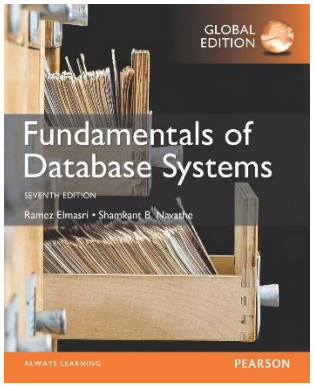
Database Systems

Department of Computer Science
Chungbuk National University

Seo-Young Noh

CHAPTER 3:
Data Modeling Using the Entity-Relationship (ER) Model



Chapter Outline

- **Overview of Database Design Process**
- **Example Database Application (`COMPANY`)**
- **ER Model Concepts**
  - Entities and Attributes
  - Entity Types, Value Sets, and Key Attributes
  - Relationships and Relationship Types
  - Weak Entity Types
  - Roles and Attributes in Relationship Types
- **ER Diagrams - Notation**
- **ER Diagram for `COMPANY` Schema**
- **Alternative Notations – UML class diagrams, others**
- **Relationships of Higher Degree**

Using High-Level Conceptual Data Models for Database Design

Overview of Database Design Process

- **Two main activities:**
  - Database design
  - Applications design

- **Focus in this chapter on conceptual database design**
  - To design the conceptual schema for a database application

- **Applications design focuses on the programs and interfaces that access the database**
  - Generally considered part of software engineering

Terminologies

릴레이션 용어	같은 의미로 통용되는 용어	파일 시스템 용어
릴레이션(relation)	테이블(table)	파일(file)
스키마(schema)	내포(intension)	헤더(header)
인스턴스(instance)	외연(extension)	데이터(data)
튜플(tuple) or 레코드	행(row)	레코드(record)
속성(attribute)	열(column)	필드(field)

MySQL로 배우는 개론과 실습

Overview of Database Design Process

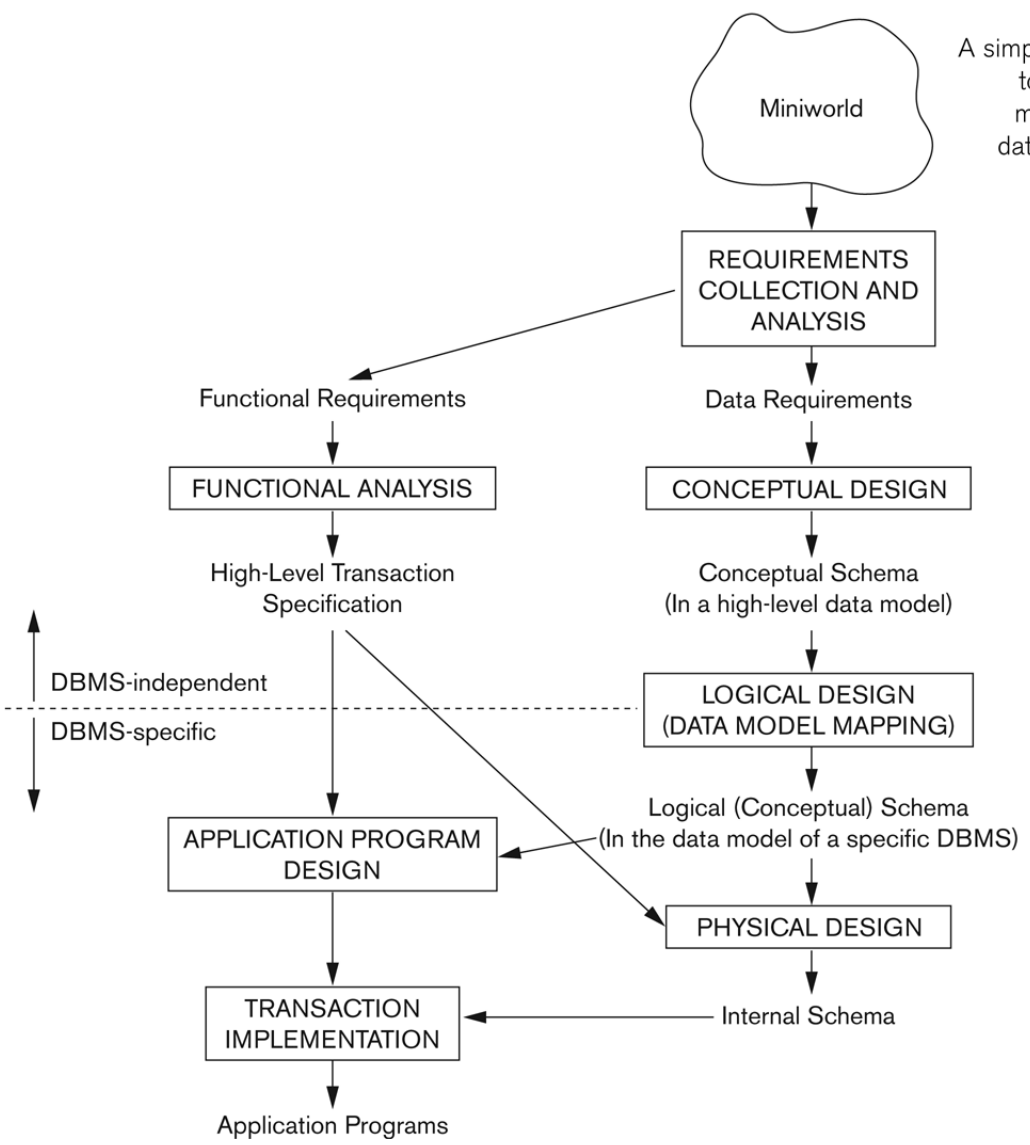


Figure 3.1
A simplified diagram to illustrate the main phases of database design.

E-R Model (Entity types, Constraints, Relationships)

Relational Model (Database Schema)

Storage structure, Index, Access path Database file

Data Modeling Process

- **Conceptual Modeling**
  - E-R Model → E-R Diagram
  - Object-Oriented Model → Class Diagram
- **Logical Modeling**
  - Oracle, MySQL, SQL Server, DB2, Postgress, …
- **Physical Modeling**
  - Modeling the physical model in storage devices

Methodologies for Conceptual Design

- **Entity Relationship (ER) Diagrams (This Chapter)**

- ~~**Enhanced Entity Relationship (EER) Diagrams (Chapter 4)**~~

- **Use of Design Tools in industry for designing and documenting large scale designs**

- **The UML (Unified Modeling Language) Class Diagrams are popular in industry to document conceptual database designs**

A Sample Database Application

Example COMPANY Database

- **We need to create a database schema design based on the following (simplified) requirements of the COMPANY Database:**
  - 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.

Example COMPANY Database (Continued)

- The database will store each EMPLOYEE's social security number, address, salary, sex, and birthdate.
  - Each employee *works for* one department but may *work on* several projects.
  - The DB will keep track of the number of hours per week that an employee currently works on each project.
  - It is required to keep track of the *direct supervisor* of each employee.
- Each employee may *have* a number of DEPENDENTs.
  - For each dependent, the DB keeps a record of name, sex, birthdate, and relationship to the employee.

Example COMPANY Database (Continued)

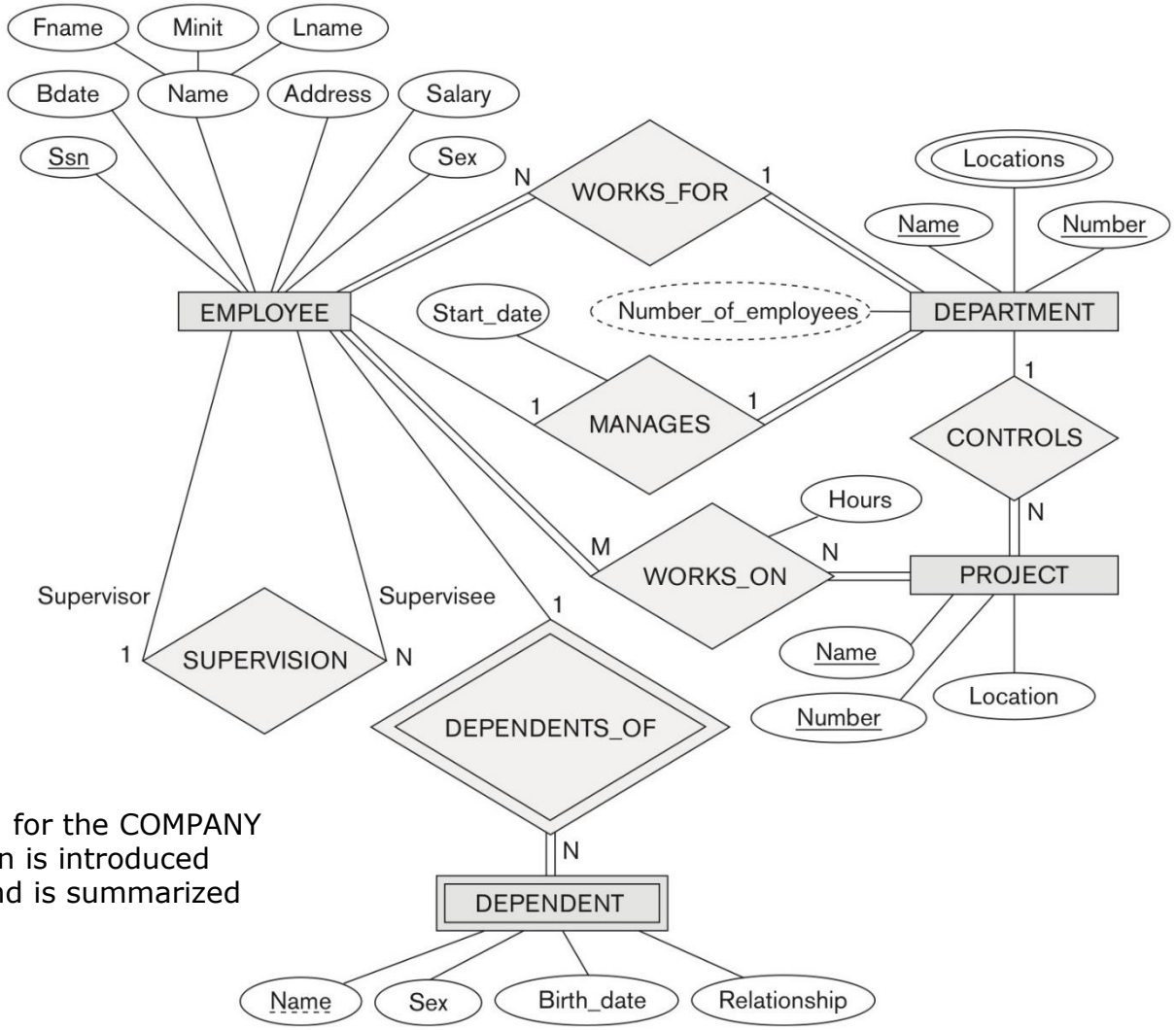


Figure 3.2 An ER schema diagram for the COMPANY database. The diagrammatic notation is introduced gradually throughout this chapter and is summarized in Figure 3.14.

Entity Types, Entity Sets, Attributes, and Keys

ER Model Concepts

- **Entities and Attributes**
  - Entity is a basic concept for the ER model. Entities are specific things or objects in the mini-world that are represented in the database.
    - For example the `EMPLOYEE` John Smith, the Research `DEPARTMENT`, the ProductX `PROJECT`
  - Attributes are properties used to describe an entity.
    - For example an `EMPLOYEE` entity may have the attributes `Name, SSN, Address, Sex, BirthDate`

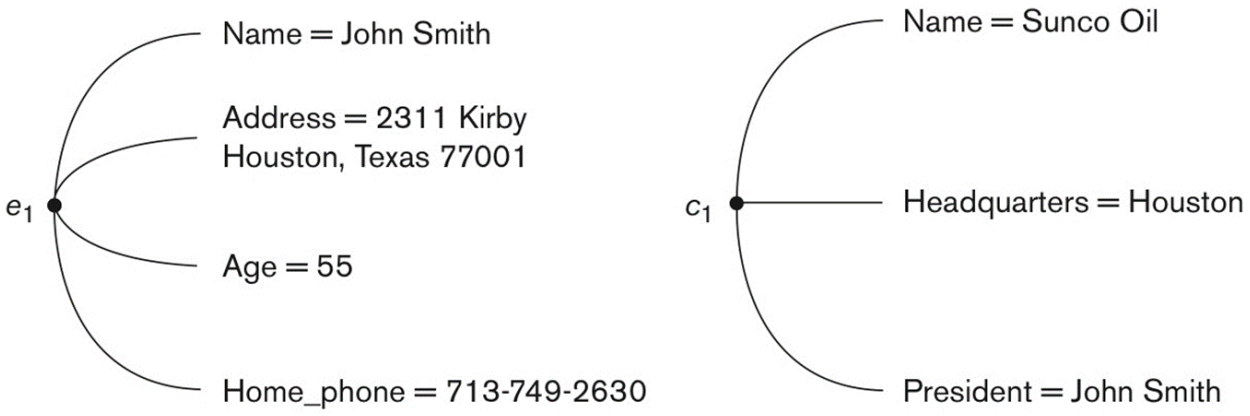


Figure 3.3 Two entities, EMPLOYEE e_1, and COMPANY c_1, and their attributes.

ER Model Concepts

- A specific entity will have a value for each of its attributes.
  - For example a specific employee entity may have `Name='John Smith', SSN='123456789', Address ='731, Fondren, Houston, TX', Sex='M', BirthDate='09-JAN-55'`

- Each attribute has a *value set* (or data type) associated with it – e.g. integer, string, date, enumerated type, …

Types of Attributes (1)

- **Simple (단순)**
  - Each entity has a single atomic value for the attribute. For example, SSN or Sex.

- **Composite (복합)**
  - The attribute may be composed of several components. For example:
    - `Address(Apt#, House#, Street, City, State, ZipCode, Country)`
    - `Name(FirstName, MiddleName, LastName).`
    - Composition may form a hierarchy where some components are themselves composite.

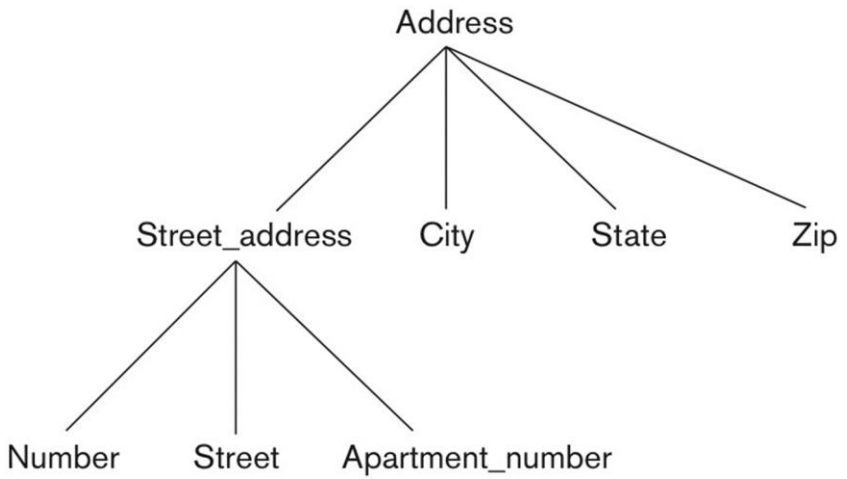


Figure 3.4 A hierarchy of composite attributes.

Types of Attributes (2)

- **Multi-valued**
  - An entity may have multiple values for that attribute. For example, `Color` of a `CAR` or `PreviousDegrees` of a `STUDENT`.
    - Denoted as {Color} or {PreviousDegrees}

two tone car

- **In general, composite and multi-valued attributes may be nested arbitrarily to any number of levels, although this is rare.**
  - For example, `PreviousDegrees` of a `STUDENT` is a composite multi-valued attribute denoted by `{PreviousDegrees (College, Year, Degree, Field)}`
  - Multiple `PreviousDegrees` values can exist
  - Each has four subcomponent attributes:
    - `College, Year, Degree, Field`

Entity Types and Key Attributes (1)

- **Entities with the same basic attributes are grouped or typed into an entity type.**
  - For example, the entity type `EMPLOYEE` and `PROJECT`.

