Database Systems

LESSON 03: ENTITY-RELATIONSHIP (ER) MODEL

September 2019

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- Entity Types, Value Sets, and Key Attributes
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ER Diagrams - Notation

ER Diagram for COMPANY Schema

Alternative Notations – UML class diagrams, others

Relationships of Higher Degree

Overview of Database Design Process

Two main activities:

- Database design
- Applications design

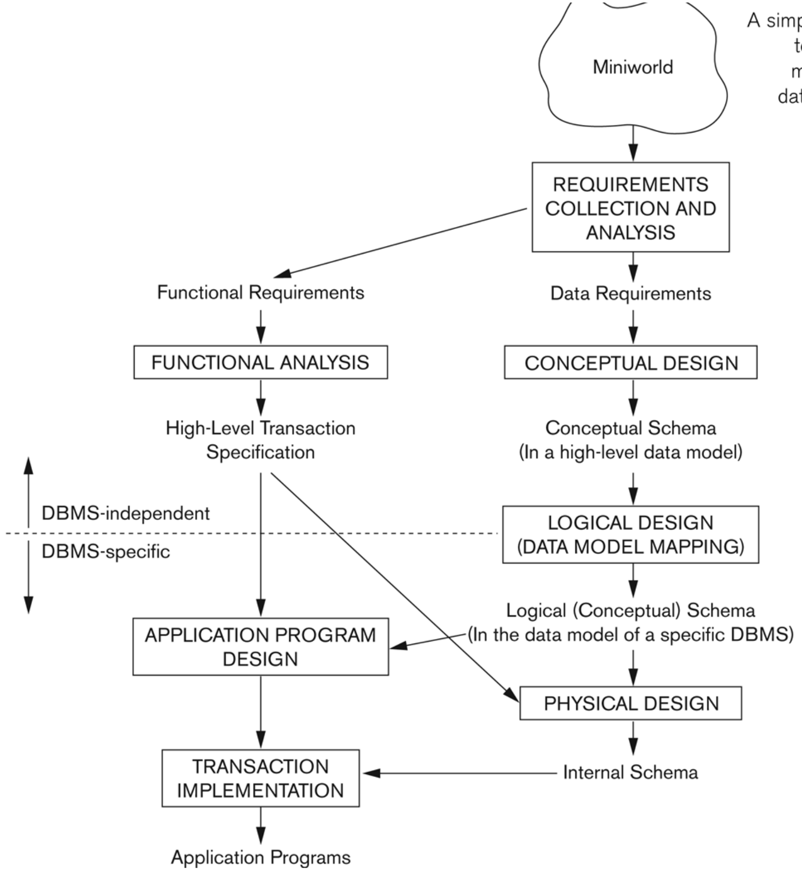
This lesson focuses on *conceptual database design*

- 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

Overview of Database Design Process


Miniworld
REQUIREMENTS COLLECTION AND ANALYSIS
Functional Requirements
Data Requirements
FUNCTIONAL ANALYSIS
CONCEPTUAL DESIGN
High-Level Transaction Specification
Conceptual Schema (In a high-level data model)
DBMS-independent
DBMS-specific
LOGICAL DESIGN (DATA MODEL MAPPING)
Logical (Conceptual) Schema (In the data model of a specific DBMS)
APPLICATION PROGRAM DESIGN
PHYSICAL DESIGN
TRANSACTION IMPLEMENTATION
Internal Schema
Application Programs

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

Methodologies for Conceptual Design

Entity Relationship (ER) Diagrams (This Lesson)

Enhanced Entity Relationship (EER) Diagrams (Next Lesson)

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

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.

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, …

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}.

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

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.

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).

Entity Set

Each entity type will have a collection of entities stored in the database

- Called the **entity set** or sometimes **entity collection**

Previous slide shows three CAR entity instances in the entity set for CAR

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

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 up to 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

Attributes and Value Sets

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

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).

Displaying an Entity type

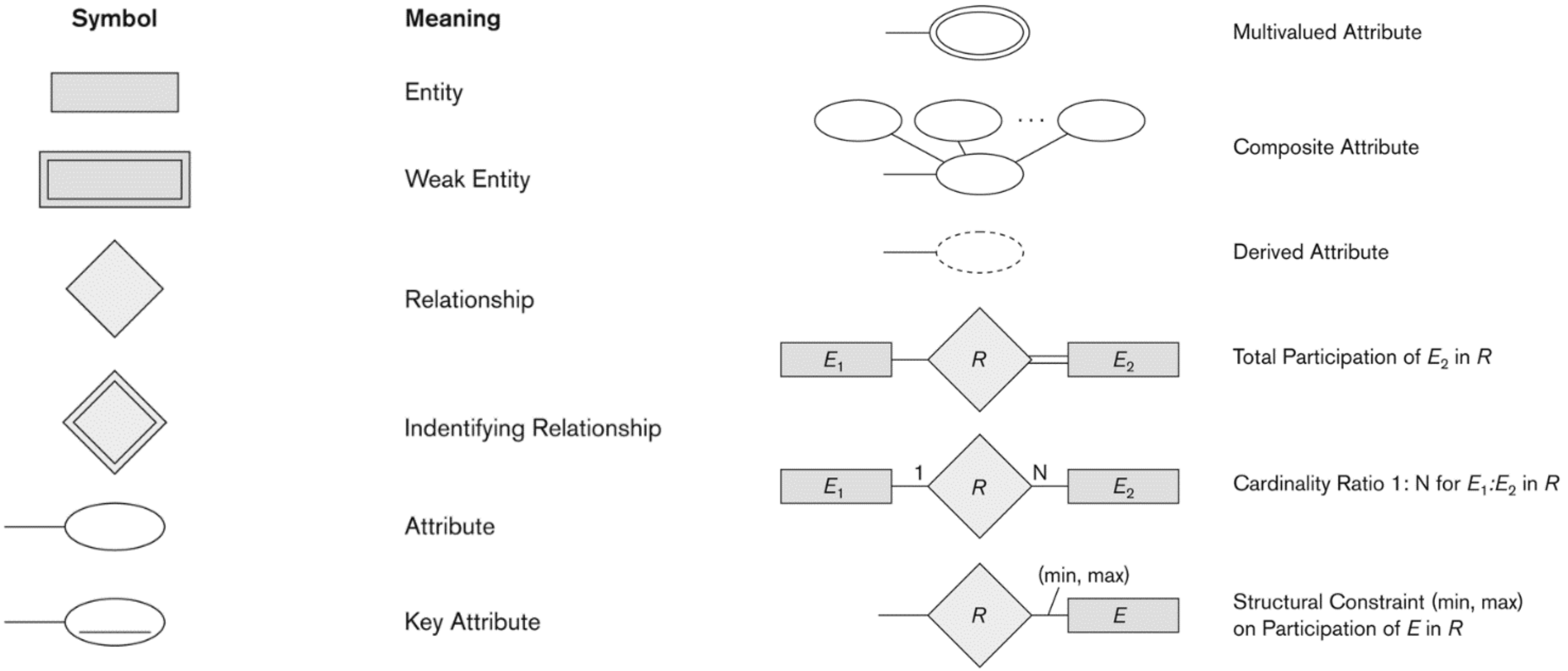
In ER diagrams, an entity type is displayed in a rectangular box

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

NOTATION for ER diagrams



Symbol

Meaning

Entity

Weak Entity

Relationship

Indentifying Relationship

Attribute

Key Attribute

Multivalued Attribute

Composite Attribute

Derived Attribute

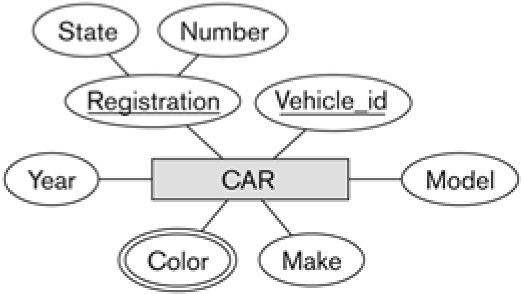
Total Participation of E_2 in R

Cardinality Ratio 1: N for E_1:E_2 in R

Structural Constraint (min, max)
on Participation of E in R

Entity Type CAR with two keys and a corresponding Entity Set

(a)



