

## 第4章：概念数据库设计

### Conceptual Database Design

邹兆年

哈尔滨工业大学  
计算机科学与技术学院  
海量数据计算研究中心  
电子邮件: [znzou@hit.edu.cn](mailto:znzou@hit.edu.cn)

2021年春

## 教学内容<sup>1</sup>

- 1 数据库设计的过程
- 2 实体-联系模型(ER模型)
  - ▶ 与实体相关的概念
  - ▶ 与联系相关的概念
- 3 实体-联系图(ER图)
- 4 数据库概念设计案例
- 5 增强实体-联系图(EER图)

<sup>1</sup>课件更新于2021年3月25日

## 4.1 数据库设计的过程

### Overview of Database Design Process

## 数据库设计的过程

- 数据密集型应用的设计有两个主要任务
  - ▶ 数据库设计: 设计数据库的模式(本课程的内容)
  - ▶ 应用程序设计: 设计访问数据库的应用程序(软件工程课的内容)
- 数据库设计的过程
  - ① 概念设计(conceptual design): 设计数据库的(抽象)概念模式 (第4章)
  - ② 逻辑设计(logical design): 根据所使用的DBMS, 设计数据库的逻辑模式 (第5章)
  - ③ 物理设计(physical design): 根据性能需求和应用访问数据库的特点, 设计数据库的物理模式(内模式) (第6章)

## 4.2 实体-联系模型

### The Entity-Relationship (ER) Model

## 实体-联系模型(ER模型)

- 实体-联系模型(the entity-relationship model): 简称ER模型, 是概念数据库设计阶段使用的一种重要概念模型, 用于将现实世界抽象为实体(entity)及实体间的联系(relationship)
- ER模型提供了数据建模所需的多种概念
  - ▶ 与实体相关的概念
  - ▶ 与联系相关的概念
- 实体-联系图(the entity-relationship diagram): 简称ER图, 是ER模型的一种图形化表示方法

# ER模型概念

- 与实体相关的概念
  - ▶ 实体
  - ▶ 属性
  - ▶ 键
  - ▶ 实体型、实体集
  - ▶ 弱实体型
- 与联系相关的概念
  - ▶ 联系
  - ▶ 联系型、联系集
  - ▶ 联系型的约束
  - ▶ 联系型的属性
  - ▶ 多元联系

## 例: COMPANY数据库设计需求

- The company is organized into DEPARTMENTS. Each department has a name, number and an employee who manages the department. We keep track of the start date of the department manager. A department may have several locations.
- Each department controls a number of PROJECTs. Each project has a unique name, unique number and is located at a single location.
- We store each EMPLOYEE's social security number (SSN), address, salary, sex, and birthdate.
  - ▶ Each employee works for one department but may work on several projects.
  - ▶ We keep track of the number of hours per week that an employee currently works on each project.
  - ▶ We also keep track of the direct supervisor of each employee.
- Each employee may have a number of DEPENDENTs.
  - ▶ For each dependent, we keep track of their name, sex, birthdate, and relationship to the employee.

## 4.2.1 与实体相关的概念

### Concepts Related to Entities

## 实体(Entity)与属性(Attribute)

- 实体(entity): 数据库中表示的现实世界中的具体对象或事物
  - ▶ 例: 雇员 John Smith、科研部、ProductX项目
- 属性(attribute): 用于刻画实体的特性
  - ▶ 例: 雇员实体具有姓名、性别、出生日期、身份证号、住址等属性
  - ▶ 每个实体的每个属性都具有一个值, 全部属性值共同刻画了该实体
  - ▶ 每个属性都关联着它的取值域(或数据类型)

## 属性的类型

- **简单属性(simple attribute)**: 具有原子(atomic)属性值的属性, 其属性值不可再分
  - ▶ 例如, 性别、身份证号、民族等
- **复合属性(composite attribute)**: 由多个成分构成的属性
  - ▶ 姓名→(姓, 名)
  - ▶ 地址→(省, 市, 区, 街道, 门牌号, 邮编)
  - ▶ 复合属性的某个成分还可以是复合的
- **多值属性(multi-valued attribute)**: 一个实体可具有多个值的属性
  - ▶ 例如, 电话号码、论文作者等, 记作{电话号码}、{论文作者}
- **派生属性(derived attribute)**: 由其他属性派生出来的属性
  - ▶ 例如, 年龄可根据出生日期算出
- 复合属性和多值属性可以是相互嵌套的
  - ▶ 例如, 已取得的学位是一个复合多值属性, 该属性可具有多个值, 每个值由4部分构成, 记作{(学校, 专业, 学位, 日期)}

## 实体型与实体集

- **实体型(entity type)**: 具有相同属性的实体共同具有的类型
- **键属性(key attribute)**: 同一实体型的任意实体都具有不同值的属性
  - ▶ 例如, 雇员实体型的身份证号属性
  - ▶ 键属性可以是复合属性
  - ▶ 一个实体型可以具有多个键属性
- **实体集(entity set)**: 当前存储在数据库中的某实体型的实例的集合
- 实体 vs. 实体型 vs. 实体集
  - ▶ 实体: 对象
  - ▶ 实体型: 类型
  - ▶ 实体集: 对象集合

## 实体型的ER图表示

- 实体型表示为矩形

实体型的名称

- 属性表示为椭圆

- ▶ 简单属性表示为实线椭圆
- ▶ 多值属性表示为双实线椭圆
- ▶ 派生属性表示为虚线椭圆
- ▶ 键属性的属性名加下划线

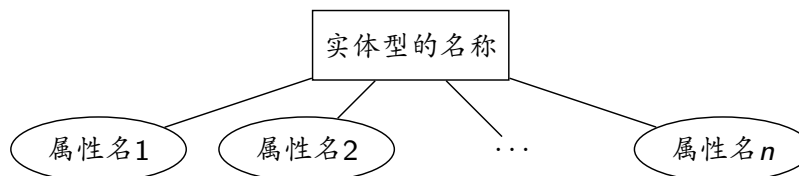
属性名

多值属性名

派生属性名

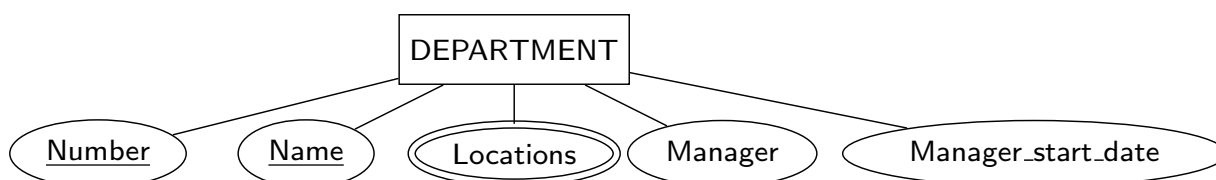
键属性名

- 实体型与其属性用线连接起来



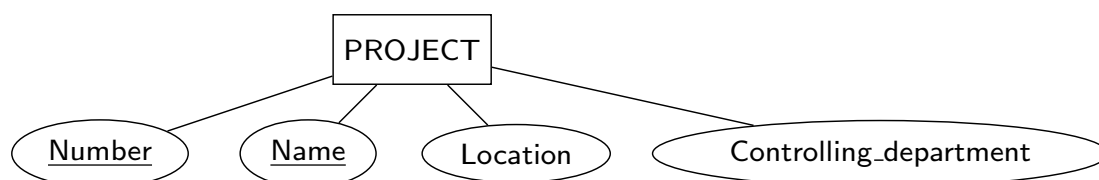
## 案例: COMPANY数据库的初步设计

The company is organized into **DEPARTMENTS**. Each department has a **name**, **number** and an **employee who manages the department**. We keep track of the **start date of the department manager**. A department may have **several locations**.



