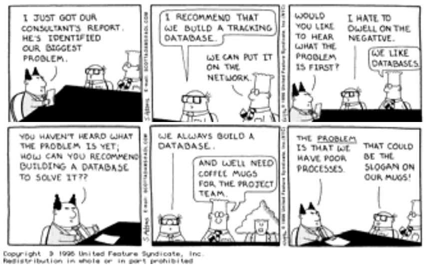
CS5208: Foundations on Database Systems
(http://www.comp.nus.edu.sg/~cs5208)

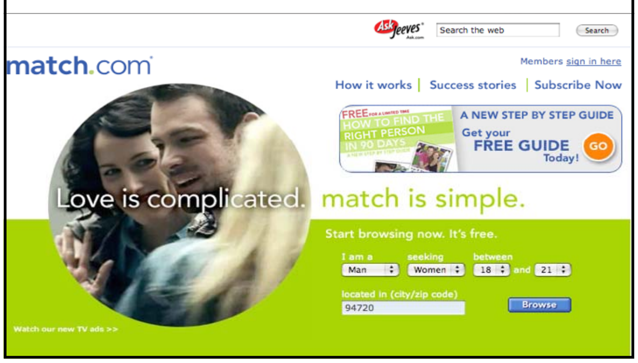


"Knowledge is of two kinds: we know a subject ourselves,
or we know where we can find information upon it."
-- Samuel Johnson (1709-1784)

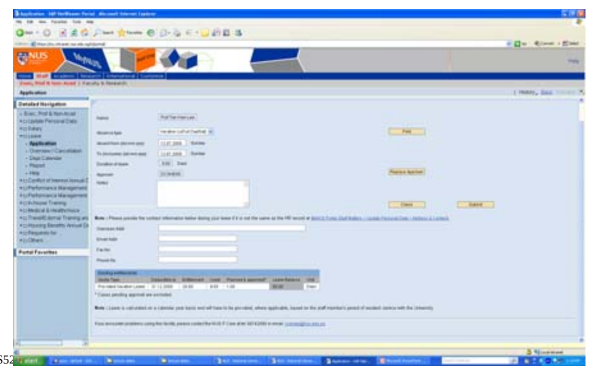
Lecture 1

Introduction
&
Data Design and Modeling

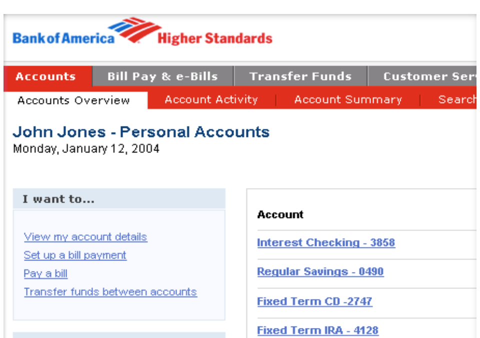
What: Database Systems Today



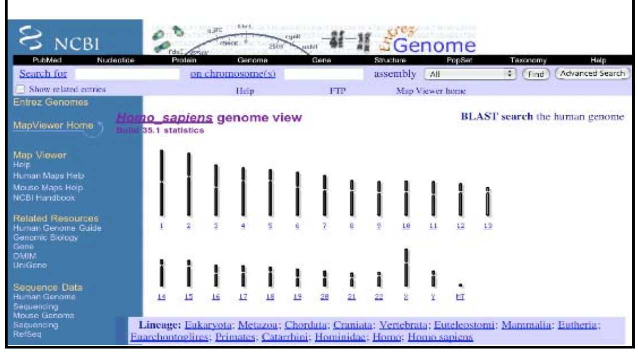
What: Database Systems Today



What: Database Systems Today



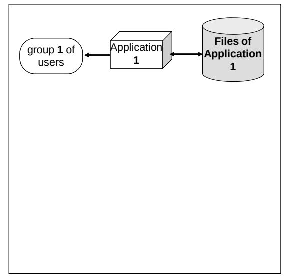
What: Database Systems Today



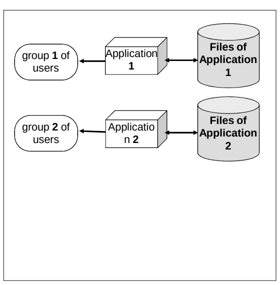
What Is a Database *System*?

