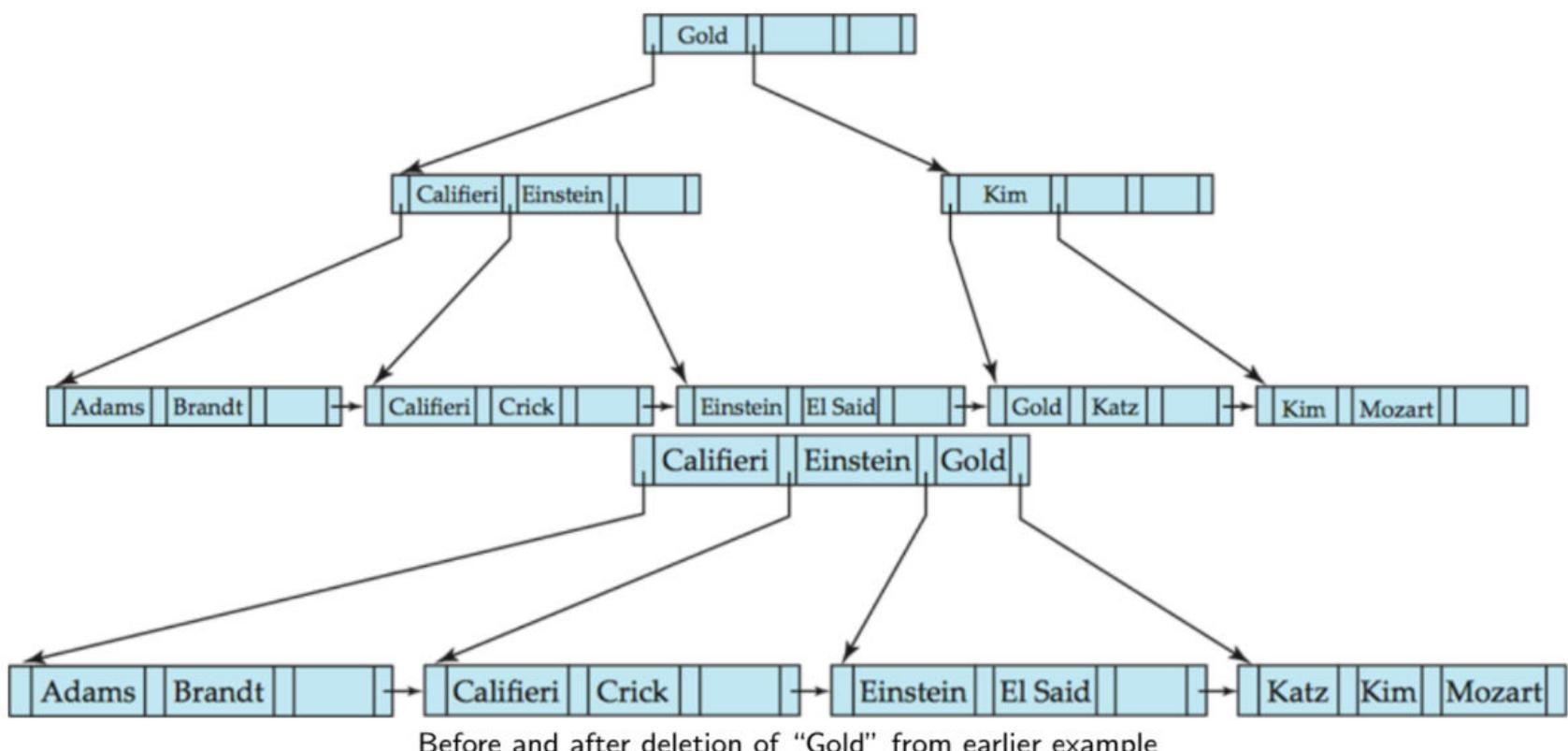
- Find the record to be deleted, and remove it from the main file and from the bucket (if present)
- Remove (search-key value, pointer) from the leaf node if there is no bucket or if the bucket has become empty
- If the node has too few entries due to the removal, and the entries in the node and a sibling fit into a single node, then merge siblings:
  - Insert all the search-key values in the two nodes into a single node (the one of the left) and delete the other node
  - Delete the pair  $(K_{i-1}, P_i)$  where  $P_i$  is the pointer to the deleted node, from its parent, recursively using the above procedure
- Otherwise, if the node has too few entries due to the removal, but the entries in the node and a sibling do not fit into a single node, then redistribute pointers:
  - Redistribute the pointers between the node and a sibling such that both have more than the minimum number of entries
  - Update the corresponding search-key value in the parent of the node

- The node deletions may cascade upwards till a node which has  $\lceil \frac{n}{2} \rceil$  or more pointers is found
- If the root node has only one pointer after deletion, it is deleted and the sole child becomes the root

## Updates on B<sup>+</sup> Trees: Deletion Example



- Leaf containing Singh and Wu became underfull, and borrowed a value from Kim from its left sibling
- Search-key value in the parent changes as a result

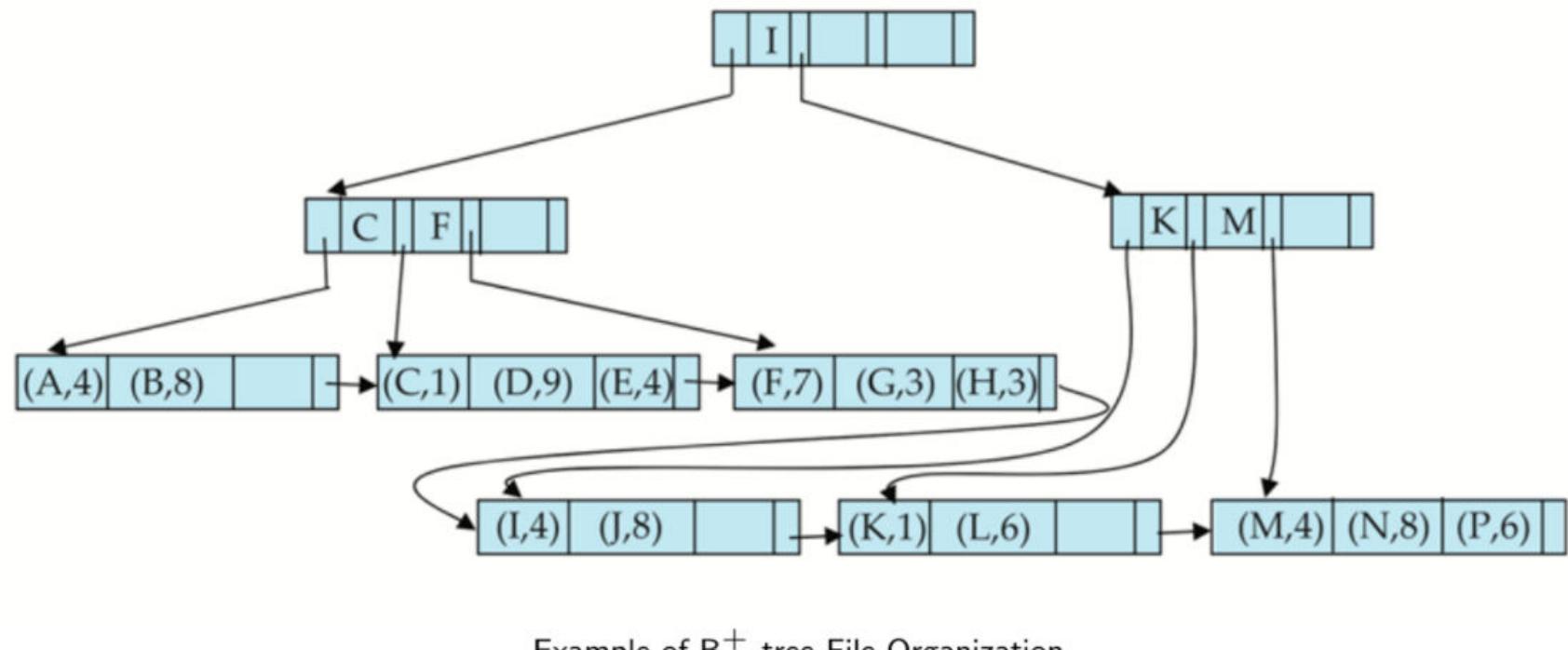


- Node with "Gold" and "Katz" became underfull, and was merged with its sibling
- Parent node becomes underfull, and is merged with its sibling
  - Value separating two nodes (at the parent) is pulled down when merging
- Root node then has only one child and is deleted

## B<sup>+</sup> Tree File Organization

- Index file degradation problem is solved by using B<sup>+</sup> Tree indices
- Data file degradation problem is solved by using B<sup>+</sup> Tree File Organization
- The leaf nodes in a B<sup>+</sup> tree file organization store records, instead of pointers
- Leaf nodes are still required to be half full
  - Since records are larger than pointers, the maximum number of records that can be stored in a leaf node is less than the number of pointers in a non-leaf node
- Insertion and deletion are handled in the same way as insertion and deletion of entries in a B<sup>+</sup> tree index

## B<sup>+</sup> Tree File Organization: Example



- Good space utilization important since records use more space than pointers
- To improve space utilization, involve more sibling nodes in redistribution during splits and merges
  - Involving 2 siblings in redistribution (to avoid split/merge where possible) results in each node having at least  $\lceil \frac{2n}{3} \rceil$  entries

## Non-Unique Search Keys

- Alternatives to scheme described earlier
  - Buckets on separate block (bad idea)
  - List of tuple pointers with each key
    - Extra code to handle long lists
    - Deletion of a tuple can be expensive if there are many duplicates on search key
    - Low space overhead, no extra cost for queries
  - Make search key unique by adding a record-identifier
    - Extra storage overhead for keys
    - Simpler code for insertion/deletion
    - Widely used

## Record Relocation and Secondary Indices

- If a record moves, all secondary indices that store record pointers have to be updated

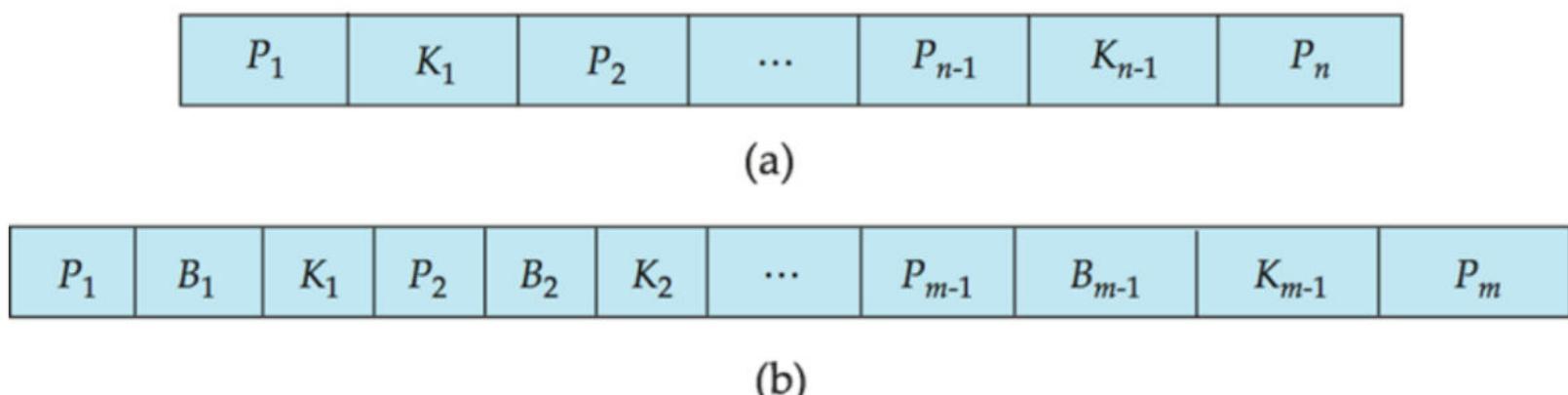
- Node splits in  $B^+$  tree file organizations become very expensive
- **Solution** → Use primary-index search key instead of record pointer in secondary index
  - Extra traversal of primary index to locate record
    - Higher cost for queries, but node splits are cheap
  - Add record-id if primary-index search key is non-unique