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

(b)

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})

⋮

Initial Conceptual Design of Entity Types for the COMPANY Database Schema

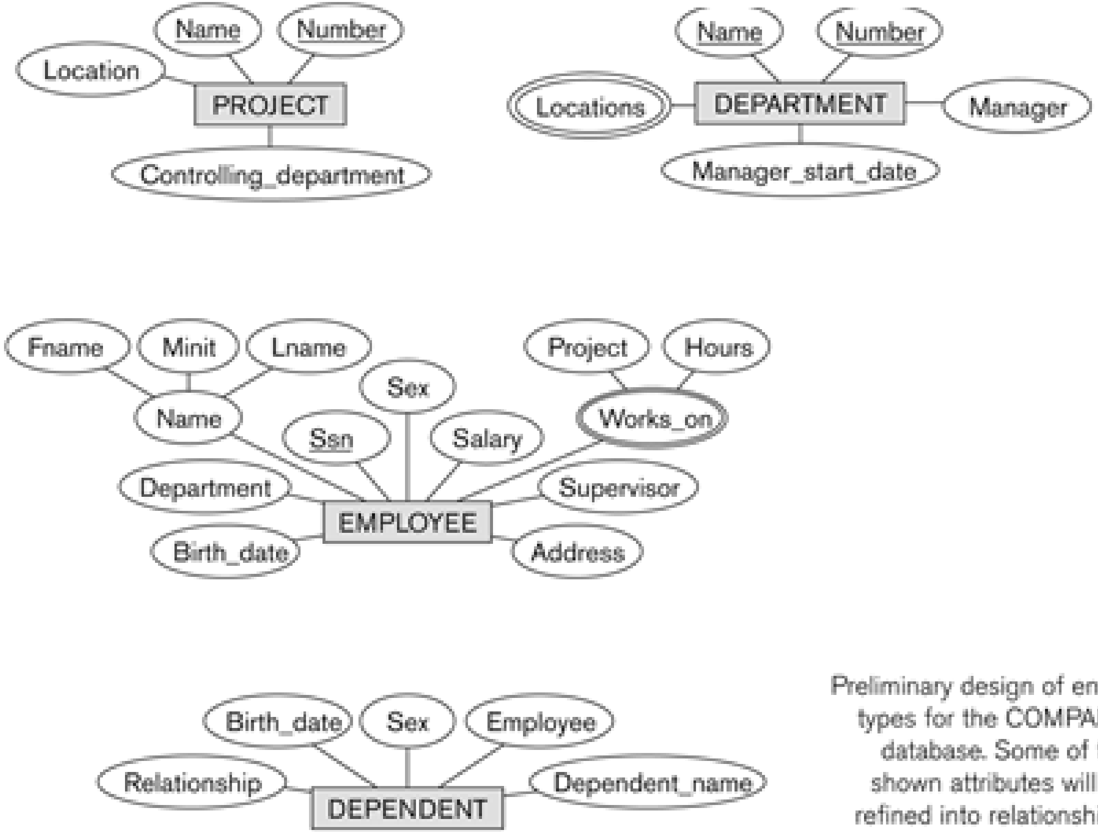
Based on the requirements, we can identify four initial entity types in the COMPANY database:

- 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



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

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

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.

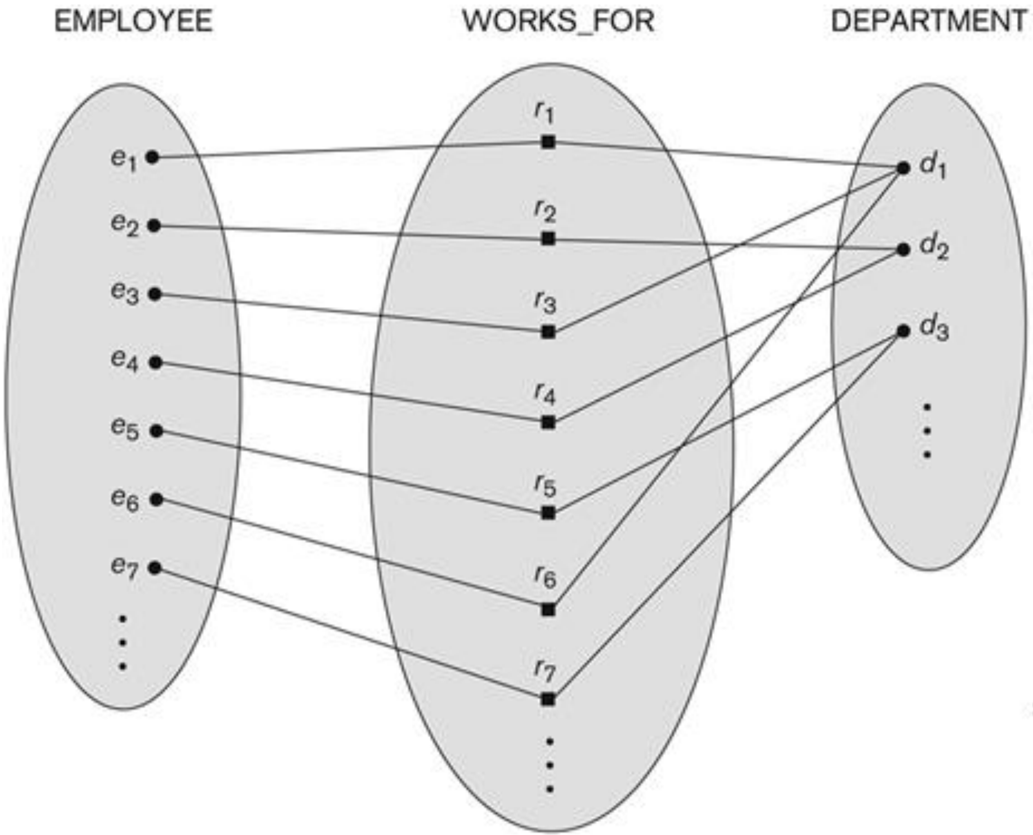
Relationships of the same type are grouped or typed into a **relationship type**.

- For example, the WORKS_ON relationship type in which 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.

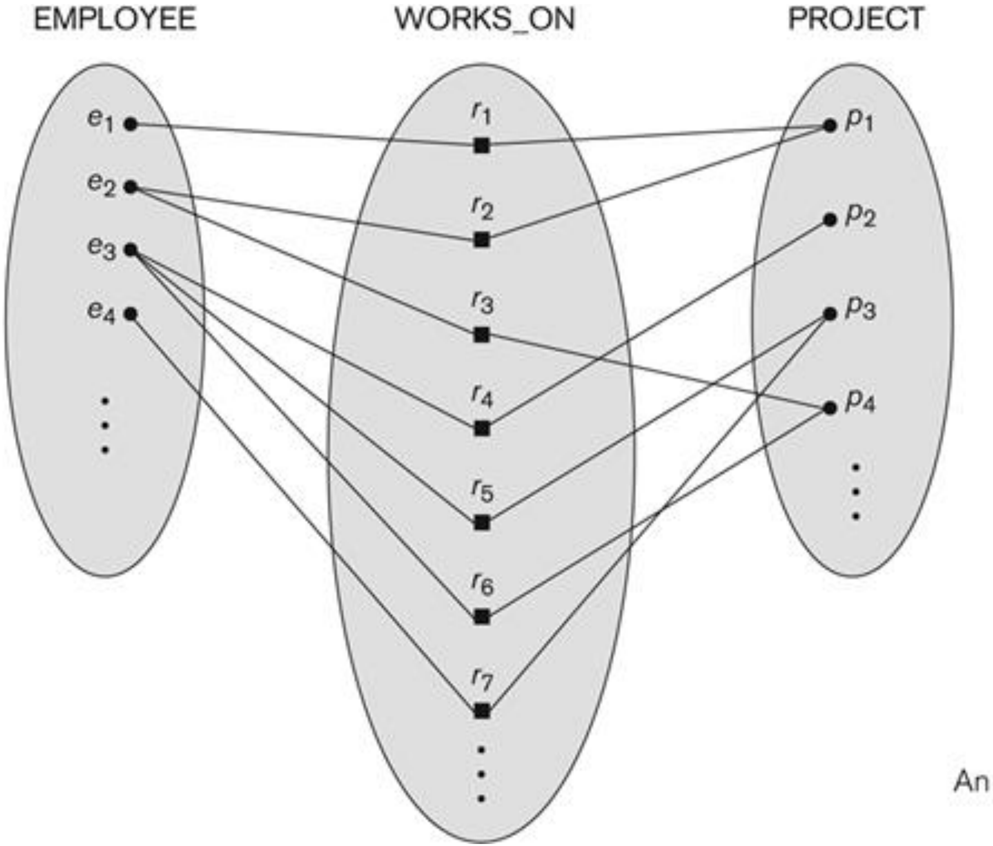
- Both MANAGES and WORKS_ON are *binary* relationships.