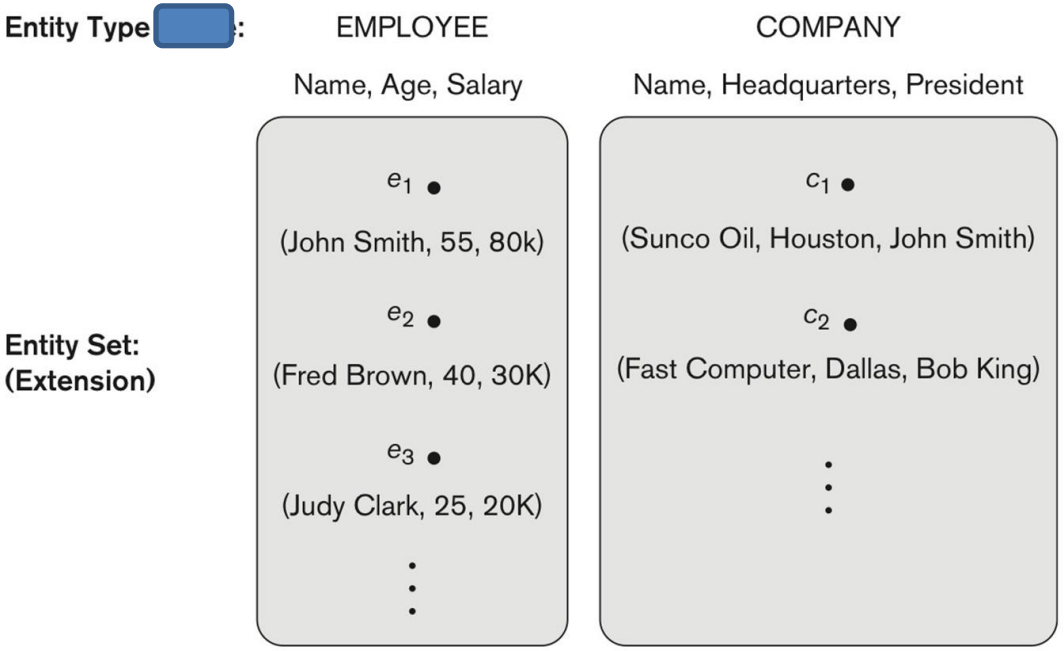


Figure 3.6 Two entity types, EMPLOYEE and COMPANY, and some member entities of each.

Entity Types and Key Attributes (2)

- **An attribute of an entity type for which each entity must have a unique value is called a key attribute of the entity type.**
  - For example, `SSN` of `EMPLOYEE`.

- **A key attribute may be composite.**
  - `VehicleTagNumber` is a key of the `CAR` entity type with components `(Number, State)`.

- **Each key is underlined (Note: this is different from the relational schema where only one "primary key is underlined).**

Entity Types and Key Attributes (3)

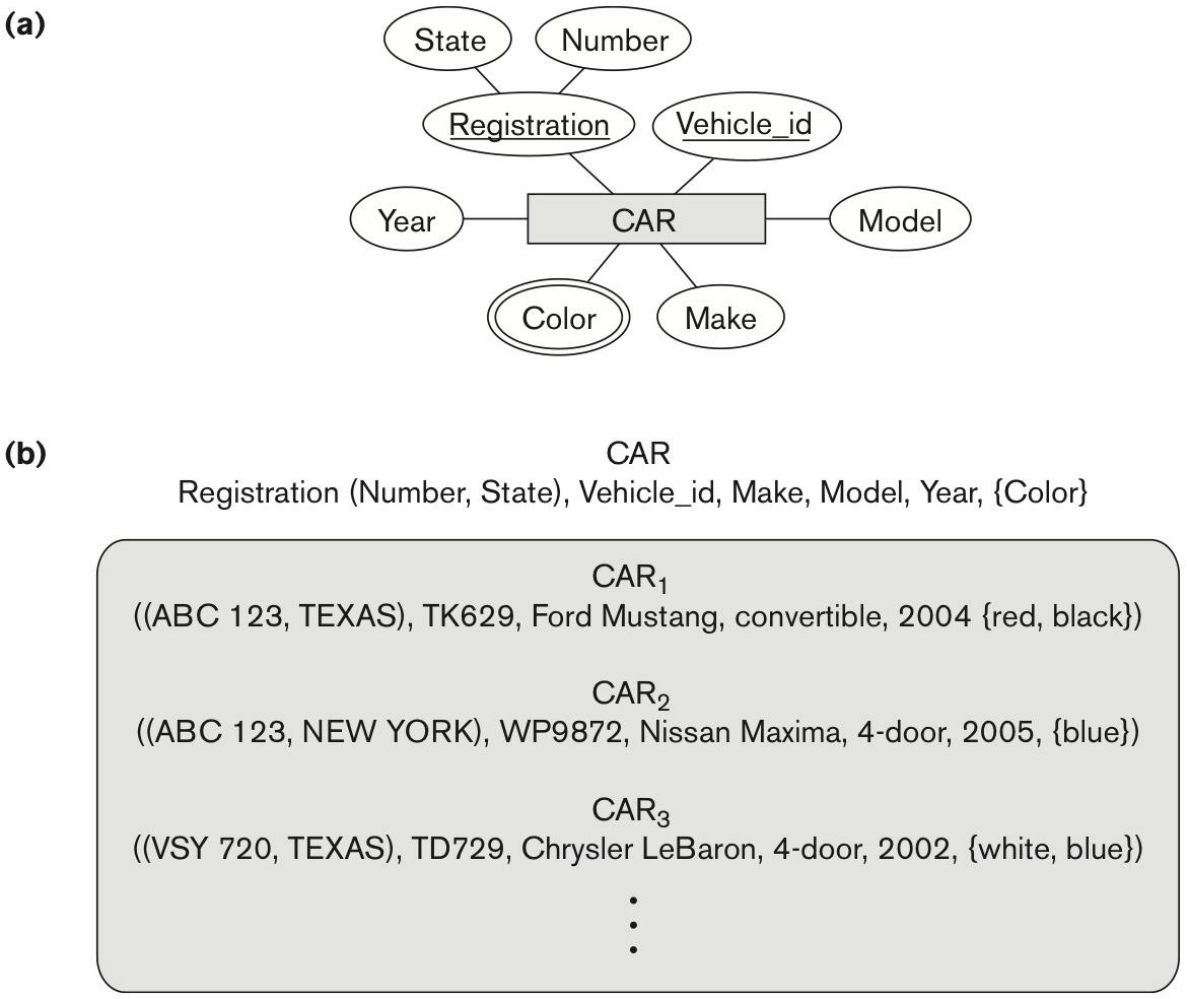
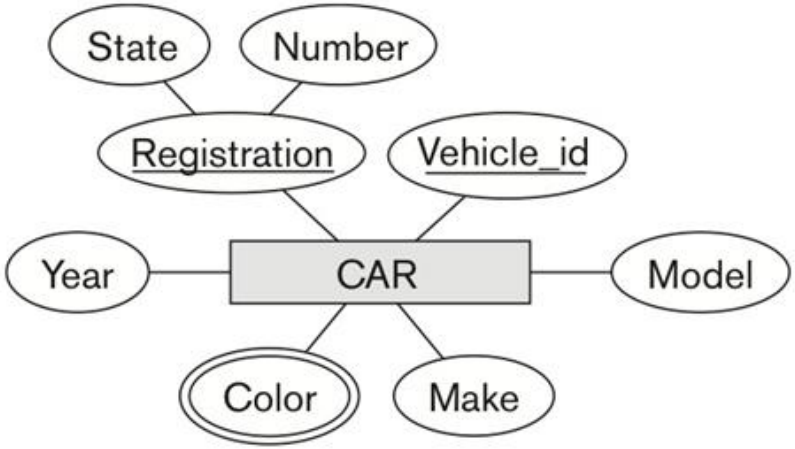


Figure 3.7 The CAR entity type with two key attributes, Registration and Vehicle_id. (a) ER diagram notation. (b) Entity set with three entities.

Entity Types and Key Attributes (4)

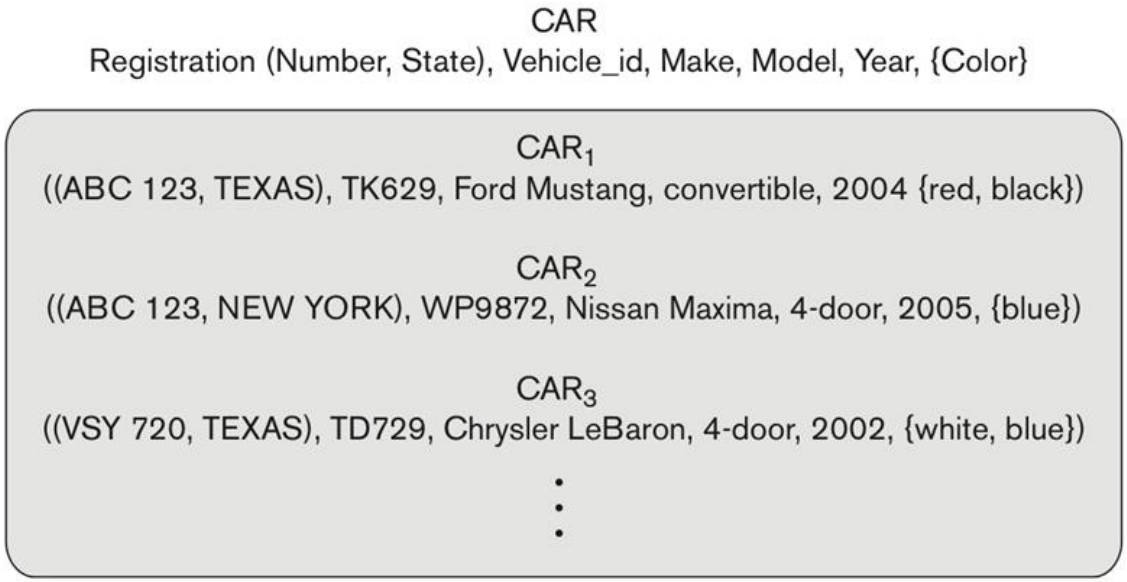
- **An entity type may have more than one key.**
  - The CAR entity type may have two keys:
    - `VehicleIdentificationNumber` (popularly called VIN)
    - `VehicleTagNumber` (Number, State), aka license plate number.



Entity Set (1)

- **Each entity type will have a collection of entities stored in the database**
  - Called the **entity set** or sometimes **entity collection**

- **Same name (CAR) used to refer to both the entity type and the entity set**



Entity Set (2)

- **However, entity type and entity set may be given different names**

- **Entity set is the current *state* of the entities of that type that are stored in the database**

Value Sets (Domains) of Attributes

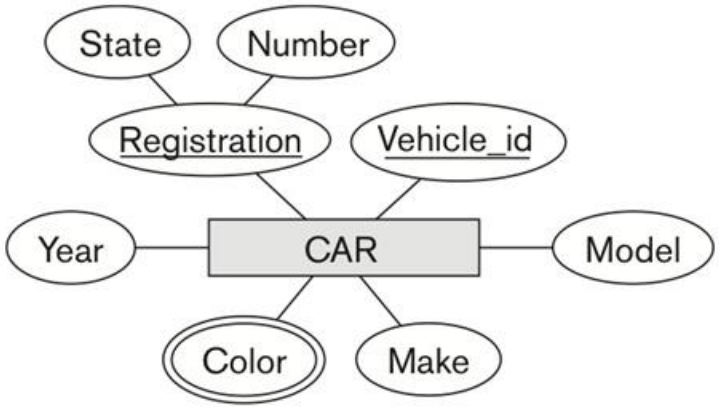
- **Each simple attribute is associated with a value set**
  - E.g., `Lastname` has a value which is a character string of upto 15 characters
  - `Date` has a value consisting of `MM-DD-YYYY` where each letter is an integer

- **A value set specifies the set of values associated with an attribute. Value set = domain of values**

- **Value sets are similar to data types in most programming languages – e.g., integer, character (n), real, bit**

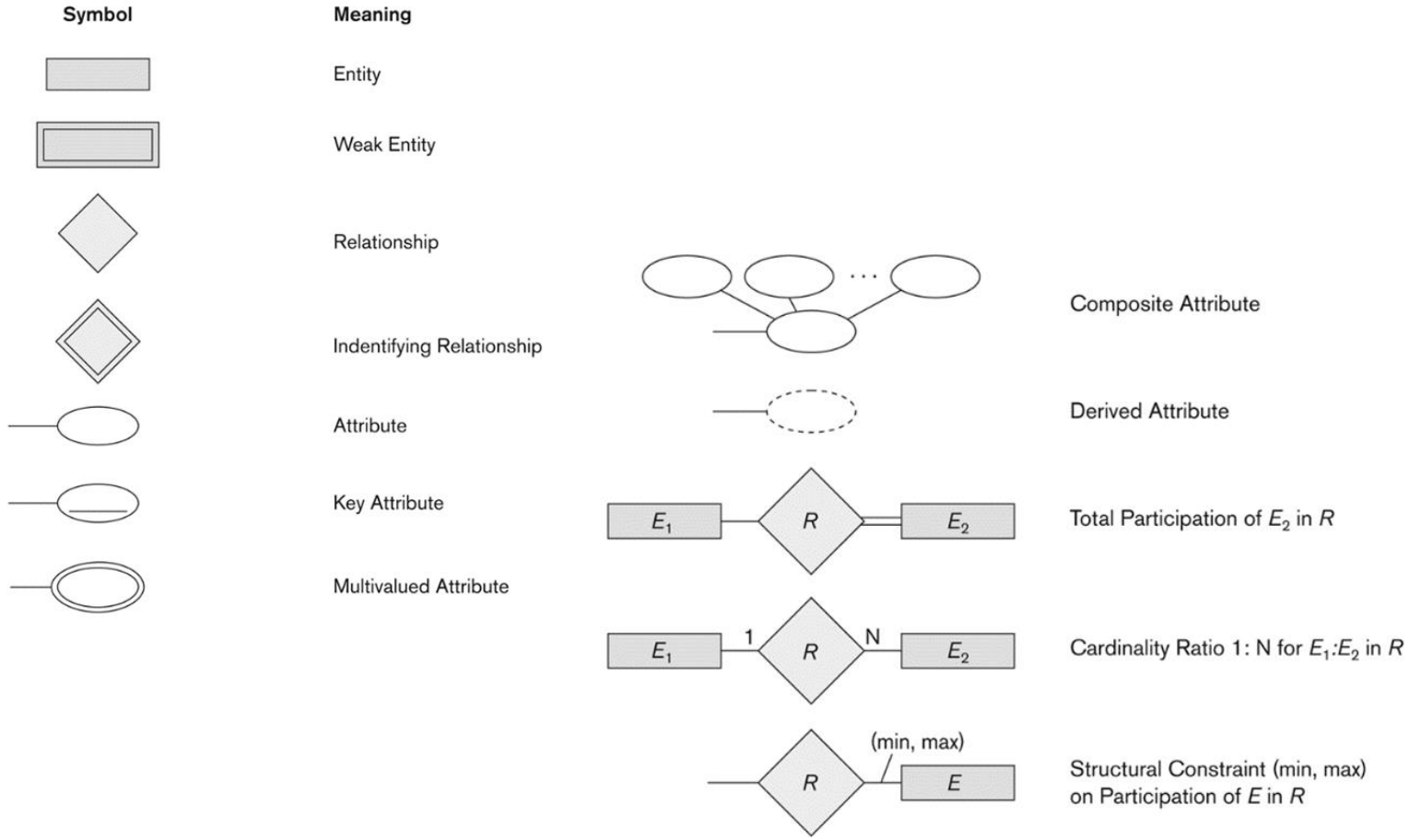
Displaying an Entity type

- **In ER diagrams, an entity type is displayed in a rectangular box**
- **Attributes are displayed in ovals**
  - Each attribute is connected to its entity type
  - Components of a composite attribute are connected to the oval representing the composite attribute
  - Each key attribute is underlined
  - Multivalued attributes displayed in double ovals



NOTATION for ER diagrams

Figure 3.14
Summary of the notation for ER diagrams.