## Indexing Strings

- Variable length strings as keys
  - Variable fanout
  - Use space utilization as criterion for splitting, not numbers of pointers
- Prefix compression
  - Key values at internal nodes can be prefixes of full key
    - Keep enough characters to distinguish entries in the subtrees separated by the key value
      - For example → "Silas" and "Silberschatz" can be separated by "Silb"
  - Keys in leaf nodes can be compressed by sharing common prefixes

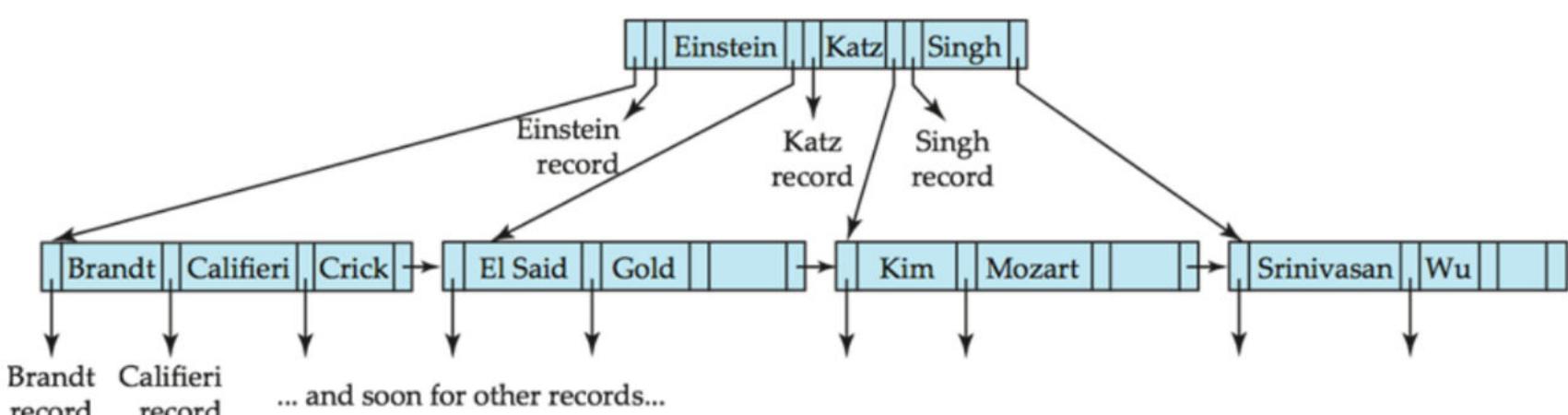
## B-Tree Index Files

- Similar to  $B^+$  tree, but B-tree allows search-key values to appear only once; eliminates redundant storage of search keys
- Search keys in non-leaf nodes appear nowhere else in the B-tree; an additional pointer field for each search key in a non-leaf node must be included
- Generalized B-tree leaf node

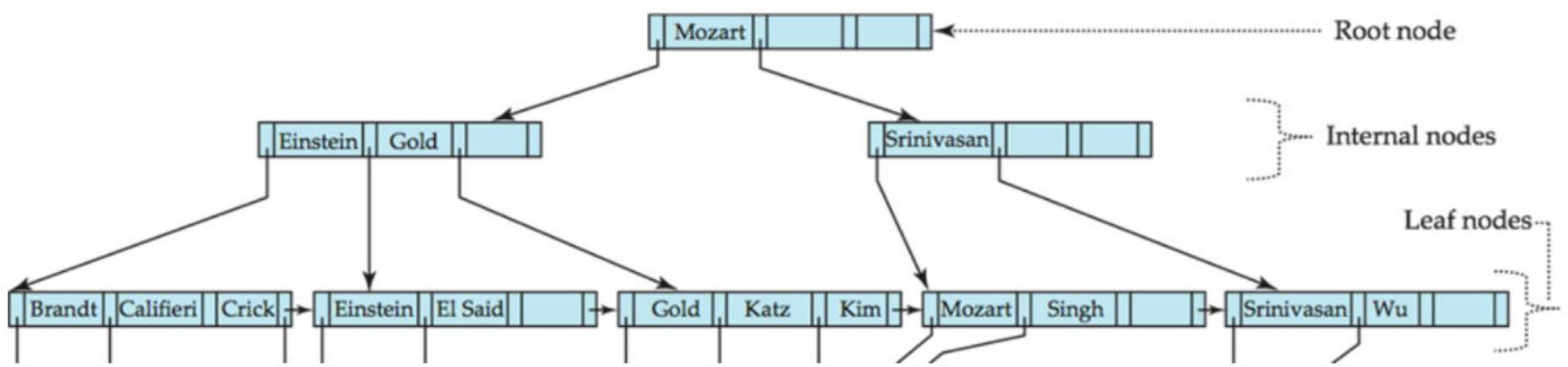


- Non-leaf node → pointers  $B_i$  are the bucket or file record pointers

## B-Tree Index Files: Example

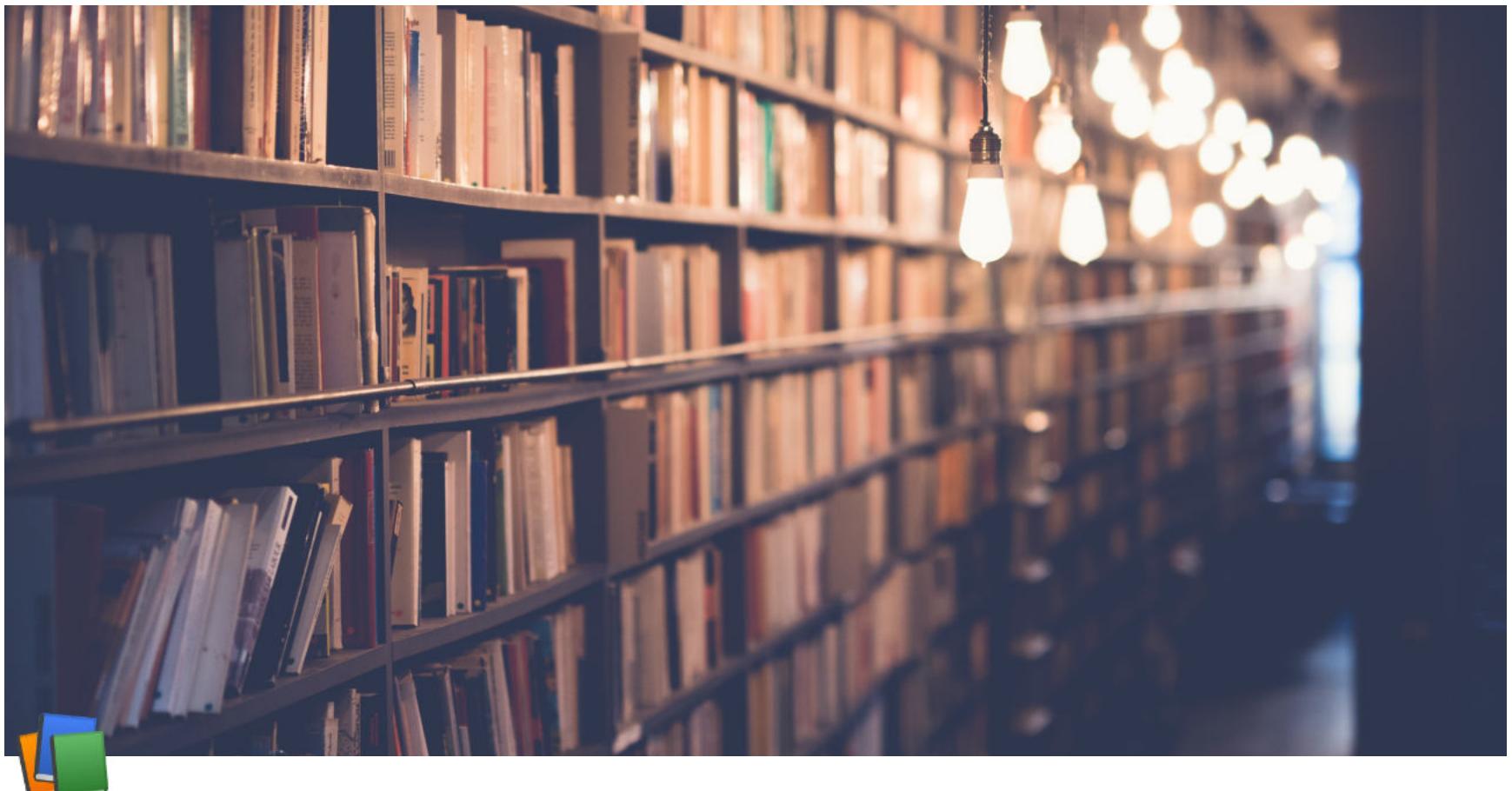


B-tree (above) and  $B^+$  tree (below) on same data



## Comparison of B-Tree and B<sup>+</sup> Tree Index Files

- Advantages of B-Tree indices:
  - May use less tree nodes than a corresponding B<sup>+</sup> Tree
  - Sometimes possible to find search-key value before reaching the leaf node
- Disadvantages of B-Tree indices
  - Only small fraction of all search-key values are found early
  - Non-leaf nodes are larger, so fan-out is reduced
    - Thus, B-Trees typically have greater depth than corresponding B<sup>+</sup> Tree
  - Insertion and deletion more complicated than in B<sup>+</sup> Trees
  - Implementation is harder than B<sup>+</sup> Trees
- Typically, advantages of B-Trees do not outweigh the disadvantages