- Database:
  a very large, integrated collection of data.
- Models a real-world *enterprise*
  - Entities (e.g., course, instructor)
  - Relationships
    (e.g., Tan *teaches* Database Technology)
- A *Database Management System (DBMS)* is a software system designed to store, manage, and facilitate access to databases.

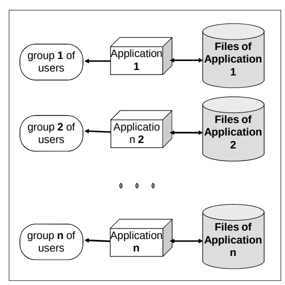
File-based vs database approach

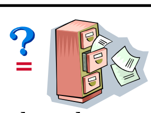


File-based vs database approach



File-based vs database approach





Is a File System a DBMS?

- Thought Experiment 1:
  - You and your project partner are editing the same file.
  - You both save it at the same time.
  - Whose changes survive?

A) Yours B) Partner's C) Both D) Neither E) ???

- Thought Experiment 2:
  - You're updating a file.
  - The power goes out.
  - Which of your changes survive?

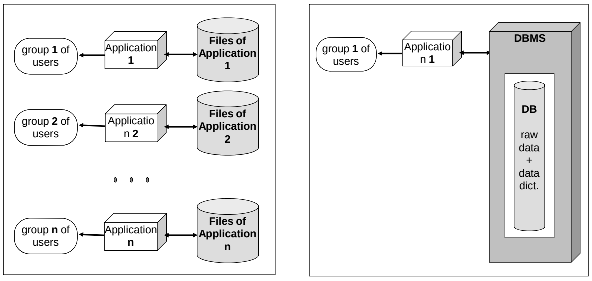
Q: How do you write programs over a subsystem when it promises you only "???" ?
A: Very, very carefully!!

A) All B) None C) All Since last save D) ???

OS Support for Data Management

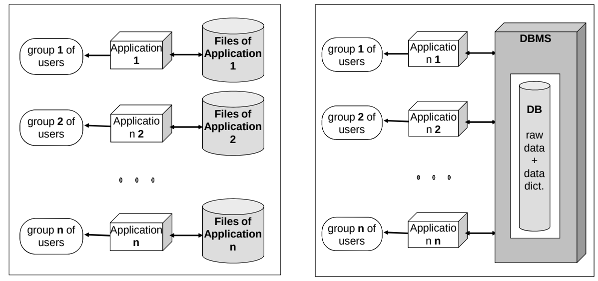
- Data can be stored in RAM
  - this is what every programming language offers!
  - RAM is fast, and random access
  - Isn't this heaven?
- Every OS includes a File System
  - manages *files* on a magnetic disk
  - allows *open, read, seek, close* on a file
  - allows protections to be set on a file
  - drawbacks relative to RAM?

File-based vs database approach



CS5208 13

File-based vs database approach



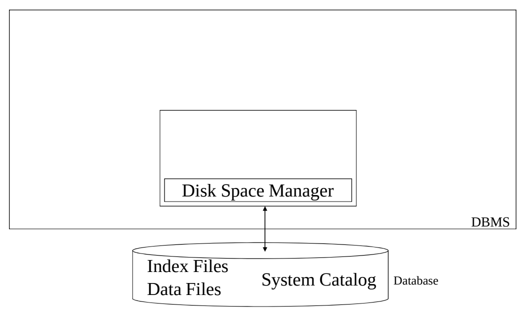
CS5208 14

Capabilities of a Modern DBMS

- **Persistence** - permanent storage of data
- **Efficiency** - manage *large* volumes of data and *ad-hoc* queries efficiently
- **High-level access** - data model & language for defining database structures, retrieval and manipulation
- **Transaction management** - provide correct, concurrent access to the database by many users at once
- **Access control** - limit access by unauthorized users
- **Integrity management** - assure compliance to known constraints imposed by application semantics
- **Resiliency** - ability to recover from system failures without losing data

