CS 2451
Database Systems:
Entity-Relationship (ER) Model

http://www.seas.gwu.edu/~bhagiweb/cs2541
Spring 2020
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Course Summary….

- Relational Data Model
- Formal query languages
  - Relational algebra and Relational Calculus
- SQL
  - DDL to define schema and constraints
  - Query component…basic SQL + non-RA operators (GroupBy etc.)
- Experience working with commercial DBMS and developing DB applications
  - MySQL, PHP
- Next - Database schema design: how to design a "good" schema, how to measure "good"?
  - Normal Forms (3NF, BCNF)
- Detour (this class): Conceptual Level Database design
  - Entity-Relationship (ER) Model

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Database Design

- The ability to design databases and associated applications is critical to the success of the modern enterprise.
- Database design requires understanding both the operational and business requirements of an organization as well as the ability to model and realize those requirements in a database.
- Developing database and information systems is performed using a ***development lifecycle***, which consists of a series of steps.

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The Importance of Database Design

- Just as proper design is critical for developing large applications, success of database projects is determined by the effectiveness of database design.
- Some statistics on software projects:
  - 80 - 90% do not meet their performance goals
  - 80% delivered late and over budget
  - 40% fail or abandoned
  - 10 - 20% meet all their criteria for success
  - Have you been on a project that failed? Yes ? No ?
- The primary reasons for failure are improper requirements specifications, development methodologies, and design techniques.

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How Does One Build a Database?

- Requirements Analysis: what data, apps, critical operations
  - Get from "client"
    - Typically expressed in some natural language
  - May require going back to the client for resolving questions

  - Query and app development depends on client specifications

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Building Database Applications: Steps

1. Start with a conceptual model
   - "On paper" using certain techniques
     E-R Model
   - ignore low-level details – focus on logical representation
   - "step-wise refinement" of design with client input
2. Design & implement schema
   - Design and codify (in SQL) the relations/tables
   - Refine the schema – *normalization*
   - Do physical layout – indexes, etc.
3. Import the data
4. Write applications using DBMS and other tools
   - Many of the hard problems are taken care of by other people (DBMS, API writers, library authors, web server, etc.)
   - DBMS takes care of Query Optimization, Efficiency, etc.
5. Test!!

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Conceptual Model- Why ?

- Convey database design and properties in simple but precise manner
  - Interpreted by any type of user
    Does not need to know anything about CS
  - Capture the business rules of the application

- Picture is worth a thousand words

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Conceptual Database Design

- ***Conceptual database design*** involves modeling the collected information at a high-level of abstraction without using a particular data model or DBMS.

- Since conceptual database design occurs independently from a particular DBMS or data model, we need high-level modeling languages to perform conceptual design.

- The entity-relationship (ER) model was originally proposed by Peter Chen in 1976 for conceptual design.
  - Can also do ER modeling using Unified Modeling Language (UML) syntax.

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An Example: “mini” banner

- Database containing information about
  - Students
  - Faculty
  - Courses
- Students take courses
- Faculty teach courses
- How to ‘define’ student/faculty/course ?
  - What data is needed ?

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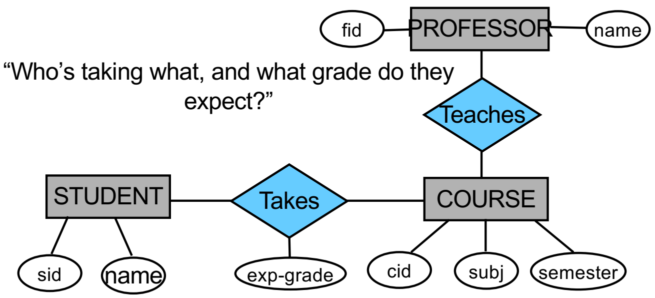
Example: ER Design for mini-banner:

“Who’s taking what, and what grade do they expect?”



One picture provides info on what your system stores and models

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Entity-Relationship Modeling

- ***Entity-relationship modeling*** is a top-down approach to database design that models the data as entities, attributes, and relationships.
- The ER model refines entities and relationships by including properties of entities and relationships called *attributes*, and by defining *constraints* on entities, relationships, and attributes.
- The ER model conveys knowledge at a high-level (conceptual level) which is suitable for interaction with technical and non-technical users.
- Since the ER model is data model independent, it can later be converted into the desired logical model (e.g. relational model).

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Entity Relationship Model

- Based on collection of real world objects or concept called *entities;* ex: employee, student
  - *attribute* represents properties of entity; s.s.num
- *relationship* represents interaction between entities
- overall logical structure represented by ER diagram representing entity sets, relationships, attributes
- *Conceptual design*:
  - What are the *entities* and *relationships* in the enterprise?
  - What information about these entities and relationships should we store in the database?
  - What are the *integrity constraints* or *business rules* that hold?
- Can map an ER diagram into a relational schema.

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ER Model Definitions

- *Entity*: Real-world object distinguishable from other objects.
  - An entity is described (in DB) using a set of *attributes*.
- *Entity Set*: A collection of similar entities. E.g., all employees.
  - All entities in an entity set have the same set of attributes. (Until we consider ISA hierarchies, anyway!)
  - Each entity set has a *key*.
  - Each attribute has a *domain*.
- An *entity instance* is a particular example or occurrence of an entity type…eg: Employee John Doe
- Representation/Syntax:
  - **Entity** set represented by **rectangle**
  - **Attribute** represented by **Oval**
    - Key attribute underlined
    - **Composite Attribute**: when it has multiple fields (ex: address)

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ER Model Basics (Contd.)