## Week 9 Lecture 4

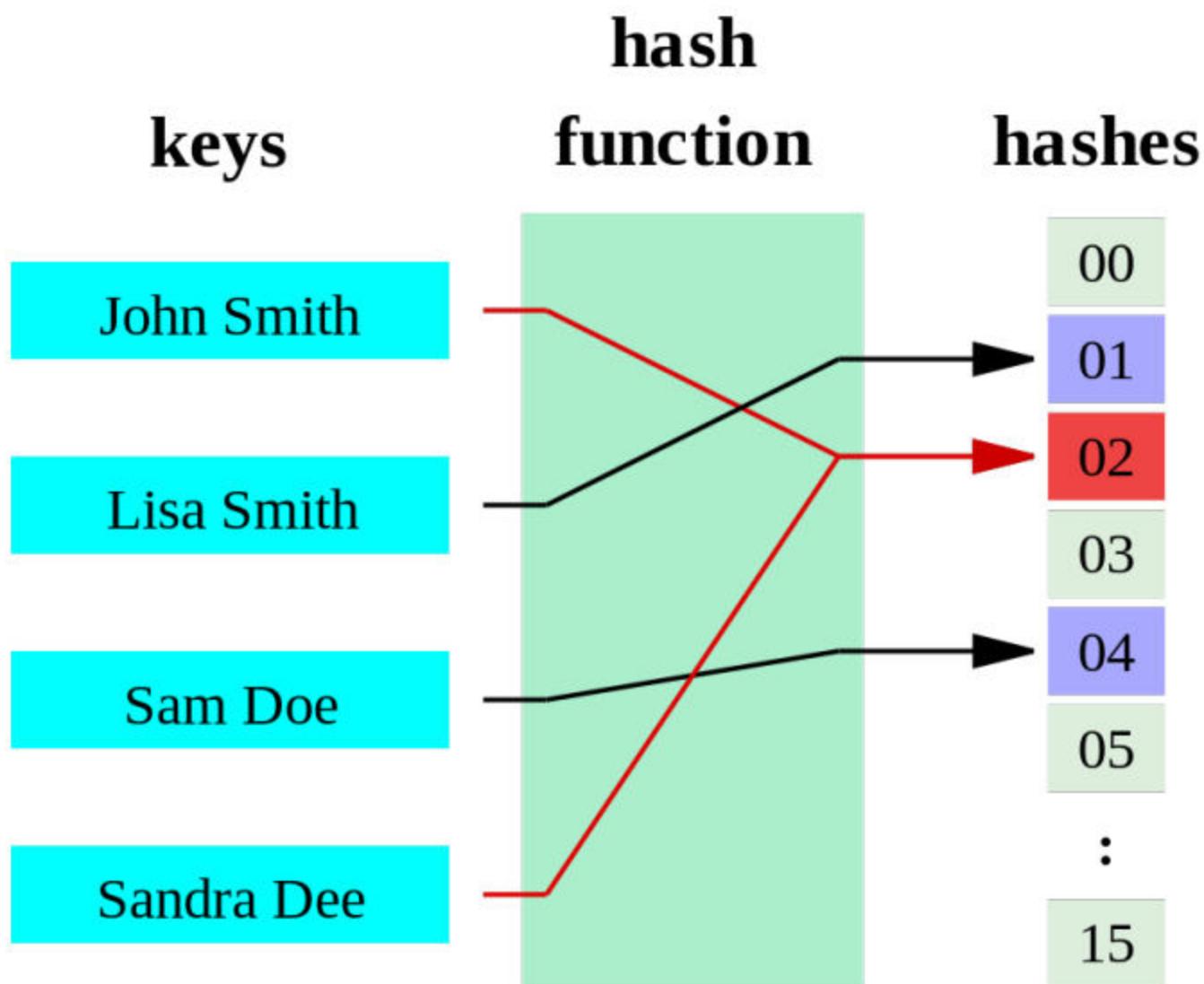
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📎 Materials	
☰ Module #	44
▼ Type	Lecture
# Week #	9

## Indexing and Hashing → Hashing

### Static Hashing

#### Hash function

- A hash function  $h$  maps data of arbitrary size (from domain  $D$ ) to fixed-size values (say, integers from 0 to  $N > 0$ )  
$$h : D \rightarrow [0..N]$$
- Given key  $k$ ,  $h(k)$  is called hash values, hash codes, digests or simply hashes
- If for two keys  $k_1 \neq k_2$ , we have  $h(k_1) = h(k_2)$ , we say a collision has occurred
- A hash function should be Collision free and Fast



### Static hashing

- A **bucket** is a unit of storage containing one or more records (a bucket is typically a disk block)
- In a **hash file organization** we obtain the bucket of a record directly from its search-key value using a **hash function**
- Hash function  $h$  is a function from the set of all search-key values  $K$  to the set of all bucket addresses  $B$
- Hash function is used to locate records for access, insertion as well as deletion
- Records with different search-key values may be mapped to the same bucket; thus, entire bucket has to be searched sequentially to locate a record

### Example of Hash File Organization

Hash file organization of instructor file, using dept\_name as key

- There are 10 buckets
- The binary representation of the  $i^{th}$  character is assumed to be integer  $i$
- The hash function returns the sum of the binary representations of the characters modulo 10
  - For example

$$h(\text{Music}) = 1 \quad h(\text{History}) = 2$$

$$h(\text{Physics}) = 3 \quad h(\text{Elec. Eng.}) = 3$$

bucket 0			

bucket 1			
15151	Mozart	Music	40000

bucket 2			
32343	El Said	History	80000
58583	Califieri	History	60000

bucket 3			
22222	Einstein	Physics	95000
33456	Gold	Physics	87000
98345	Kim	Elec. Eng.	80000

bucket 4			
12121	Wu	Finance	90000
76543	Singh	Finance	80000

bucket 5			
76766	Crick	Biology	72000

bucket 6			
10101	Srinivasan	Comp. Sci.	65000
45565	Katz	Comp. Sci.	75000
83821	Brandt	Comp. Sci.	92000

bucket 7			

Hash file organization of instructor file, using dept\_name as key

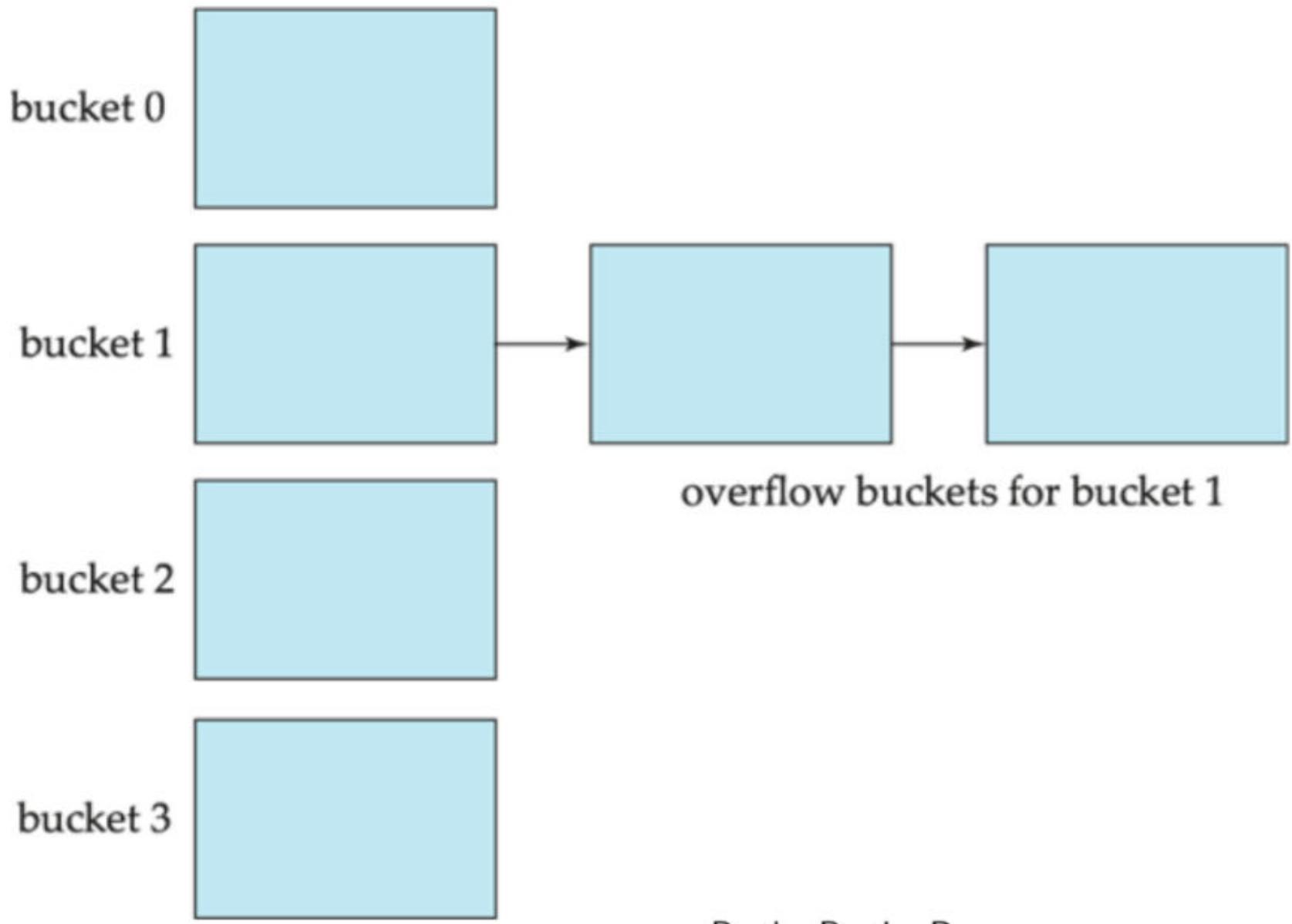
## Hash functions

- Worst hash function maps all search-key values to the same bucket; this makes access time proportional to the number of search-key values in the file
- An ideal hash function is uniform ie. each bucket is assigned the same number of search-key values from the set of all possible values
- Ideal hash functions is random, so each bucket will have the same number of records assigned to it irrespective of the actual distribution of search-key values in the file
- Typical hash functions perform computation on the internal binary representation of the search-key
  - For example, for a string search-key, the binary representations of all the characters in the string could be added and the sum modulo the number of buckets could be returned

## Handling of bucket overflows

- Bucket overflow can occur because of
  - Insufficient buckets
  - Skew in distribution of records
    - This can occur due to two reasons:
      - Multiple records have the same search-key value
      - Chose hash function produces non-uniform distribution of key values
- Although, the probability of bucket overflow can be reduced, it cannot be eliminated
  - it is handled by using overflow buckets
- **Overflow chaining** → the overflow buckets of a given bucket are chained together in a linked list
- Above scheme is called ***closed hashing***