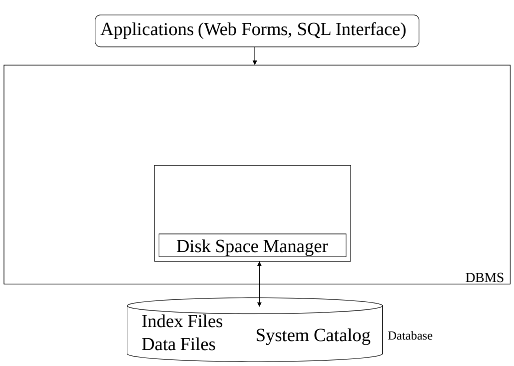
CS5208 15

Architecture of a DBMS



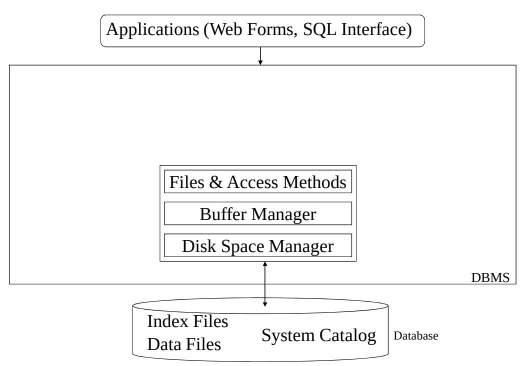
CS5208 16

Architecture of a DBMS



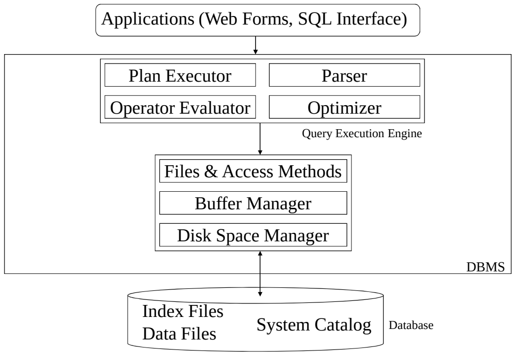
CS5208 17

Architecture of a DBMS

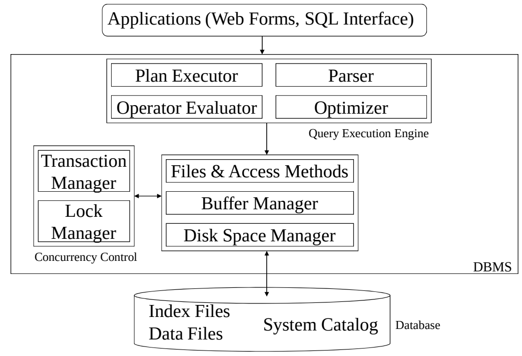


CS5208 18

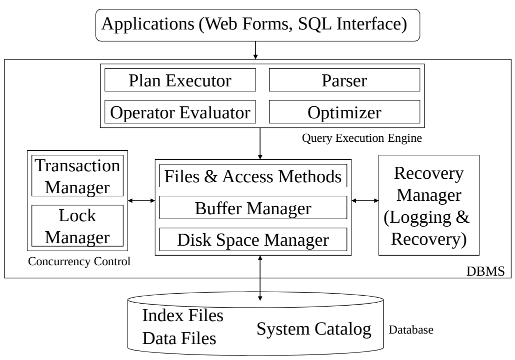
Architecture of a DBMS



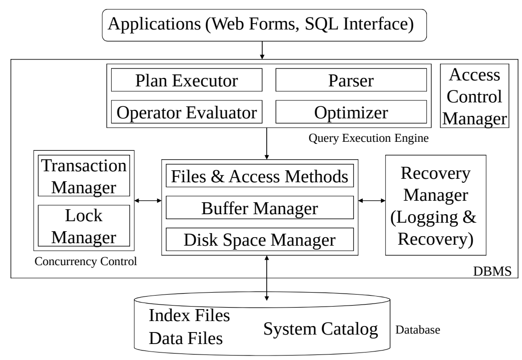
Architecture of a DBMS



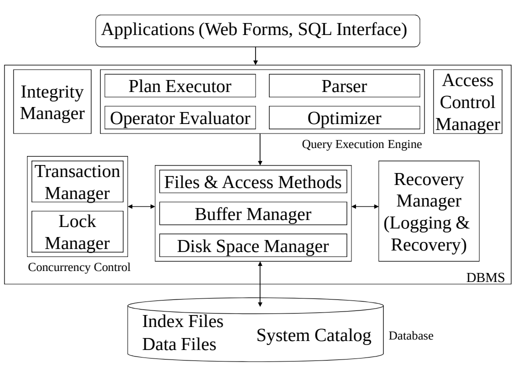
Architecture of a DBMS



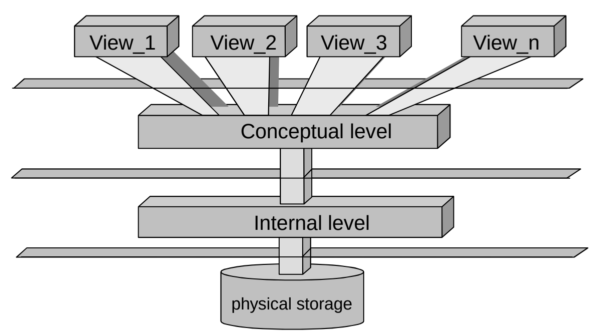
Architecture of a DBMS



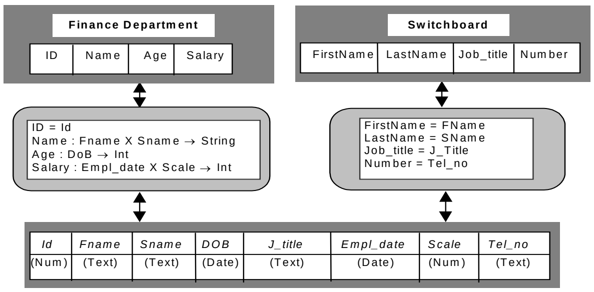
Architecture of a DBMS



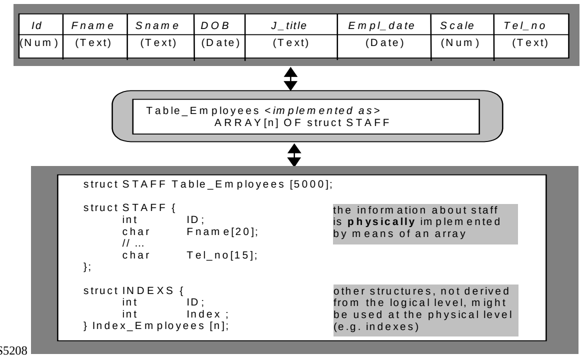
3-level Abstraction



External / conceptual example



Conceptual / internal - example



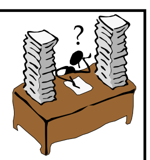
Data Independence

- Applications insulated from how data is structured and stored.
- Ability to modify a schema definition in one level without affecting a schema definition in the next higher level.
- The interfaces between the various levels and components should be well defined so that changes in some parts do not seriously influence others.
- *Logical* and *physical* data independence

Current Commercial Outlook

- A major part of the software industry:
  - Oracle, IBM, Microsoft
  - also Sybase, Informix (now IBM), Teradata
  - smaller players: java-based dbms, devices, OO, ...
- Well-known benchmarks (esp. TPC)
- Lots of related industries
  - data warehouse, document management, storage, backup, reporting, business intelligence, ERP, CRM, app integration
- Relational products dominant and evolving
  - adapting for extensibility (user-defined types), adding native XML support.
  - Microsoft merging file system/DB for "longhorn" (abandoned?)
- Open Source coming on strong
  - MySQL, PostgreSQL, BerkeleyDB

Why Study Databases??



