



## SOFTENG 351 Fundamentals of Database Systems

Data Modeling Using the Entity-Relationship (ER) Model



## Overview of Database Design Process

- ▶ Two main activities:
  - ▶ Database design
  - ▶ Applications design
- ▶ Focus 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



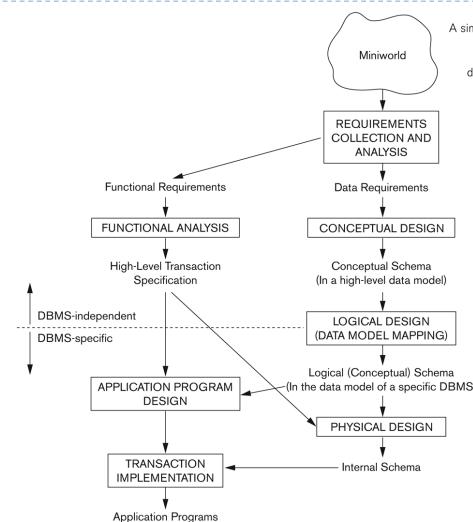
## Outline

- ▶ 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



## Overview of Database Design Process

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





## Methodologies for Conceptual Design

- ▶ Entity Relationship (ER) Diagrams
- ▶ Enhanced Entity Relationship (EER) Diagrams
- ▶ 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

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## 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.

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## 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.

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## 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
  - ▶ 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, ...

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## Types of Attributes (1)

### ▶ Simple

- ▶ Each entity has a single atomic value for the attribute. For example, SSN or Sex.

### ▶ Composite

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

### ▶ 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}.

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## Types of Attributes (2)

- ▶ In general, composite and multi-valued attributes may be nested arbitrarily to any number of levels, although this is rare.

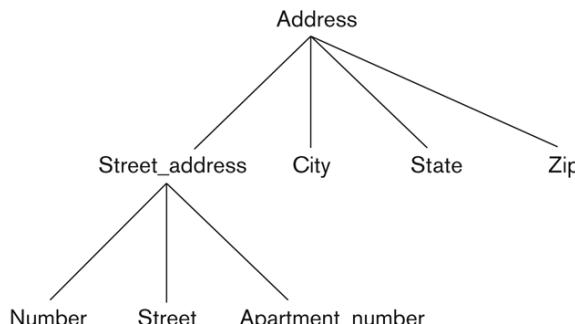
- ▶ For example, PreviousDegrees of a STUDENT is a composite multi-valued attribute denoted by {PreviousDegrees (College, Year, Degree, Field)}
- ▶ Multiple PreviousDegrees values can exist
- ▶ Each has four subcomponent attributes:
  - ▶ College, Year, Degree, Field

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## Example of a composite attribute



**Figure 3.4**

A hierarchy of composite attributes.

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## 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.

- ▶ 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.

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## Entity Types and Key Attributes (2)

- ▶ A key attribute may be composite.
  - ▶ VehicleTagNumber is a key of the CAR entity type with components (Number, State).
- ▶ 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.
- ▶ Each key is underlined (Note: this is different from the relational schema where only one “primary key is underlined”).

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## Entity Set

- ▶ Each entity type will have a collection of entities stored in the database, e.g., CAR entity instances
  - ▶ Called the **entity set** or sometimes **entity collection**

CAR  
Registration (Number, State), Vehicle\_id, Make, Model, Year, {Color}

$CAR_1$	((ABC 123, TEXAS), TK629, Ford Mustang, convertible, 2004 {red, black})
$CAR_2$	((ABC 123, NEW YORK), WP9872, Nissan Maxima, 4-door, 2005, {blue})
$CAR_3$	((VSY 720, TEXAS), TD729, Chrysler LeBaron, 4-door, 2002, {white, blue})
:	

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

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

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## Attributes and Value Sets

- ▶ Mathematically, an attribute A for an entity type E whose value set is V is defined as a function
 
$$A : E \rightarrow P(V)$$

Where  $P(V)$  indicates a power set (which means all possible subsets) of V. The above definition covers simple and multivalued attributes.
- ▶ We refer to the value of attribute A for entity e as  $A(e)$ .