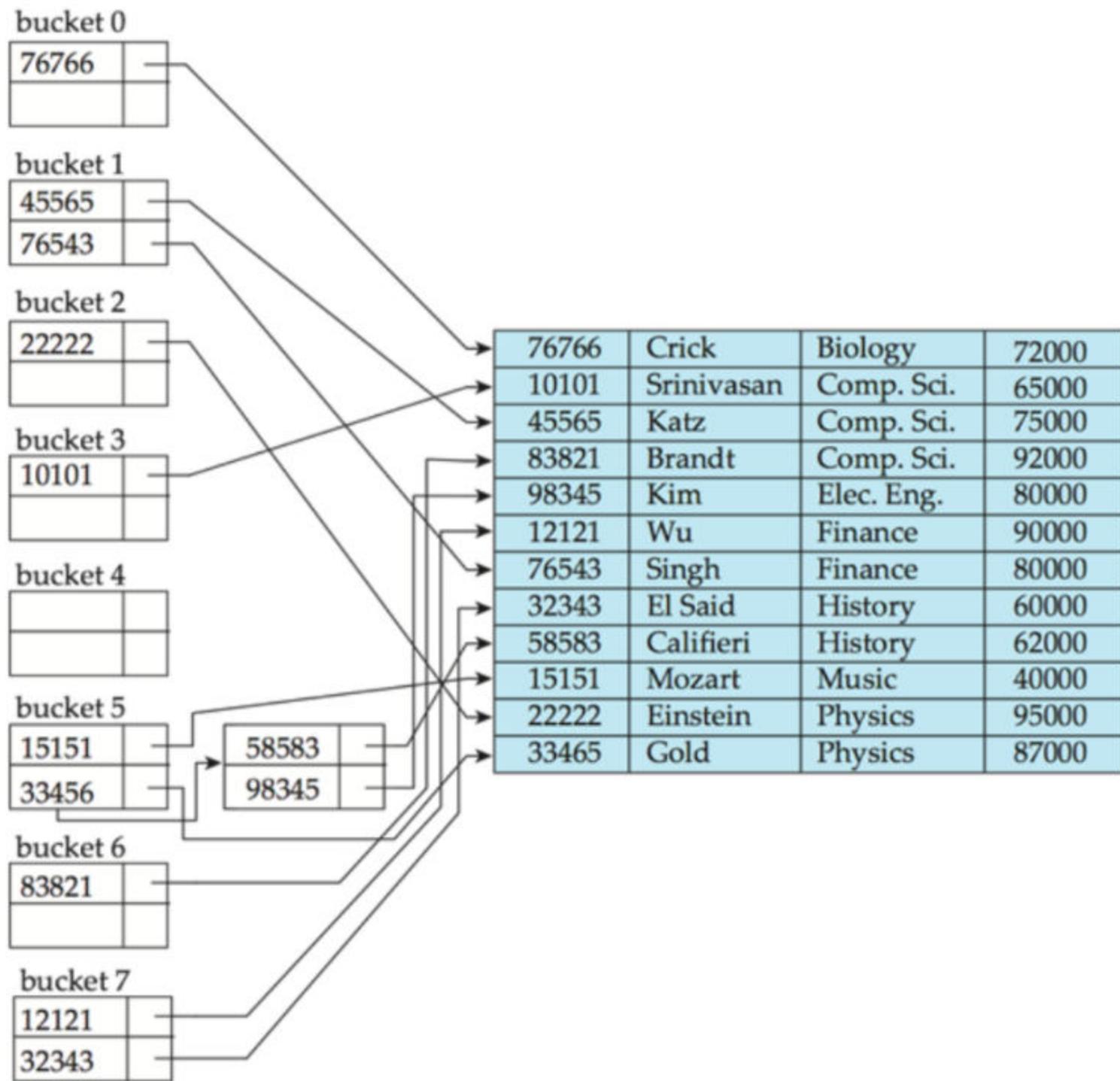
- An alternative, called ***open hashing***, which does not use overflow buckets, is not suitable for database applications



## Hash Indices

- Hashing can be used not only for file organization, but also for index-structure creation
- A ***hash index*** organizes the search keys, with their associated record pointers, into a hash file structure
- Strictly speaking, hash indices are always secondary indices
  - If the file itself is organized using hashing, a separate primary hash index on it using the same search-key is unnecessary
  - However, we use the term hash index to refer to both secondary index structures and hash organized files

## Example of Hash Index



- Hash index on instructor, on attribute ID
- Computed by adding the digits modulo 8

## Deficiencies of Static Hashing

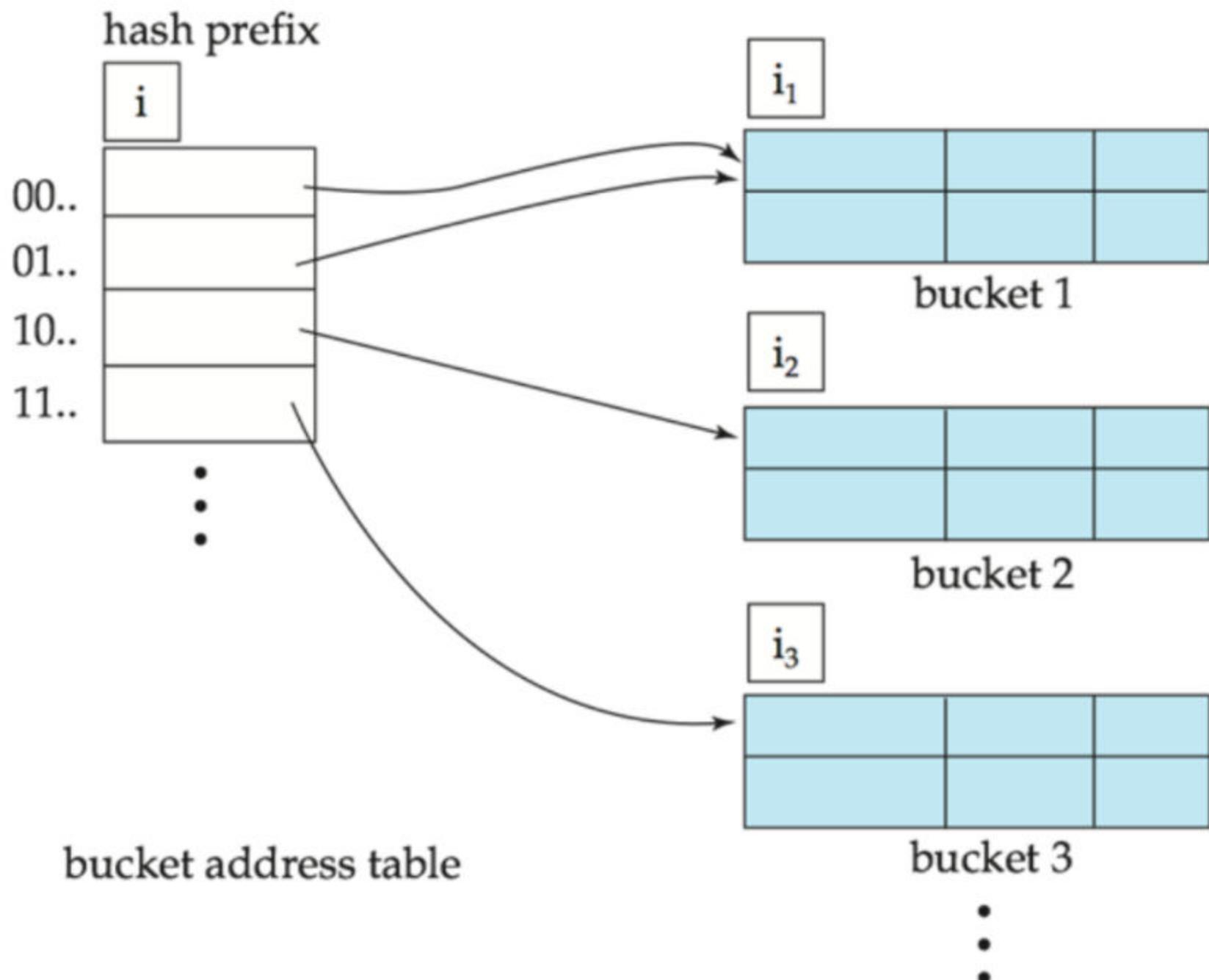
- In static hashing, function  $h$  maps search-key values to a fixed set of  $B$  of bucket addressed
  - Databases grow or shrink with time
    - If initial number of buckets is too small, and the file grows, performance will degrade due to too much overflows
    - If space is allocated for anticipated growth, a significant amount of space will be wasted initially (and the buckets will be underfull)
    - If database shrinks, again space will be wasted
- One solution → Periodic re-organization of the file with a new hash function
  - Expensive, disrupts normal operations
- Better solution → Allow the number of buckets to be modified dynamically

## Dynamic Hashing

- Good for database that grows and shrinks in size
- Allows the hash function to be modified dynamically
- **Extendable hashing** → one form of dynamic hashing
  - Hash function generates values over a large range — typically  $b$ -bit integers with  $b = 32$
  - At any time, use only a prefix of the hash function to index into a table of bucket addresses
  - Let the length of the prefix be  $i$  bits,  $0 \leq i \leq 32$

- Bucket address table size =  $2^i$ 
  - Initially,  $i = 0$
  - Value of  $i$  grows and shrinks as the size of the database grows and shrinks
- Multiple entries in the bucket address table may point to a bucket (Why?)
- Thus, actual number of buckets is  $< 2^i$ 
  - The number of buckets also changes dynamically due to coalescing and splitting of buckets

## General Extendable Hash Structure



In this structure,  $i_2 = i_3 = i$ , whereas  $i_1 = i - 1$

Decode  $i_j$  number of bits to find the record in bucket  $j$

$$i_j \leq i$$

## Use of Extendable Hash Structure

- Each bucket  $j$  stores a value  $i_j$ 
  - All the entries that point to the same bucket have the same values on the first  $i_j$  bits
- To locate the bucket containing search-key  $K_j$ 
  - Compute  $h(K_j) = X$
  - Use the first  $i$  high order bits of  $X$  as a displacement into bucket address table and follow the pointer to appropriate bucket
- To insert a record with search-key value  $K_j$ 
  - Follow same procedure as look-up and locate the bucket, say  $j$
  - If there is room in the bucket  $j$  insert record in the bucket
  - Else the bucket must be split and insertion re-attempted

- Overflow buckets used instead of some cases

## Insertion in Extendable Hash Structure

To split a bucket  $j$  when inserting record with search-key value  $K_j$

- If  $i > i_j$  (more than one pointer to bucket  $j$ )
  - Allocate a new bucket  $z$ , and set  $i_j = i_z = (i_j + 1)$
  - Update the second half of the bucket address table entries originally pointing to  $j$ , to point to  $z$
  - Remove each record in the bucket  $j$  and re-insert (in  $j$  or  $z$ )
  - Re-compute new bucket for  $K_j$  and insert record in the bucket (further splitting is required if the bucket is still full)
- If  $i = i_j$  (only one pointer to bucket  $j$ )
  - If  $i$  reach some limit  $b$ , or too many splits have happened in this insertion, create an overflow bucket
  - Else
    - Increment  $i$  and double the size of the bucket address table
    - Replace each entry in the table by 2 entries that point to the same bucket
    - Re-compute new bucket address table entry for  $K_j$ 
      - Now,  $i > i_j$  so use the first case above

## Deletion in Extendable Hash Structure

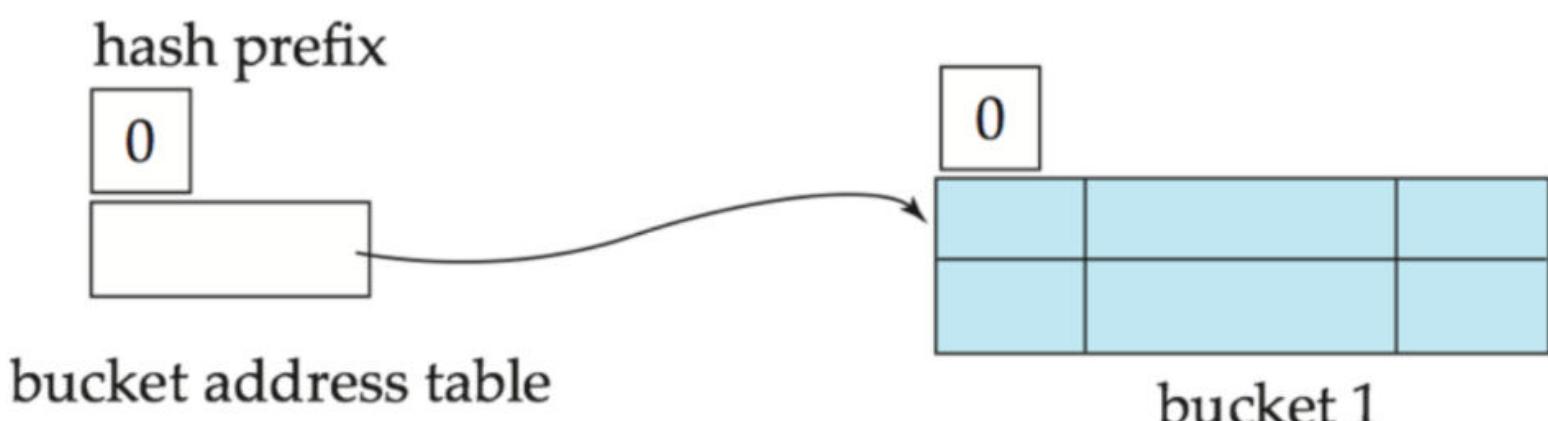
- To delete a key value
  - Locate it in its bucket and remove it
  - The bucket itself can be removed if it becomes empty (with appropriate updates to the bucket address table)
  - Coalescing of buckets can be done (can coalesce only with a "buddy" bucket having same value of  $i_j$  and  $i_j - 1$  prefix, if it is present)
  - Decreasing bucket address table size is also possible
    - Note → decreasing bucket address table size is an expensive operation and should be done only if number of buckets becomes much smaller than the size of the table