## 案例: COMPANY数据库的初步设计(续)

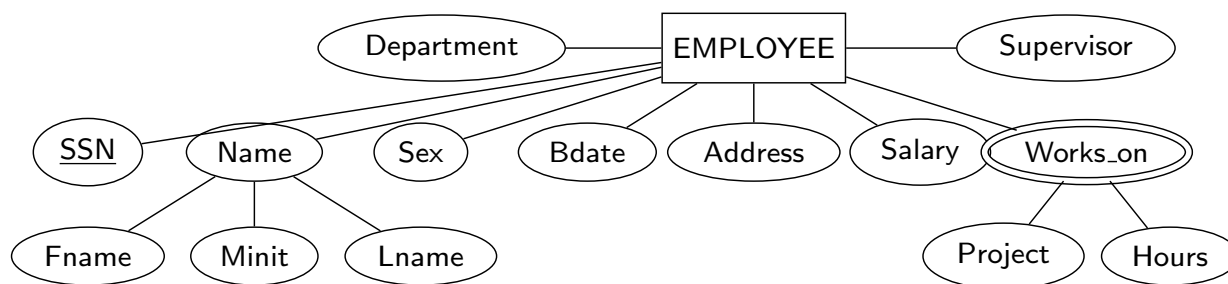
Each department *controls* a number of **PROJECT**s. Each project has a **unique name**, **unique number** and is located at a **single location**.



## 案例: COMPANY数据库的初步设计(续)

We store each **EMPLOYEE**'s **social security number (SSN)**, **address**, **salary**, **sex**, and **birthdate**.

- Each employee *works for one department* but may *work on several projects*.
- We keep track of the **number of hours** per week that an employee currently works on each project.
- We also keep track of the **direct supervisor** of each employee.

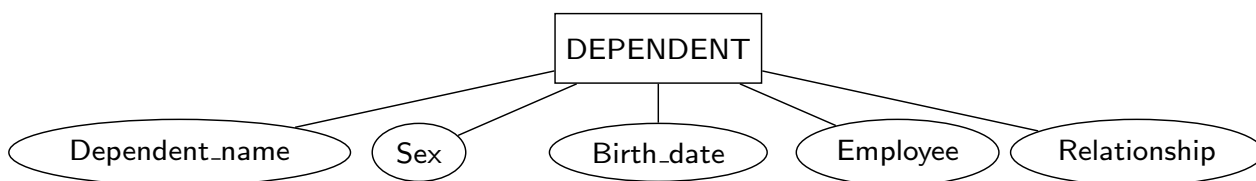




## 案例: COMPANY数据库的初步设计(续)

Each employee may *have* a number of **DEPENDENTs**.

- For each dependent, we keep track of their **name**, **sex**, **birthdate**, and **relationship** to the **employee**.



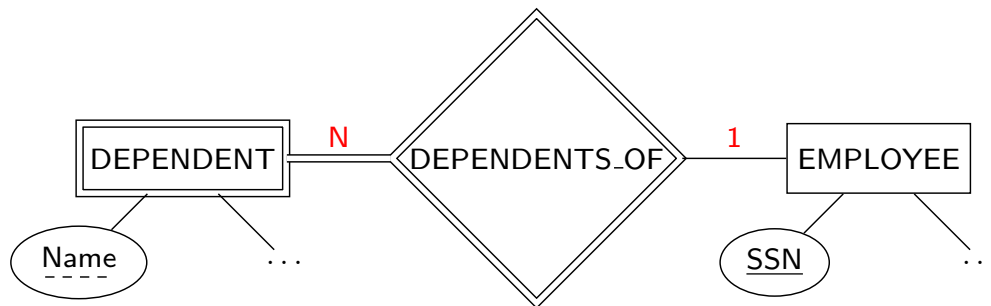
## 案例: COMPANY数据库的初步设计(续)

- 初步设计方案并不完善: 只有实体
- 需求中很多内容需要表示为实体间的联系



## 案例: COMPANY数据库设计的细化

- Each employee may **have** a number of DEPENDENTs. For each dependent, we keep track of their name, sex, birthdate, and relationship to the employee.



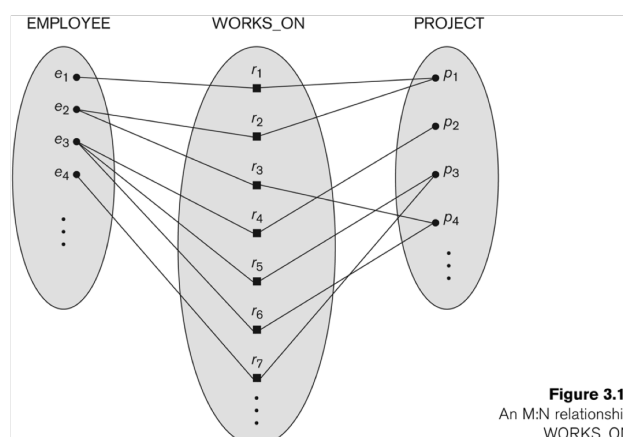
### 4.2.2 与联系相关的概念 Concepts Related to Relationships

## 联系、联系型、联系集

- **联系(relationship)**: 一个联系表示多个实体之间有意义的关联关系
  - ▶ EMPLOYEE John Smith **works on** the ProductX PROJECT
  - ▶ EMPLOYEE Franklin Wong **manages** the Research DEPARTMENT
- **联系型(relationship type)**: 同一类联系共同具有的类型
  - ▶ The **WORKS\_ON** relationship type in which EMPLOYEEs and PROJECTs participate
  - ▶ The **MANAGES** relationship type in which EMPLOYEEs and DEPARTMENTs participate
- **联系型的度(degree)**: 参与到一个联系型中的实体型的个数
  - ▶ 联系型WORKS\_ON和MANAGES的度都是2
  - ▶ 度为2的联系称作二元联系(binary relationship)
  - ▶ 度为3的联系称作三元联系(ternary relationship)
  - ▶ 度为 $n$ 的联系称作 $n$ 元联系( $n$ -ary relationship)
- **联系集(relationship set)**: 数据库中当前存储的联系型的实例的集合

## 联系、联系型、联系集(续)

- 实体型: EMPLOYEE, PROJECT
- 实体集:  $\{e_1, e_2, \dots\}$ ,  $\{p_1, p_2, \dots\}$
- 联系型: WORKS\_ON
- 联系集:  $\{r_1, r_2, \dots\}$
- WORKS\_ON是二元联系型, 参与实体型有EMPLOYEE和PROJECT
- 实体 $e_1$ 和 $p_1$ 参与到联系 $r_1$ 中, 实体 $e_2$ 和 $p_1$ 参与到联系 $r_2$ 中, ...