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## 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
- ▶ See the full ER notation in advance on the next slide

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## NOTATION for ER diagrams

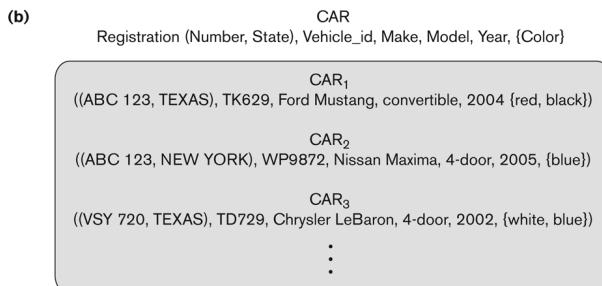
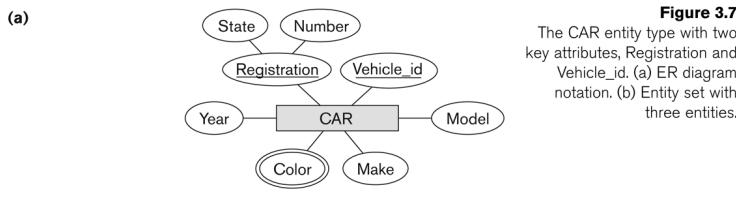
Symbol	Meaning
rectangle	Entity
rectangle with thick border	Weak Entity
diamond	Relationship
double diamond	Identifying Relationship
oval	Attribute
underlined oval	Key Attribute
double oval	Multivalued Attribute
three ovals connected by lines	Composite Attribute
line with dashed oval	Derived Attribute

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## Entity Type CAR with two keys and a corresponding Entity Set



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## Initial Conceptual Design of Entity Types

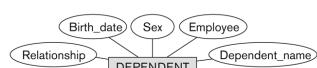
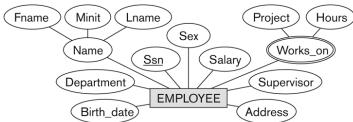
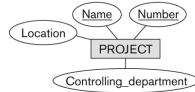
- ▶ Based on the requirements, we can identify four initial entity types in the COMPANY database:
- ▶ DEPARTMENT
- ▶ PROJECT
- ▶ EMPLOYEE
- ▶ DEPENDENT
- ▶ Their initial conceptual design is shown on the following slide
- ▶ The initial attributes shown are derived from the requirements description

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## Initial Design of Entity Types:



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

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## 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)
- ▶ We introduce relationship concepts next

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## Relationships and Relationship Types

- ▶ 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 EMPLOYEES and PROJECTS participate, or the MANAGES relationship type in which EMPLOYEES and DEPARTMENTS participate.
- ▶ The degree of a relationship type is the number of participating entity types.
  - ▶ Both MANAGES and WORKS\_ON are *binary* relationships.

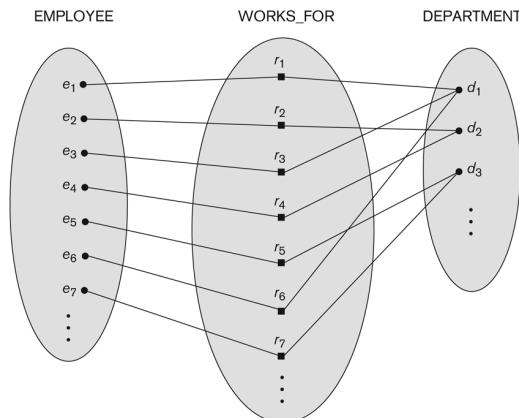
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## Relationship instances of WORKS\_FOR: N:1

WORKS\_FOR N:1 relationship between 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.

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## Relationship instances of WORKS\_ON: M:N

M:N WORKS\_ON relationship between EMPLOYEE and PROJECT

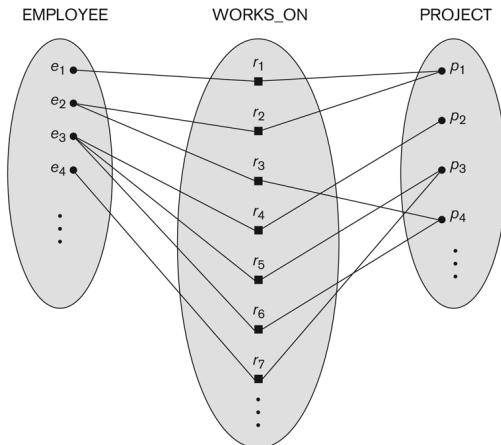


Figure 3.13  
An M:N relationship,  
WORKS\_ON.