## Use of Extendable Hash Structure: Example

$dept\_name$	$h(dept\_name)$
Biology	0010 1101 1111 1011 0010 1100 0011 0000
Comp. Sci.	1111 0001 0010 0100 1001 0011 0110 1101
Elec. Eng.	0100 0011 1010 1100 1100 0110 1101 1111
Finance	1010 0011 1010 0000 1100 0110 1001 1111
History	1100 0111 1110 1101 1011 1111 0011 1010
Music	0011 0101 1010 0110 1100 1001 1110 1011
Physics	1001 1000 0011 1111 1001 1100 0000 0001

## Example

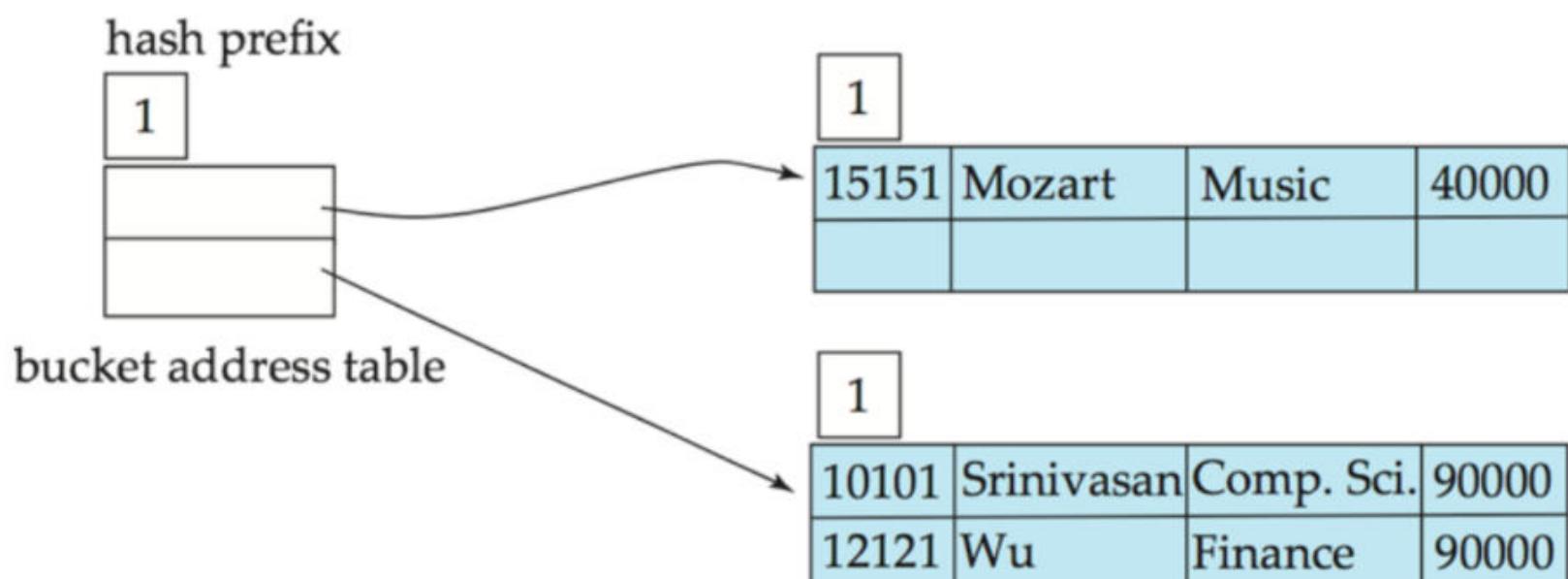
- Initial Hash structure; bucket size = 2



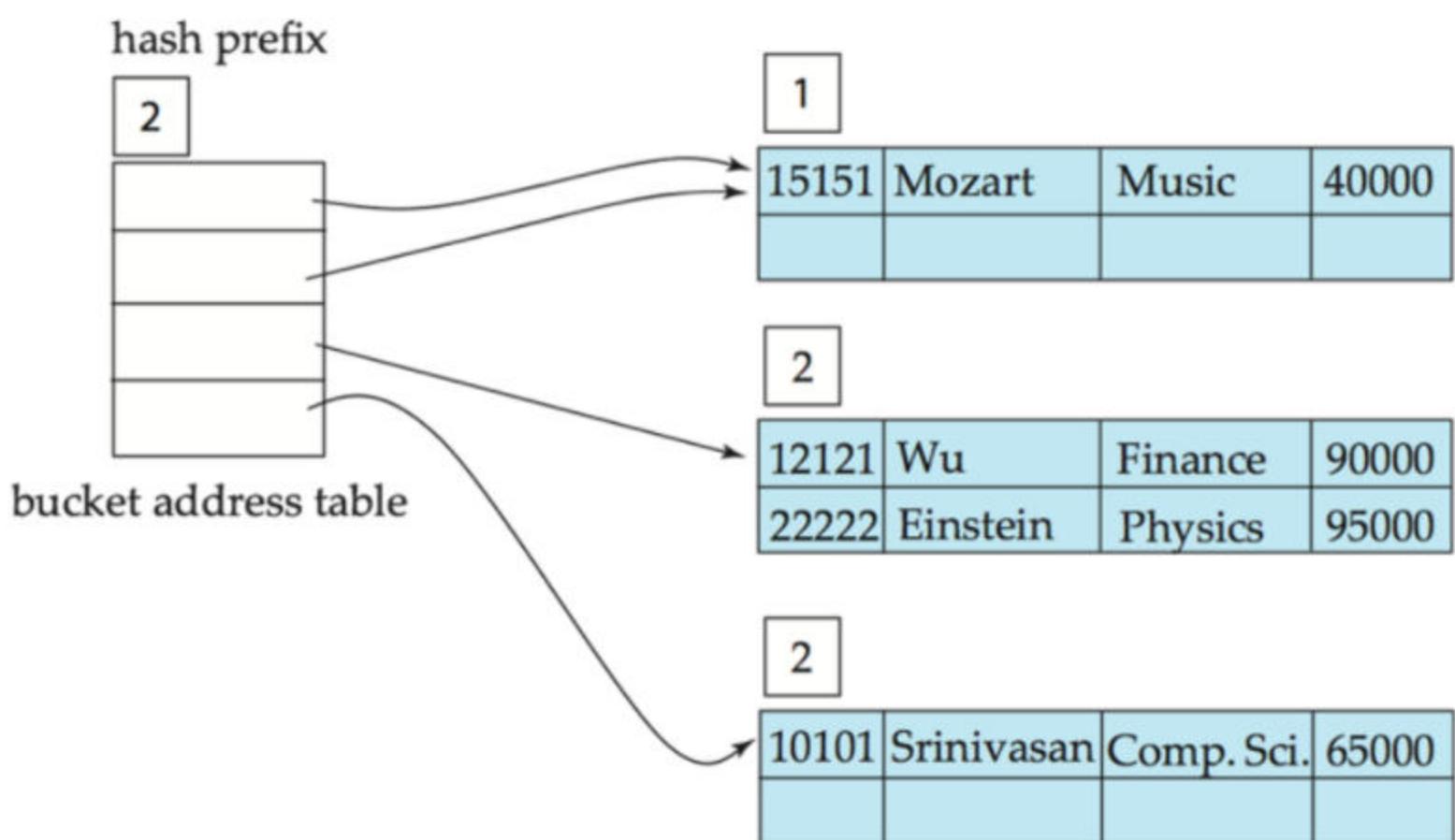
- Insert "Mozart", "Srinivasan" and "Wu" records

76766	Crick	Biology	72000
10101	Srinivasan	Comp. Sci.	65000
45565	Katz	Comp. Sci.	75000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000
12121	Wu	Finance	90000
76543	Singh	Finance	80000
32343	El Said	History	60000
58583	Califieri	History	62000
15151	Mozart	Music	40000
22222	Einstein	Physics	95000
33465	Gold	Physics	87000

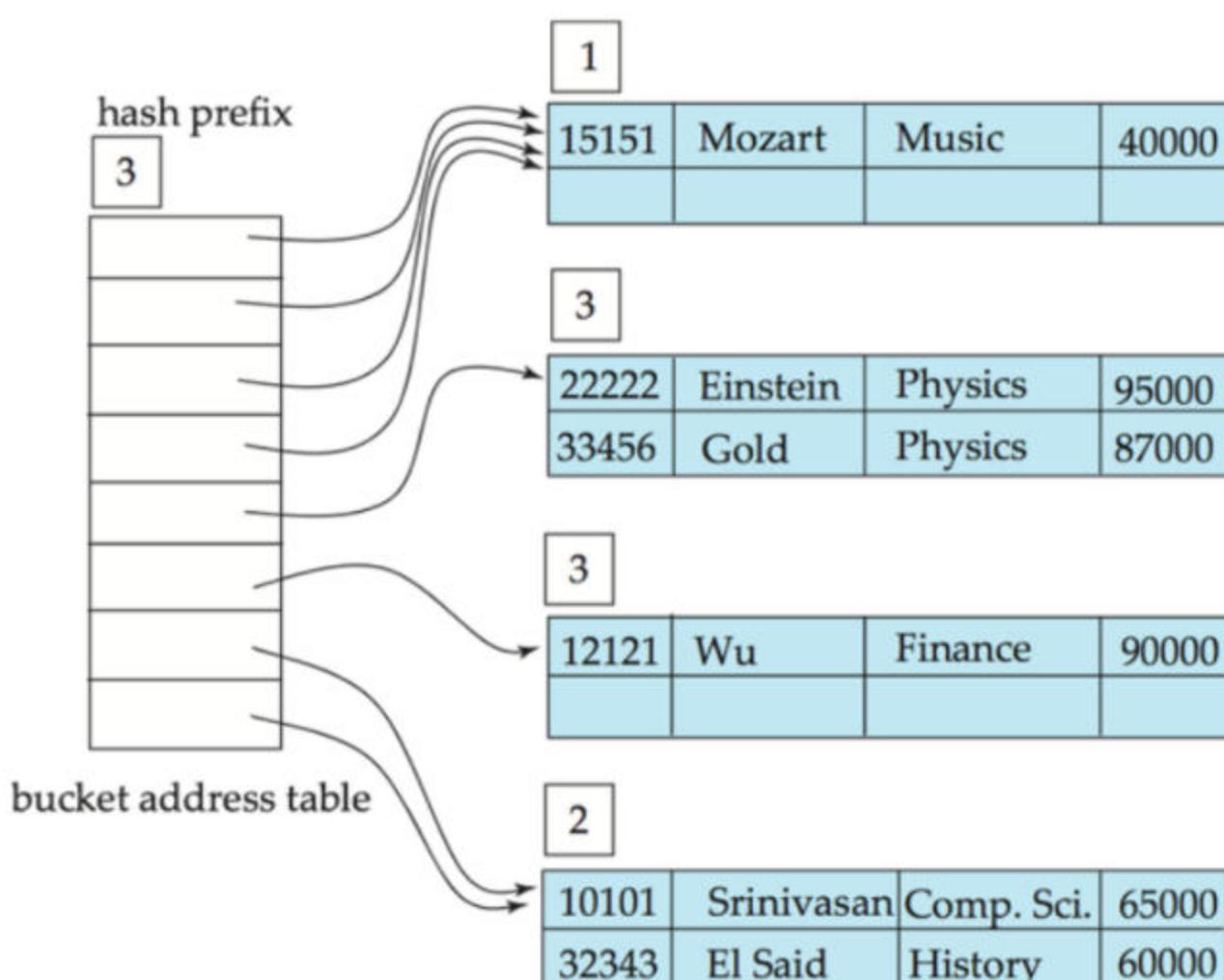
- Hash structure after insertion of "Mozart", "Srinivasan" and "Wu" records