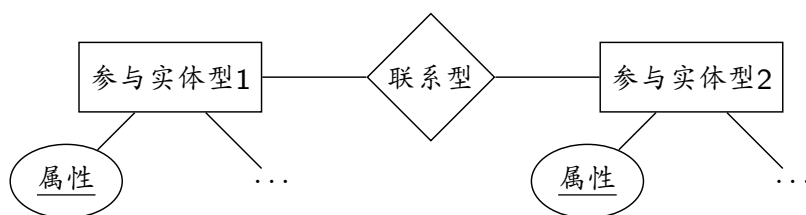
**Figure 3.13**  
An M:N relationship,  
WORKS\_ON.

## 联系型的ER图表示

- 联系型表示为菱形

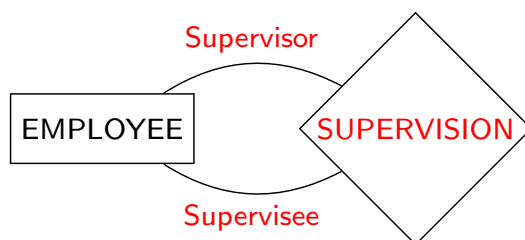
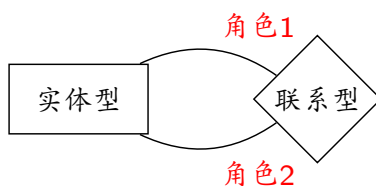


- 用直线将联系型与参与到联系型中的实体型连接起来



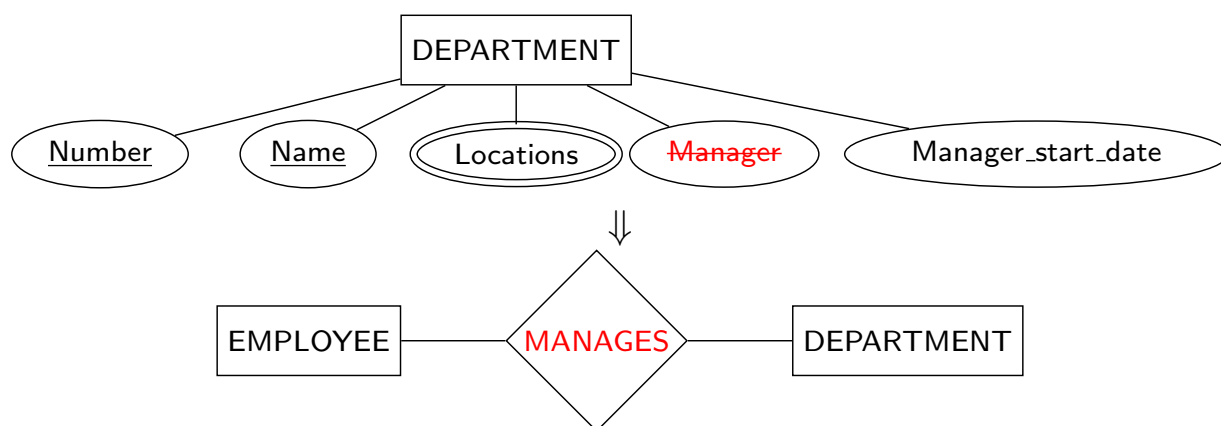
## 联系型的ER图表示(续)

- 相同的参与实体型之间可以存在多种不同的联系型
- 一个实体型可以和自身参与到同一个联系型中
  - ▶ EMPLOYEE Jill is the direct supervisor of EMPLOYEE Jack
  - ▶ 该实体型在该联系型中担任不同的角色(role)
  - ▶ 需要在ER图中标出实体型参与在联系型中的角色



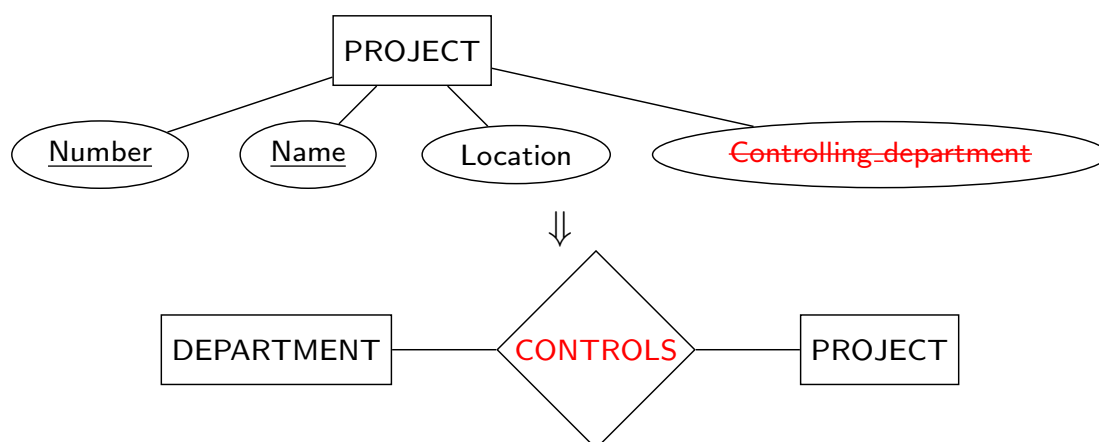
## 案例: COMPANY数据库设计的细化

- The company is organized into DEPARTMENTS. Each department has a name, number and an employee who **manages** the department. We keep track of the start date of the department manager. A department may have several locations.



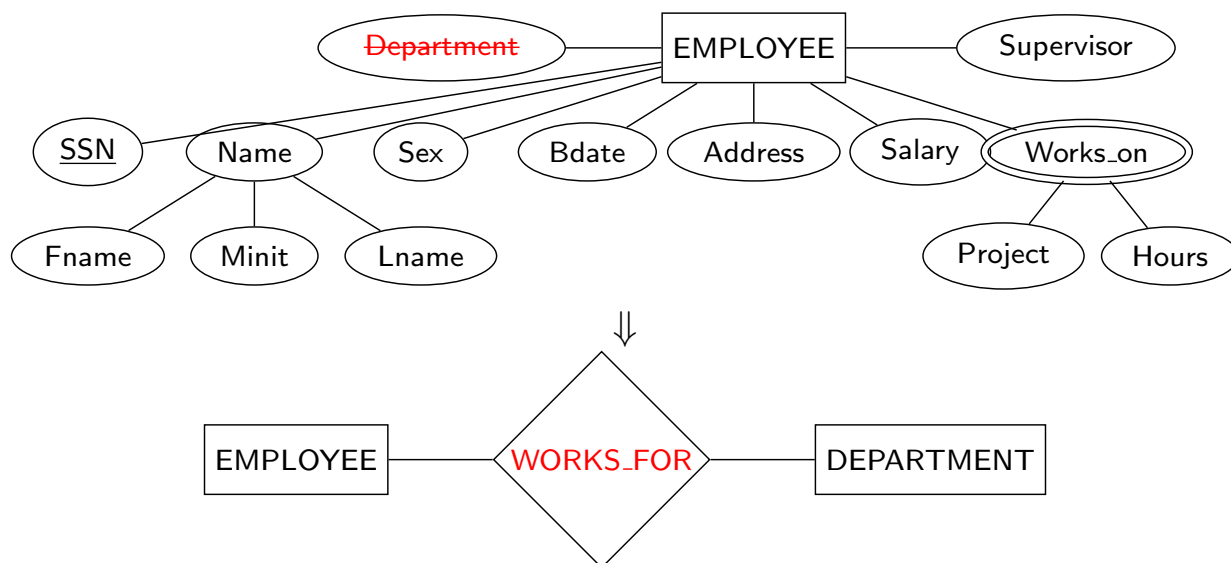
## 案例: COMPANY数据库设计的细化(续)