Initial Conceptual Design of Entity Types for the COMPANY Database Schema

- **Based on the requirements, we can identify four initial entity types in the COMPANY database:**
  - DEPARTMENT
  - PROJECT
  - EMPLOYEE
  - DEPENDENT
- **Their initial conceptual design is shown on the following slide**
- **The initial attributes shown are derived from the requirements description**

Initial Design of Entity Types:
EMPLOYEE, DEPARTMENT, PROJECT, DEPENDENT

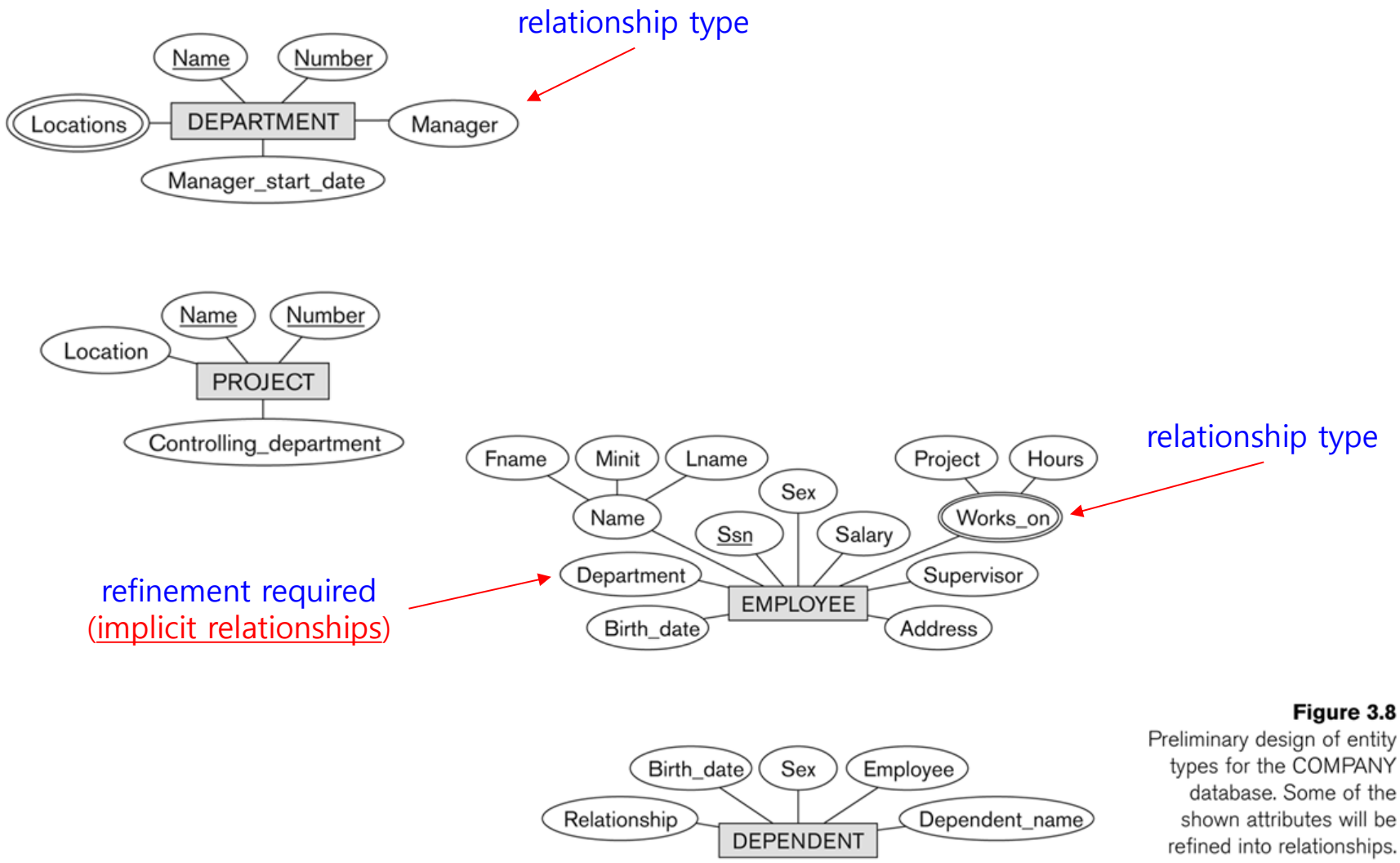


Figure 3.8
Preliminary design of entity types for the COMPANY database. Some of the shown attributes will be refined into relationships.

Relationship Types, Relationship Sets, Roles, and Structural Constraints

Refining the initial design by introducing relationships

- **The initial design is typically not complete**

- **Some aspects in the requirements will be represented as relationships**

- **ER model has three main concepts:**
  - Entities (and their entity types and entity sets)
  - Attributes (simple, composite, multivalued)
  - Relationships (and their relationship types and relationship sets)

Relationships and Relationship Types (1)

- **A relationship relates two or more distinct entities with a specific meaning.**
  - For example, `EMPLOYEE John Smith` *works on* the `ProductX PROJECT`, or `EMPLOYEE Franklin Wong` *manages* the `Research DEPARTMENT`.

- **Relationships of the same type are grouped or typed into a relationship type.**
  - For example, the `WORKS_ON` relationship type in which `EMPLOYEE`s and `PROJECT`s participate, or the `MANAGES` relationship type in which `EMPLOYEE`s and `DEPARTMENT`s participate.

- **The degree of a relationship type is the number of participating entity types.**
  - Both `MANAGES` and `WORKS_ON` are *binary* relationships.

N:1 Relationship: EMPLOYEE and DEPARTMENT

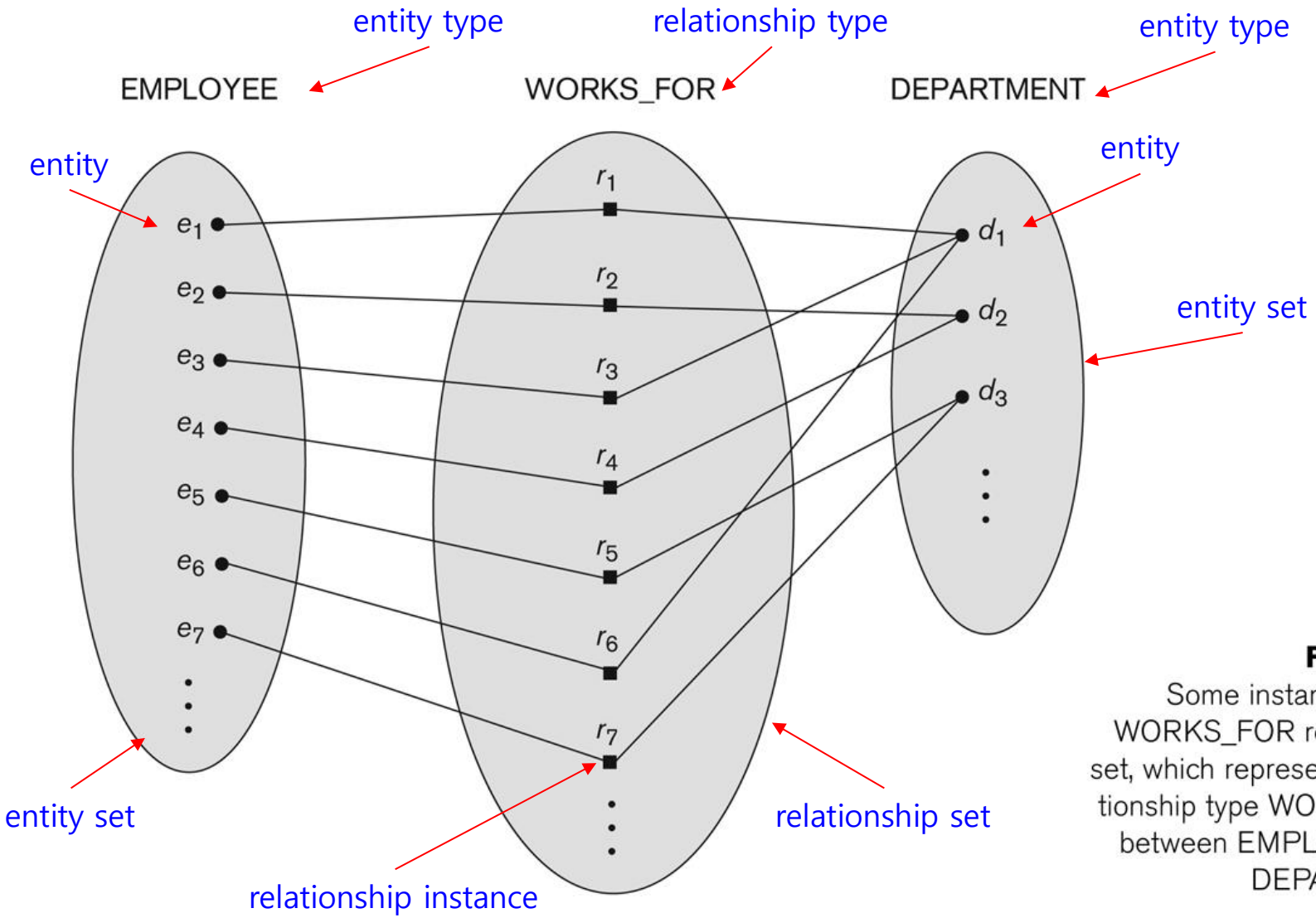


Figure 3.9
Some instances in the WORKS_FOR relationship set, which represents a relationship type WORKS_FOR between EMPLOYEE and DEPARTMENT.

M:N Relationship: EMPLOYEE and PROJECT

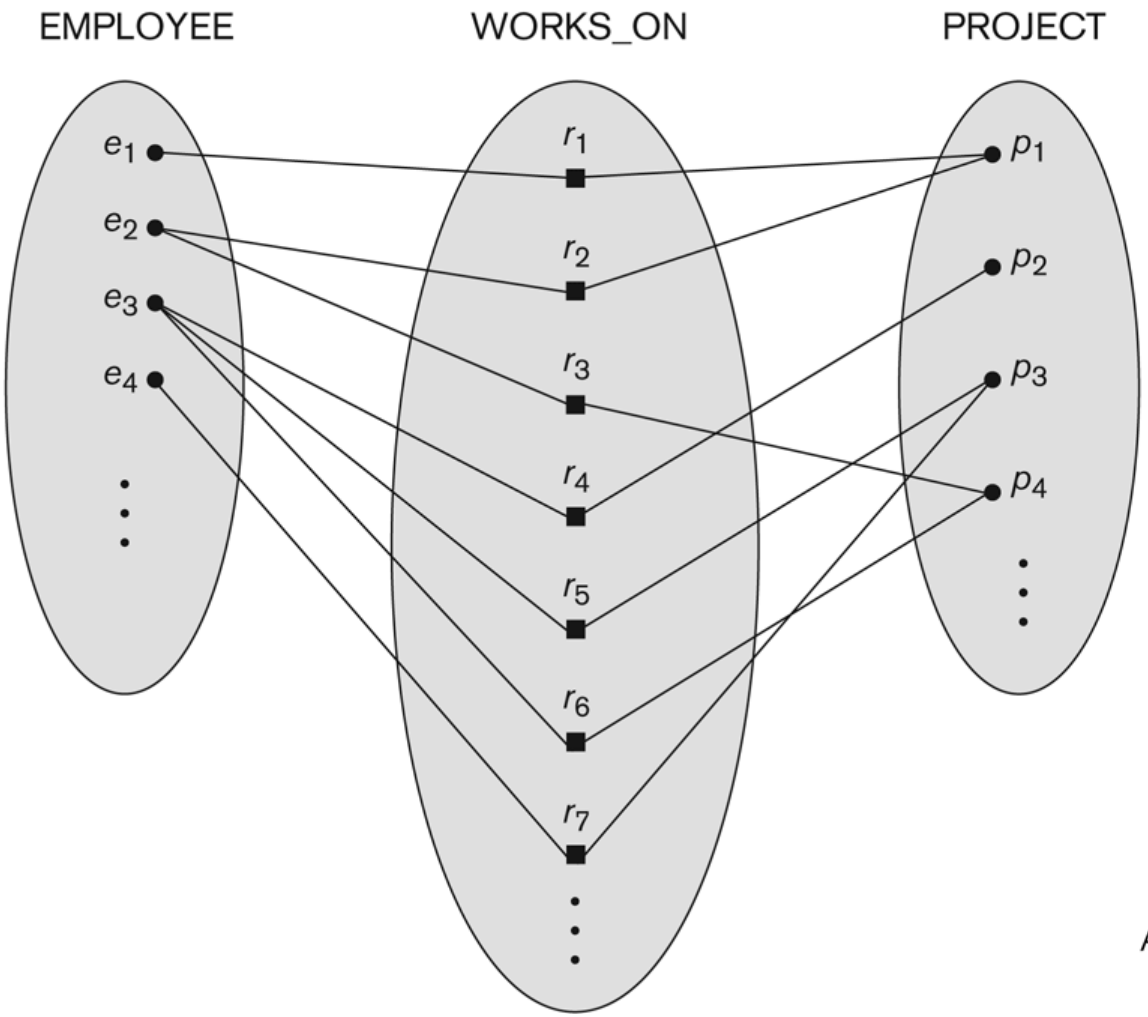


Figure 3.13
An M:N relationship, WORKS_ON.