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## Relationship type vs. relationship set

### ► 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

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## Relationship type vs. relationship set

- Previous figures displayed the relationship sets
- 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.

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## 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)

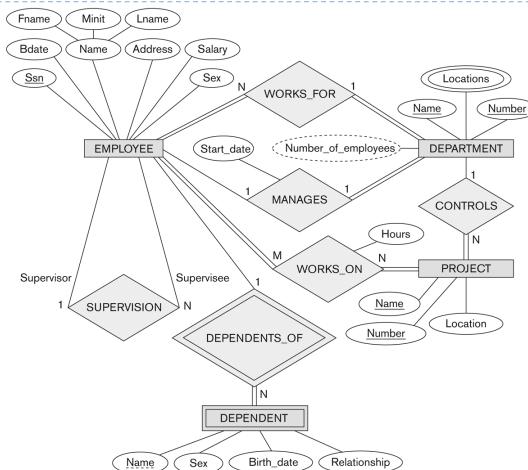
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## ER DIAGRAM – Relationship Types

**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.

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## 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
- In general, more than one relationship type can exist between the same participating entity types
  - MANAGES and WORKS\_FOR are distinct relationship types between EMPLOYEE and DEPARTMENT
  - Different meanings and different relationship instances.

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## Constraints on Relationships

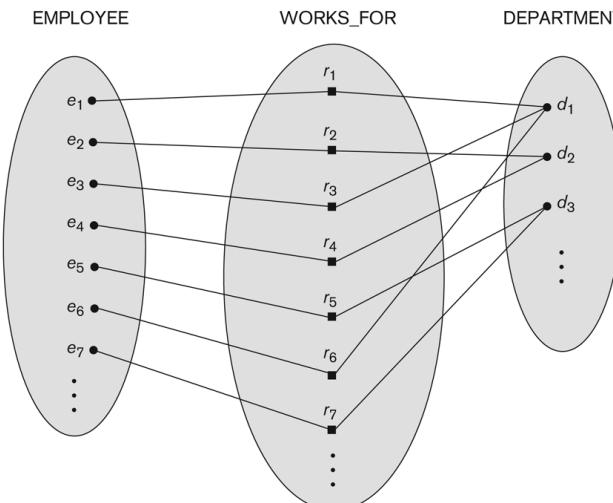
- Constraints on Relationship Types
  - (Also known as ratio constraints)
  - Cardinality Ratio (specifies *maximum* participation)
    - One-to-one (1:1)
    - One-to-many (1:N) or Many-to-one (N:1)
    - Many-to-many (M:N)
  - Existence Dependency Constraint (specifies *minimum* participation) (also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

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## Many-to-one (N:1) Relationship



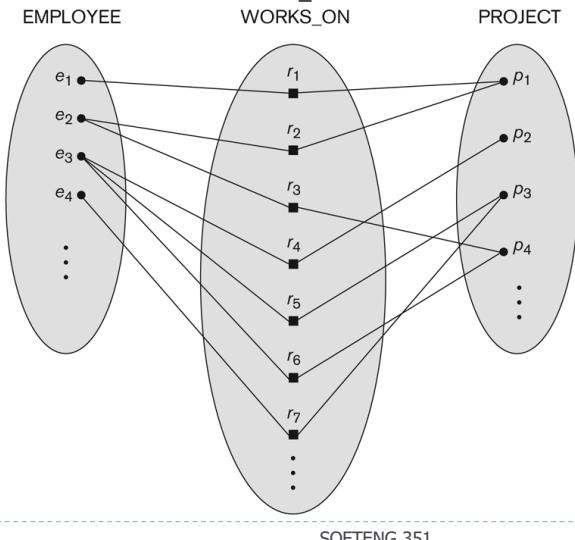
**Figure 3.9**  
Some instances in the WORKS\_FOR relationship set, which represents a relationship type WORKS\_FOR between EMPLOYEE and DEPARTMENT.