Relationship instances of the WORKS_FOR N:1 relationship between EMPLOYEE and DEPARTMENT



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

Relationship instances of the M:N WORKS_ON relationship between EMPLOYEE and PROJECT



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)

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.

Refining the COMPANY database schema by introducing relationships

By examining the requirements, six relationship types are identified

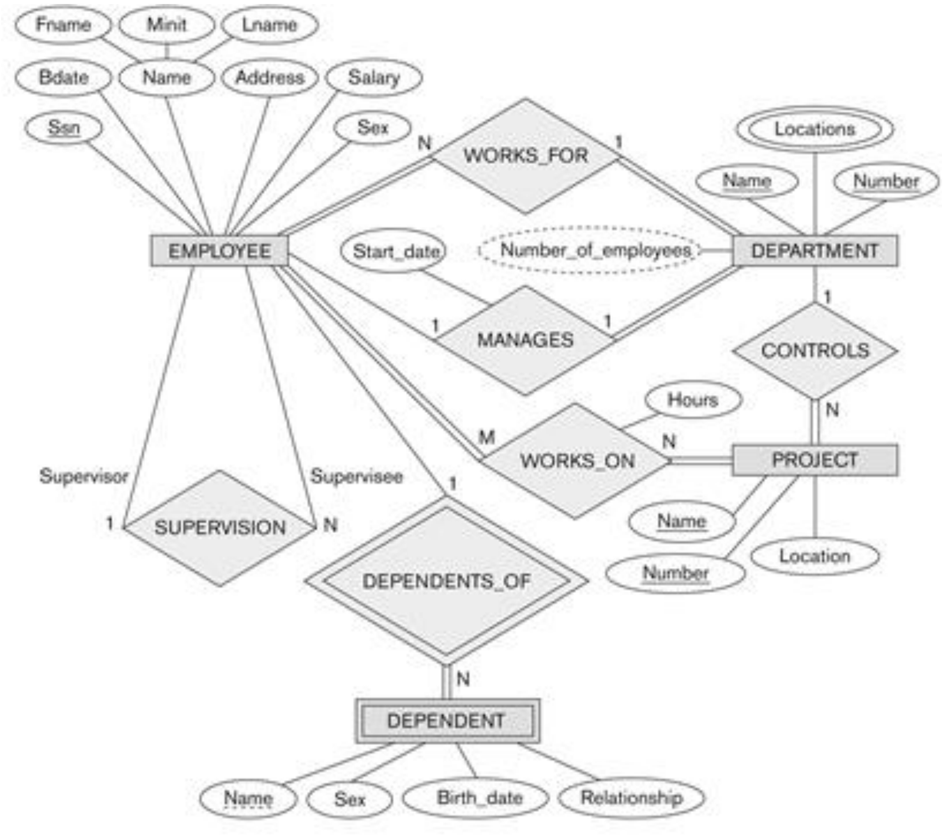
All are *binary* relationships(degree 2)

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 are:

WORKS_FOR, MANAGES, WORKS_ON, CONTROLS, SUPERVISION, DEPENDENTS_OF



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, more than one relationship type can exist between the same participating entity types

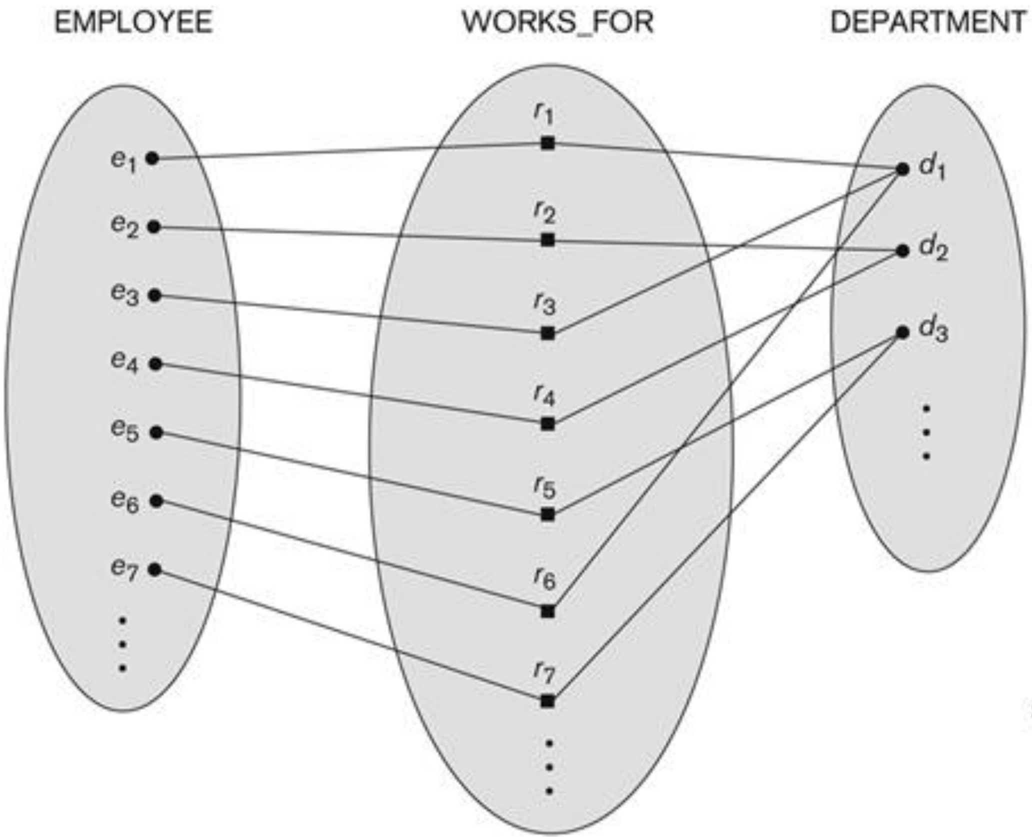
- MANAGES and WORKS_FOR are distinct relationship types between EMPLOYEE and DEPARTMENT
- Different meanings and different relationship instances.

