Database Management Systems: An Architectural View

Lecture 1

Outline

1. What is a Database? A DBMS?
2. Why use a DBMS?
3. Databases in Context
4. Design and Implementation Process

What is a Database?

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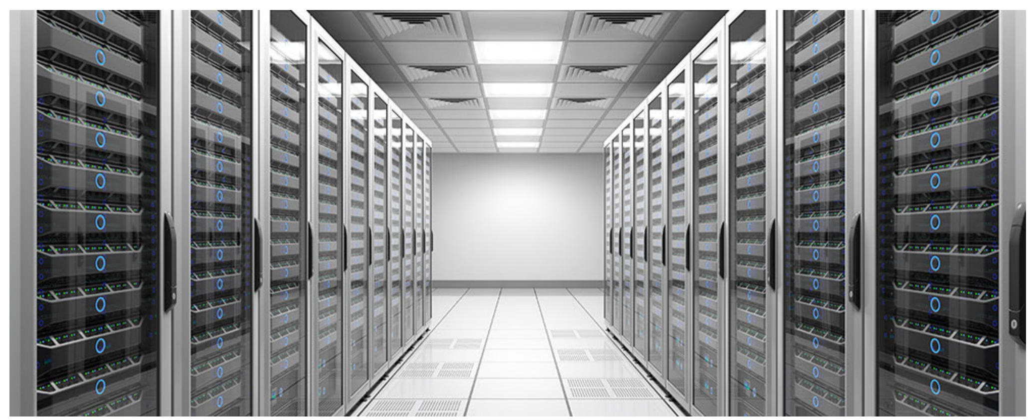


What is a Database?

A collection of related data, most often…

- reflects some aspect of the real world
- logically coherent with inherent meaning
- designed, built, and populated with data for a specific purpose
  - intended group of users
  - some preconceived applications with which these users are interested
  - application requirements in terms of performance, security, redundancy, concurrency, etc.

Database Management System

DBMS

A collection of programs that enables users to create and maintain a database

- Supports specifying the data types, structures, and constraints of the data
- Stores the data on some medium under control of the DBMS
- Supports querying and updating the database
- Protects data against malfunction and unauthorized access

Why use a DBMS?

Common tradeoff in CS:

A. Code from scratch
   - Pros: you know your problem best (so fast, customized)
   - Cons: slow, labor intensive, need to add/change features?

B. Find a library/tool that solves [part of] your problem
   - Pros: fast via bootstrapping, better designed?
   - Cons: understand the tool, may not be efficient, support?

DBMSs adopt some set of limiting assumptions in order to <u>efficiently</u> support a <u>useful</u> feature set over a wide class of possible databases

Example: Student Records

- Given a school with MANY students (NEU: ~25k, UM: ~45k), each with some data (name, ID, DOB, classes)

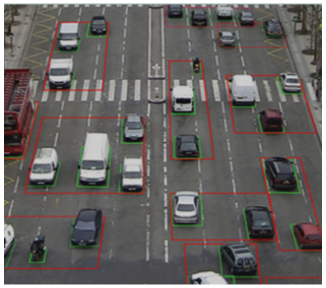
- Write a program that can efficiently…
  - Retrieve a random student
  - Retrieve the first/last student, according to…
    - Last name
    - DOB
  - Retrieve a student by…
    - ID
    - Name (with *'s)
  - Retrieve a class roster (all students in class X)
  - Handles adding/removing/editing students/classes
  - Handles multiple simultaneous reads/writes
  - Provides differing access rights
  - Handles OS faults/power outages

  …

Many Kinds of DBMSs (1)

- Graph databases Neo4j
  - Create nodes, edges, labels
  - Query about relationships and paths
    - Find your friends
    - Find someone that can help you learn databases

- Spatial databases
  - Objects in 2D/3D
  - Query locations, relations
    - Collision detection



Many Kinds of DBMSs (2)

- Document stores
  - Create dynamic documents
  - Query about contents
    - Find by author, title, content, etc. patterns

{name:"mongo", type:"DB"}

- Key-Value stores
  - Associative array
  - Scalable, fault-tolerant
  - Query

Relational DBMS

We focus on **relational** databases

Based on the relational *data model*

- Researched ~45 years, widely used
  - Free/paid implementations for personal use, embedded systems, small/large enterprise

Relational Databases (1)

Table or "Relation"

Table Name

Attributes/Columns

STUDENT

Name	<u>SSN</u>	Phone	Address	Age	GPA
Ben Bayer	305-61-2435	555-1234	1 Foo Lane	19	3.21
Chung-cha Kim	422-11-2320	555-9876	2 Bar Court	25	3.53
Barbara Benson	533-69-1238	555-6758	3 Baz Blvd	19	3.25

Rows/ Tuples

Constraints

- Has to be unique
- Must be an integer > 0
- Must be a number [0,4]

Relational Databases (2)

More Tables!