- Each department **controls** a number of PROJECTs. Each project has a unique name, unique number and is located at a single location.



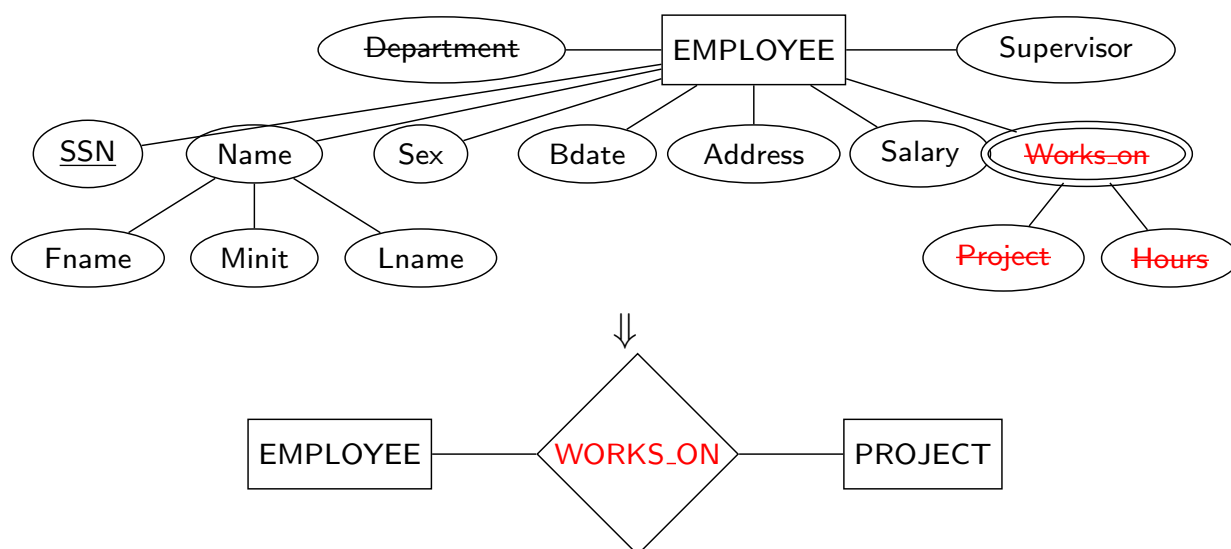
## 案例: COMPANY数据库设计的细化(续)

- Each employee **works for** one department but may work on several projects.



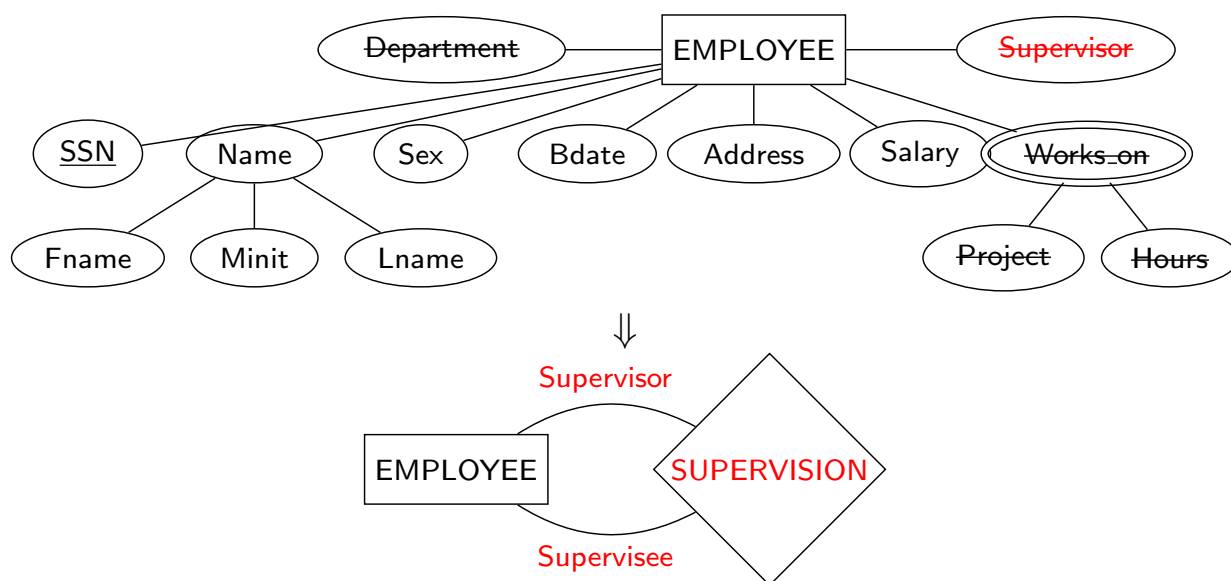
## 案例: COMPANY数据库设计的细化(续)

- Each employee works for one department but may **work on** several projects.



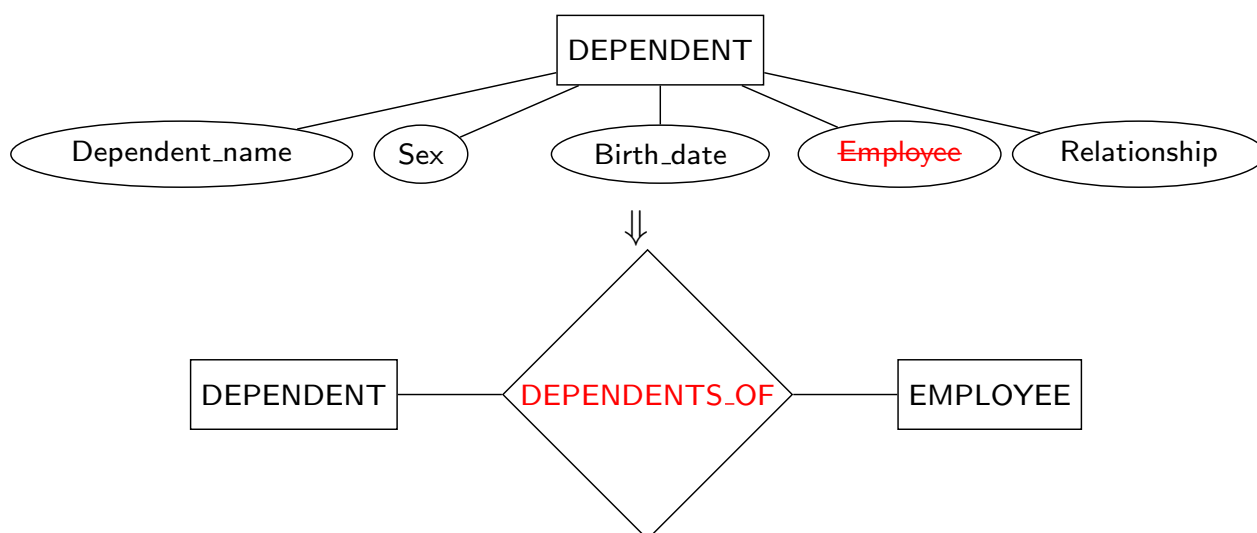
## 案例: COMPANY数据库设计的细化(续)