Constraints on Relationships

Constraints on Relationship Types

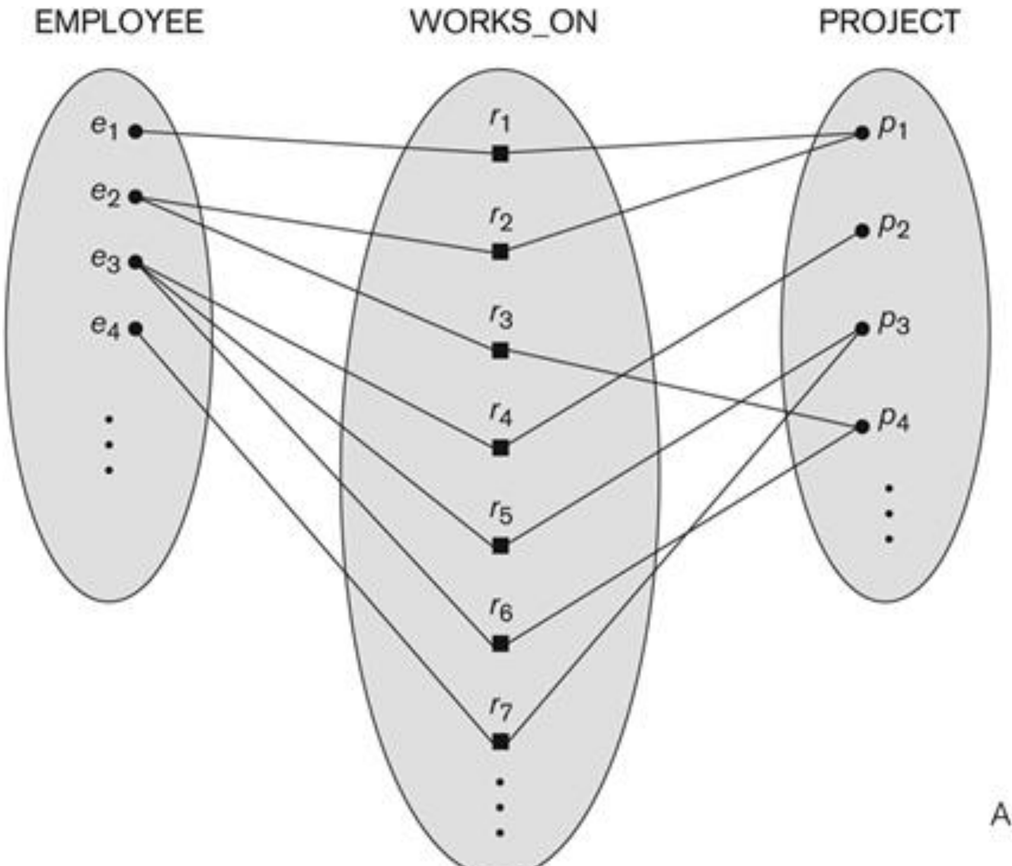
- (Also known as ratio constraints)
- Cardinality Ratio (specifies *maximum* participation)
  - One-to-one (1:1)
  - One-to-many (1:N) or Many-to-one (N:1)
  - Many-to-many (M:N)
- Existence Dependency Constraint (specifies *minimum* participation) (also called participation constraint)
  - zero (optional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

Many-to-one (N:1) Relationship



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



An M:N relationship,
WORKS_ON.

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

Displaying a recursive relationship

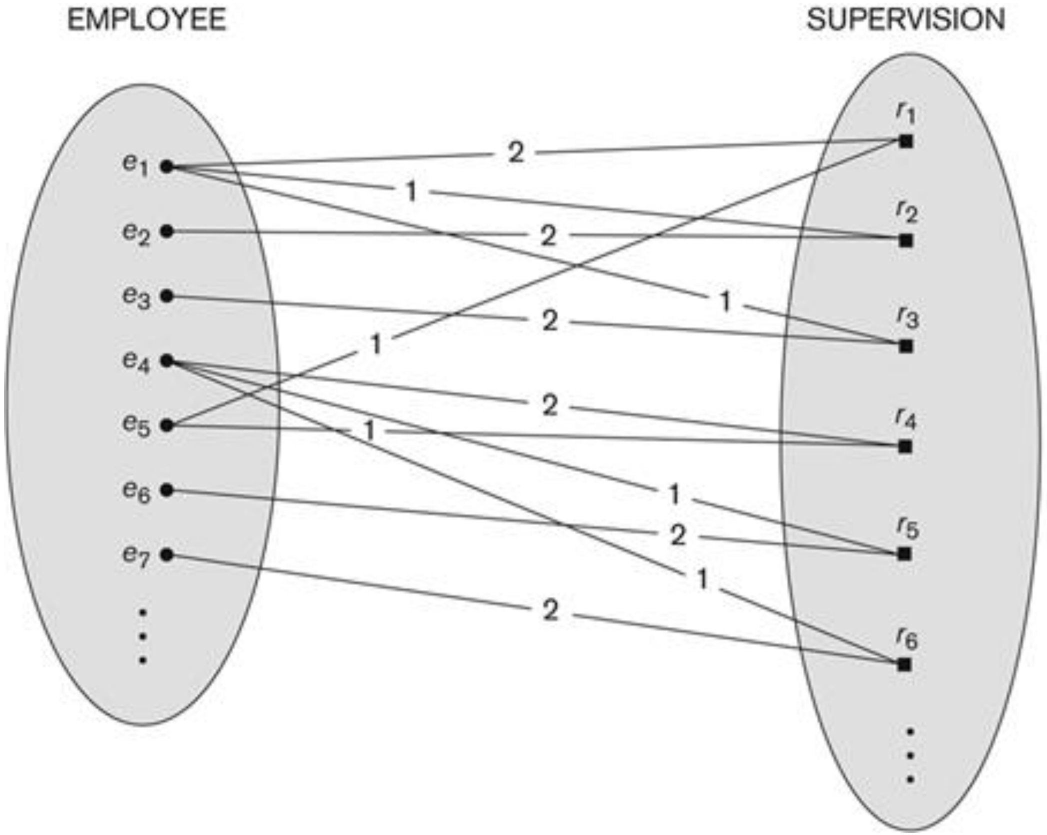
In a recursive relationship type.

- 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.

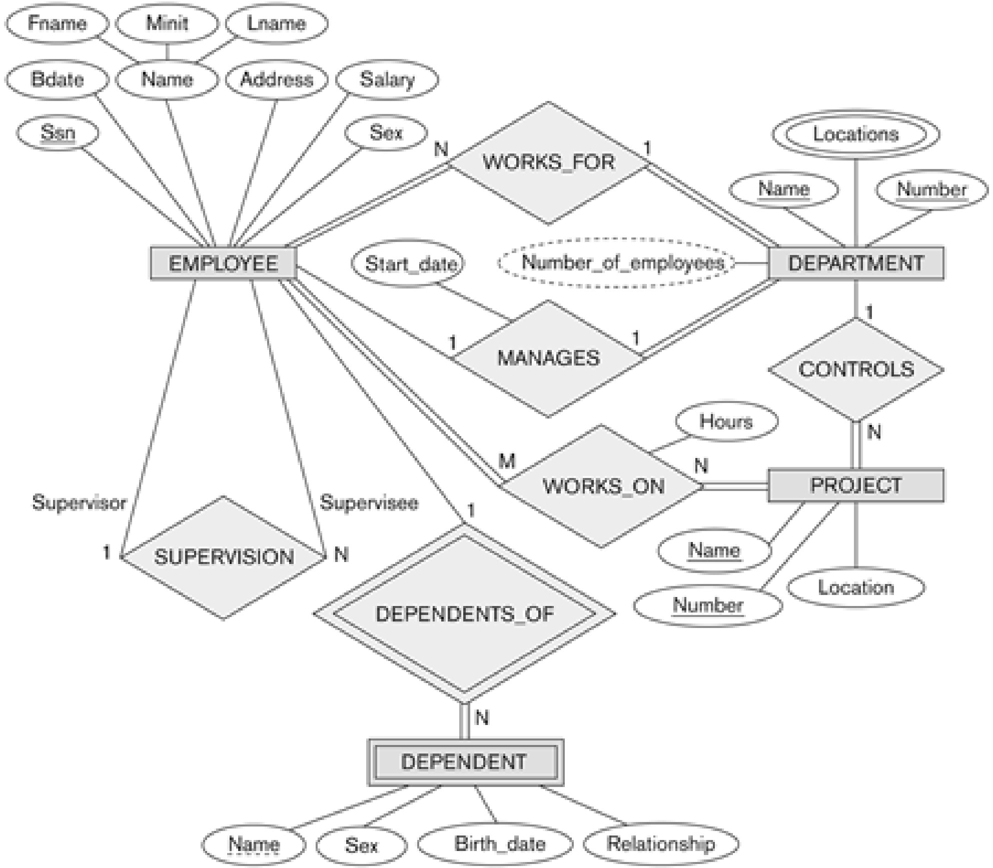
In ER diagram, need to display role names to distinguish participations.