Relationship type vs. relationship set (1)

- **Relationship Type:**
  - Is the schema description of a relationship
  - Identifies the relationship name and the participating entity types
  - Also identifies certain relationship constraints

- **Relationship Set:**
  - The current set of relationship instances represented in the database
  - The current *state* of a relationship type

Relationship type vs. relationship set (2)

- **Each instance in the set relates individual participating entities – one from each participating entity type**

- **In ER diagrams, we represent the *relationship type* as follows:**
  - Diamond-shaped box is used to display a relationship type
  - Connected to the participating entity types via straight lines
  - Note that the relationship type is not shown with an arrow. The name should be typically be readable from left to right and top to bottom.

```
EMPLOYEE WORK_ON PROJECT

EMPLOYEE WORK_FOR DEPARTMENT
```

Refining the COMPANY database schema by introducing relationships

- **By examining the requirements, six relationship types are identified**

- **All are *binary* relationships(degree 2)**

- **Listed below with their participating entity types:**
  - WORKS_FOR (between EMPLOYEE, DEPARTMENT)
  - MANAGES (also between EMPLOYEE, DEPARTMENT)
  - CONTROLS (between DEPARTMENT, PROJECT)
  - WORKS_ON (between EMPLOYEE, PROJECT)
  - SUPERVISION (between EMPLOYEE (as subordinate), EMPLOYEE (as supervisor))
  - DEPENDENTS_OF (between EMPLOYEE, DEPENDENT)

ER DIAGRAM

- **Relationship Types:**
  - WORKS_FOR
  - MANAGES
  - WORKS_ON
  - CONTROLS
  - SUPERVISION
  - DEPENDENTS_OF

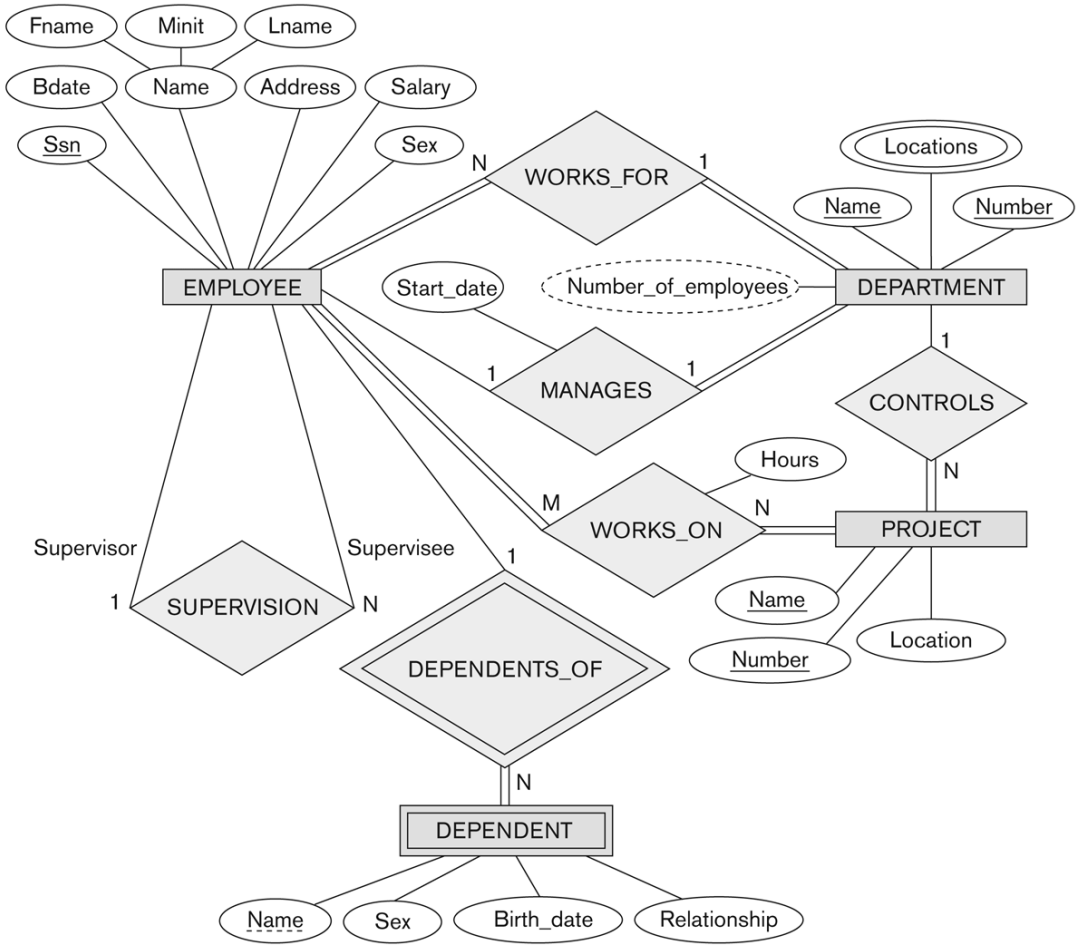


Figure 3.2
An ER schema diagram for the COMPANY database. The diagrammatic notation is introduced gradually throughout this chapter.

Discussion on Relationship Types

- **In the refined design, some attributes from the initial entity types are refined into relationships:**
  - Manager of DEPARTMENT → MANAGES
  - Works_on of EMPLOYEE → WORKS_ON
  - Department of EMPLOYEE → WORKS_FOR
  - etc

- **In general, <u>more than one relationship type can exist between the same participating entity types</u>**
  - MANAGES and WORKS_FOR are distinct relationship types between EMPLOYEE and DEPARTMENT
  - Different meanings and different relationship instances.

Constraints on Relationships

- **Constraints on Relationship Types**
  - (Also known as ratio constraints)
  - **Cardinality Ratio** (specifies *maximum* participation)
    - One-to-one (1:1)
    - One-to-many (1:N) or Many-to-one (N:1)
    - Many-to-many (M:N)
  - Existence Dependency Constraint (specifies *minimum* participation) (also called participation constraint) ex. Dependents
    - zero (optional participation, not existence-dependent)
    - one or more (mandatory participation, existence-dependent)

one-to-one (1:1) Relationship

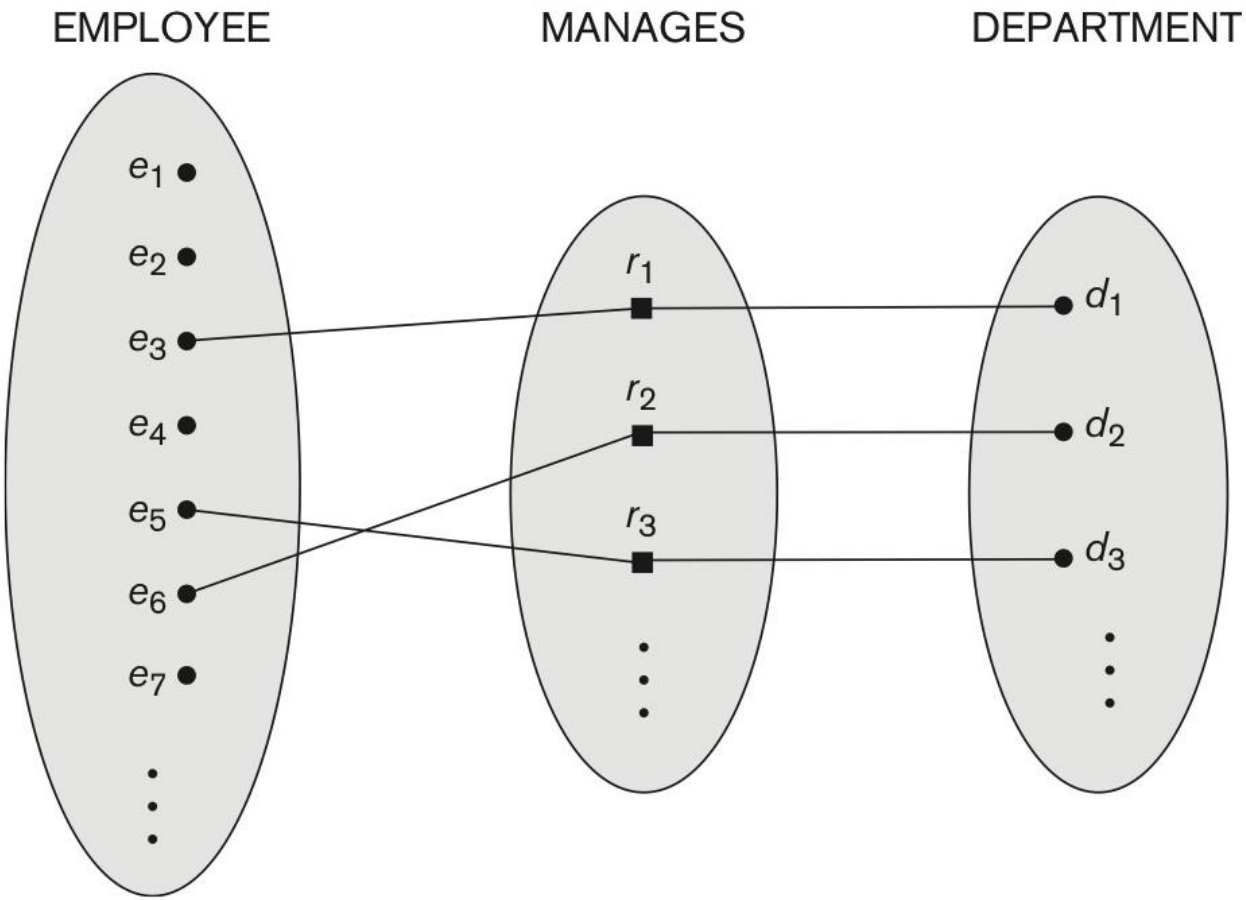


Figure 3.12 A 1:1 relationship, MANAGES.

Many-to-one (N:1) Relationship

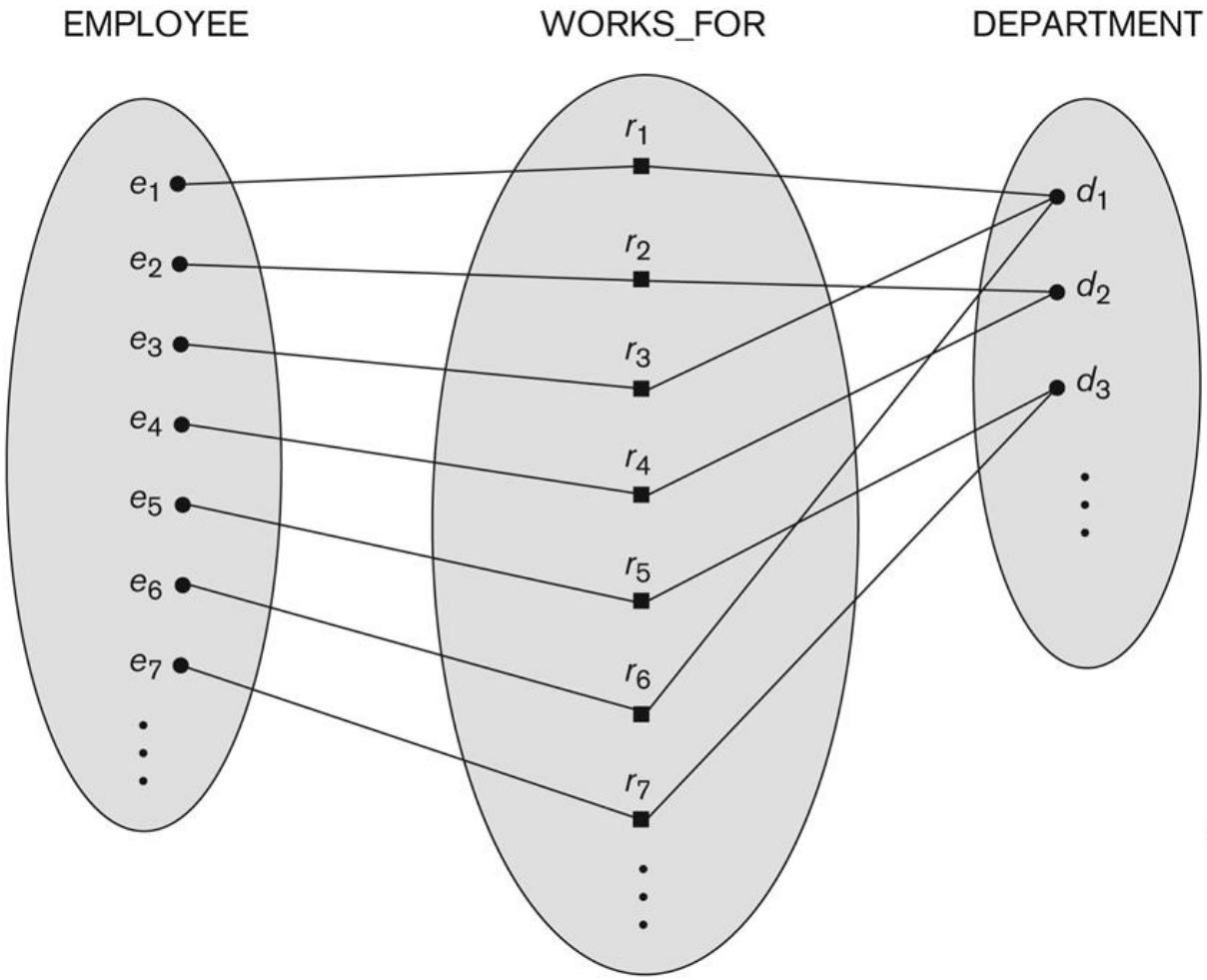
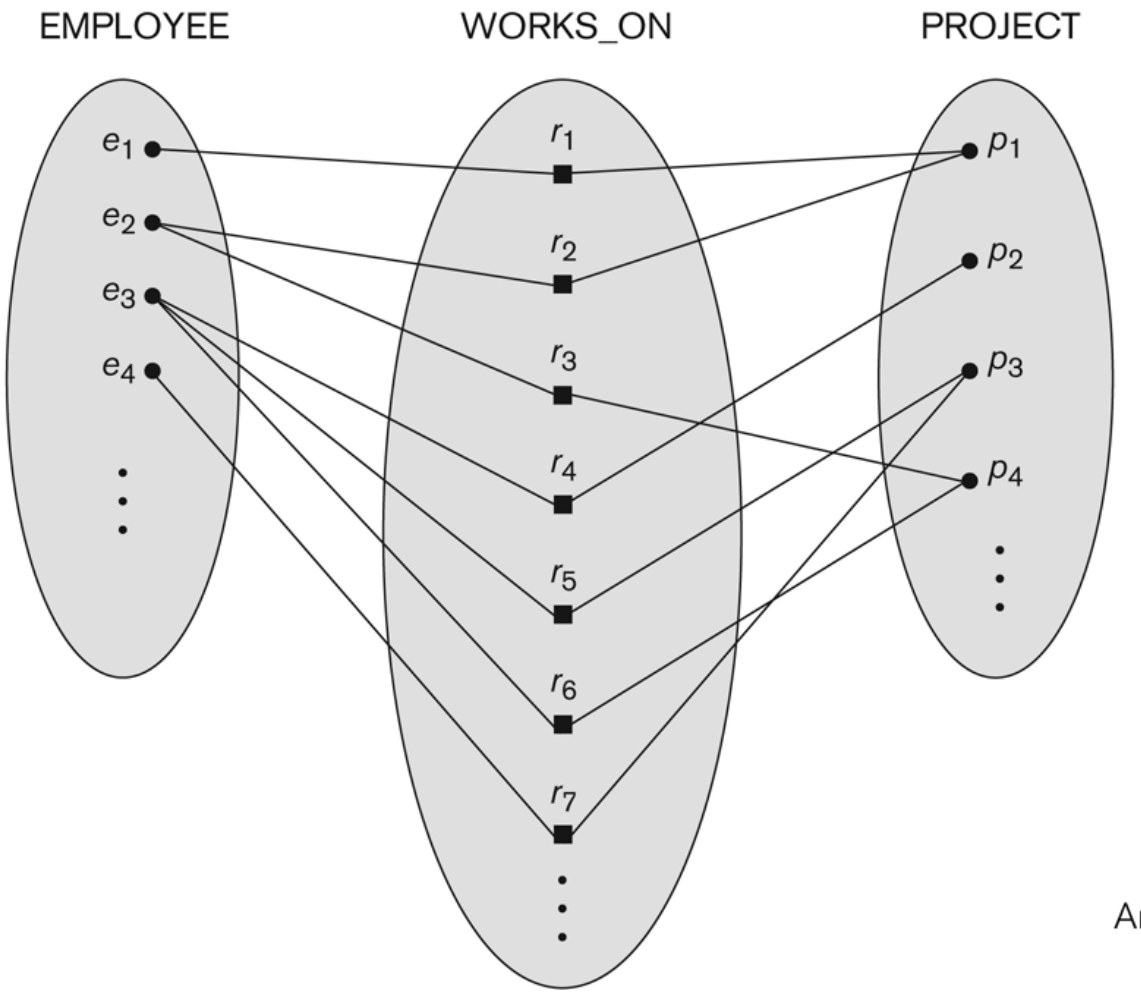


Figure 3.9
Some instances in the WORKS_FOR relationship set, which represents a relationship type WORKS_FOR between EMPLOYEE and DEPARTMENT.