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## Many-to-many (M:N) Relationship



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

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## 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
- ▶ **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

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## Displaying a recursive relationship

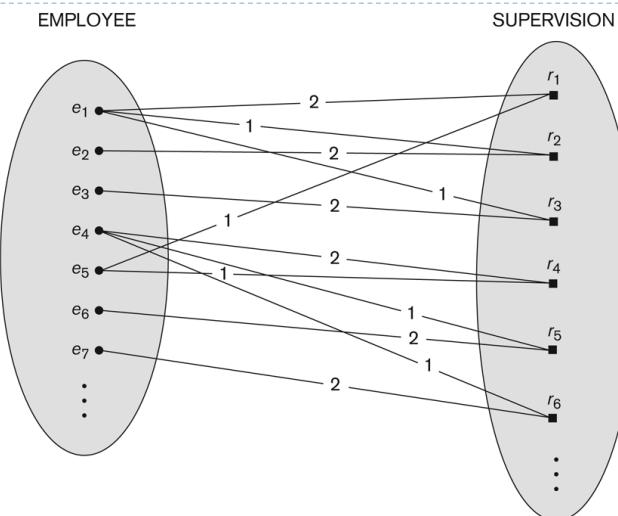
- ▶ In a recursive relationship type:
  - ▶ Both participations are same entity type in different roles.
  - ▶ For example, SUPERVISION relationships between EMPLOYEE (in role of supervisor or boss) and (another) EMPLOYEE (in role of subordinate or worker).
- ▶ In following figure, first role participation labeled with 1 and second role participation labeled with 2.
- ▶ In ER diagram, need to display role names to distinguish participations.

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## Recursive Relationship Supervision



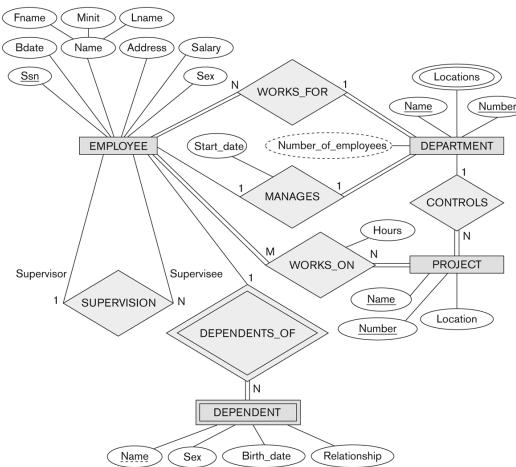
**Figure 3.11**  
A recursive relationship SUPERVISION between EMPLOYEE in the supervisor role (1) and EMPLOYEE in the subordinate role (2).

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## Recursive Relationship Type: SUPERVISION



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

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## 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

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## Attributes of Relationship types

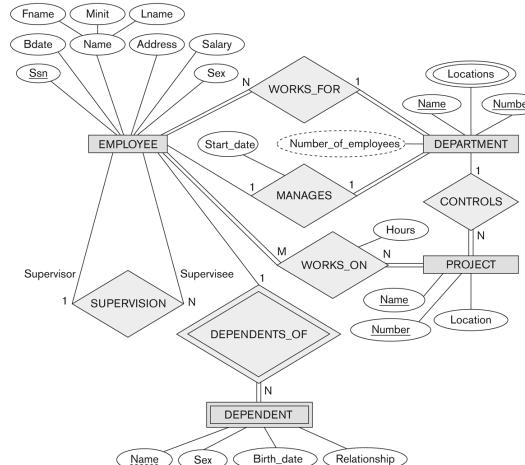
- ▶ A relationship type can have attributes:
  - ▶ For example, HoursPerWeek of WORKS\_ON
  - ▶ Its value for each relationship instance describes the number of hours per week that an EMPLOYEE works on a PROJECT.
  - ▶ A value of HoursPerWeek depends on a particular (employee, project) combination
- ▶ 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

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## 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.

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## 222 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.

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## 222 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  $\text{min} \leq \text{max}$ ,  $\text{min} \geq 0$ ,  $\text{max} \geq 1$
- ▶ Derived from the knowledge of mini-world constraints

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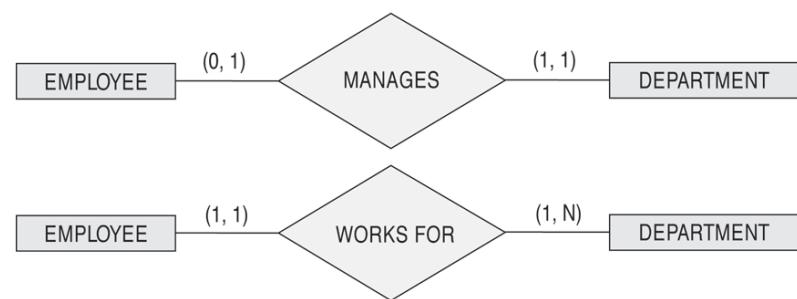
## 222 Alternative (min, max) notation for relationship structural constraints:

- ▶ 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

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## 222 The (min,max) notation for relationship constraints



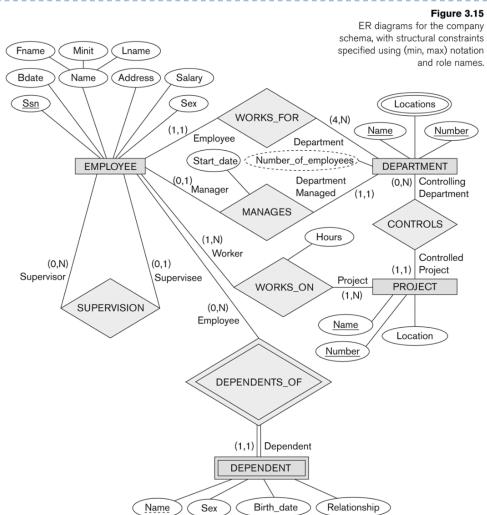
Read the min, max numbers next to the entity type and looking **away from** the entity type

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## COMPANY ER Schema Diagram using (min, max) notation



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## Alternative diagrammatic notation

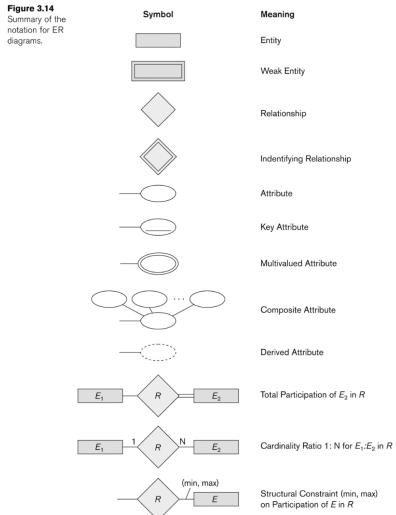
- ▶ ER diagrams is one popular example for displaying database schemas
- ▶ Many other notations exist in the literature and in various database design and modeling tools
- ▶ UML class diagrams is representative of another way of displaying ER concepts that is used in several commercial design tools

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## Summary of notation for ER diagrams



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## UML class diagrams

- ▶ Represent classes (similar to entity types) as large rounded boxes with three sections:
  - ▶ Top section includes entity type (class) name
  - ▶ Second section includes attributes
  - ▶ Third section includes class operations (operations are not in basic ER model)
- ▶ Relationships (called associations) represented as lines connecting the classes
  - ▶ Other UML terminology also differs from ER terminology
- ▶ Used in database design and object-oriented software design
- ▶ UML has many other types of diagrams for software design

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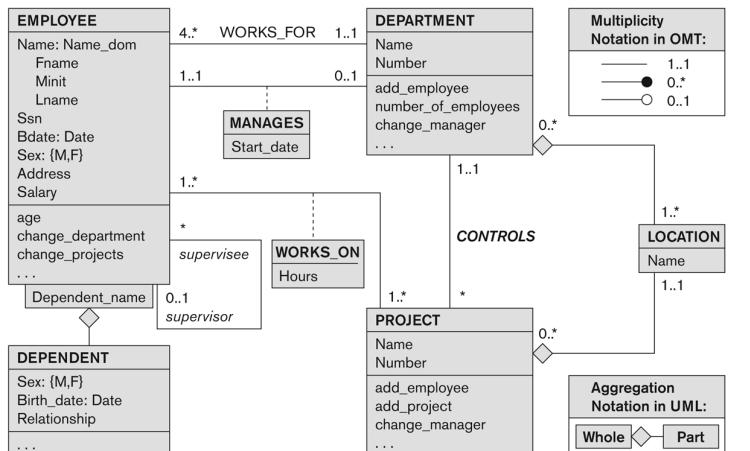
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## 222 UML class diagram for COMPANY database schema



Figure 3.16

The COMPANY conceptual schema in UML class diagram notation.