- Shift from *computation* to *information*
  - "Big-Data" phenomenon
  - always true for corporate computing
  - Web made this point for personal computing
  - more and more true for scientific computing
- Need for DBMS has exploded in the last years
  - Corporate: retail swipe/clickstreams, "customer relationship mgmt", "supply chain mgmt", "data warehouses", etc.
  - Scientific: digital libraries, Human Genome project, NASA Mission to Planet Earth, physical sensors, grid physics network
- DBMS encompasses much of CS in a practical discipline
  - OS, languages, theory, AI, multimedia, logic
  - Yet traditional focus on real-world apps

Intellectual Outlook: Research Trends

- Heavy weight DBMS
  - Extend existing DBMS capabilities for advanced applications
- Light weight DBMS
  - Component-based DBMS
  - Build and use what are necessary
- Autonomic & Self tuning DBMS
  - Making the DBMS "intelligent" to minimize maintenance cost

Databases make these folks happy ...

- DBMS vendors, programmers
  - Oracle, IBM, MS, Sybase, NCR, ...
- End users in many fields
  - Business, education, science, ...
- DB application programmers
  - Build enterprise applications on top of DBMSs
  - Build web services that run off DBMSs
- Database administrators (DBAs)
  - Design logical/physical schemas
  - Handle security and authorization
  - Data availability, crash recovery
  - Database tuning as needs evolve

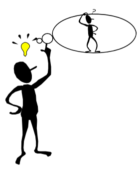
...must understand how a DBMS works

Database Design

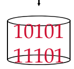
- Why do we need it?
  - Agree on structure of the database before deciding on a particular implementation.
- Issues:
  - What to model?
  - How are things related?
  - What constraints exist?
  - How to achieve *good* designs?

Data Models

- DBMS models real world
- *Data Model* is link between user's view of the world and bits stored in computer
  - A tool for describing data, data relationships, data semantics and data constraints
- Many models exist
  - Relational Model
  - Entity-Relationship Model
  - Object-oriented Model



Student *(sid: string, name: string, login: string, age: integer, gpa:real)*



Entity Relationship Model

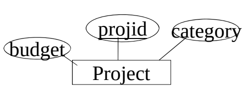
- Diagrams to represent designs

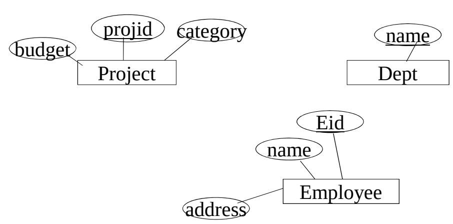
Entity = object of interest

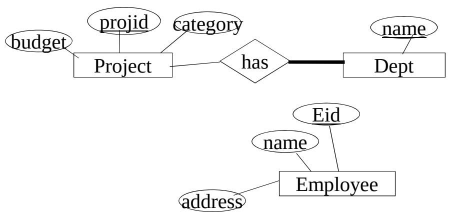
Entity set = set of similar entities.

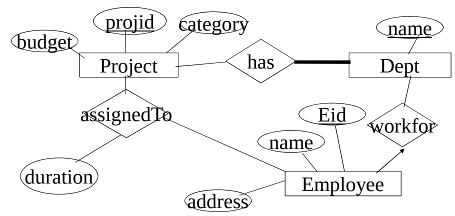
Attribute = property of entities in an entity set

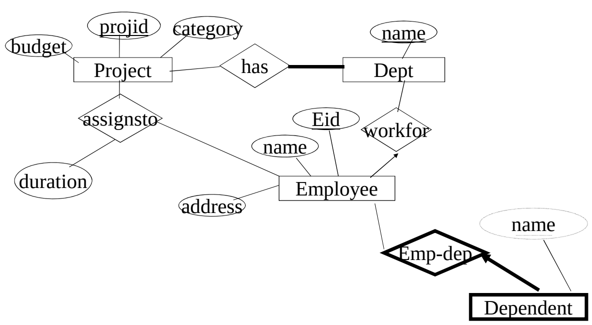
Relationship = association among entity sets

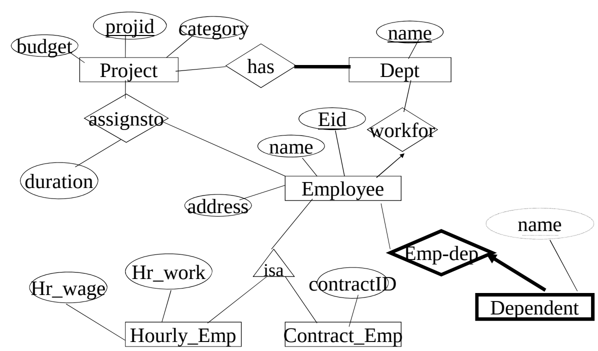












Relational Data Model

- a data model in which all data is modelled as relations (tables)
  - a way of looking at data
- a prescription for a way of
  - representing data
  - manipulating data (relational algebra)
  - representing integrity constraints