Many-to-many (M:N) Relationship

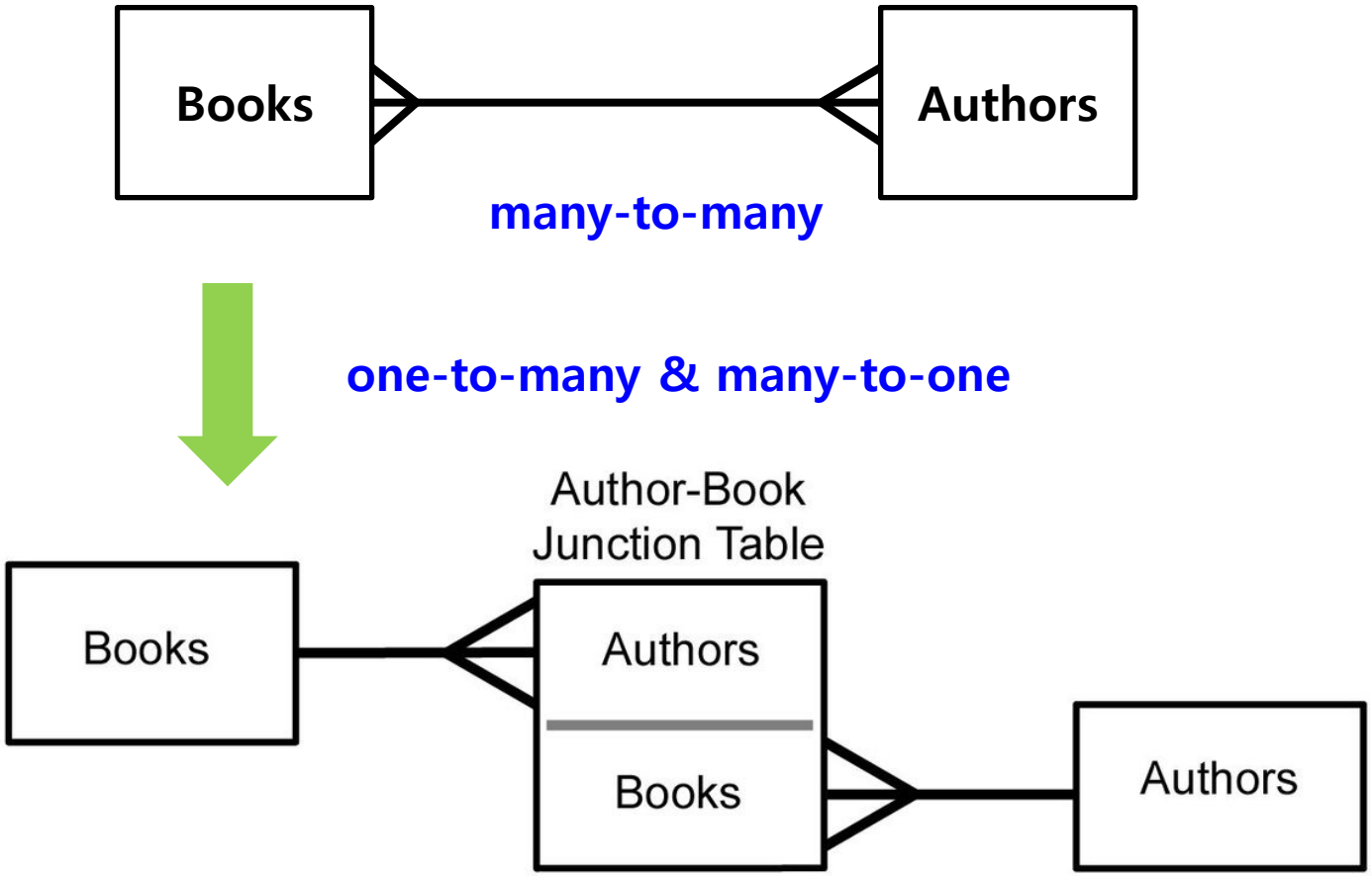


one-to-many

many-to-one

Figure 3.13
An M:N relationship, WORKS_ON.

Many-to-many (M:N) Relationship



https://en.wikipedia.org/wiki/File:Databases-ManyToManyWJunction.jpg

Ternary Relationship

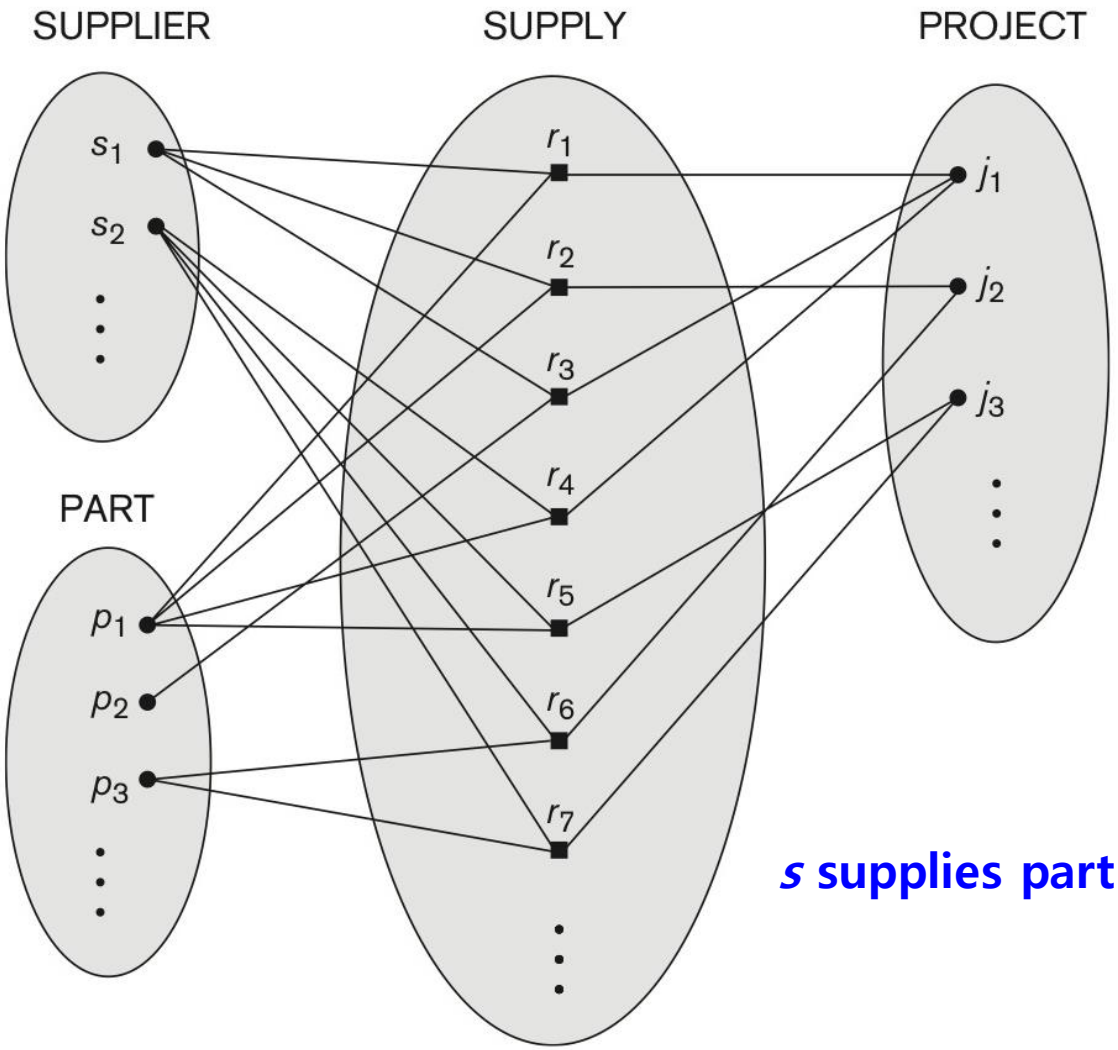


Figure 3.10 Some relationship instances in the SUPPLY ternary relationship set.

Recursive Relationship Type

- **A relationship type between the same participating entity type in distinct roles**
- **Also called a self-referencing relationship type.**
- **Example: the `SUPERVISION` relationship**
  `PREREQUISITE`
- **`EMPLOYEE` participates twice in two distinct roles:**
  - supervisor (or boss) role
  - supervisee (or subordinate) role
- **Each relationship instance relates two distinct `EMPLOYEE` entities:**
  - One employee in *supervisor* role
  - One employee in *supervisee* role

Displaying a recursive relationship

- **In a recursive relationship type.**
  - Both participations are the same entity type in different roles.
  - For example, `SUPERVISION` relationships between `EMPLOYEE` (in role of supervisor or boss) and (another) `EMPLOYEE` (in role of subordinate or worker).

- **In following figure, first role participation labeled with 1 and second role participation labeled with 2.**

- **In ER diagram, need to display role names to distinguish participations.**

A Recursive Relationship Supervision

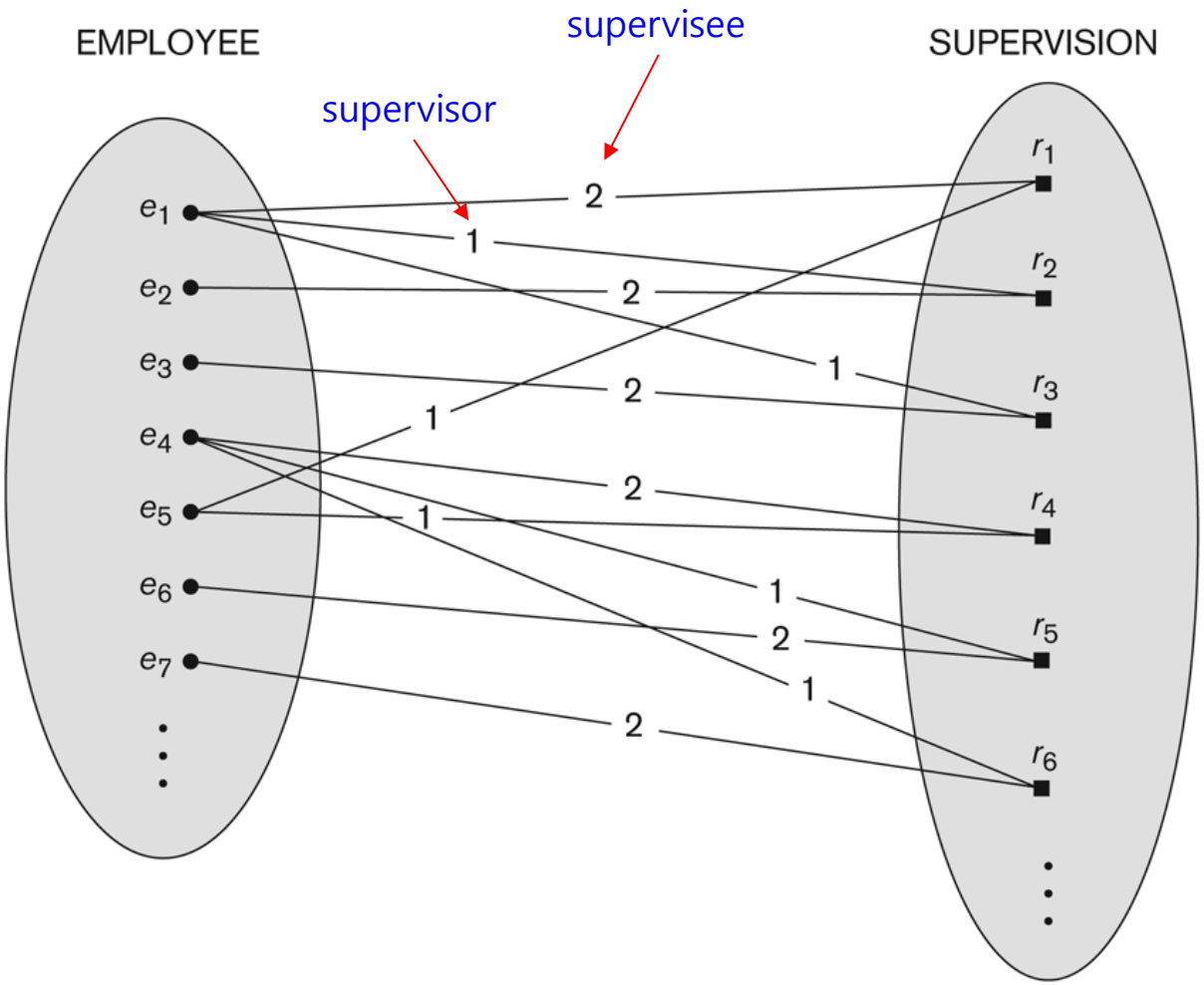


Figure 3.11
A recursive relationship SUPERVISION between EMPLOYEE in the *supervisor* role (1) and EMPLOYEE in the *subordinate* role (2).

Recursive Relationship Type is: SUPERVISION (participation role names are shown)