A Recursive Relationship Supervision`



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)



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:

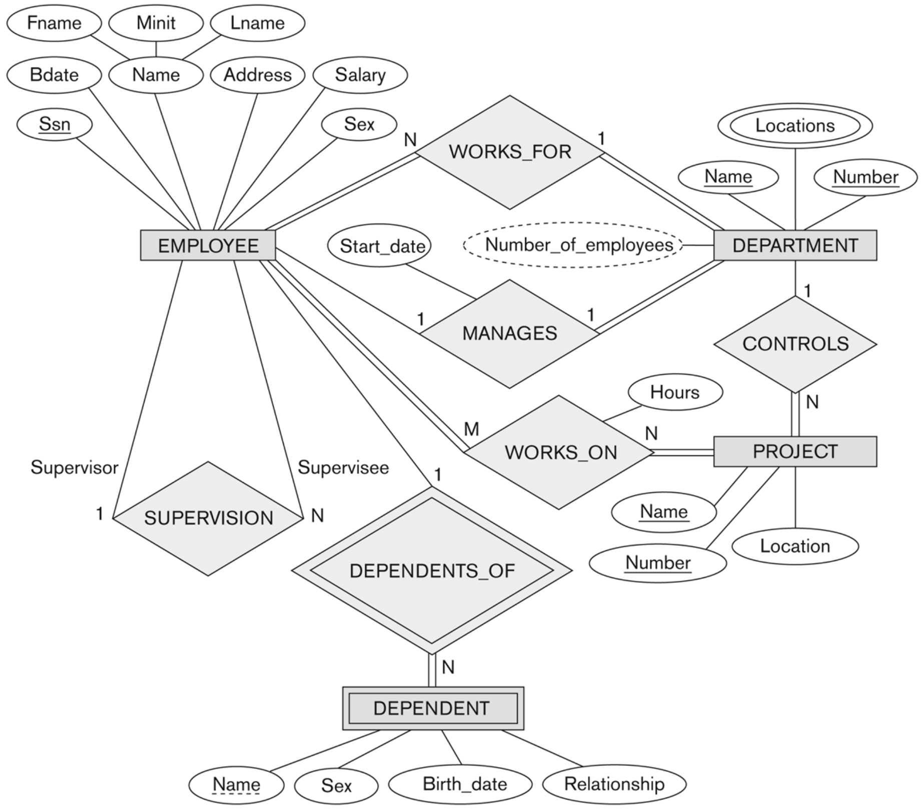
- A DEPENDENT entity is identified by the dependent's first name, *and* the specific EMPLOYEE with whom the dependent is related
- Name of DEPENDENT is the *partial key*
- DEPENDENT is a *weak entity type*
- EMPLOYEE is its identifying entity type via the identifying relationship type DEPENDENT_OF

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



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)

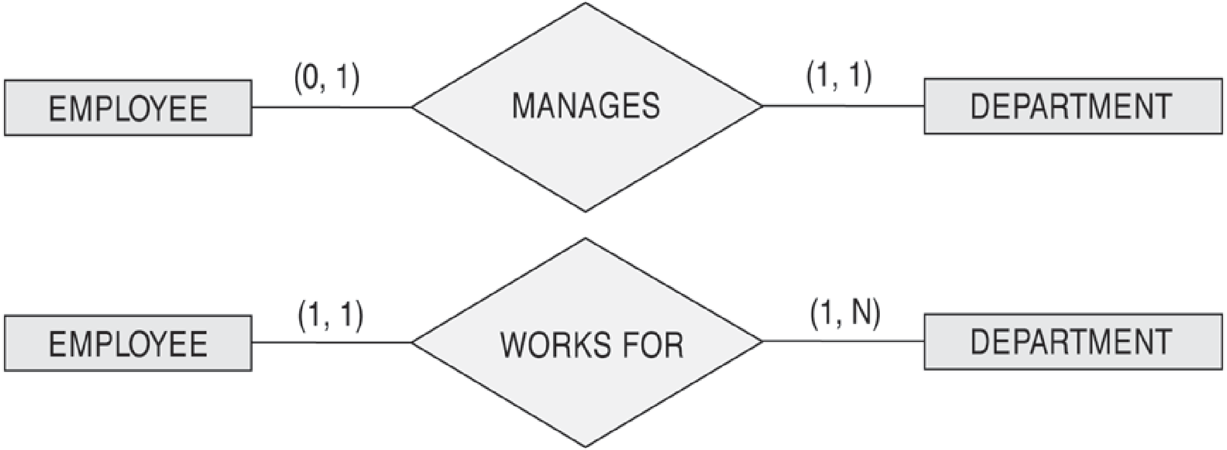
Must have min≤max, min≥0, max ≥1

Derived from the knowledge of mini-world constraints

Examples:

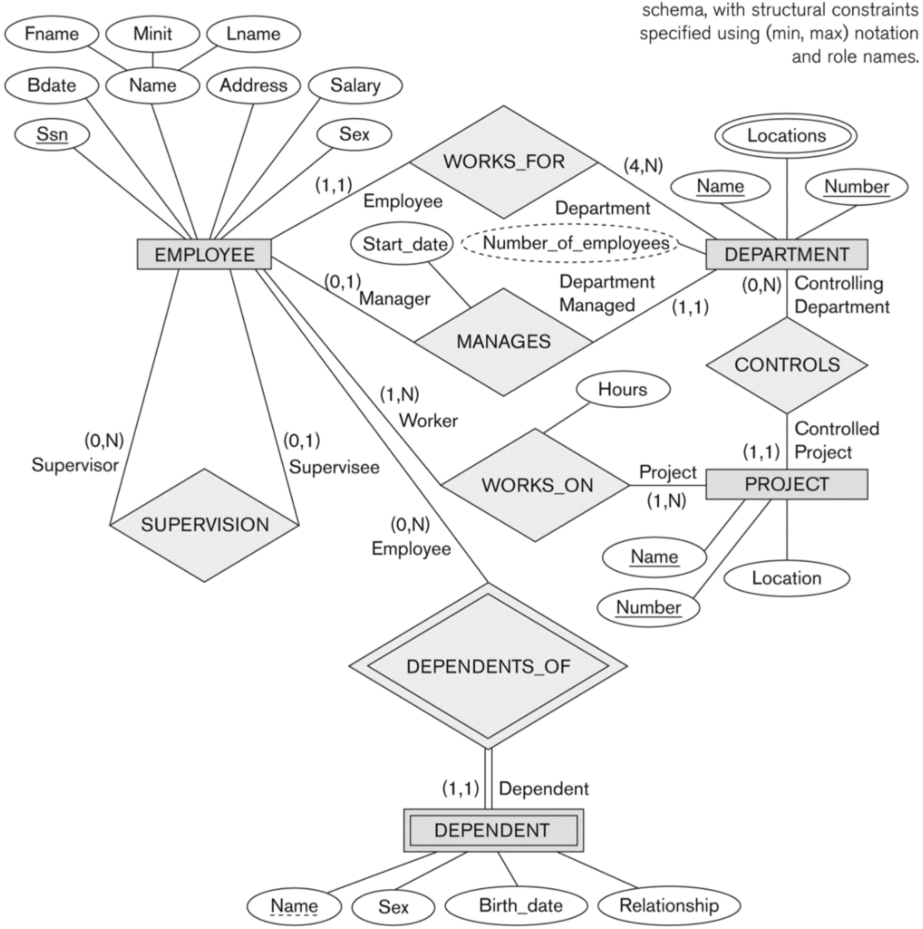
- A department has exactly one manager and an employee can manage at most one department.
  - Specify (0,1) for participation of EMPLOYEE in MANAGES
  - Specify (1,1) for participation of DEPARTMENT in MANAGES
- An employee can work for exactly one department but a department can have any number of employees.
  - 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 and looking **away from** the entity type