STUDENT

Name	SSN	Phone	Address	Age	GPA
Ben Bayer	305-61-2435	555-1234	1 Foo Lane	19	3.21
Chung-cha Kim	422-11-2320	555-9876	2 Bar Court	25	3.53
Barbara Benson	533-69-1238	555-6758	3 Baz Blvd	19	3.25

CLASS

SSN	Class
305-61-2435	COMP355
422-11-2320	COMP355
533-69-1238	MATH650
305-61-2435	MATH650
422-11-2320	BIOL110

DORM

SSN	Dorm
305-61-2435	555 Huntington
422-11-2320	Baker
533-69-1238	555 Huntington

Values in one table can be forced to come from another ("Referential Integrity")

Relational Databases (3)

Queries!

STUDENT

Name	SSN	Phone	Address	Age	GPA
Ben Bayer	305-61-2435	555-1234	1 Foo Lane	19	3.21
Chung-cha Kim	422-11-2320	555-9876	2 Bar Court	25	3.53
Barbara Benson	533-69-1238	555-6758	3 Baz Blvd	19	3.25

Result
3.23

What is the average GPA of students in MATH650?

1. Find all SSN in table Class where Class=MATH650
2. Find all GPA in table Student where SSN=#1
3. Average GPA in #2

DORM

SSN	Dorm
305-61-2435	555 Huntington
422-11-2320	Baker
533-69-1238	555 Huntington

CLASS

SSN	Class
305-61-2435	COMP355
422-11-2320	COMP355
533-69-1238	MATH650
305-61-2435	MATH650
422-11-2320	BIOL110

Relational Databases (3)

Queries!

STUDENT

Name	SSN	Phone	Address	Age	GPA
Ben Bayer	305-61-2435	555-1234	1 Foo Lane	19	3.21
Chung-cha Kim	422-11-2320	555-9876	2 Bar Court	25	3.53
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Result
3.23

CLASS

SSN	Class
305-61-2435	COMP355
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305-61-2435	MATH650
422-11-2320	BIOL110

DORM

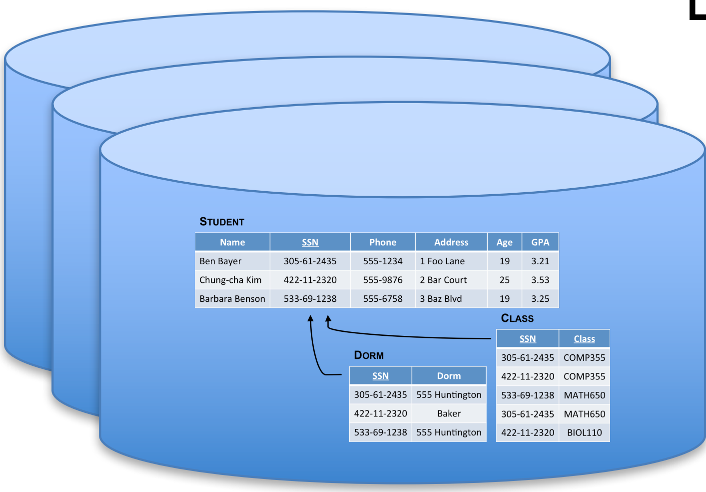
SSN	Dorm
305-61-2435	555 Huntington
422-11-2320	Baker
533-69-1238	555 Huntington

```
SELECT AVG(STUDENT.GPA)
FROM
     STUDENT INNER JOIN CLASS
     ON STUDENT.SSN=CLASS.SSN
WHERE CLASS.Class='MATH650';
```

Relational Databases (4)

Users!