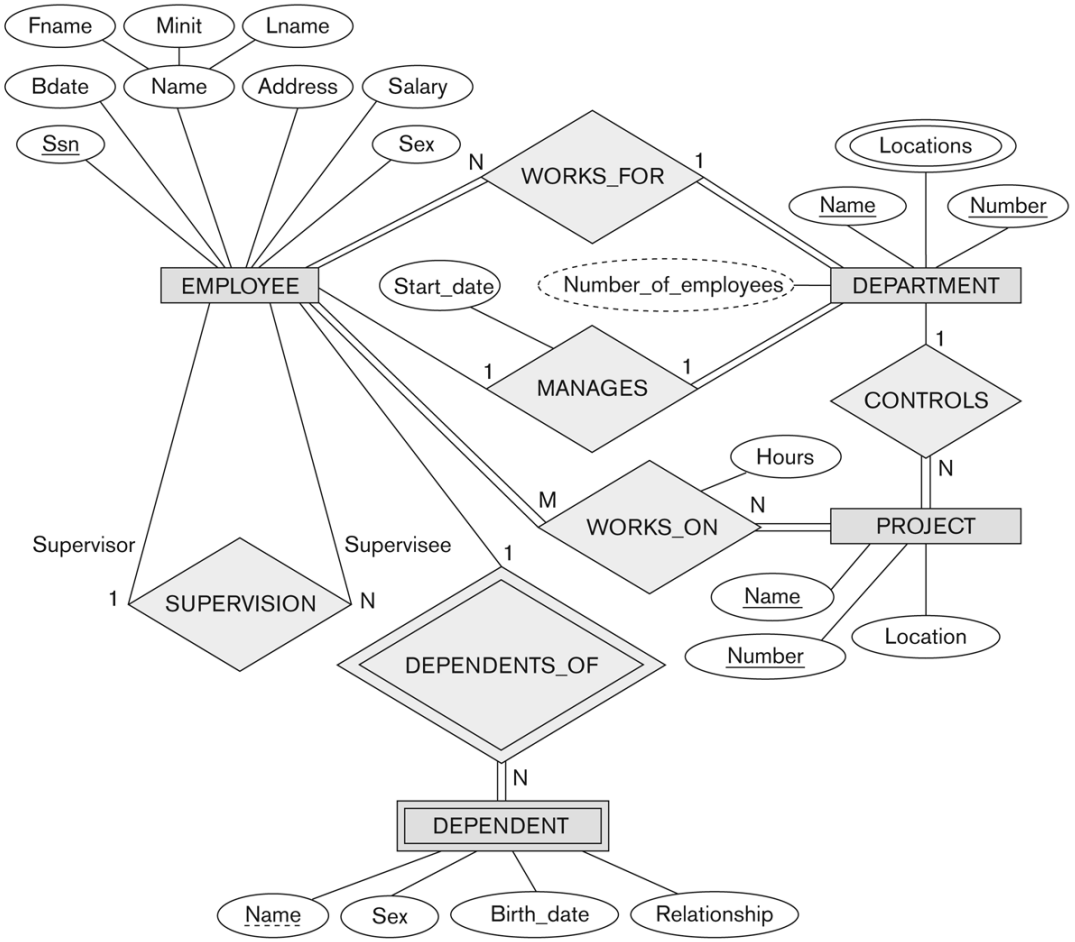


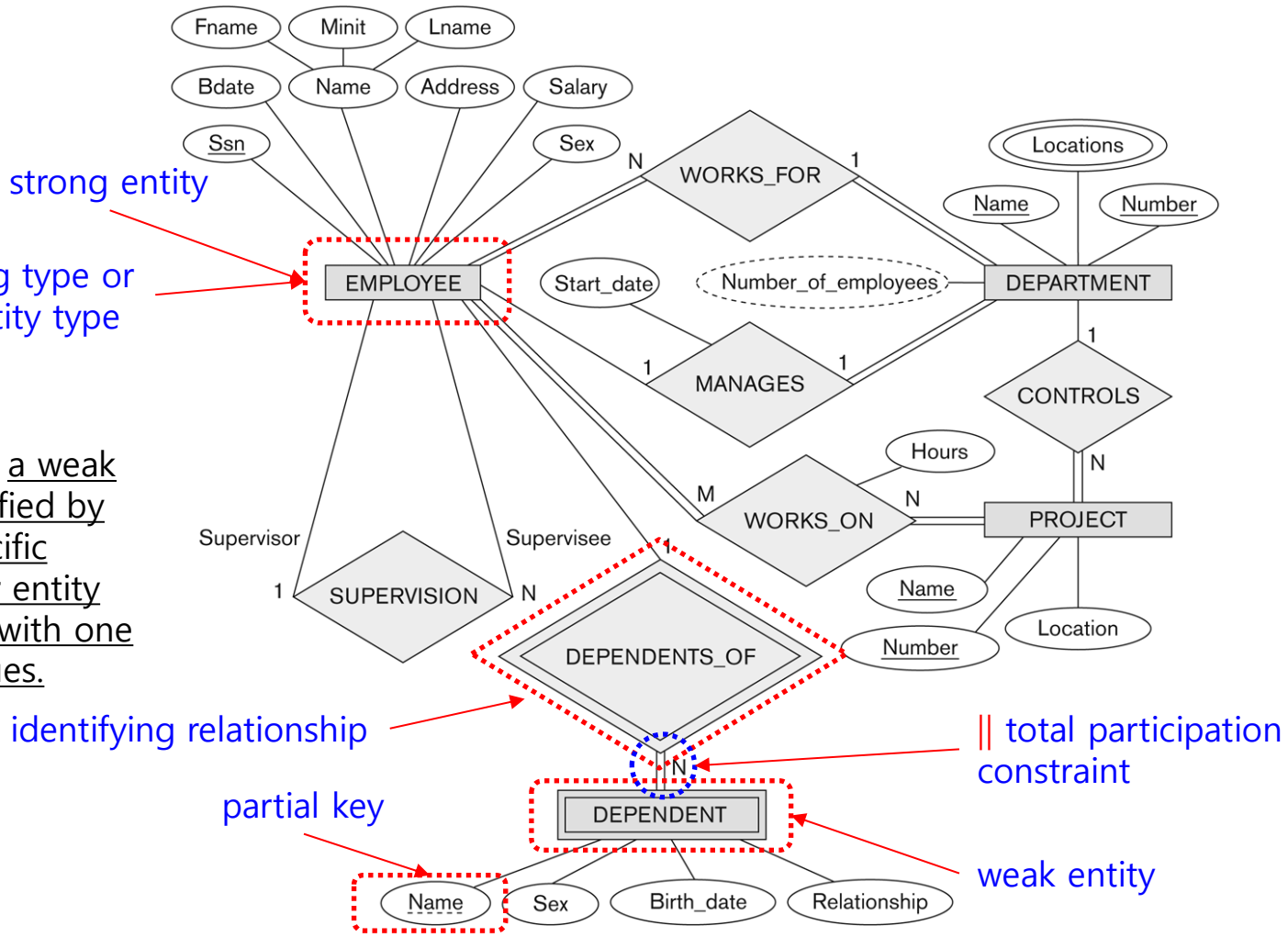
Figure 3.2
An ER schema diagram for the COMPANY database. The diagrammatic notation is introduced gradually throughout this chapter.

Weak Entity Types

Weak Entity Types

- **An entity that does not have a key attribute and that is identification-dependent on another entity type.**
- **A weak entity must participate in an identifying relationship type with an owner or identifying entity type**
- **Entities are identified by the combination of:**
  - A partial key of the weak entity type
  - The particular entity they are related to in the identifying relationship type
- **Example:**
  - A `DEPENDENT` entity is identified by the dependent's first name, *and* the specific `EMPLOYEE` with whom the dependent is related
  - Name of `DEPENDENT` is the *partial key*
  - `DEPENDENT` is a *weak entity type*
  - `EMPLOYEE` is its identifying entity type via the identifying relationship type `DEPENDENT_OF`

Weak Entity Types



Entities belonging to a weak entity type are identified by being related to specific entities from another entity type in combination with one of their attribute values.

Figure 3.2
An ER schema diagram for the COMPANY database. The diagrammatic notation is introduced gradually throughout this chapter.

Attributes of Relationship types

- **A relationship type can have attributes:**
  - For example, HoursPerWeek of WORKS_ON
  - Its value for each relationship instance describes the number of hours per week that an EMPLOYEE works on a PROJECT.
    - A value of HoursPerWeek depends on a particular (employee, project) combination
  - Most relationship attributes are used with M:N relationships
    - In 1:N relationships, they can be transferred to the entity type on the N-side of the relationship

Example Attribute of a Relationship Type: Hours of WORKS_ON

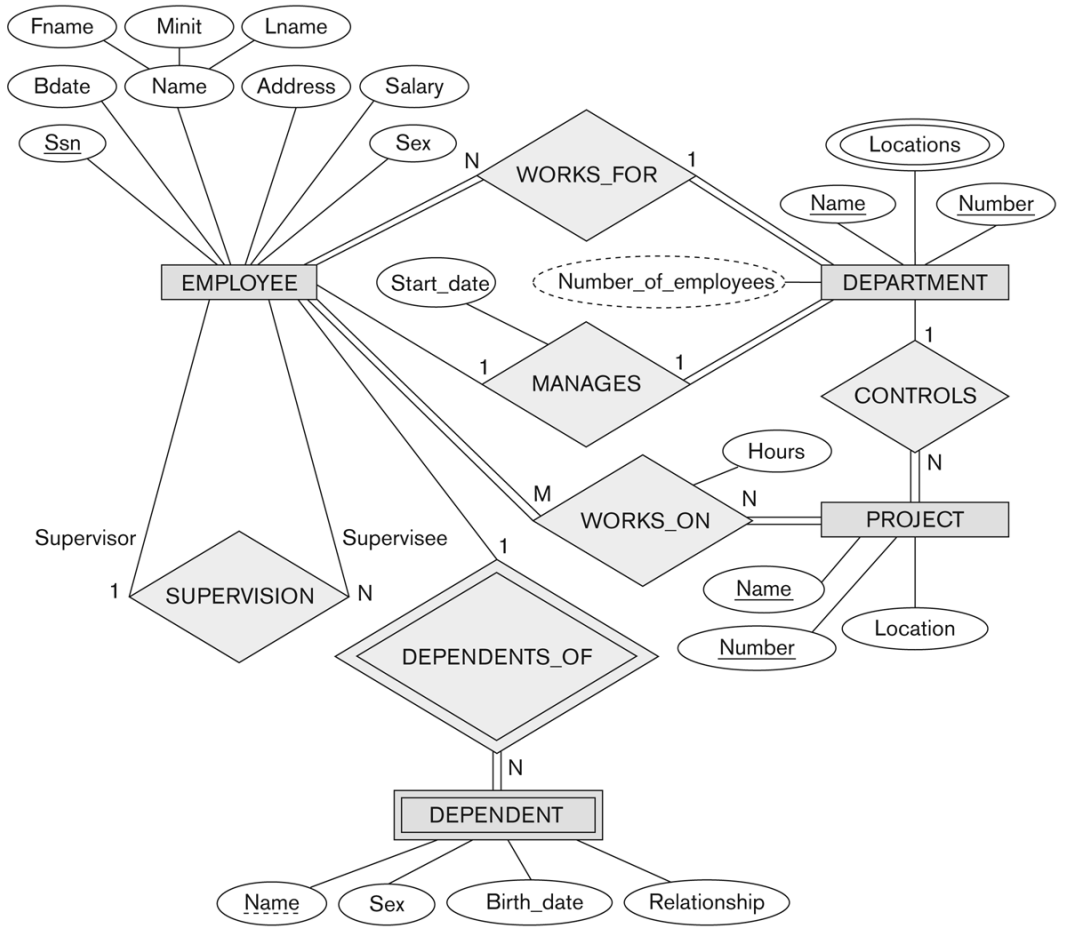


Figure 3.2
An ER schema diagram for the COMPANY database. The diagrammatic notation is introduced gradually throughout this chapter.

Notation for Constraints on Relationships

- **Cardinality ratio (of a binary relationship): `1:1`, `1:N`, `N:1`, or `M:N`**
  - Shown by placing appropriate numbers on the relationship edges.

- **Participation constraint (on each participating entity type): total (called existence dependency) or partial.**
  - Total shown by double line, partial by single line.

- **NOTE: These are easy to specify for Binary Relationship Types.**

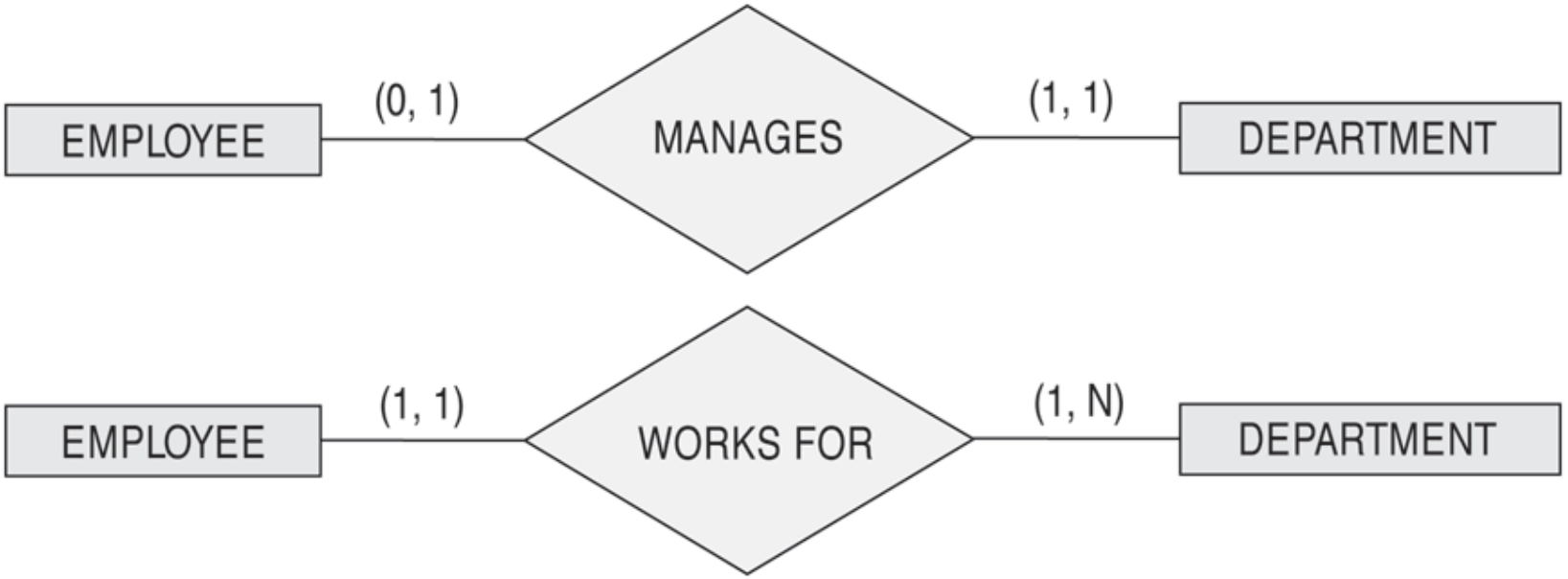
Alternative (min, max) notation for relationship structural constraints:

- Specified on each participation of an entity type E in a relationship type R
- Specifies that each entity e in E participates in at least *min* and at most *max* relationship instances in R
- Default(no constraint): min=0, max=n (signifying no limit)
- Must have min ≤ max, min ≥ 0, max ≥ 1

Alternative (min, max) notation for relationship structural constraints:

- **Derived from the knowledge of mini-world constraints**
- **Examples:**
  - A department has exactly one manager and an employee can manage at most one department.
    - Specify (0,1) for participation of `EMPLOYEE` in `MANAGES`
    - Specify (1,1) for participation of `DEPARTMENT` in `MANAGES`
  - An employee can work for exactly one department but a department can have any number of employees.
    - Specify (1,1) for participation of `EMPLOYEE` in `WORKS_FOR`
    - Specify (0,n) for participation of `DEPARTMENT` in `WORKS_FOR`

The (min, max) notation for relationship constraints



Read the min, max numbers next to the entity type

COMPANY ER Schema Diagram using (min, max) notation

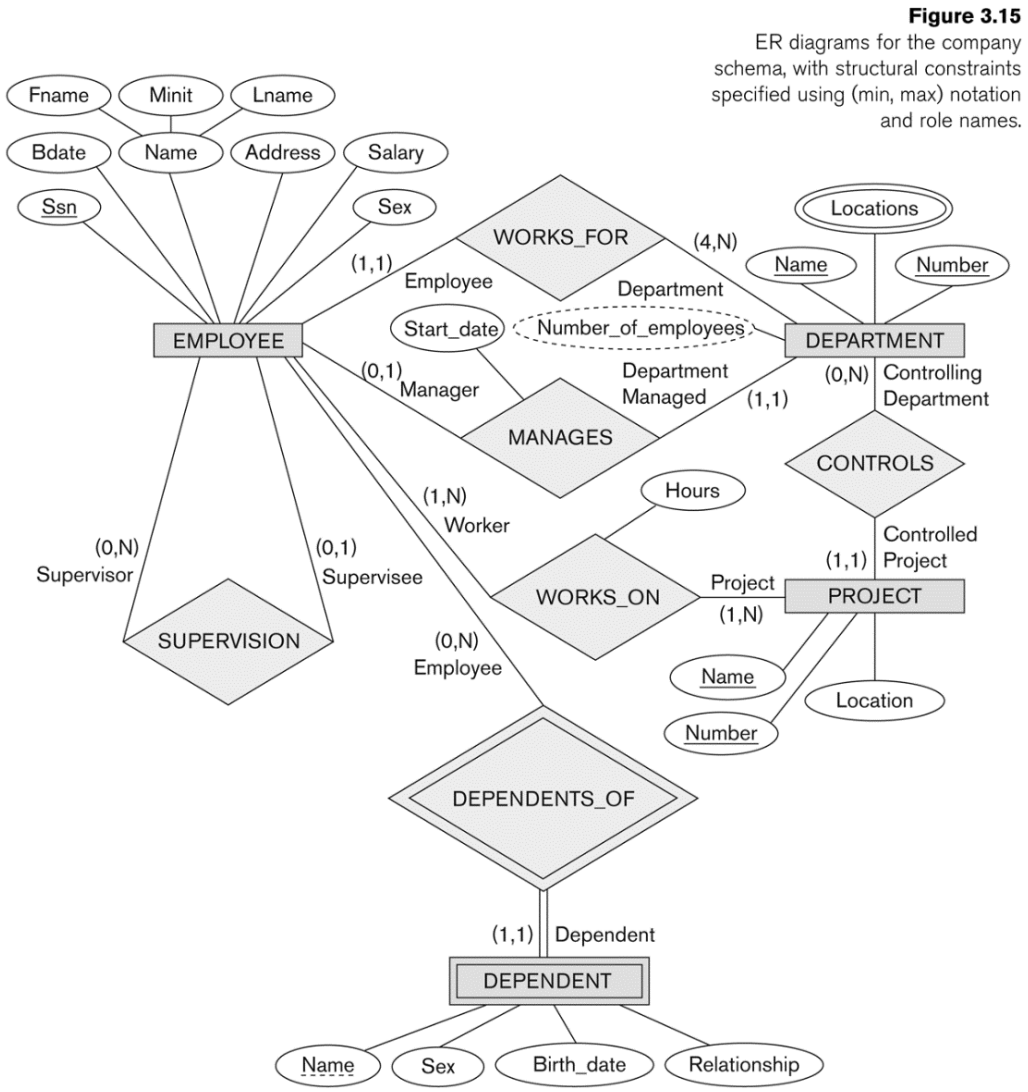


Figure 3.15
ER diagrams for the company schema, with structural constraints specified using (min, max) notation and role names.