- We also keep track of the **direct supervisor** of each employee.



## 案例: COMPANY数据库设计的细化(续)

- Each employee may **have** a number of **DEPENDENT**s. For each dependent, we keep track of their name, sex, birthdate, and relationship to the employee.

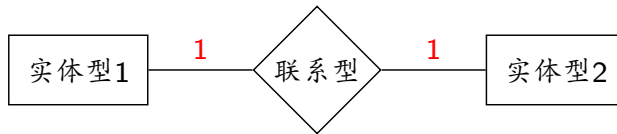




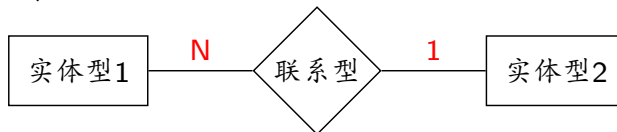
## 联系型的约束

- **基数比(cardinality ratio)**: 刻画实体型参与到联系型中的**最大基数**

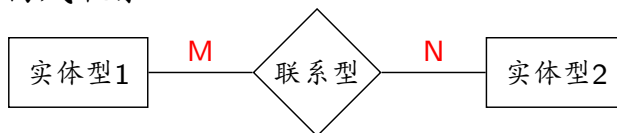
- ▶ **1对1 (1:1)**: 对实体型1的任意实体 $e$ , 最多只有1个实体型2的实体与 $e$ 构成联系; 对实体型2的任意实体 $e'$ , 最多只有1个实体型1的实体与 $e'$ 构成联系



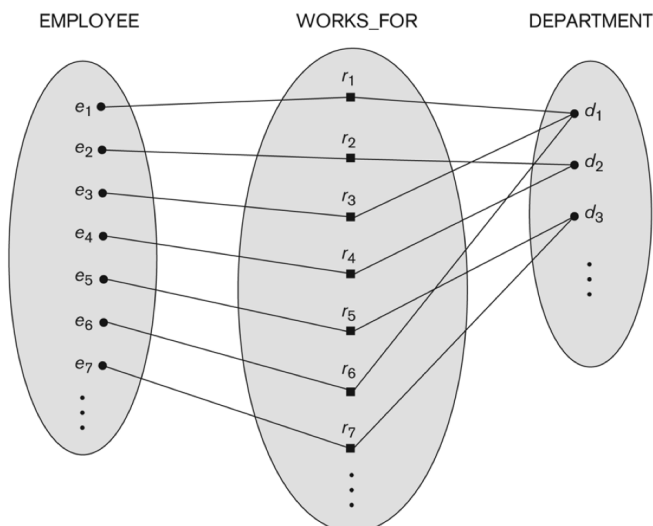
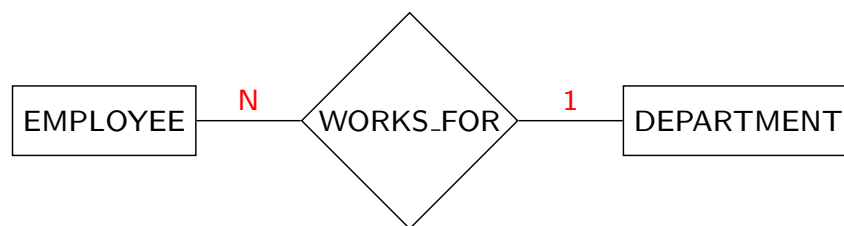
- ▶ **多对1 (N:1)**: 对实体型1的任意实体 $e$ , 最多只有1个实体型2的实体与 $e$ 构成联系; 对实体型2的任意实体 $e'$ , 最多有 $N > 1$ 个实体型1的实体与 $e'$ 构成联系



- ▶ **多对多 (M:N)**: 对实体型1的任意实体 $e$ , 最多有 $N > 1$ 个实体型2的实体与 $e$ 构成联系; 对实体型2的任意实体 $e'$ , 最多有 $M > 1$ 个实体型1的实体与 $e'$ 构成联系



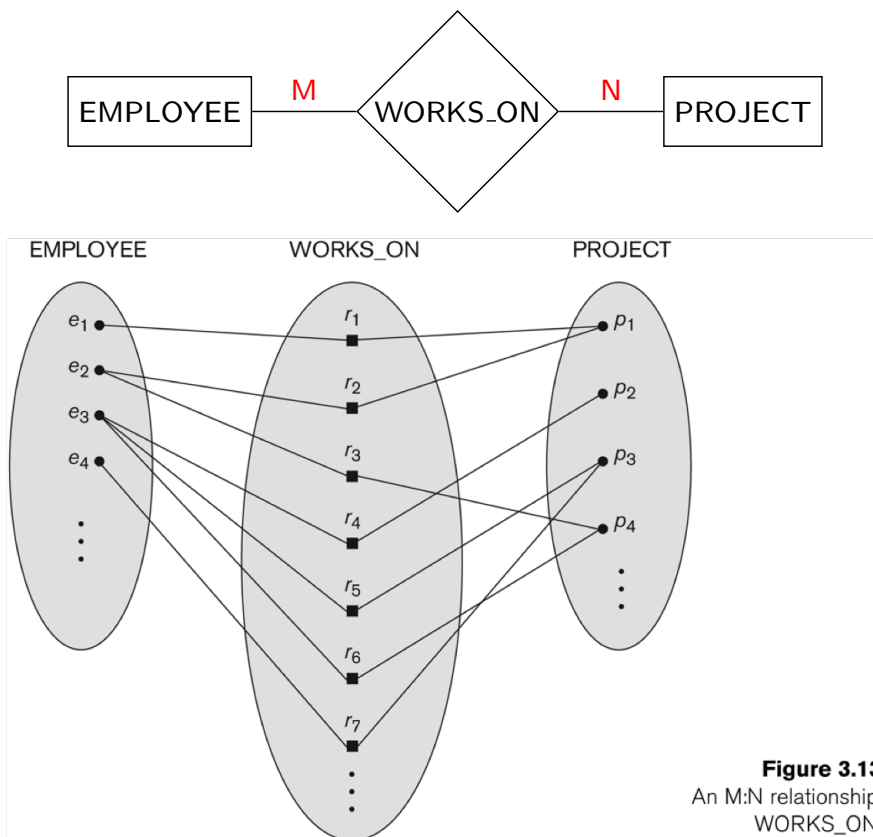
## 联系型的约束(续)



**Figure 3.9**

Some instances in the WORKS\_FOR relationship set, which represents a relationship type WORKS\_FOR between EMPLOYEE and DEPARTMENT.