DBMS | **Application Server** | **Clients**



Student

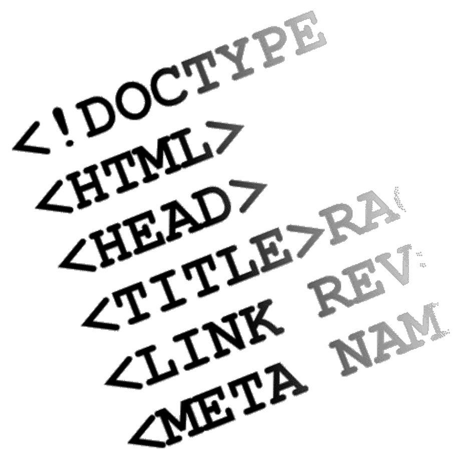
Name	SSN	Phone	Address	Age	GPA
Ben Bayer	305-61-2435	555-1234	1 Foo Lane	19	3.21
Chung-cha Kim	422-11-2320	555-9876	2 Bar Court	25	3.53
Barbara Benson	533-69-1238	555-6758	3 Baz Blvd	19	3.25

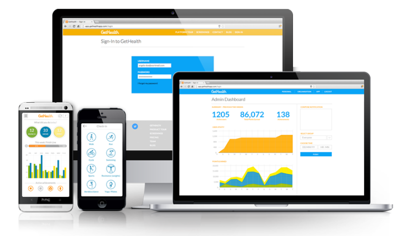
Dorm

SSN	Dorm
305-61-2435	555 Huntington
422-11-2320	Baker
533-69-1238	555 Huntington

Class

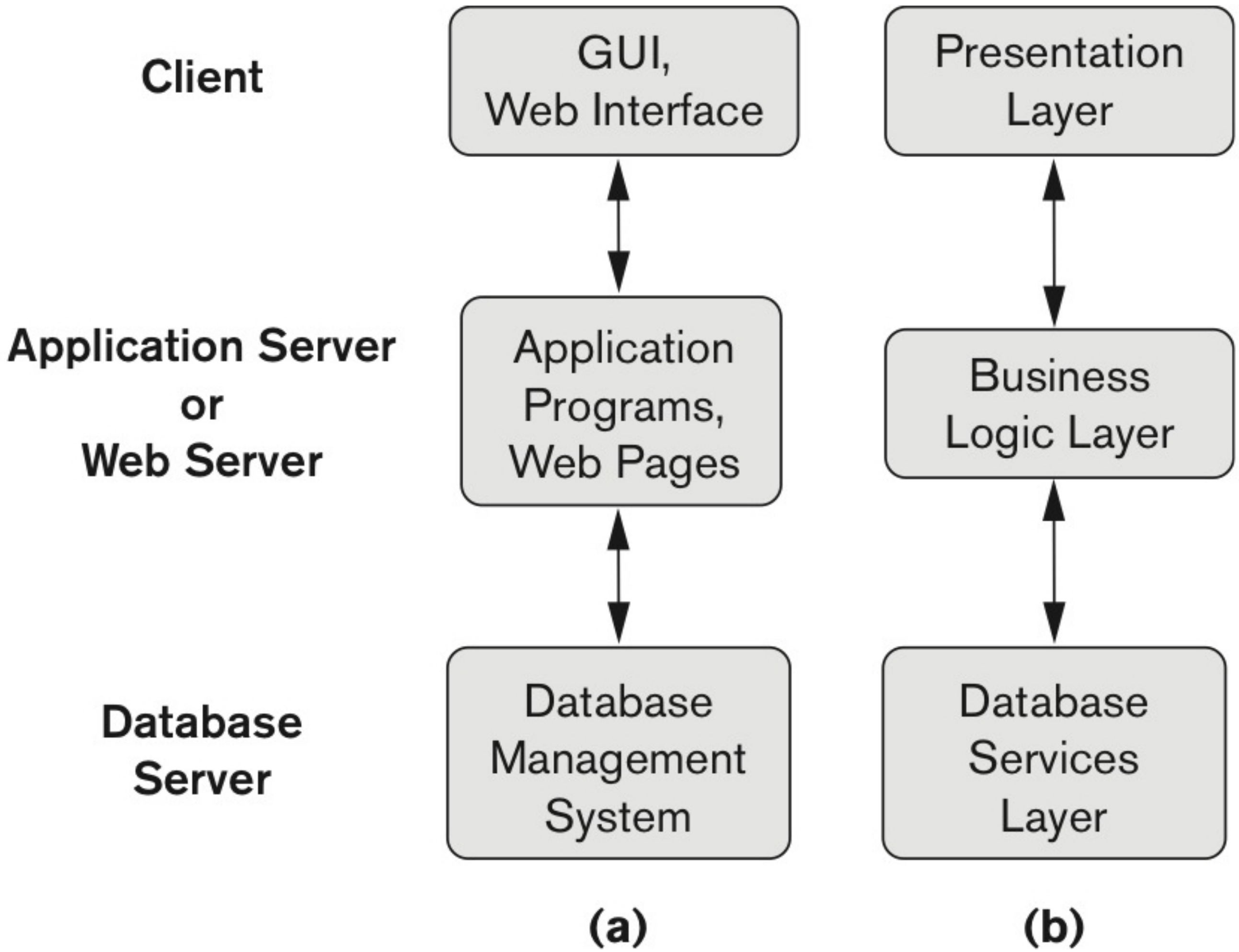
SSN	Class
305-61-2435	COMP355
422-11-2320	COMP355
533-69-1238	MATH650
305-61-2435	MATH650
422-11-2320	BIOL110