COMPANY ER Schema Diagram using (min, max) notation



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

Alternative diagrammatic notation

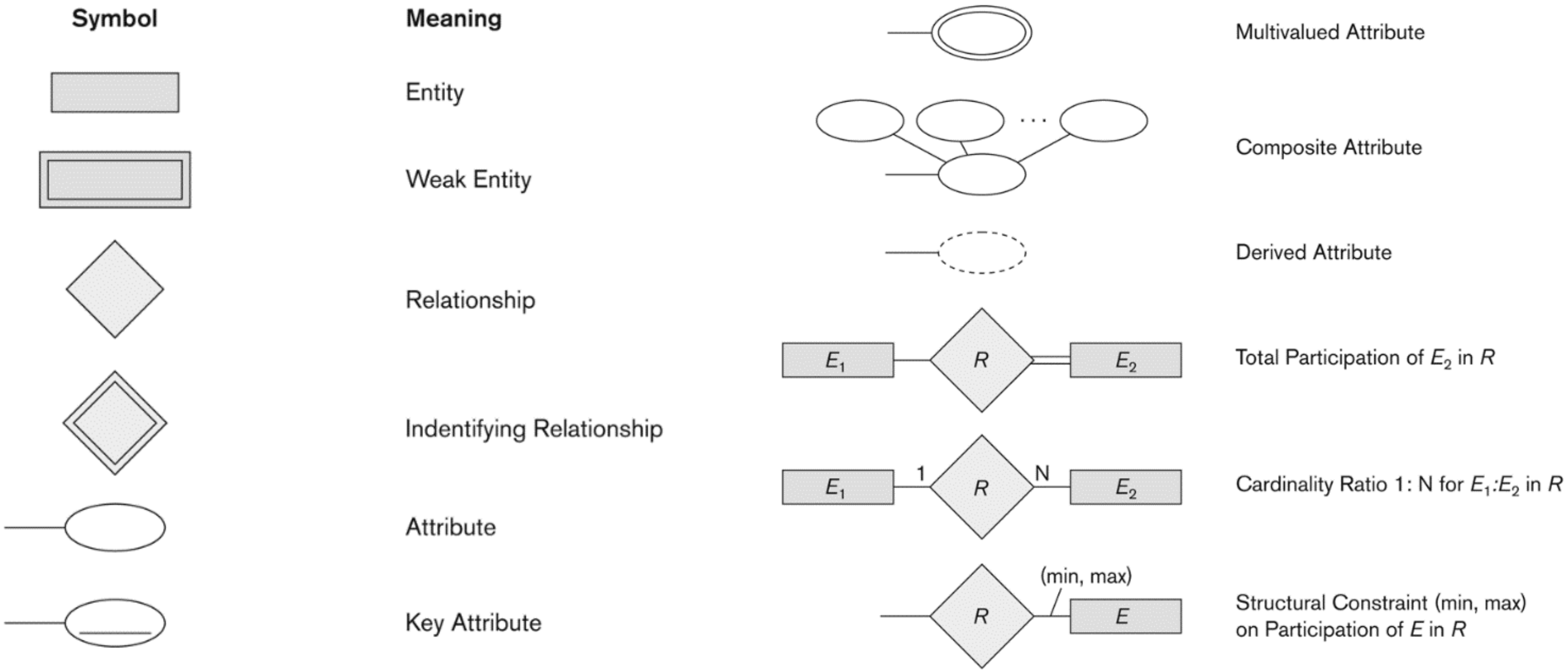
ER diagrams is one popular example for displaying database schemas

Many other notations exist in the literature and in various database design and modeling tools

Appendix A from Elmasri’s text illustrates some of the alternative notations that have been used

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



Symbol **Meaning**

Entity

Weak Entity

Relationship

Indentifying Relationship

Attribute

Key Attribute

Multivalued Attribute

Composite Attribute

Derived Attribute

Total Participation of E_2 in R

Cardinality Ratio 1: N for E_1:E_2 in R

Structural Constraint (min, max) on Participation of E in R

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

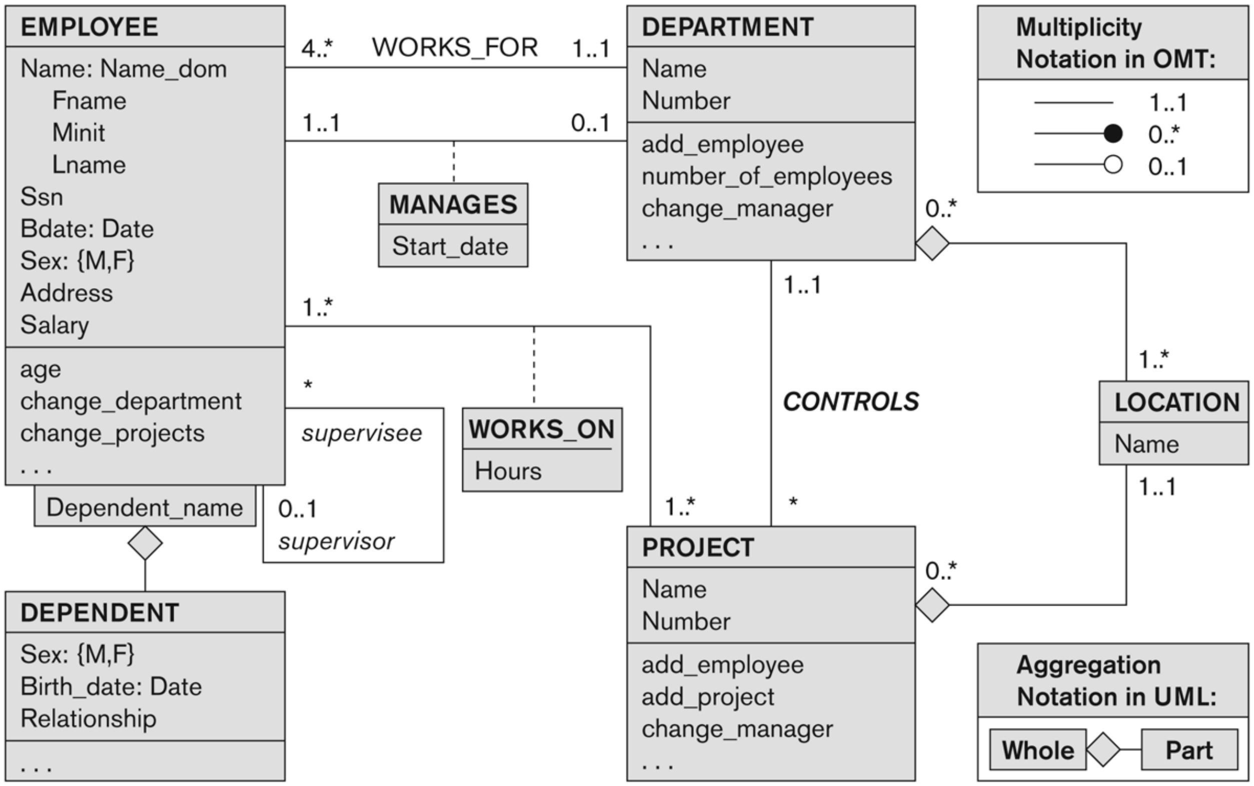
- Other UML terminology also differs from ER terminology

Used in database design and object-oriented software design

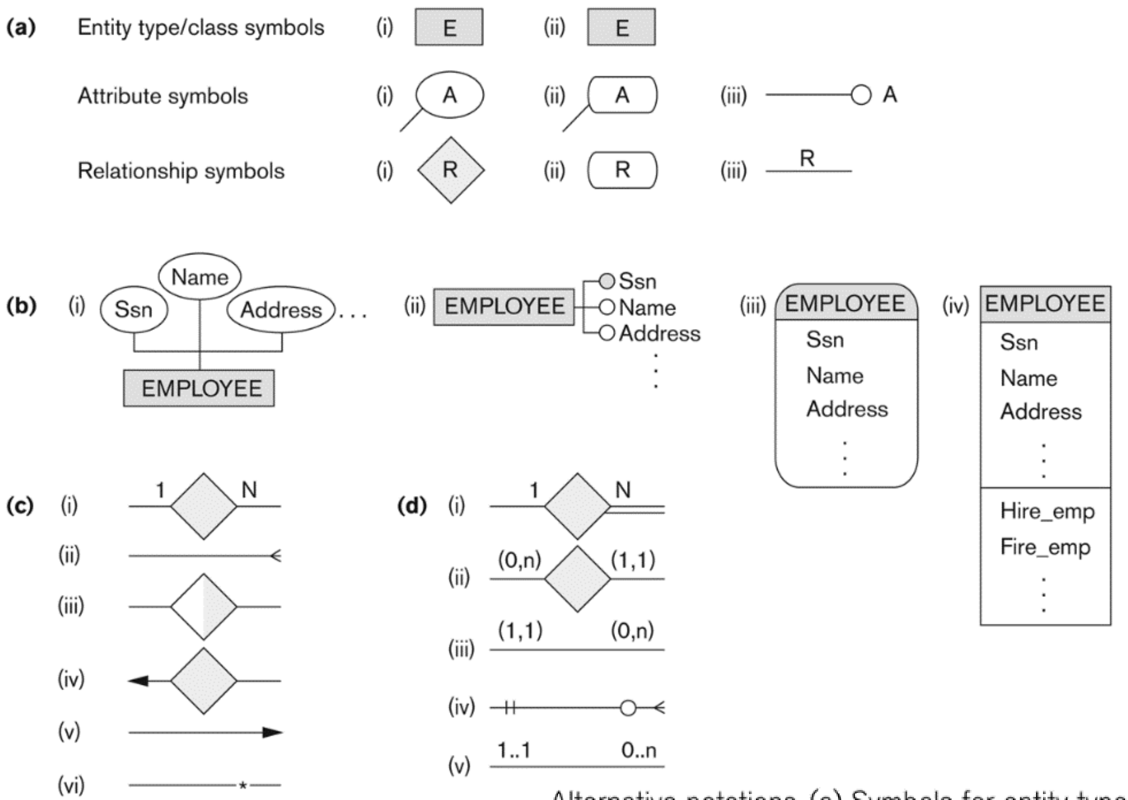
UML has many other types of diagrams for software design