## 联系型的约束(续)



**Figure 3.13**  
An M:N relationship,  
WORKS\_ON.

Navigation icons: back, forward, search, etc.

## 联系型的约束(续)

- 存在依赖约束(existence dependency constraint)/参与度约束(participation constraint): 刻画实体型参与到联系型中的**最小基数**(即一个实体最少参与到几个联系中)
  - ▶ **0个(部分参与)**: 在ER图中表示为单线
  - ▶ **≥ 1个(全部参与)**: 在ER图中表示为双线



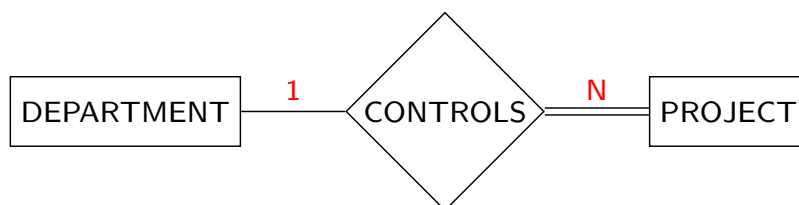
Navigation icons: back, forward, search, etc.

## 案例: COMPANY数据库设计的细化

- The company is organized into DEPARTMENTS. Each department has a name, number and an employee who **manages** the department. We keep track of the start date of the department manager. A department may have several locations.

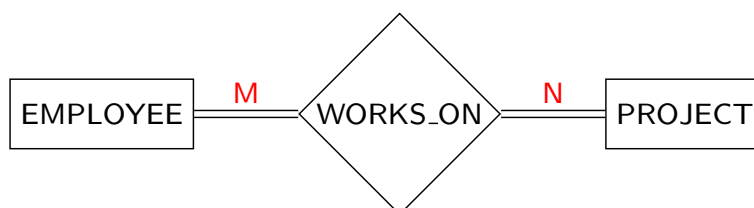
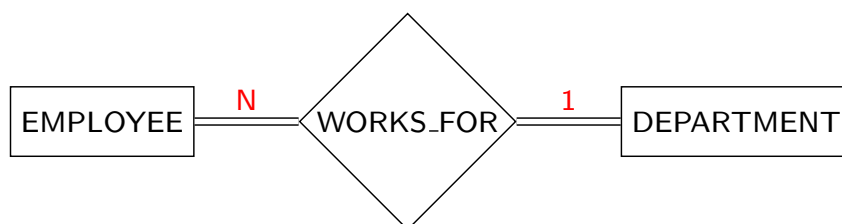


- Each department **controls** a number of PROJECTs. Each project has a unique name, unique number and is located at a single location.



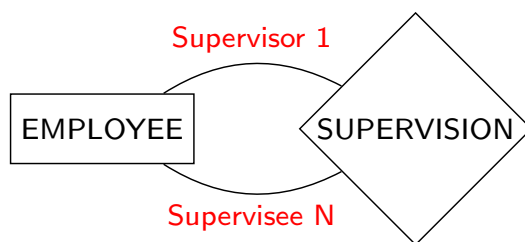
## 案例: COMPANY数据库设计的细化(续)

- Each employee **works for** one department but may **work on** several projects.

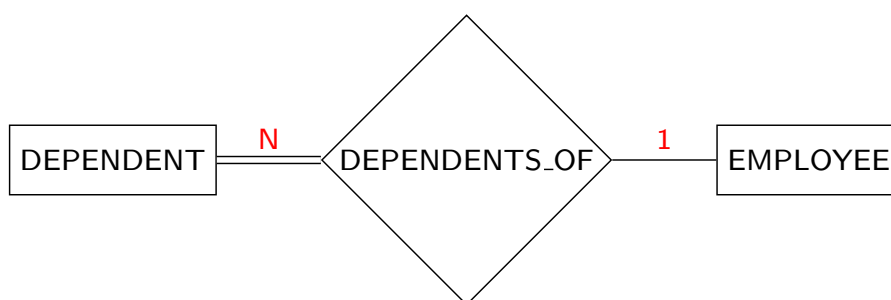


## 案例: COMPANY数据库设计的细化(续)

- We also keep track of the **direct supervisor** of each employee.

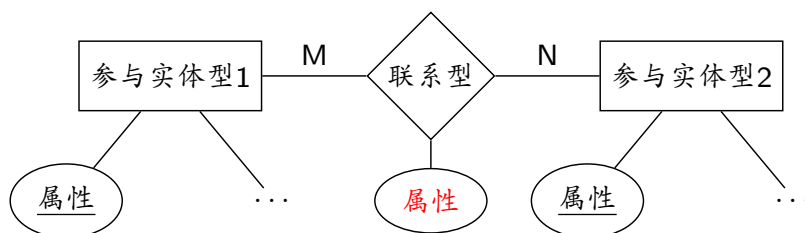


- Each employee may **have** a number of **DEPENDENTS**. For each dependent, we keep track of their name, sex, birthdate, and relationship to the employee.

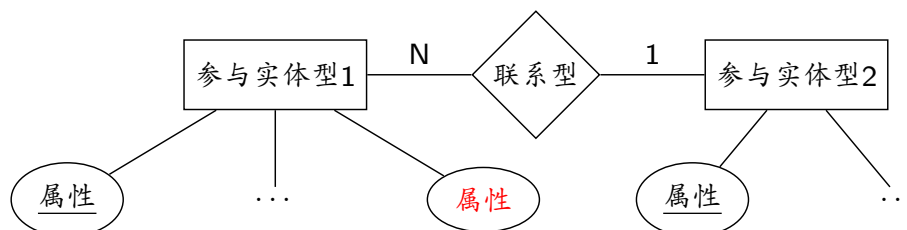


## 联系型的属性

- 联系型可以具有属性
  - ▶ **EMPLOYEE** John Smith **works on** the **ProducX Project** **40 hours/week**
- 在ER图中, 用直线将联系型与联系型的属性连接起来