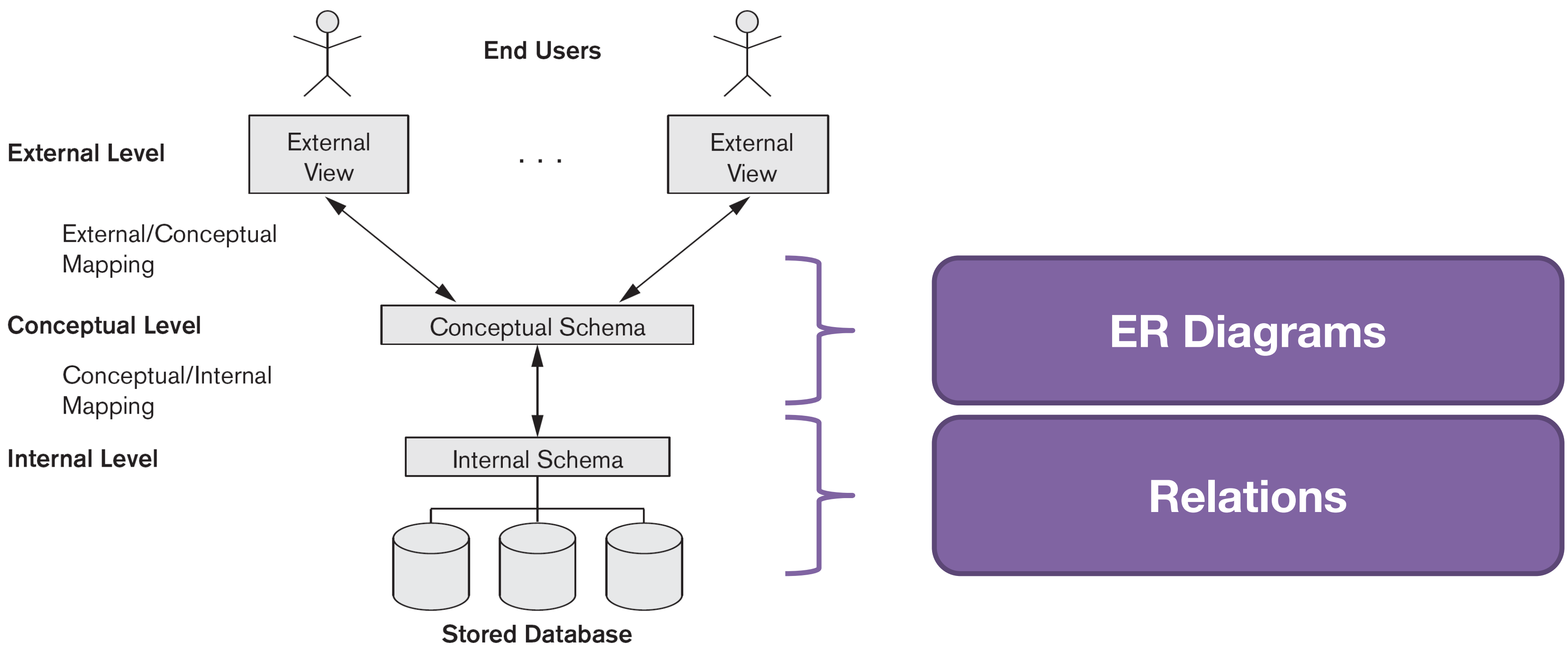
Databases in Context

Architecture



Relational DBMS Features (1)

- Data *independence* via **data models**
  - Conceptual representation independent of underlying storage or operation implementation



Relational DBMS Features (2)

- Operation abstraction via…
  - Declarative languages
    - Structured Query Language (SQL)
      - Data… definition, manipulation, query
  - Programmatic APIs
    - Function libraries (focus), embedded languages, stored procedures, etc.