UML class diagram for COMPANY database schema

The COMPANY conceptual schema in UML class diagram notation.

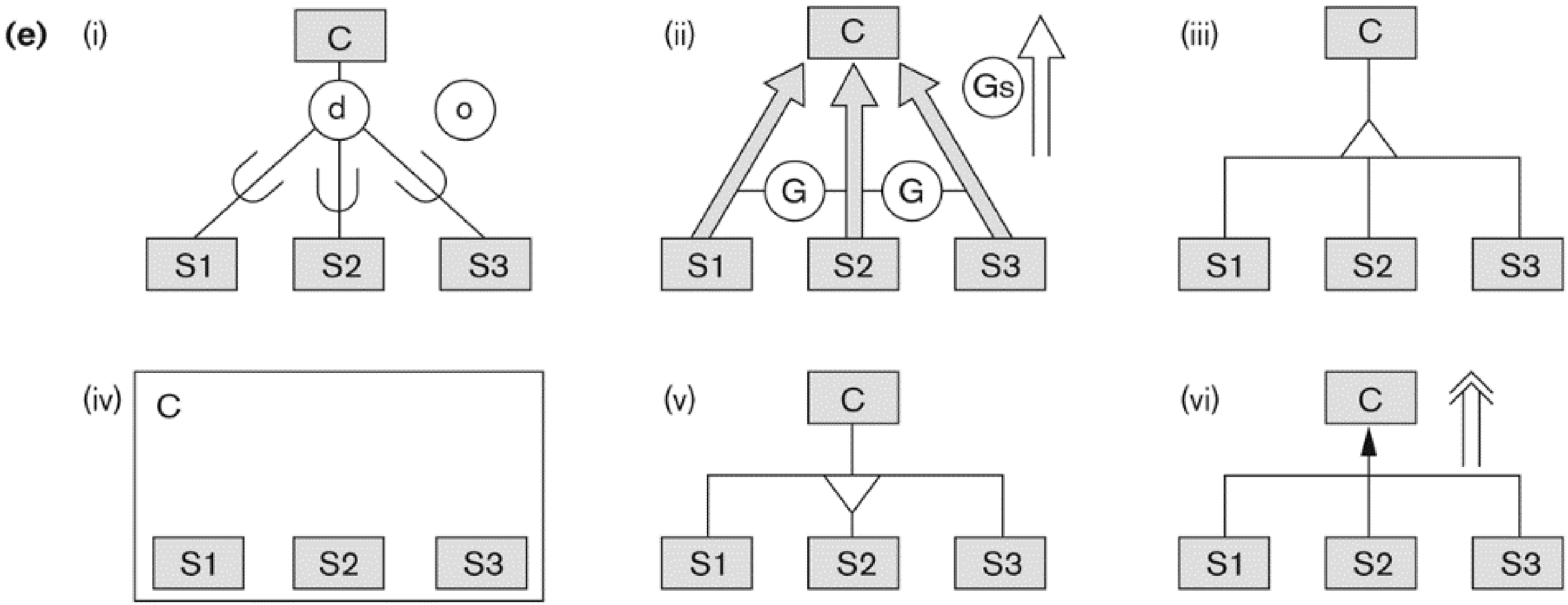


Other alternative diagrammatic notations



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.

Alternative diagrammatic notations (cont.)



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.

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

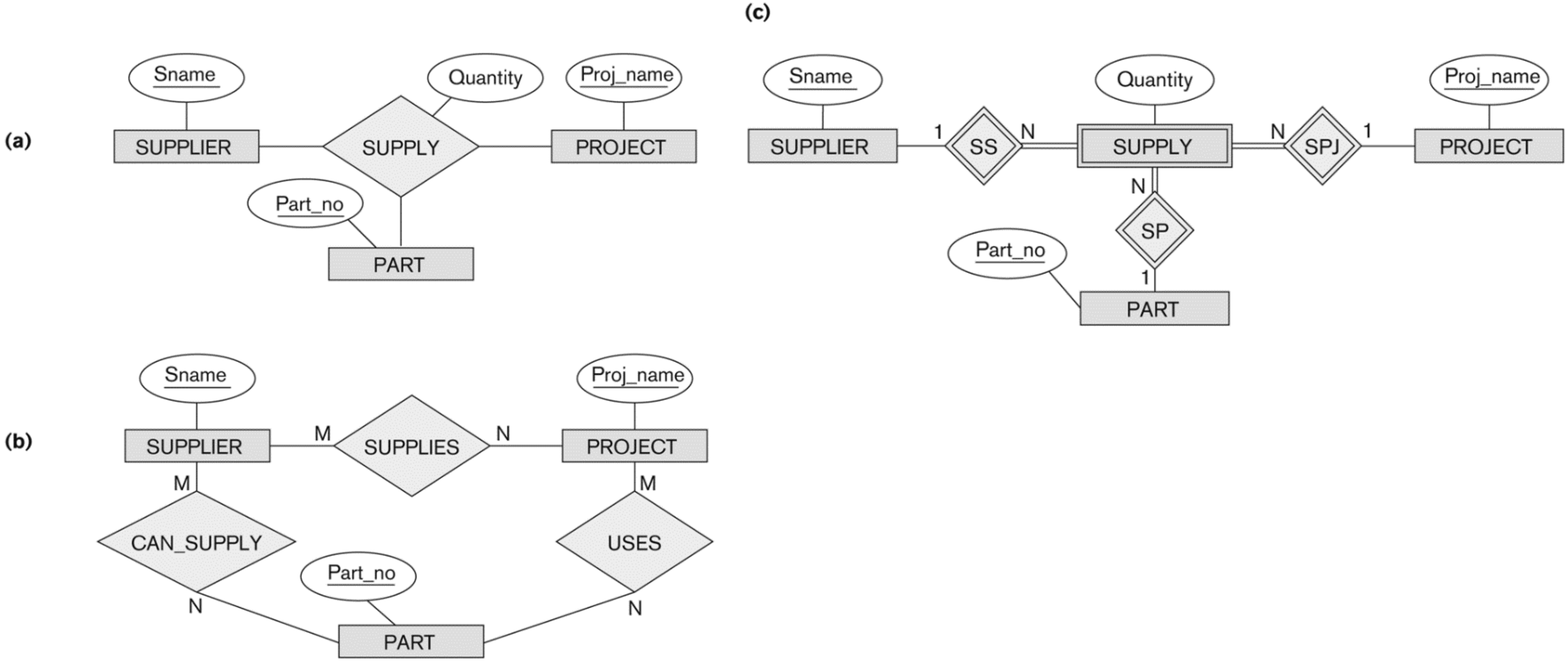
Discussion of n-ary relationships (n > 2)