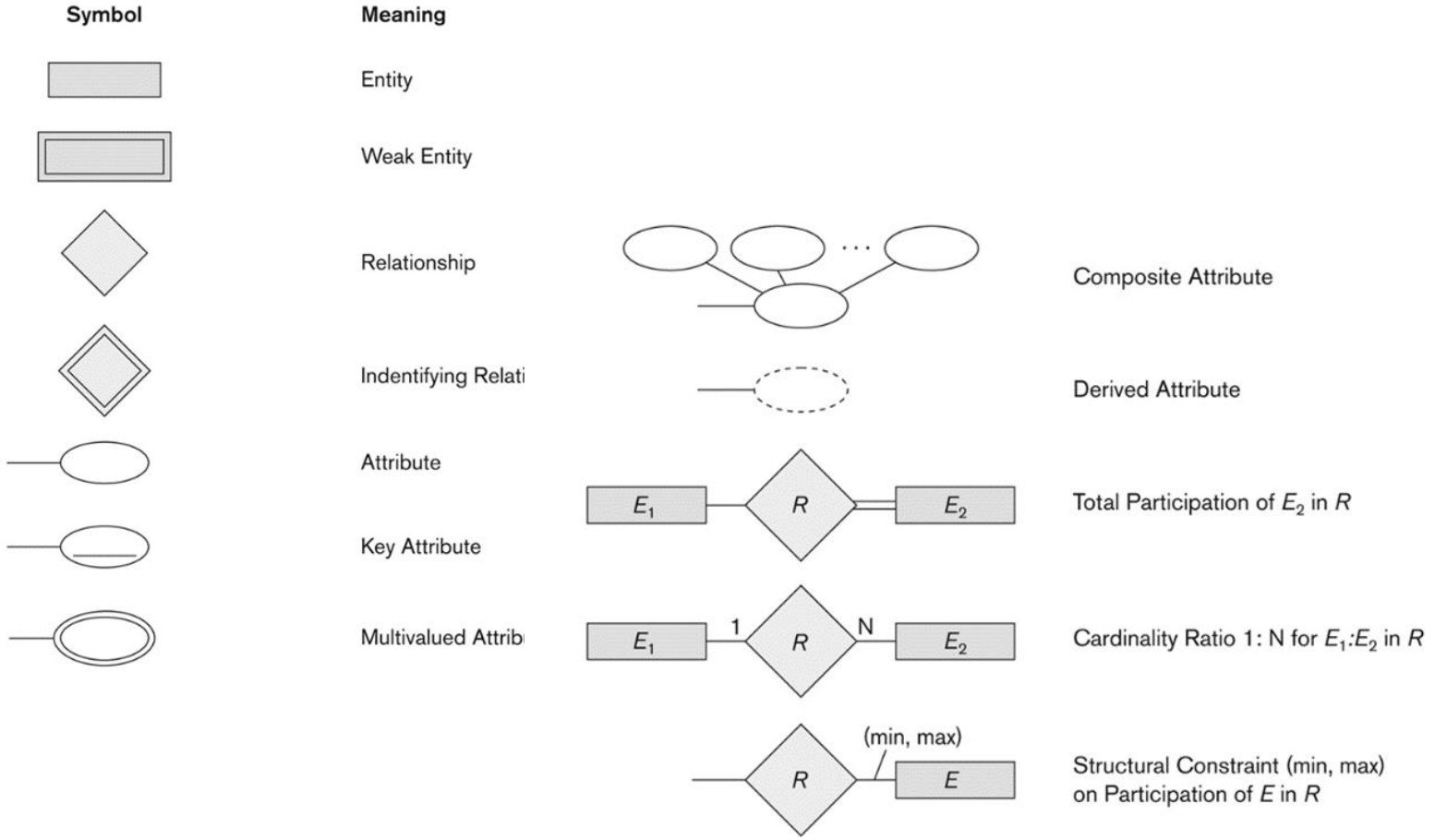
ER Diagrams, Naming Conventions and Design Issues

Alternative diagrammatic notation

- **ER diagrams is one popular example for displaying database schemas**
- **Many other notations exist in the literature and in various database design and modeling tools**
- **UML class diagrams is representative of another way of displaying ER concepts that is used in several commercial design tools**

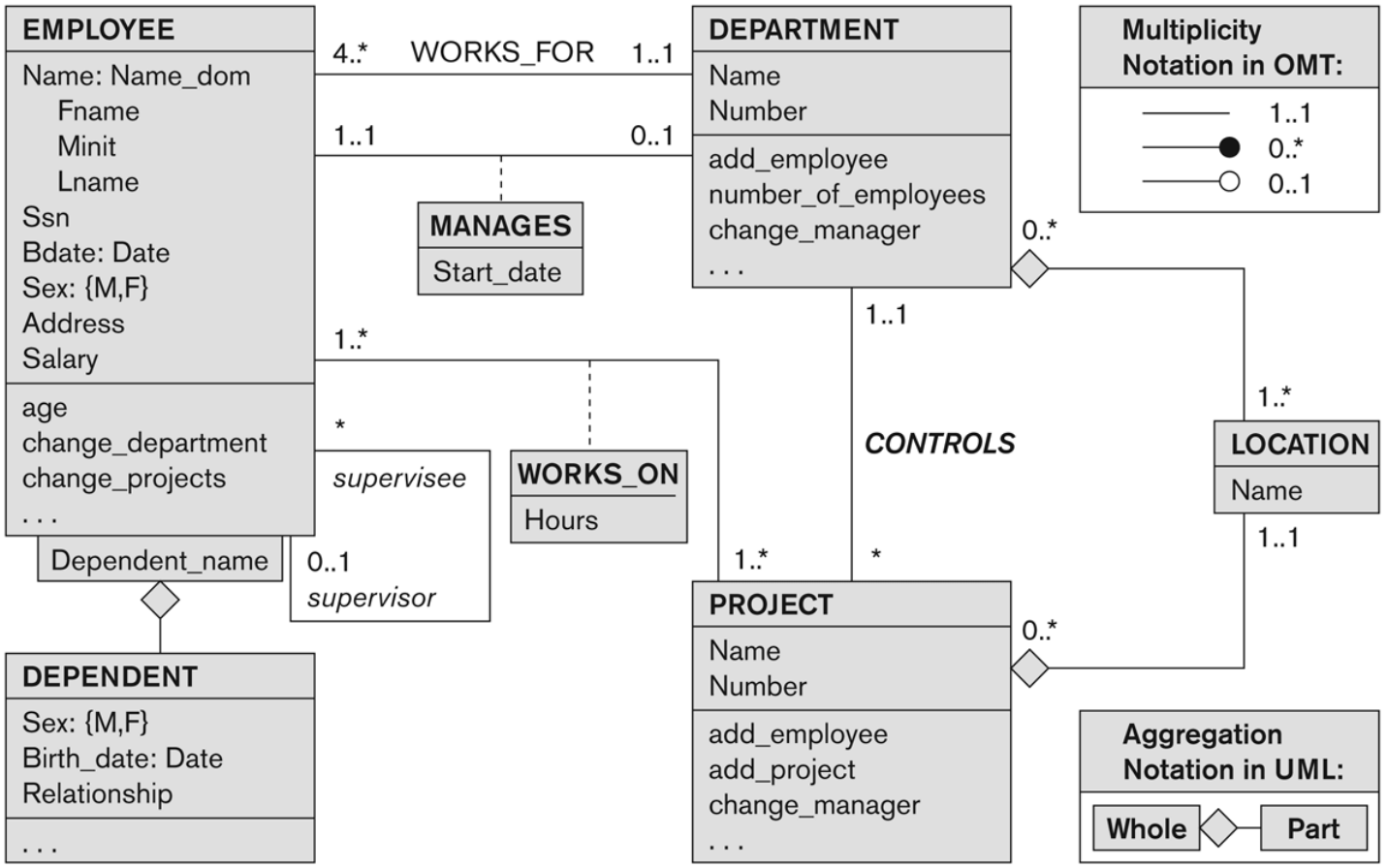
Summary of notation for ER diagrams

Figure 3.14
Summary of the notation for ER diagrams.



UML class diagram for COMPANY database schema

Figure 3.16
The COMPANY conceptual schema in UML class diagram notation.



Other alternative diagrammatic notations

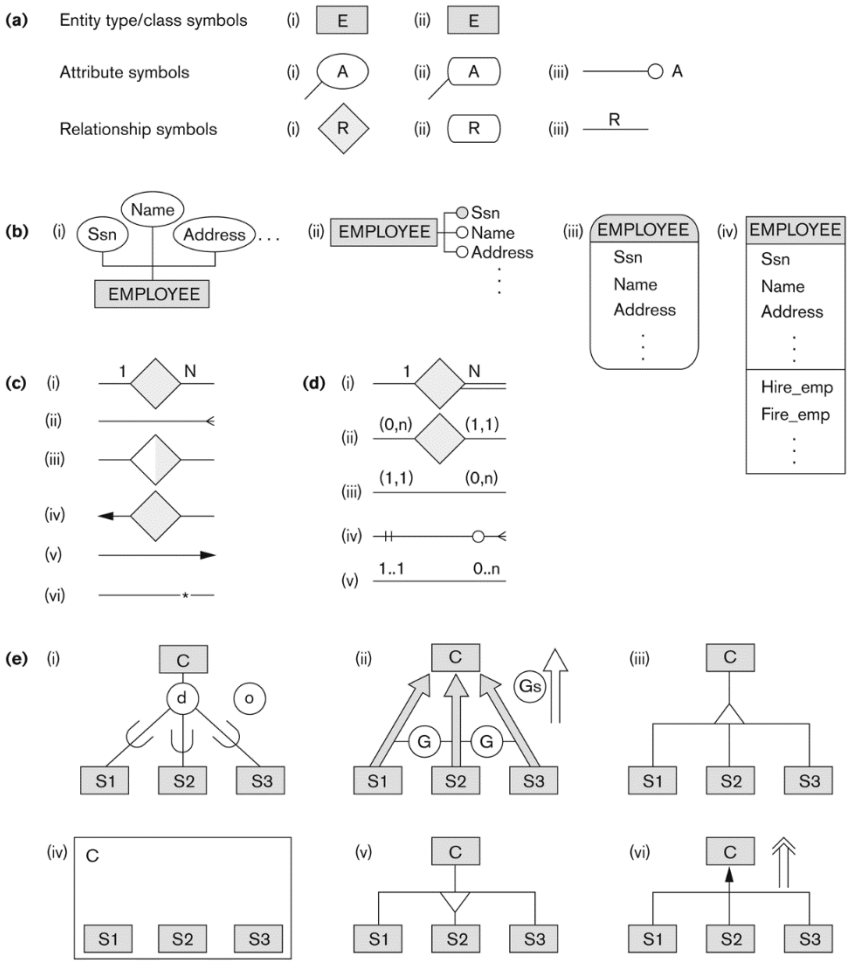


Figure A.1
Alternative notations. (a) Symbols for entity type/class, attribute, and relationship. (b) Displaying attributes. (c) Displaying cardinality ratios. (d) Various (min, max) notations. (e) Notations for displaying specialization/generalization.

Relationship Types of Degree Higher than Two

Relationships of Higher Degree

- **Relationship types of degree 2 are called binary**
- **Relationship types of degree 3 are called ternary and of degree n are called n-ary**
- **In general, an n-ary relationship is not equivalent to n binary relationships**
- **Constraints are harder to specify for higher-degree relationships (n > 2) than for binary relationships**

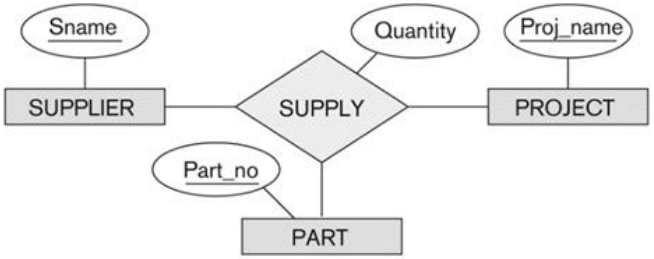
Discussion of n-ary relationships (n > 2)

- **In general, 3 binary relationships can represent different information than a single ternary relationship (see a and b)**

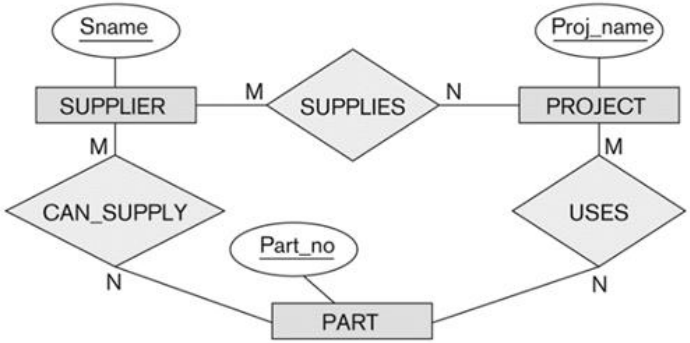
SUPPLIER s
PART p
PROJECT j

(s, j, p)

(a)



(b)



(s, j)
(s, p)
(j, p)

(s, j)
(s, p)
(j, p)

not imply (s, j, p)

Discussion of n-ary relationships (n > 2)

- **If needed, the binary and n-ary relationships can all be included in the schema design (see Figure 3.17a and b, where all relationships convey different meanings)**

- **In some cases, a ternary relationship can be represented as a weak entity if the data model allows a weak entity type to have multiple identifying relationships (and hence multiple owner entity types) (see Figure 3.17c)**

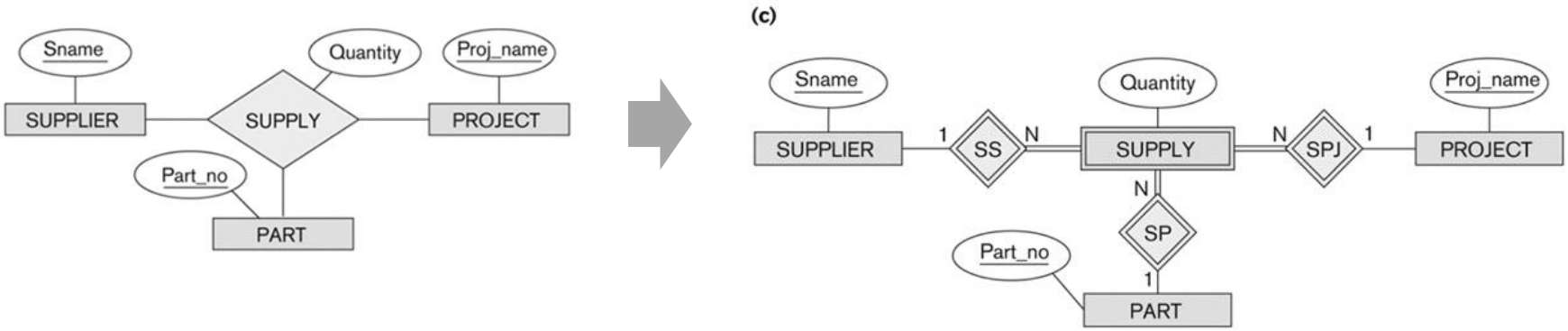
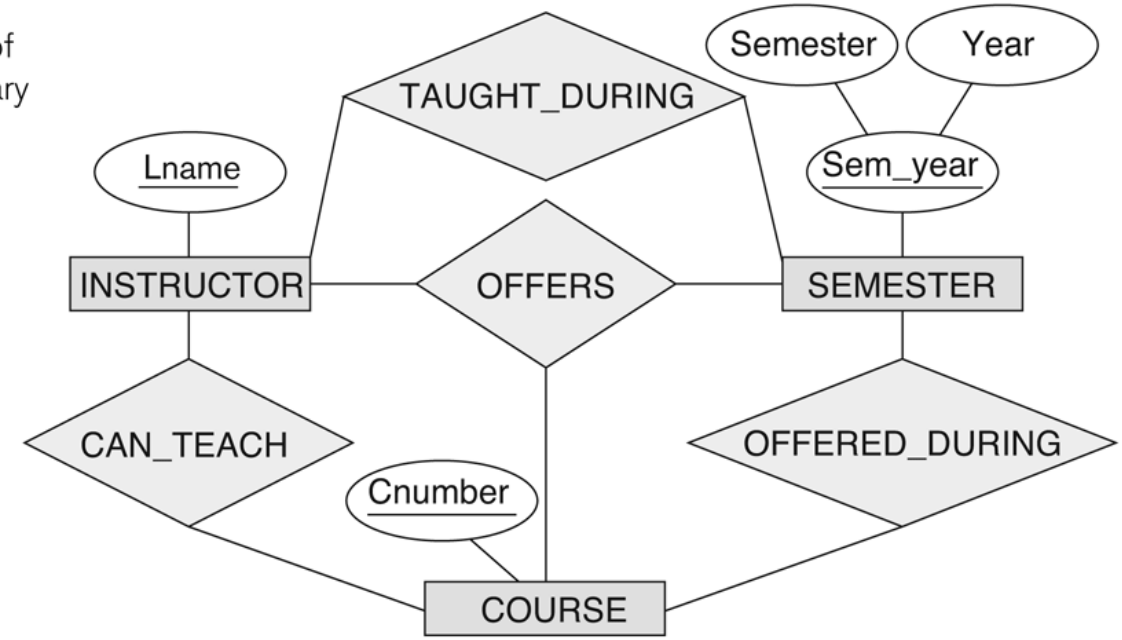


Figure 3.17
Ternary relationship types. (a) The SUPPLY relationship. (b) Three binary relationships not equivalent to SUPPLY. (c) SUPPLY represented as a weak entity type.