Relational DBMS Features (3)

- Reliable concurrent transactions
  - `(A)tomicity`: "all or nothing"
  - `(C)onsistency`: valid -> valid'
  - `(I)solation`: parallel execution, serial result
  - `(D)urability`: once it is written, it is so
- High performance
  - Buffering, caching, locking (like a mini OS)
  - Query optimization, redundant data structures (e.g. indexes, materialized views)

Relational DBMS Features (4)

- Authentication and authorization
  - Discussed in context of other security concerns/techniques
- Backup and recovery
  - Logging, replication, migration

Why NOT to use a DBMS

Your application…
- involves a single user
- has simple/well-defined data/operations
  - DBMS may be overkill

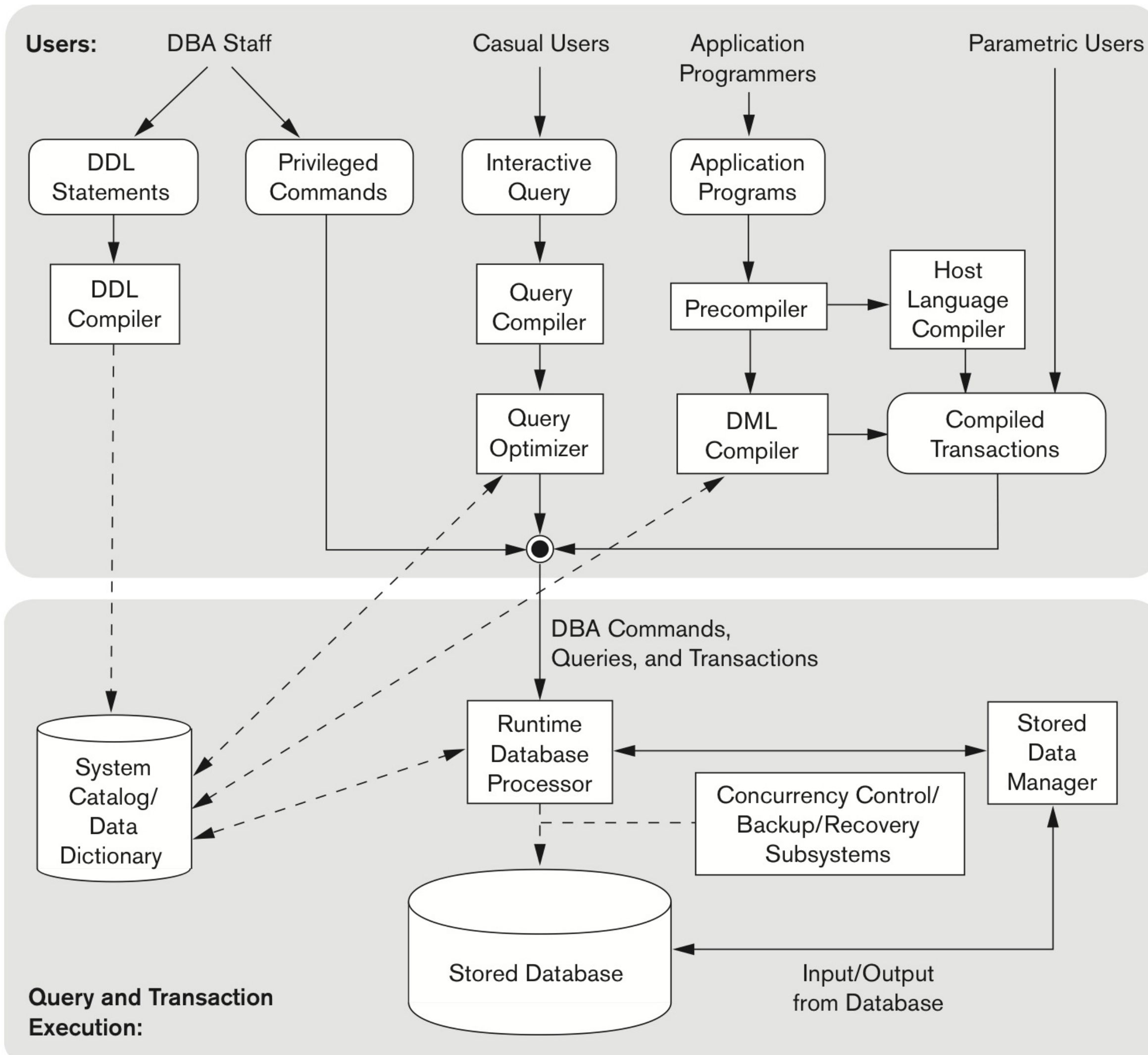
However, DBMS techniques may be useful
  - We will discuss useful and scalable indexing structures and processes