A Relation

A relation contains a SET of tuples

PARTS(Name: String; Price: Real; Category: String; Manufacturer: String)

Attribute names

Name	Price ($)	Category	Manufacturer
Gizmo	19.99	gadgets	GizmoWorks
Power gizmo	29.99	gadgets	GizmoWorks
SingleTouch	149.99	photography	Canon
MultiTouch	203.99	household	Hitachi

Tuples (record)

Each attribute has an atomic type

Integrity

- restrictions on data defined by users
  - on individual tables
    - age > 18; salary < 100k
  - on more than one table
    - *if* budget < 10M *then* salary < 50k
- implicit in the data model

Integrity Constraints (ICs)

- IC: condition that must be true for *any* instance of the database
  - e.g., *domain constraints*
    - Each attribute has values taken from a *domain*. ICs are specified when schema is defined.

Primary and foreign keys

E_id	E_name	Dept_id	Salary
E1	Smith	D1	40K
E2	John	D1	42K
E3	Stella	D2	30K
E4	Art	D3	35K

foreign

Dept_id	Dept_name	Budget
D1	Marketing	10M
D2	Development	12M
D3	Research	5M

primary

More Integrity Constraints

- *Key constraints*: each tuple must be distinct. A key is a subset of fields that uniquely identifies a tuple (*superkey*), and for which no subset of the key has this property.
- *Referential integrity constraints*: a field in one relation may refer to a tuple in another relation by including its key (*foreign key*). The referenced tuple must exist in the other relation for the database instance to be valid.
- Typically, a relation may have several *candidate* keys one of which is chosen as the *primary* key.

From E/R Diagrams to Relational Schema

Database Model (E/R) → Relational Schema → Physical storage

Diagrams (E/R)

Tables:
columns: attributes
rows: tuples

Complex file organization and index structures.

From E/R Diagrams to Relational Schema

Database Model (E/R) → Relational Schema → Physical storage

Diagrams (E/R)

Tables:
columns: attributes
rows: tuples

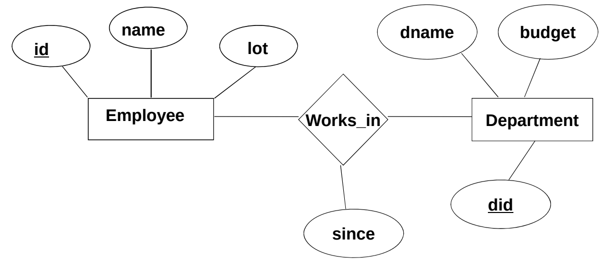
Complex file organization and index structures.

Entity sets → relations
Relationships → relations
Special care for weak entity sets.

Relationships to Relations

- In translating a relationship set to a relation, attributes of the relation must include:
  - Keys for each participating entity set (as foreign keys).
    - This set of attributes forms a ***superkey*** for the relation.
  - All descriptive attributes.

Example



Example continued

Relation Employee
 id : CHAR(9),
 name : CHAR(20),
 lot : INTEGER
 PRIMARY KEY id

Example continued

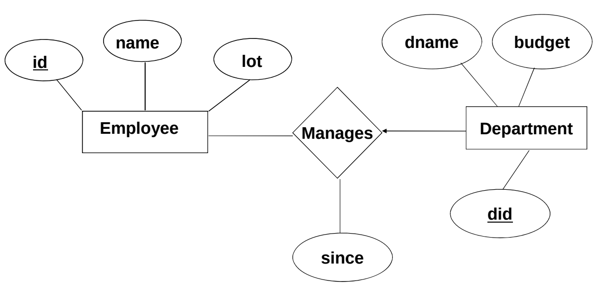
Relation Employee
 id : CHAR(9),
 name : CHAR(20),
 lot : INTEGER
 PRIMARY KEY id

Relation Department
 did : INTEGER,
 dname : CHAR(20),
 budget : REAL
 PRIMARY KEY did

Relation Works_In
 id : CHAR(9),
 did : INTEGER,
 since : DATE,
 PRIMARY KEY (id, did),
 FOREIGN KEY (id) REFERENCES Employee,
 FOREIGN KEY (did) REFERENCES Department

Key constraints

Each dept has at most one manager, *key constraint* on Manages.