Discussion of n-ary relationships (n > 2)

- **If a particular binary relationship can be derived from a higher-degree relationship at all times, then it is redundant**

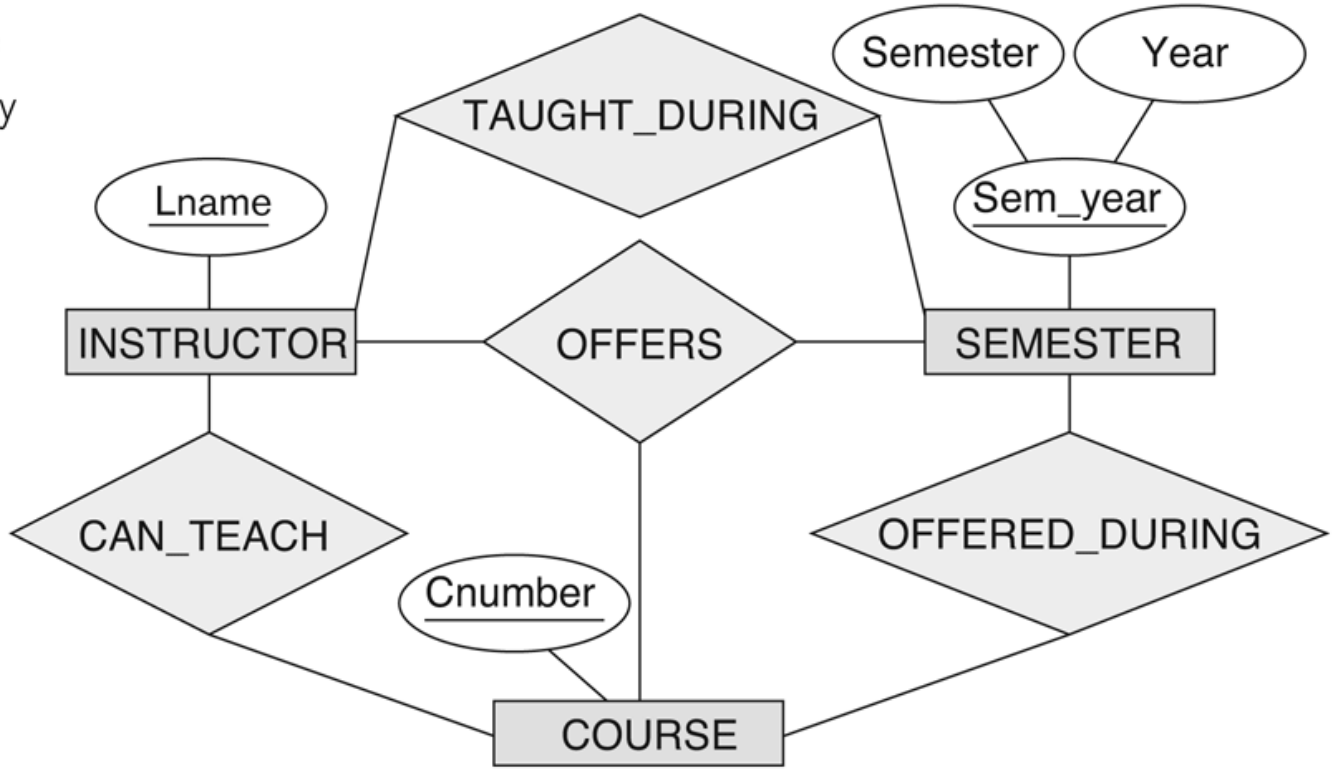
Figure 3.18
Another example of ternary versus binary relationship types.



For example, the `TAUGHT_DURING` binary relationship in Figure 3.18 can be derived from the ternary relationship `OFFERS` (based on the meaning of the relationships)

Another example of a ternary relationship

Figure 3.18
Another example of ternary versus binary relationship types.

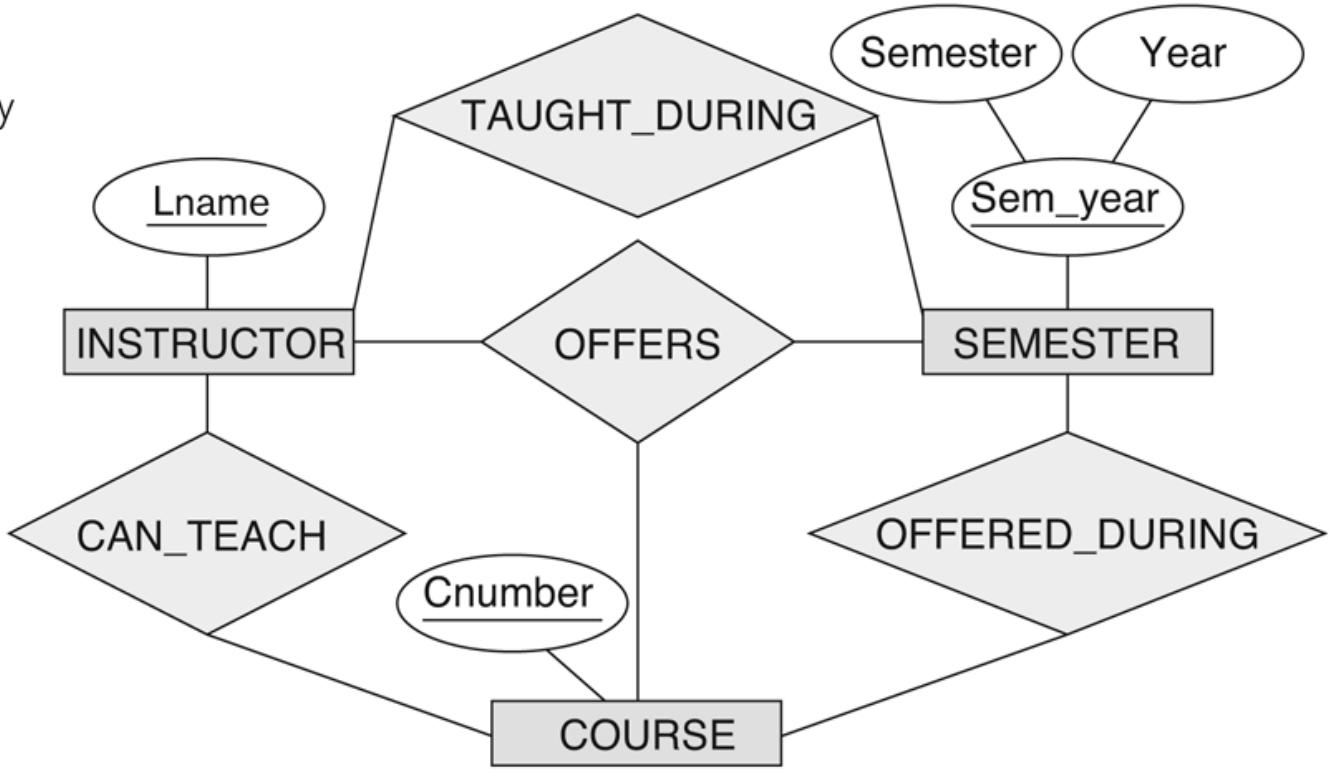



```
INSTRUCTOR i
SEMESTER s
COURSE c
```

a relationship instance `(i, s, c)` should not exist in **`OFFERS`** unless an instance (i, s) exists in **`TAUGHT_DURING`**, and instance `(s, c)` exists in `OFFERED_DURING`, and an instance `(i, c)` exists in `CAN_TEACH`. However, the reverse is not always true.

Another example of a ternary relationship

Figure 3.18
Another example of ternary versus binary relationship types.




```
INSTRUCTOR i
SEMESTER s
COURSE c
```

We can infer the instances of TAUGHT_DURING and OFFERED_DURING from the instances in OFFERS, but we cannot infer the instances of CAN_TEACH; therefore, TAUGHT_DURING and OFFERED_DURING are redundant and can be left out.

Not all (i, c) can be inferred from all (i, s, c).

Another Example: A UNIVERSITY Database

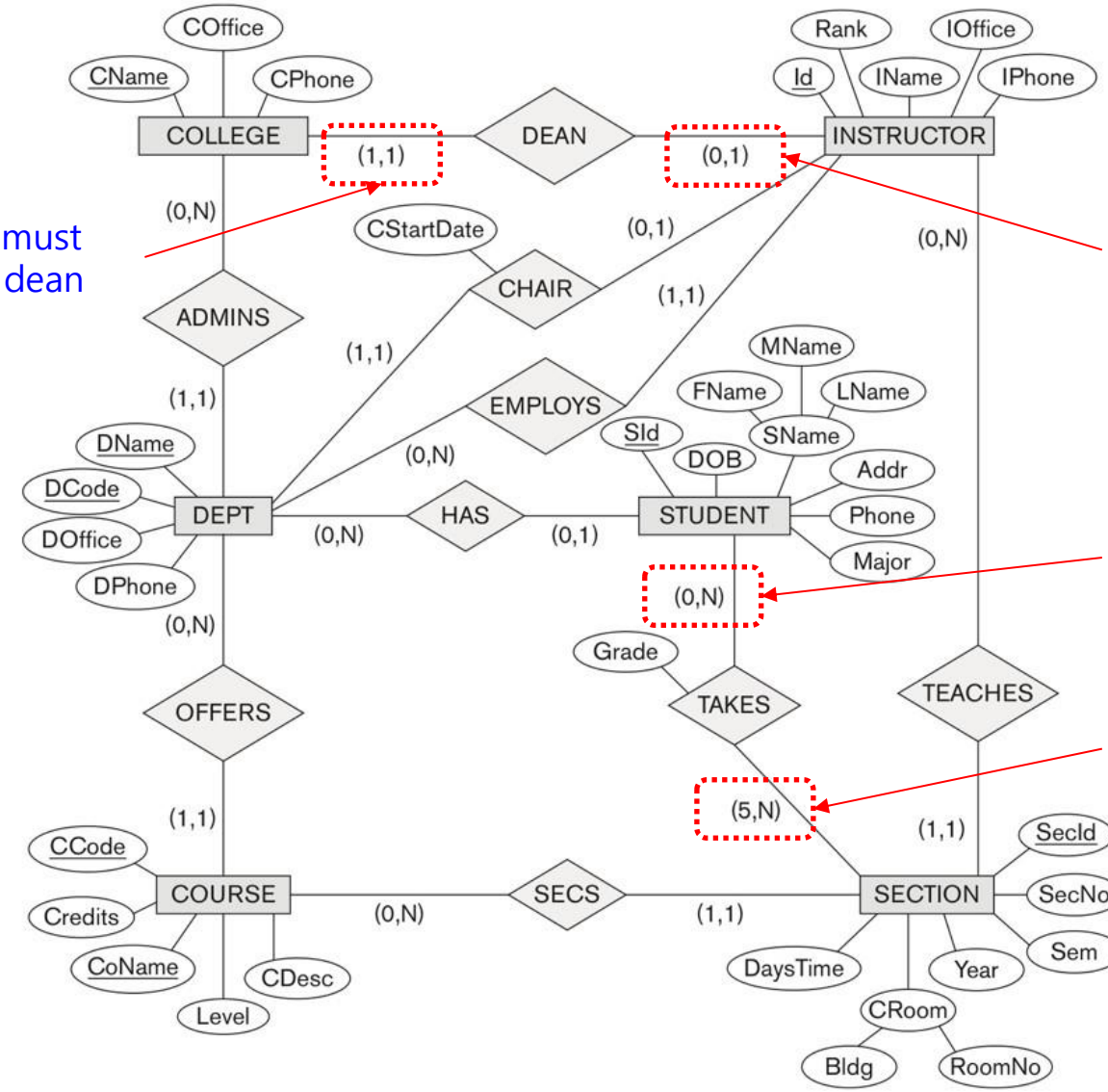
Another Example: A UNIVERSITY Database(p122)

- To keep track of the enrollments in classes and student grades, another database is to be designed.

- It keeps track of the COLLEGEs, DEPARTMENTs within each college, the COURSEs offered by departments, and SECTIONs of courses, INSTRUCTORs who teach the sections etc.

- These entity types and the relationships among these entity types are shown on the next slide.

UNIVERSITY database conceptual schema



a college must have one dean

an instructor may or may not be a dean of a college

~~*(zero or more) students take section~~

a students takes *(zero or more) sections

section must have at least 5 students

Chapter Summary

- **ER Model Concepts: Entities, attributes, relationships**
- **Constraints in the ER model**
- **Using ER in step-by-step mode conceptual schema design for the `COMPANY` database**
- **ER Diagrams - Notation**
- **Alternative Notations – UML class diagrams, others**
- **Binary Relationship types and those of higher degree.**

Data Modeling Tools (Additional Material)

- **A number of popular tools that cover conceptual modeling and mapping into relational schema design.**
  - Examples: ERWin, S- Designer (Enterprise Application Suite), ER-Studio, etc.

- **POSITIVES:**
  - Serves as documentation of application requirements, easy user interface - mostly graphics editor support

- **NEGATIVES:**
  - Most tools lack a proper distinct notation for relationships with relationship attributes
  - Mostly represent a relational design in a diagrammatic form rather than a conceptual ER-based design

Some of the Automated Database Design Tools (Note: Not all may be on the market now)

COMPANY	TOOL	FUNCTIONALITY
Embarcadero Technologies	ER Studio	Database Modeling in ER and IDEF1X
	DB Artisan	Database administration, space and security management
Oracle	Developer 2000/Designer 2000	Database modeling, application development
Popkin Software	System Architect 2001	Data modeling, object modeling, process modeling, structured analysis/design
Platinum (Computer Associates)	Enterprise Modeling Suite: Erwin, BPWin, Paradigm Plus	Data, process, and business component modeling
Persistence Inc.	Pwertier	Mapping from O-O to relational model
Rational (IBM)	Rational Rose	UML Modeling & application generation in C++/JAVA
Resolution Ltd.	Xcase	Conceptual modeling up to code maintenance
Sybase	Enterprise Application Suite	Data modeling, business logic modeling
Visio	Visio Enterprise	Data modeling, design/reengineering Visual Basic/C++