Databases in Context

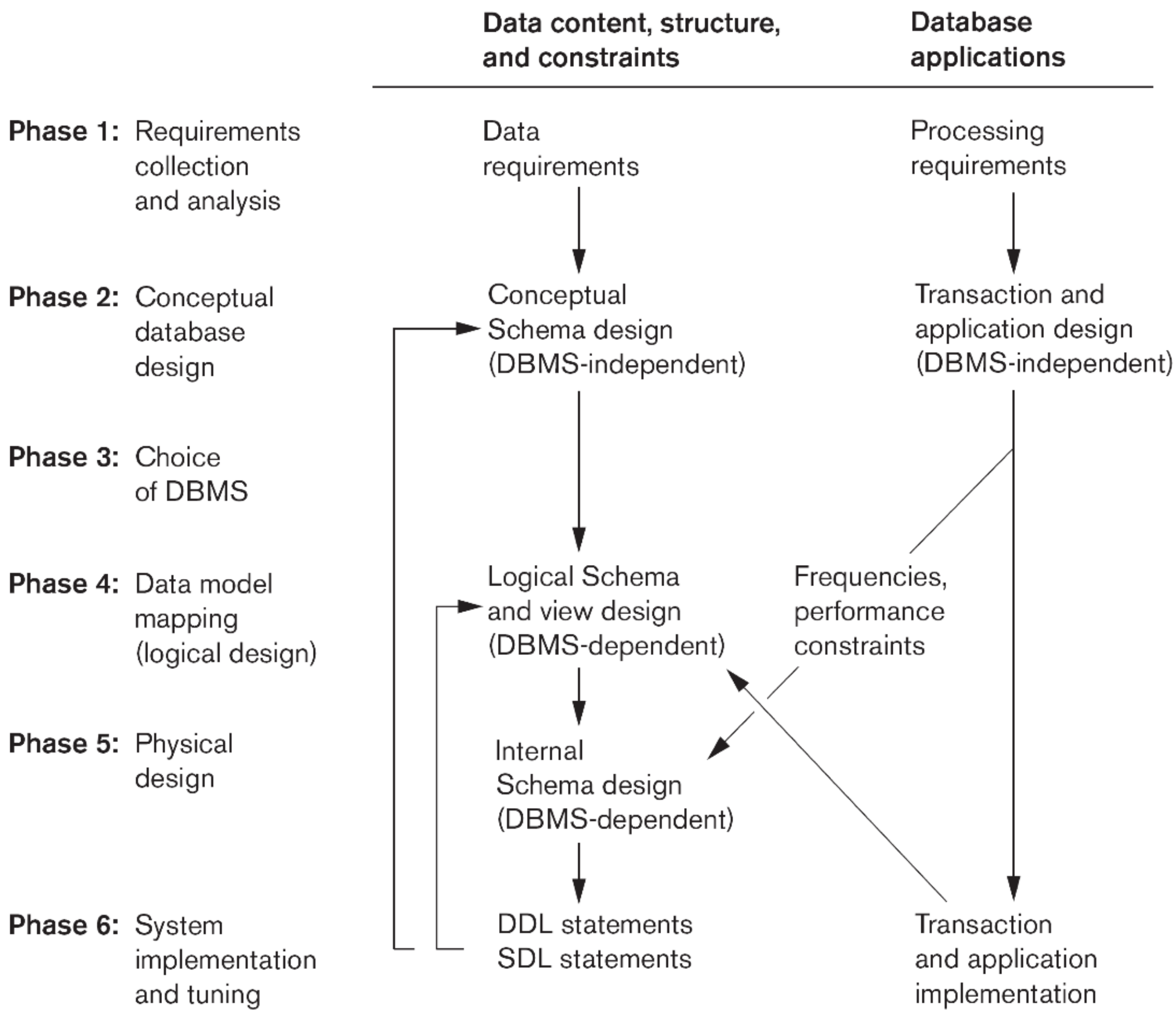
People

1. **Database designers**
2. **System analysts & application programmers**
3. Database administrators
4. End users
5. Back-end
   a. DBMS designer/implementer
   b. Tool developers
   c. SysAdmins