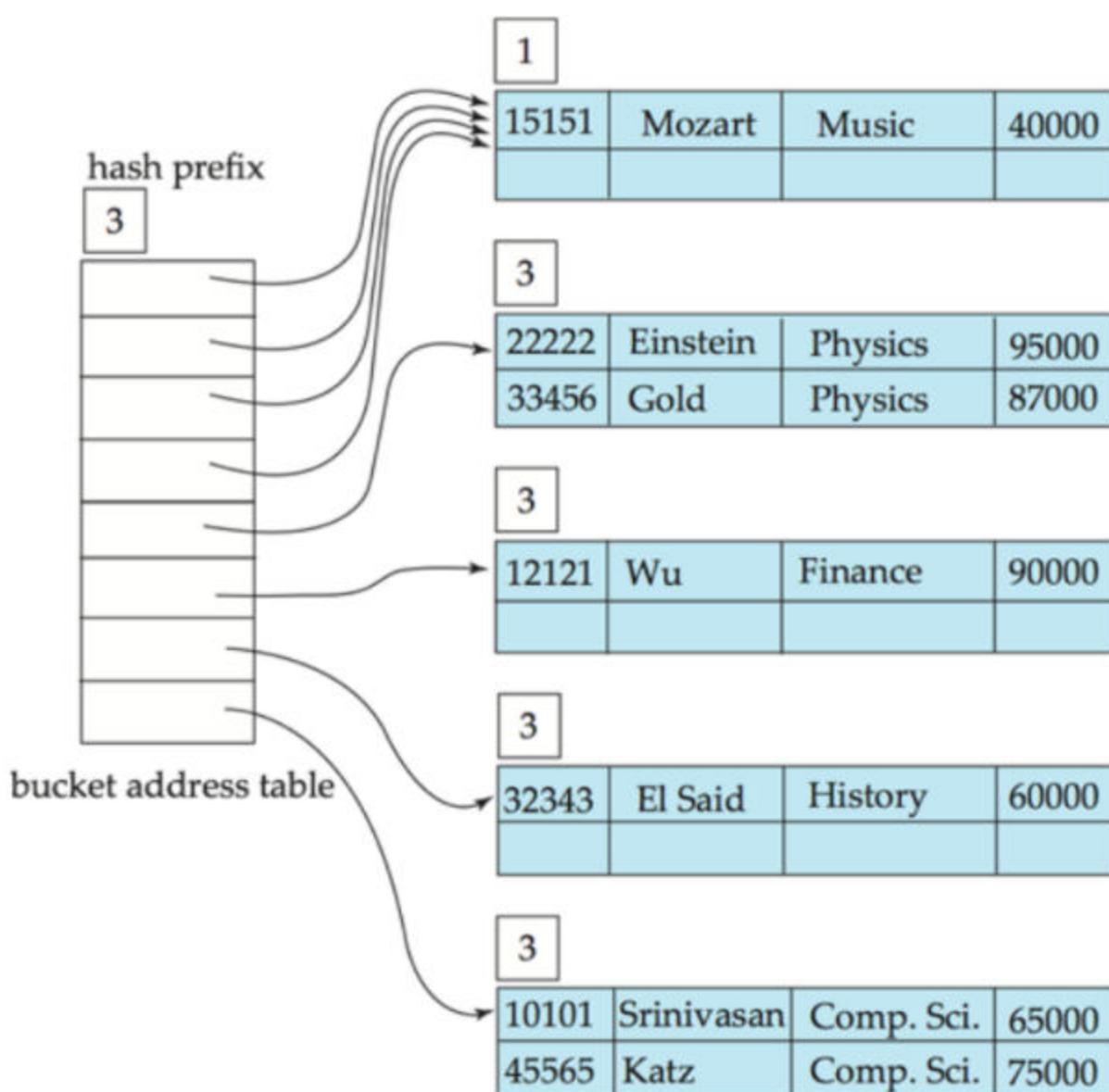
- Insert Einstein record
- Hash structure after insertion of "Einstein" record



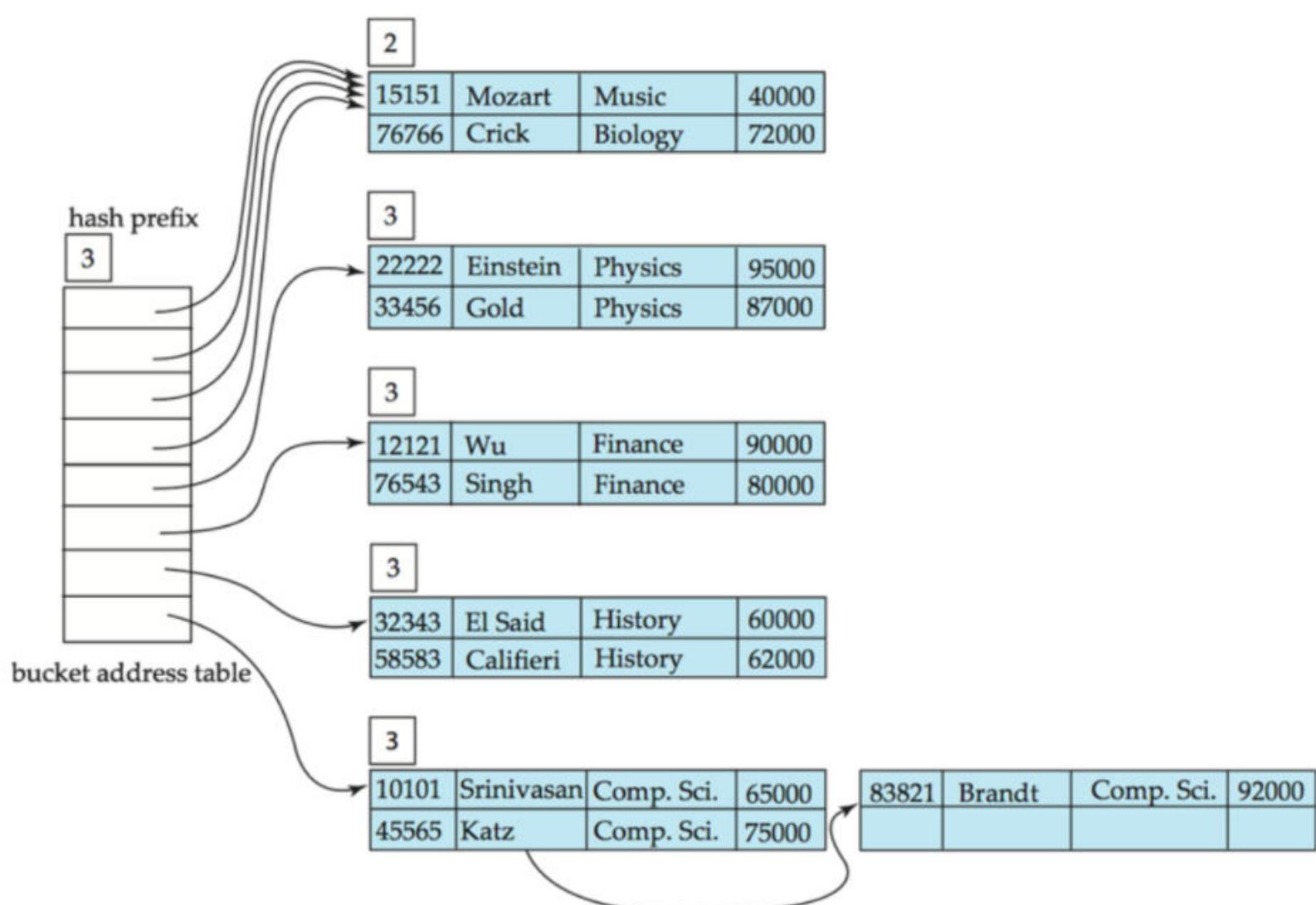
- Insert "Gold" and "El Said" records
- Hash structure after insertion of "Gold" and "El Said" records



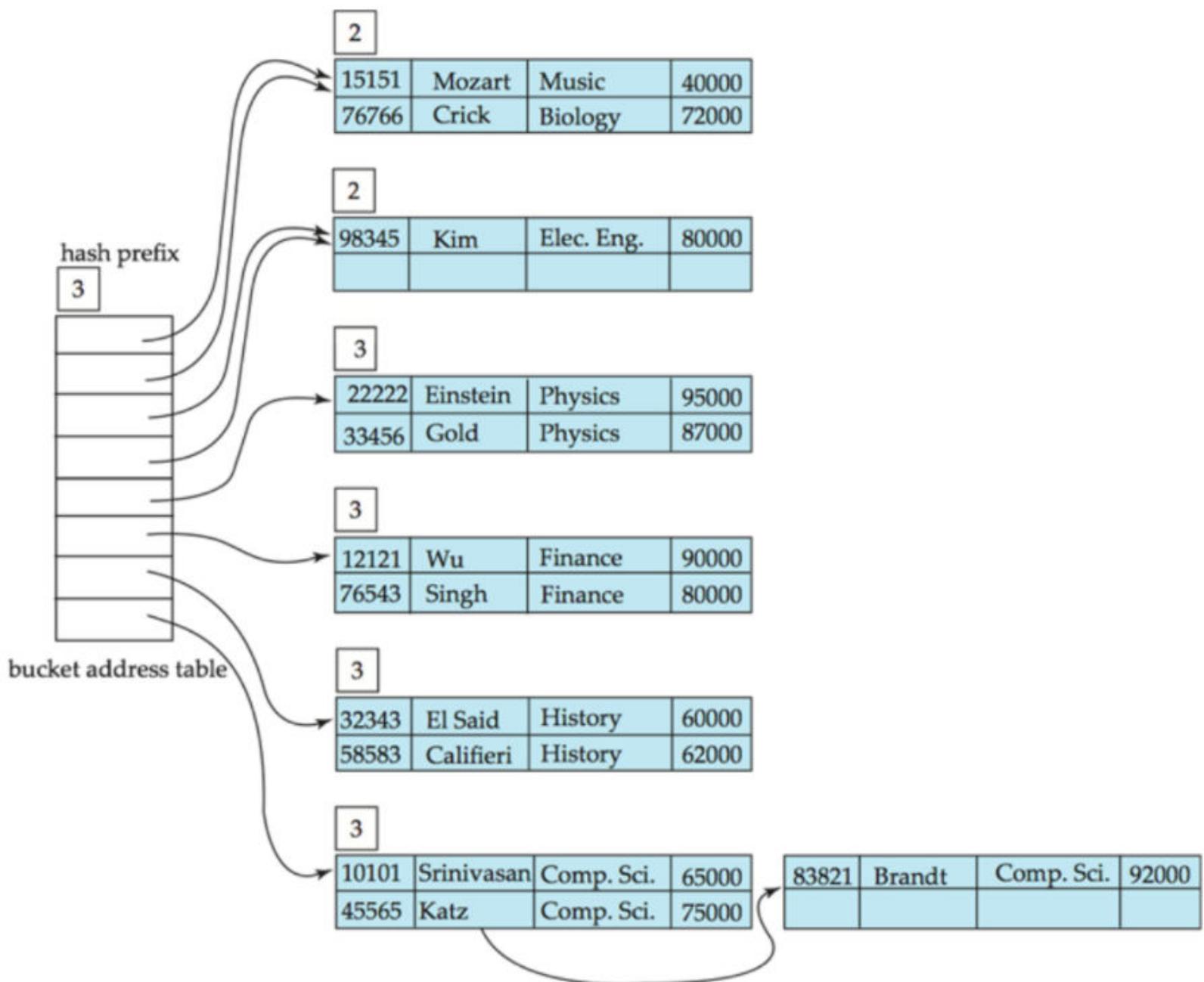
- Insert Katz record
- Hash structure after insertion of "Katz" record