Key Constraints

- Map relationship to a table:
  - Note that ***did*** is the key now!

Relation Manages
 id : CHAR(9),
 did : INTEGER,
 since : DATE,
 PRIMARY KEY did,
 FOREIGN KEY id REFERENCES Employee,
 FOREIGN KEY did REFERENCES Department

Key Constraints

Since each department has a unique manager, we could instead combine Manages and Departments.

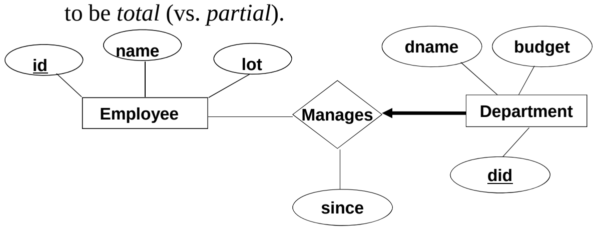
Key Constraints

Since each department has a unique manager, we could instead combine Manages and Departments.

```
Relation   Dept_Mgr
   did  : INTEGER,
   dname  : CHAR(20),
   budget  : REAL,
   id :  CHAR(11),
   since  : DATE,
   PRIMARY KEY  did,
   FOREIGN KEY id REFERENCES Employee
```


Participation Constraints

- Does every department have a manager?
  - If so, this is a *participation constraint*: the participation of Departments in Manages is said to be *total* (vs. *partial*).



Participation Constraints

- Every *did* value in Department table must appear in a row of the Manages table (with a non-null id value!)

Participation Constraints

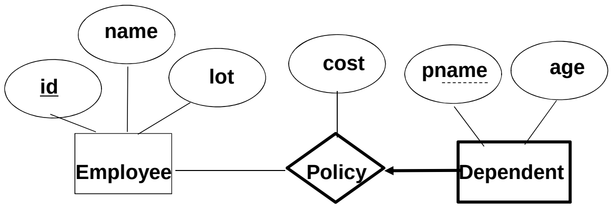
- Every *did* value in Department table must appear in a row of the Manages table (with a non-null id value!)

```
Relation  Dept_Mgr
   did  : INTEGER,
   dname  : CHAR(20),
   budget  : REAL,
   id  : CHAR(9) NOT NULL,
   since : DATE,
   PRIMARY KEY  did,
   FOREIGN KEY  (id) REFERENCES Employee,
   ON DELETE NO ACTION
```


Weak Entities to Relations

- A *weak entity* can be identified uniquely only by considering the primary key of another (*owner*) entity.
  - a one-to-many relationship set (1 owner, many weak entities).
  - Weak entity set must have total participation in this *identifying* relationship set.

Weak Entities to Relations



CS5208 61

Translating Weak Entity Sets

- Weak entity set and identifying relationship set are translated into a single table.
  - When the owner entity is deleted, all owned weak entities must also be deleted.

```
Relation  Dep_Policy
  pname  CHAR(20),
  age  INTEGER,
  cost  REAL,
  id  CHAR(9) NOT NULL,
  PRIMARY KEY  (pname, id),
  FOREIGN KEY  (id) REFERENCES Employee,
    ON DELETE CASCADE
```

CS5208 62

Translating ISA Hierarchies

- 3 relations: Employees, Hourly_Emps and Contract_Emps.
- *Hourly_Emps*: Every employee is recorded in Employees.
  - extra info recorded in Hourly_Emps (*hourly_wages*, *hours_worked*, <u>id</u>);
  - must delete Hourly_Emps tuple if referenced Employees tuple is deleted.

CS5208 63

You are now a *trained* database designer!

CS5208 64