Relational DBMS



Database Design and Implementation Process



Requirements Collection & Analysis

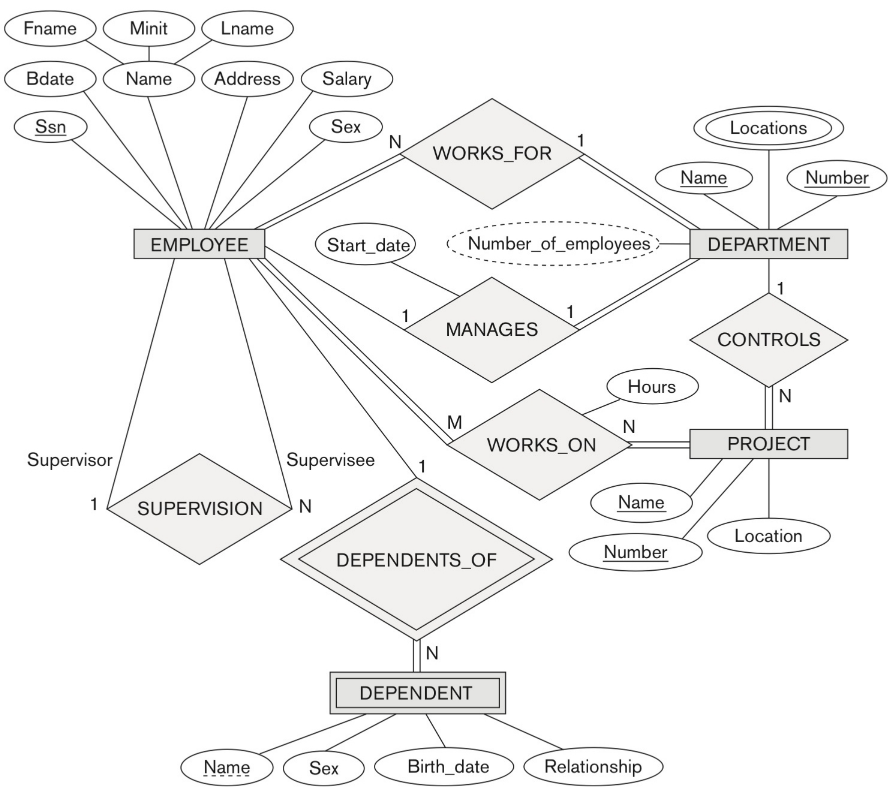
- Data/Constraints

  "The company is organized into departments. Each department has a unique name, number, and a particular employee who manages the department. We keep track…"

- Functional Needs
  - Operations/queries/reports
    - Frequency
  - Performance, security, etc.

Conceptual Design

Data



Application

- Software
  - UML
  - Form design
- Database
  - Transaction design
  - Report design

Logical Design

Data

EMPLOYEE

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno

DEPARTMENT

Dname	Dnumber	Mgr_ssn	Mgr_start_date

DEPT_LOCATIONS

Dnumber	Dlocation

PROJECT

Pname	Pnumber	Plocation	Dnum

WORKS_ON

Essn	Pno	Hours

DEPENDENT

Essn	Dependent_name	Sex	Bdate	Relationship

- Normalization

Application

- Supporting code (that does not depend upon database)
  - Possibly using techniques from databases (e.g. indexing)

Physical Design

Data

- Index, materialized view selection and analysis

Application

- Implementing operations as queries
- Implementing constraints as keys, triggers, views
- Implementing multi-user security as grants

Implementation and Tuning

Data

- DDL statements
- De-normalization, updating indexes/materialized views

Application

- Query integration
- Profiling queries/operations
- Security, concurrency, performance, etc. analysis

Summary

- A **database** is a collection of related data that reflects some aspect of the real world; is logically coherent with inherent meaning; and is designed, built, and populated with data for a specific purpose
- A **database management system** (DBMS) is a collection of programs that enables users to create and maintain a database
- There are many types – we will focus on **relational** databases (RDBMS)
- The typical database design process is an iterative process of requirements collection/analysis, conceptual design, logical design, physical design, and system implementation/tuning