- Insert "Singh", "Califieri", "Crick", "Brandt" records
- Hash structure after insertion of "Singh", "Califieri", "Crick", "Brandt" records



- Insert Kim record
- Hash structure after insertion of "Kim" record



76766	Crick	Biology	72000
10101	Srinivasan	Comp. Sci.	65000
45565	Katz	Comp. Sci.	75000
83821	Brandt	Comp. Sci.	92000
98345	Kim	Elec. Eng.	80000
12121	Wu	Finance	90000
76543	Singh	Finance	80000
32343	El Said	History	60000
58583	Califieri	History	62000
15151	Mozart	Music	40000
22222	Einstein	Physics	95000
33465	Gold	Physics	87000

## Comparison Schemes

### Extendable Hashing vs Other Schemes

- Benefits of extendable hashing
  - Hash performances does not degrade with growth of file
  - Minimal space overhead
- Disadvantages of extendable hashing
  - Extra level of indirection to find the desired record
  - Bucket address table may itself become very big (larger than memory)
    - Cannot allocate very large contiguous areas on the disk either
    - Solution →  $B^+$ -tree structure to locate desired record in bucket address table
  - Changing size of bucket address table is an expensive operation

- Linear hashing is an alternative mechanism
  - Allows incremental growth of its directory (equivalent to bucket address table)
  - At the cost of more bucket overflows

## Comparison of Ordered Indexing and Hashing

- Cost of periodic re-organization
- Relative frequency of insertions and deletion
- Is it desirable to optimize average access time at the expense of worst-case access time?
- Expected type of queries:
  - Hashing is generally better at retrieving records having a specified value of the key
  - If range queries is common, ordered indices are to be preferred
- **In practice:**
  - PostgreSQL supports hash indices, but discourages use due to poor performance
  - Oracle supports static hash organization, but not hash indices
  - SQLServer supports only B<sup>+</sup> Trees

## Bitmap Indices

- Bitmap indices are a special type of index designed for efficient querying on multiple keys
- Records in a relation are assumed to be numbered sequentially from, say 0
  - Given a number  $n$  it must be easy to retrieve record  $n$ 
    - Particularly easy if records are of fixed size
- Applicable on attributes that take on a relatively small number of distinct values
  - For example, gender, country, state, ...
  - For example, income-level (income broken up into small number of levels such as 0-9999, 10000-19999, 20000-50000, 50000-infinity)
- A bitmap is simply an array of bits
- In its simplest form a bitmap index on an attribute has a bitmap for each value of the attribute
  - Bitmap has as many bits as records
  - In a bitmap for value  $v$ , the bit for a record is 1 if the record has the value  $v$  for the attribute and is 0 otherwise

record number	<i>ID</i>	<i>gender</i>	<i>income_level</i>
0	76766	m	L1
1	22222	f	L2
2	12121	f	L1
3	15151	m	L4
4	58583	f	L3

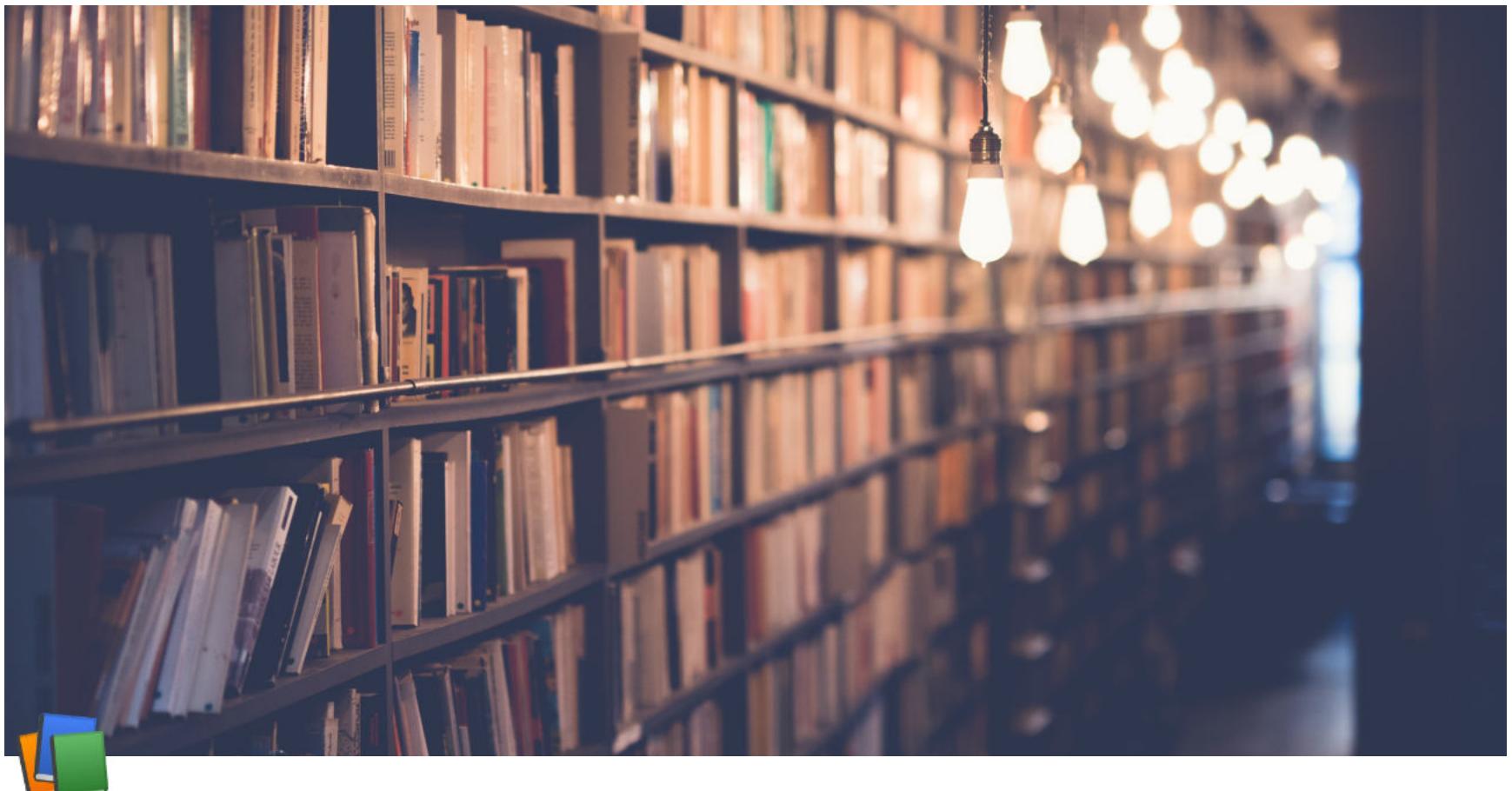
Bitmaps for <i>gender</i>		Bitmaps for <i>income_level</i>	
m	10010	L1	10100
f	01101	L2	01000
		L3	00001
		L4	00010
		L5	00000

- Bitmap indices are useful for queries on multiple attributes
  - not particularly useful for single attribute queries
- Queries are answered using bitmap operations

- Intersection (AND)
- Union (OR)
- Complementation (NOT)
- Each operation takes two bitmaps of the same size and applies the operation on corresponding bits to get the result bitmap
  - For example,  $100110 \text{ AND } 110011 = 100010$ 
    - $100110 \text{ OR } 110011 = 110111$
    - $\text{NOT } 100110 = 011001$
  - Males with income level L1:  $10010 \text{ AND } 10100 = 10000$ 
    - Can then retrieve required tuples
    - Counting number of matching tuples is even faster
- Bitmap indices generally very small compared with relation size
  - For example, if record is 100 bytes, space for a single bitmap is 1/800 of space and by relation
    - If number of distinct attribute values is 8, bitmap is only 1% of relation size
- Deletion needs to be handled properly
  - Existence bitmap to note if there is a valid record at a record location
  - Needed for complementation
    - $\text{not}(A=v) : (\text{NOT bitmap-}A\text{-}v) \text{ AND ExistenceBitmap}$
- Should keep bitmaps for all values, even null value
  - To correctly handle SQL null semantics for  $\text{NOT}(A=v)$ :
    - intersect above result with  $(\text{NOT bitmap-}A\text{-Null})$

## Bitmap Indices: Efficient Bitmap Operations

- Bitmaps are packed into words; a single word and (a basic CPU instruction) computes and of 32 or 64 bits at once
  - For example, 1-million-bit maps can be and-ed with just 31,250 instructions
- Counting number of 1s can be done fast by a trick:
  - Use each byte to index into a pre-computed array of 256 elements each storing the count of 1s in the binary representation
    - Can use pairs of bytes to speed up further at a higher memory cost
  - Add up the retrieved counts
- Bitmaps can be used instead of Tuple-ID lists at leaf levels of  $B^+$ -trees for values that have a large number of matching records
  - Worthwhile, if  $> 1/64$  of the records have that value, assuming a tuple-id is 64 bits
  - Above technique merges benefits of bitmap and  $B^+$ -tree indices



## Week 9 Lecture 5

Class	BSCCS2001
Created	@November 4, 2021 2:11 PM
Materials	
Module #	45
Type	Lecture
# Week #	9

## Indexing and Hashing → Index Design

### Index Definition in SQL

#### Index in SQL

- Create an index

```
create index <index-name> on <relation-name> (<attribute-list>)
```

For example: **create index b-index on branch (branch\_name)**

- Use **create unique index** to indirectly specify and enforce the condition that the search key is a candidate key