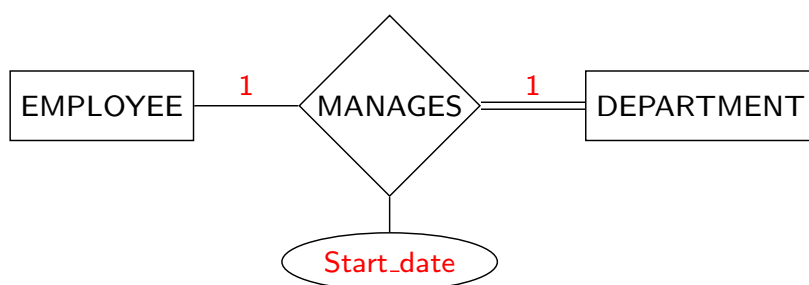


- 联系型的属性主要出现在M:N联系型中
- N:1联系型的属性可以被移到N一方的实体型中



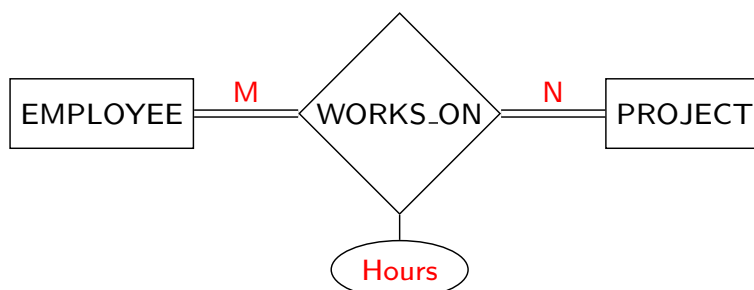
## 案例: COMPANY数据库设计的细化

- The company is organized into DEPARTMENTS. Each department has a name, number and an employee who **manages** the department. We keep track of the **start date** of the department manager. A department may have several locations.



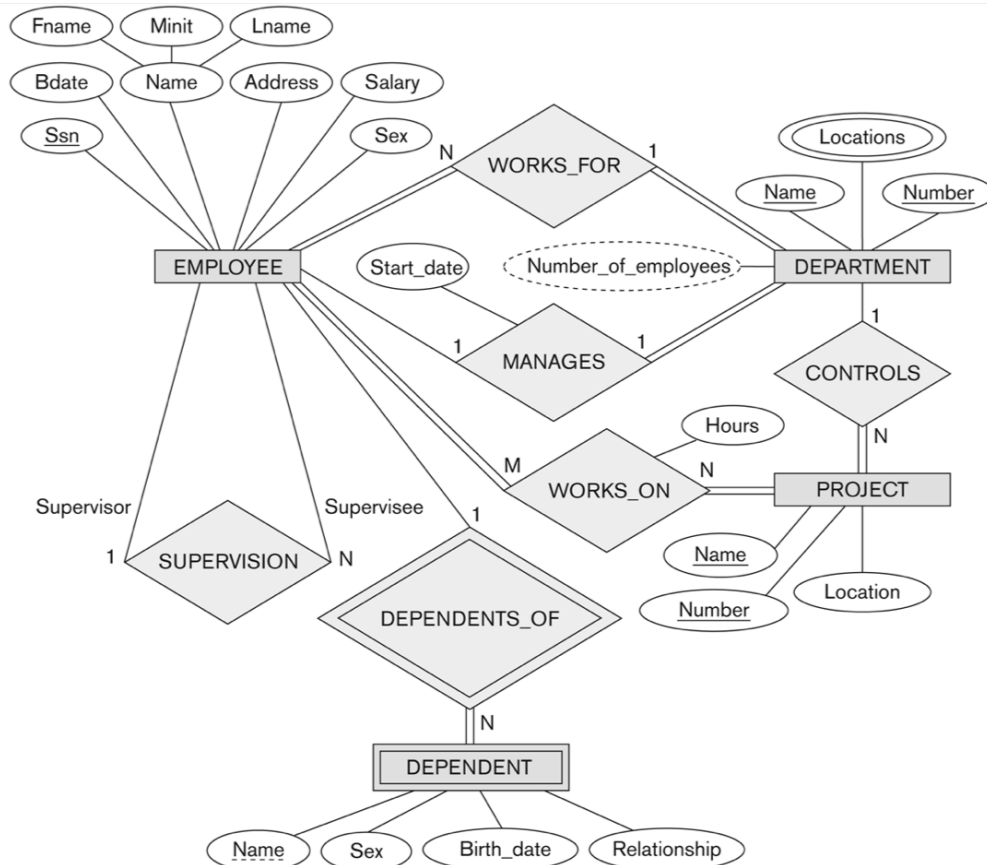
## 案例: COMPANY数据库设计的细化(续)

- We keep track of the number of **hours** per week that an employee currently **works on** each project.



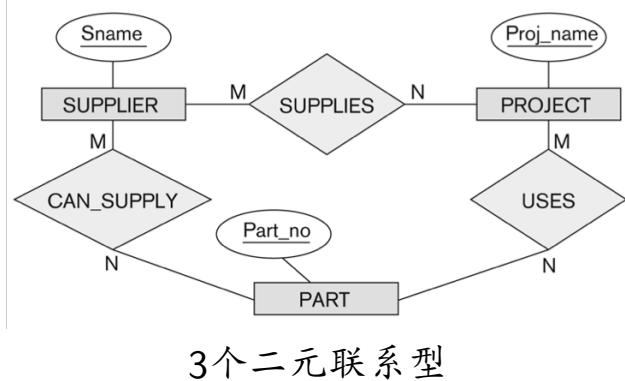
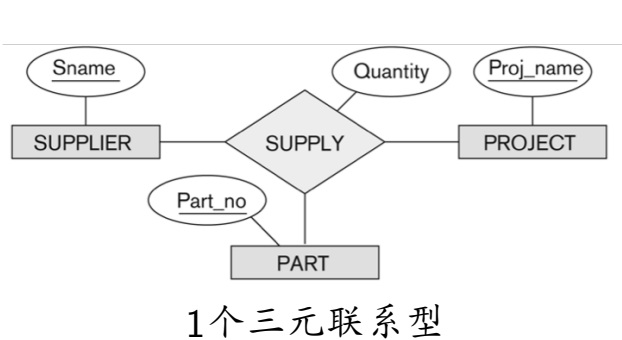
转到弱实体型 [弱实体型](#)

## 案例: COMPANY概念数据库设计



## 多元联系(Higher-degree Relationships)

- 多元联系(higher-degree relationships): 3个以上实体参与的联系
- 一个 $n$ 元联系通和 $n$ 个二元联系所表示的意义通常是不同的

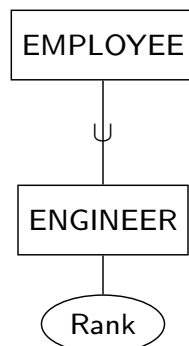


## 4.3 增强ER模型

### Enhanced ER Model

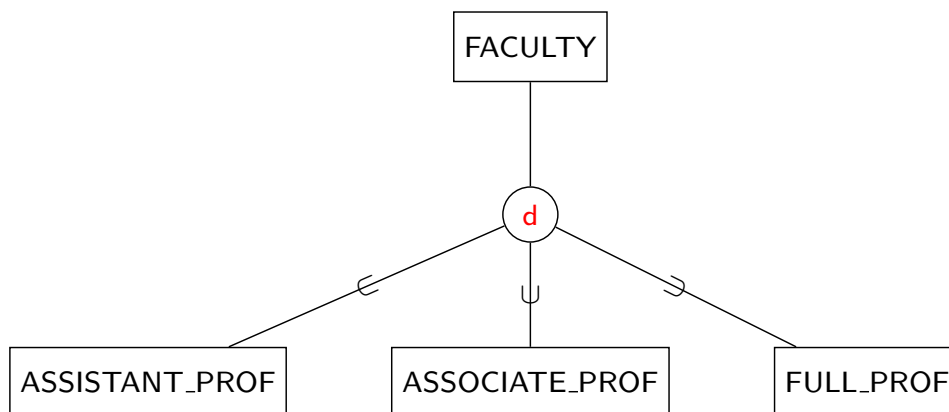
### 子类(subclass)/超类(superclass)