In general, 3 binary relationships can represent different information than a single ternary relationship (Fig. a, b on next slide)

If needed, the binary and n-ary relationships can all be included in the schema design (Fig. a, b on next slide, 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) (Fig. c on next slide)

Example of a ternary relationship



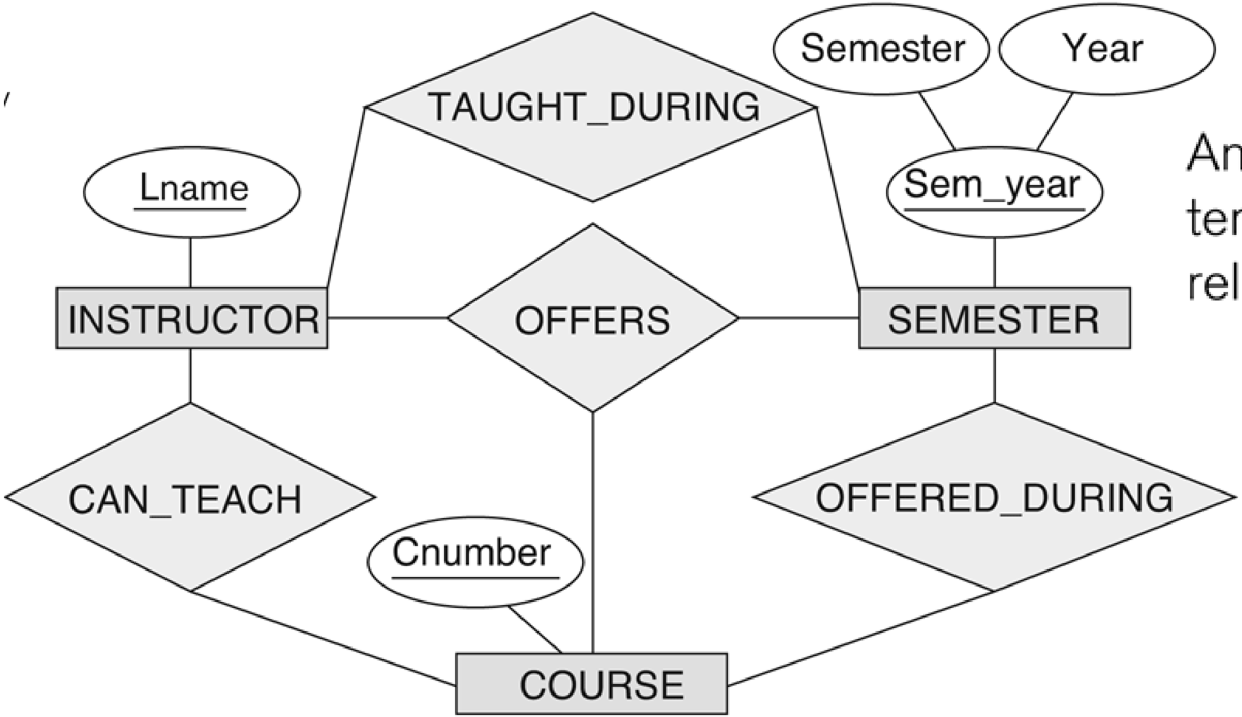
Ternary relationship types. (a) The SUPPLY relationship. (b) Three binary relationships not equivalent to SUPPLY. (c) SUPPLY represented as a weak entity type.

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

For example, the TAUGHT_DURING binary relationship on next slide can be derived from the ternary relationship OFFERS (based on the meaning of the relationships)

Another example of a ternary relationship



Another example of ternary versus binary relationship types.

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

- An M or N indicates no constraint
- A 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

Overall, the constraint specification is difficult and possibly ambiguous when we consider relationships of a degree higher than two.

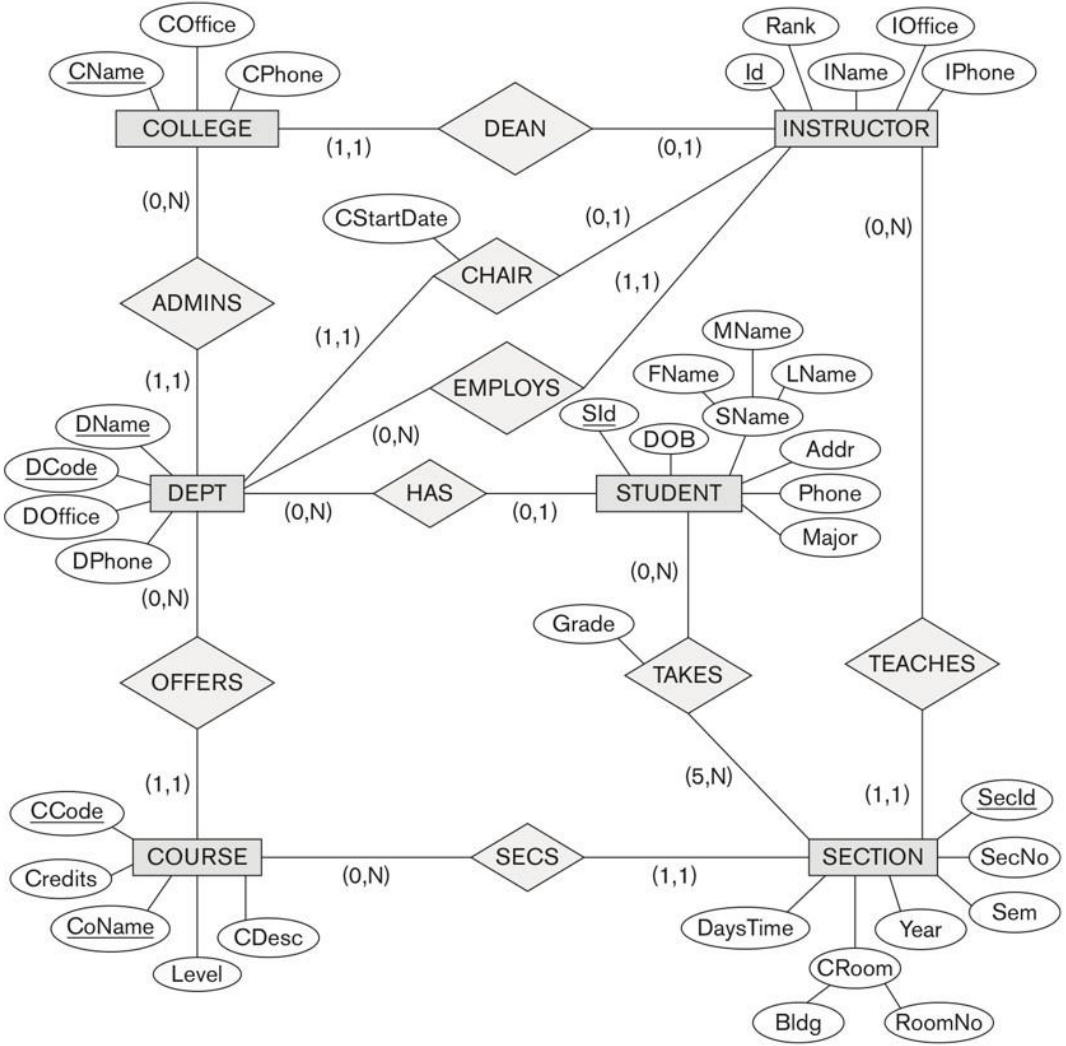
Another Example: A UNIVERSITY Database

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.

UNIVERSITY database conceptual schema


COffice
CName
CPhone
COLLEGE
(1,1)
DEAN
(0,1)
Rank
IOffice
Id
IName
IPhone
INSTRUCTOR
(0,N)
CStartDate
(0,1)
CHAIR
(1,1)
ADMINS
(1,1)
(1,1)
(0,N)
MName
FName
LName
EMPLOYS
SName
SId
DOB
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DEPT
(0,N)
HAS
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STUDENT
Phone
Major
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Grade
TAKES
TEACHES
OFFERS
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(1,1)
SecId
CCode
Credits
CoName
Level
CDesc
COURSE
(0,N)
SECS
(1,1)
SECTION
SecNo
Sem
Year
DaysTime
CRoom
Bldg
RoomNo