- Not really required if SQL **unique** integrity constraint is supported — it is preferred

- To drop an index

```
drop index <index-name>
```

- Most database systems allow specification of type of index and clustering

- You can also create an index for a cluster

- You can create a composite index on multiple columns up to a maximum of 32 columns

- A composite index key cannot exceed roughly one-half (minus some overhead) of the available space in the data block

#### Index in SQL: Examples

- Create an index for a single column, to speed up queries that test that column:

- CREATE INDEX emp\_ename ON emp\_tab(ename);

- Specify several storage settings explicitly for the index

```

CREATE INDEX emp_ename ON emp_tab(ename)
  TABLESPACE users // Allocation of space in the Database to contain schema objects
  STORAGE ( // Specify how Database should store a database object
    INITIAL 20K // Specify the size of the 1st extent of the object
    NEXT 20K // Specify in bytes the size of the 2nd extent to be allocated to the object
    PCTINCREASE 75) // Specify the percent by which later extents grow over
    PCTFREE 0 // 0% of each data block this table's data segment be free for updates
    COMPUTE STATISTICS;
  
```

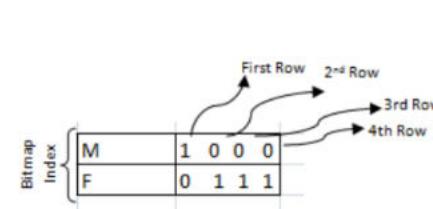
- Create index on two columns, to speed up queries that test either the first column or both columns
  - CREATE INDEX emp\_ename ON emp\_tab(ename, empno) COMPUTE STATISTICS;
- If a query is going to sort on the function UPPER(ENAME), an index on the ENAME column itself would not speed up this operation and it might be slow to call the function for each result row
  - A function-based index pre-computes the result of the function for each column value, speeding up queries that use the function for searching or sorting:

```
CREATE INDEX emp_upper_ename ON emp_tab(UPPER(ename)) COMPUTE STATISTICS;
```

## Index in SQL: Bitmap

- create bitmap index <index-name> on <relation-name> (<attribute-list>)**
- Example:
  - Student (Student\_ID, Name, Address, Age, Gender, Semester)
  - CREATE BITMAP INDEX Idx\_Gender ON Student (Gender);
  - CREATE BITMAP INDEX Idx\_Semester ON Student (Semester);

STUDENT					
STUDENT_ID	STUDENT_NAME	ADDRESS	AGE	GENDER	SEMESTER
100	Joseph	Alaiedon Township	20	M	1
101	Allen	Fraser Township	21	F	1
102	Chris	Clinton Township	20	F	2
103	Patty	Troy	22	F	4



SEMESTER				
1	1	1	0	0
2	0	0	1	0
3	0	0	0	0
4	0	0	0	1

- SELECT \* FROM Student WHERE Gender = 'F' AND Semester = 4;
  - AND 0 1 1 1 with 0 0 0 1 to get the result

## Multiple-Key Access

- Use multiple indices for certain types of queries
- Example:
 

```
select ID
from instructor
where dept_name = "Finance" and salary = 80000
```
- Possible strategies for processing query using indices on single attributes:
  - Use index on *dept\_name* to find instructors with department name Finance; test *salary* = 80000
  - Use index on *salary* to find instructors with a salary of 80000; test *dept\_name* = "Finance"
  - Use *dept\_name* index to find pointers to all records pertaining to the "Finance" department
    - Similarly use index on *salary*
      - Take intersection of both sets of pointers obtained

## Multiple-Key Access: Indices

- Composite Search Keys** are search keys containing more than one attribute
  - For example, (*dept\_name*, *salary*)
- Lexicographic ordering:  $(a_1, a_2) < (b_1, b_2)$  if either

- $a_1 < b_1$  or
- $a_1 = b_1$  and  $a_2 < b_2$
- Hence, the order is important

## Multiple-Key Access: Indices on Multiple Attributes

Suppose we have an index on combined search-key:

*(dept\_name, salary)*

- With the **where** clause

**where dept\_name = "Finance" and salary = 80000**

the index on *(dept\_name, salary)* can be used to fetch only records that satisfy both conditions

- Using separate indices is less efficient — we may fetch many records (or pointers) that satisfy only one of the conditions
  - Can also efficiently handle
- where dept\_name = "Finance" and salary < 80000**
- But cannot efficiently handle
- where dept\_name < "Finance" and balance = 80000**
- May fetch many records that satisfy the first but not the second condition

## Privileges Required to Create an Index

- When using indexes in an application, you might need to request that the DBA grant privileges or make changes to initialization parameters
- To create a new index
  - You must own, or have the INDEX object privilege for the corresponding table
  - The schema that contains the index must also have a quota for the tablespace intended to contain the index, or the UNLIMITED TABLESPACE system privilege
  - To create an index in another user's schema, you must have the CREATE ANY INDEX system privilege
- Function-based indexes also require the QUERY\_REWRITE privilege and that the QUERY\_REWRITE\_ENABLED initialization parameter to be set to TRUE

## Guidelines for Indexing

- Previously we had studied various issues for a proper design of a relational database system
- This focused on:
  - **Normalization of Tables** leading to:
    - Reduction of Redundancy to minimize possibilities of Anomaly
    - Easier adherence to constraints (various dependencies)
    - Efficiency of access and update — a better normalized design often gives better performance
- The performance of a database system, however, is also significantly impacted by the way the data is physically organized and managed
  - These are done through:
    - Indexing and Hashing
- While normalization and design are startup time activities that are usually performed once at the beginning (and rarely changed later), the performance behavior continues to evolve as the database is used over time
  - Hence we need to continually
    - **Collect Statistics** about data (of various tables) to learn of the patterns
    - **Adjust the Indexes** on the tables to optimize performance
- There is no sound theory that determines optimal performance

- Rather, we take a quick look into a few common guidelines that can help you keep your database agile in its behaviour

## Guidelines for Indexing: Ground Rules

- Some guidelines — heuristic and common sense, but time-tested are - are summarized here as a set of Ground Rules for Indexing
  - **Rule 0** → *Indexes lead to Access — Update Tradeoff*
  - **Rule 1** → *Index the Correct Tables*
  - **Rule 2** → *Index the Correct Columns*
  - **Rule 3** → *Limit the Number of Indexes for Each Table*
  - **Rule 4** → *Choose the Order of Columns in Composite Indexes*
  - **Rule 5** → *Gather Statistics to Make Index Usage More Accurate*
  - **Rule 6** → *Drop Indexes That Are No Longer Required*

## Guidelines for Indexing: Rule 0

- **Rule 0** → *Indexes lead to access — Update tradeoff*
  - Every query (access) results in a 'search' on the underlying physical data structures
    - Having specific index on search field can significantly improve performance
  - Every update (insert/delete/values update) results in update of the index files — an overhead or penalty for quicker access
    - Having unnecessary indexes can cause significant degradation or performance of various operations
    - Index files may also occupy significant space on your disk and/or
    - Cause slow behavior due to memory limitations during index computations
  - Use informed judgment to index

## Guidelines for Indexing: Rule 1

- **Rule 1** → *Index the correct tables*
  - Create an index if you frequently want to **retrieve less than 15%** of the rows in a large table
    - The percentage varies greatly according to the relative speed of a table scan and how clustered the row data is about the index key
      - The faster the table scan, the lower the percentage
      - More clustered the row data, the higher the percentage
  - Index columns used for joins to improve performance on **joins of multiple tables**
  - Primary and unique keys automatically have indexes, but you might want to create an **index on a foreign key**
  - **Small tables** do not require indexes
    - If a query is taking too long, then the table might have grown from small to large

## Guidelines for Indexing: Rule 2

- **Rule 2** → *Index the correct columns*
  - Columns with the following characteristics are candidates for indexing:
    - Values are relatively unique in the column
    - There is a wide range of values (good for regular indexes)
    - There is a small range of values (good for bitmap indexes)
    - The column contains many nulls, but queries often select all rows having a value
      - In this case, a comparison that matches all the non-null values, such as:
        - WHERE COL\_X > -9.99 \*power(10, 125) is preferable to WHERE COL\_X IS NOT NULL
        - This is because the first uses an index on COL\_X (if COL\_X is a numeric column)

- Columns with the following characteristics are less suitable for indexing:
  - There are many nulls in the column and you do not search on the non-null values
  - LONG and LONG RAW columns cannot be indexed
- The size of single index entry cannot exceed roughly one-half (minus some overhead) of the available space in the data block

### Guidelines for Indexing: Rule 3

- **Rule 3** → *Limit the number of indexes for each table*
  - The more indexes, the more overhead is incurred as the table is altered
    - When rows are inserted or deleted, all indexes on the table must be updated
    - When a column is updated, all indexes on the column must be updated
  - You must weigh the performance benefit of indexes for queries against the performance overhead of the updates
    - If a table is primarily read-only, you might use more indexes, but, if a table is heavily updated, you might use fewer indexes

### Guidelines for Indexing: Rule 4

- **Rule 4** → *Choose the order of columns in composite indexes*
  - The order of columns in the CREATE INDEX statement can affect performance
    - Put the column used most often first in the index
    - You can create a composite index (using several columns) and the same index can be used for queries that reference all of these columns, or just some of them

Table VENDOR_PARTS		
VEND ID	PART NO	UNIT COST
1012	10-440	.25
1012	10-441	.39
1012	457	4.95
1010	10-440	.27
1010	457	5.10
1220	08-300	1.33
1012	08-300	1.19
1292	457	5.28

- For the VENDOR\_PARTS table, assume that there are 5 vendors and each vendor has about 1,000 parts
  - Suppose, VENDOR\_PARTS is commonly queried as:
    - `SELECT * FROM vendor_parts WHERE part_no = 457 AND vendor_id = 1012;`
    - Create a composite index with the most selective (with most values) column first
      - `CREATE INDEX ind_vendor_id ON vendor_parts (part_no, vendor_id);`
- Composite indexes speed up queries that use the leading portion of the index:
  - So, queries with WHERE clauses using only PART\_NO column also run faster
  - With only 5 distinct values, a separate index on VENDOR\_ID does not help

### Guidelines for Indexing: Rule 5

- **Rule 5** → *Gather statistics to make index usage more accurate*
  - The database can use indexes more effectively when it has statistical information about the tables involved in the queries

- Gather statistics when the indexes are created by including the keywords COMPUTE STATISTICS in the CREATE INDEX statement
- As data is updated and the distribution of values changes, periodically refresh the statistic by calling procedures like (in Oracle):
  - `DBMS_STATS.GATHER_TABLE_STATISTICS`
  - `DBMS_STATS.GATHER_SCHEMA_STATISTICS`

## Guidelines for Indexing: Rule 6

- **Rule 6** → *Drop indexes that are no longer required*
  - You might drop an index if:
    - It does not speed up queries
      - The table might be very small, or there might be many rows in the table but very few index entries
    - The queries in your applications do not use the index
    - The index must be dropped before being rebuilt
  - When you drop an index, all extents of the index's segment are returned to the containing tablespace and become available for other objects in the tablespace
  - Use the SQL command `DROP INDEX` to drop an index
    - For example, the following statement drops a specific named index:
      - `DROP INDEX Emp_ename;`
  - If you drop a table, then all associated indexes are dropped too
  - To drop an index, the index must be contained in your schema or you must have the `DROP ANY INDEX` system privilege