- 实体型 $E$ 的一部分实体构成了一个有特殊含义的子集，这部分实体的实体型 $E'$ 称为 $E$ 的**子类(subclass)**，同时 $E$ 称为 $E'$ 的**超类(superclass)**
  - ▶ 超类: EMPLOYEE
  - ▶ 子类: Engineer, DBA
- 子类继承了父类的全部属性及父类所参与的全部联系型
- 子类/超类联系的表示方法:



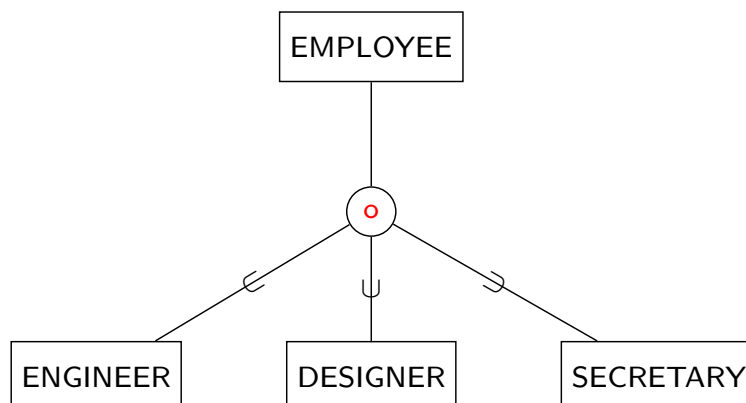
## 不相交子类

- 如果超类的每个实体属于最多一个子类，则子类是**不相交的(disjoint)**
  - ▶ 超类: FACULTY
  - ▶ 子类: ASSISTANT\_PROF, ASSOCIATE\_PROF, FULL\_PROF



## 重叠子类

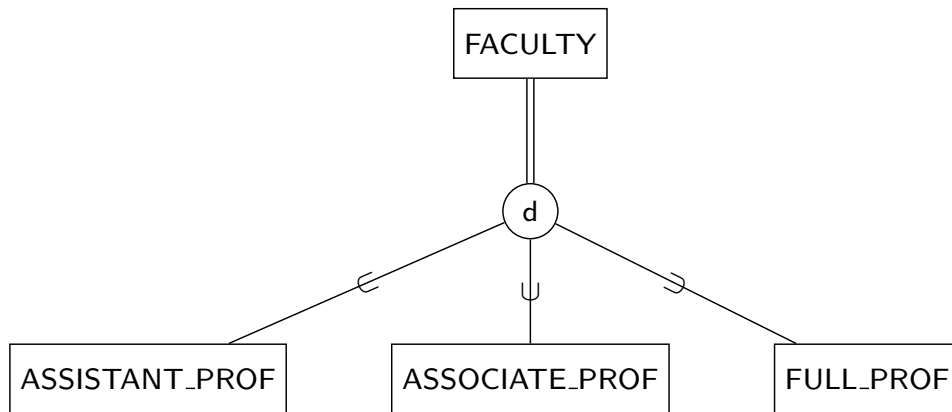
- 如果超类的每个实体可以属于多个子类，则子类是**重叠的(overlap)**
  - ▶ 超类: EMPLOYEE
  - ▶ 子类: ENGINEER, DESIGNER, SECRETARY





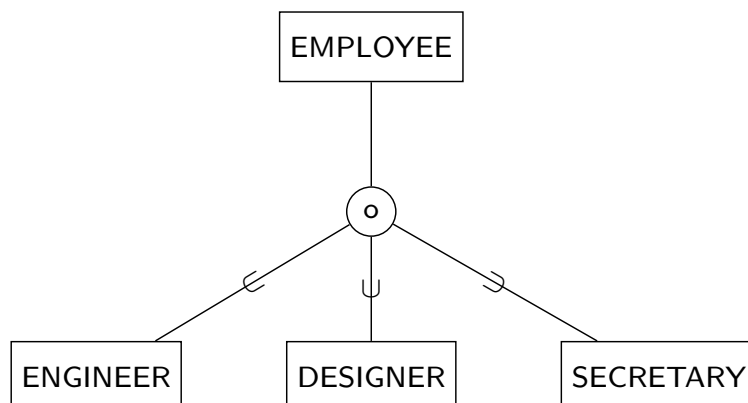
## 全部特化(Total Specialization)

- 超类的每个实体必须属于至少一个子类
  - ▶ 超类: FACULTY
  - ▶ 子类: ASSISTANT\_PROF, ASSOCIATE\_PROF, FULL\_PROF



## 部分特化(Partial Specialization)

- 超类的某些实体可以不属于任何子类
  - ▶ 超类: EMPLOYEE
  - ▶ 子类: ENGINEER, DESIGNER, SECRETARY



## 总结

- ① 数据库设计的过程: 概念数据库设计→ 逻辑数据库设计→ 物理数据库设计
- ② 实体-联系模型(ER模型)
  - ▶ 与实体相关的概念
    - ★ 实体
    - ★ 属性: 简单属性、复合属性、多值属性、派生属性
    - ★ 键属性
    - ★ 实体型、实体集
    - ★ 弱实体型: 标识实体型、标识联系型、部分键
  - ▶ 与联系相关的概念
    - ★ 联系
    - ★ 联系型、联系集
    - ★ 联系型的约束: 基数比(1:1、N:1、M:N)、参与度约束(全部参与、部分参与)
    - ★ 联系型的属性
    - ★ 多元联系
- ③ 实体-联系图(ER图)<sup>2</sup>
- ④ 增强实体-联系图(EER图)

<sup>2</sup>课件中的ER图使用Tikz绘

制<http://www.texample.net/tikz/examples/er-diagram/>

## 习题

- ① 数据库设计过程分为哪些阶段? 为什么不宜从需求出发直接在DBMS上创建关系?
- ② 说明实体、实体型、实体集的区别
- ③ 为什么弱实体型全部参与到标识联系型中?
- ④ 举例说明1个三元联系通和3个二元联系表示的意义通常是不同的
- ⑤ 什么情况下1个三元联系通和3个二元联系表示的意义是相同的?
- ⑥ Design a database for a bank, including information about customers and their accounts.
  - ▶ Information about a customer includes their name, address, phone, and Social Security number (SSN).
  - ▶ A customer can have a set of addresses (which are street-city-state triples), and at each address there is a set of phones.
  - ▶ Accounts have numbers, types (e.g., savings, checking) and balances. Also record the customer who own an account.
  - ▶ An account can have only one customer.

# 致谢

- 感谢李一鸣同学指出了课件中的错误