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## 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

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## 222 Discussion of n-ary relationships ( $n > 2$ )

- ▶ In general, 3 binary relationships can represent different information than a single ternary relationship (see Figure 3.17a and b on next slide)
- ▶ 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)

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## Example of a ternary relationship

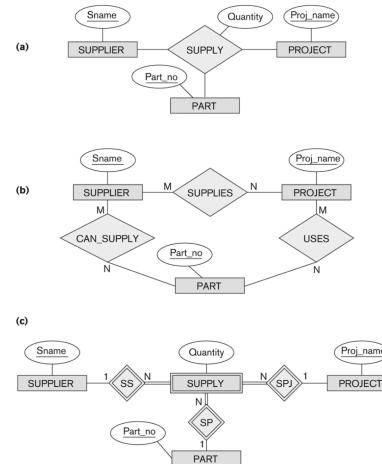


Figure 3.17

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

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## 222 Discussion of n-ary relationships ( $n > 2$ )

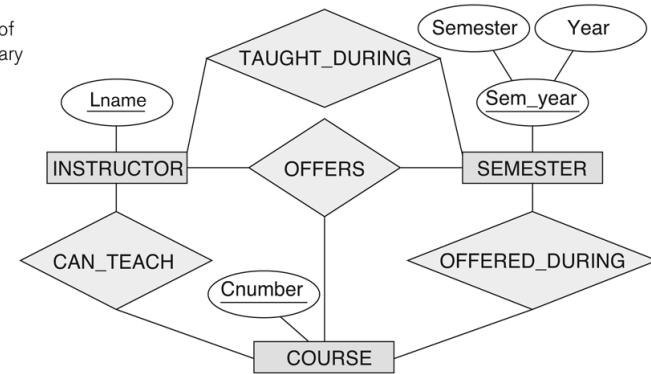
- ▶ If a particular binary relationship can be derived from a higher-degree relationship at all times, then it is redundant
- ▶ For example, the TAUGHT\_DURING binary relationship in Figure 3.18 (see next slide) can be derived from the ternary relationship OFFERS (based on the meaning of the relationships)

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## 222 Another example of a ternary relationship

**Figure 3.18**  
Another example of ternary versus binary relationship types.



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## 222 Displaying constraints on higher-degree relationships

- ▶ The (min, max) constraints can be displayed on the edges – however, they do not fully describe the constraints
- ▶ Displaying a 1, M, or N indicates additional constraints
  - ▶ M or N indicates no constraint
  - ▶ 1 indicates that an entity can participate in at most one relationship instance *that has a particular combination of the other participating entities*
- ▶ In general, both (min, max) and 1, M, or N are needed to describe fully the constraints
- ▶ The constraint specification is difficult and possibly ambiguous when we consider relationships of a degree higher than two.

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## 222 Another Example: A UNIVERSITY Database

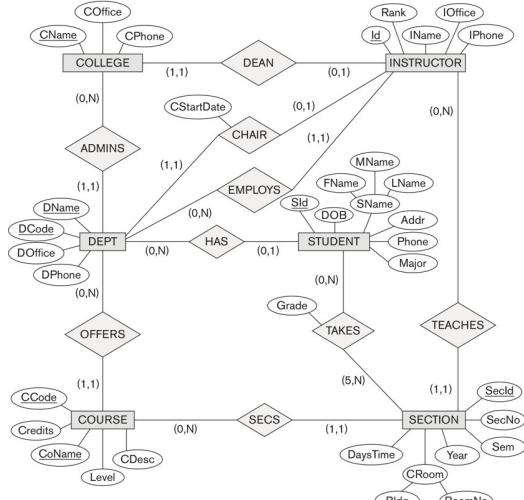
- ▶ To keep track of the enrollments in classes and student grades, another database is to be designed.
- ▶ It keeps track of the COLLEGES, DEPARTMENTs within each college, the COURSEs offered by departments, and SECTIONs of courses, INSTRUCTORs who teach the sections etc.
- ▶ These entity types and the relationships among these entity types are shown on the next slide in Figure 3.20.

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# UNIVERSITY database conceptual schema



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# Some of the Automated Database Design Tools

COMPANY	TOOL	FUNCTIONALITY
Embarcadero Technologies	ER Studio	Database Modeling in ER and IDEF1X
	DB Artisa	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.	Pwrtier	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++

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## Data Modeling Tools

- ▶ 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

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## 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.

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