- *Relationship*: Association among two or more entities. E.g., Dan takes Database Course; Attishoo works in Pharmacy department.
  - Relationship can also have attributes (that appear only for this relationship set)
- Representation/Syntax: a Diamond symbol
  - Attributes represented by Oval (same as before)
- *Relationship Set*: Collection of similar relationships.
  - An n-ary relationship set R relates n entity sets E1 ... En; each relationship in R involves entities e1 ∈ E1, ..., en ∈ En
    - Same entity set could participate in different relationship sets, or in different “roles” in same set.

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Conceptual Design Process

- What are the entities being represented? STUDENTS
- What are the relationships? Takes
- What info (attributes) do we store about each? name sid exp-grade
- What keys & integrity constraints do we have?

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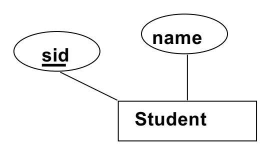
Student Entity



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Example of a composite attribute

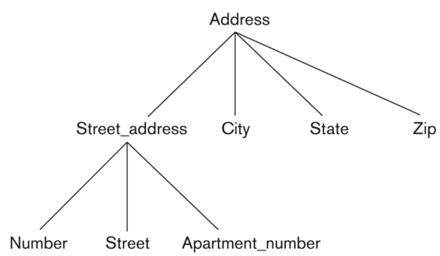

Figure 3.4
A hierarchy of composite attributes.

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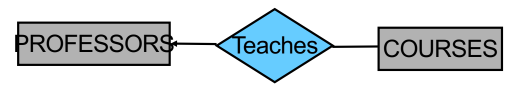
Connectivity in the E-R Diagram?

- Attributes can *only* be connected to entities or relationships
- Entities can *only* be connected via relationships
- As for the edges, let's consider kinds of relationships and integrity constraints…



(warning: different ER implementations have slightly different notation here!)

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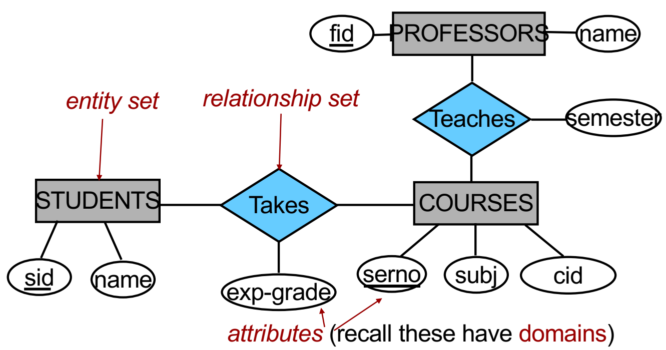
Entity-Relationship Diagram for the Example

Underlined attributes are keys



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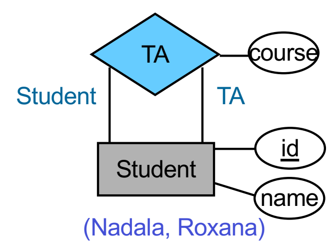
Roles: Labeled Edges

Sometimes a relationship connects the same entity, and the entity has more than one role:



This often indicates the need for recursive queries

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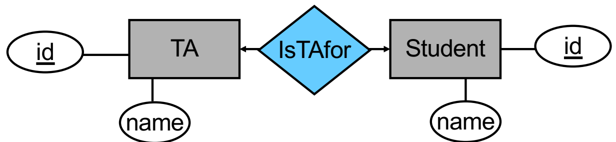
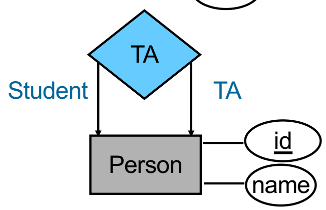
Roles vs. Separate Entities



What is the difference between these two representations?



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Weak Entity Sets

- A *weak entity* can be identified uniquely only by considering the primary key of another (*owner*) entity.
  - Owner entity set and weak entity set must participate in a one-to-many relationship set (one owner, many weak entities).
  - Weak entity set must have total participation in this *identifying* relationship set.
  - If Student is deleted, then we MUST delete the Parent
  - Syntax: Bold face rectangles, Double lined rectangles,…

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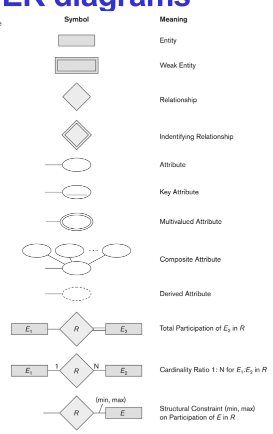
NOTATION for ER diagrams

Figure 3.14
Summary of the 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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UML Diagrams – Alternate Syntax for ER Diagrams

- Unified Modeling Language (UML)
- Read on your own
- You've seen an example on the lab slides!

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Defining Constraints in ER Model

- Contraints capture properties of the relationship and entities
  - Convey the business rules of the application
- Every entity set has a key attribute..similar to Rel. Model
  - No two elements can have the same value on this attribute
    - Example: Student ID
- How many elements in entity set are associated with another entity in the relationship ?
  - Can a student take more than one course ?
- Does every element in the entity set appear/participate in the relationship ?
  - Must every student take a course ?
- Define constraints based on properties of the mapping/relation between entity sets

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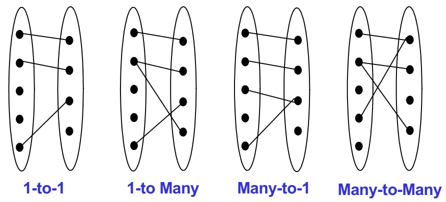
Properties of relations

- Binary relationships can be classified as one-to-one, many-to-one, one-to-many, many-to-many
- What is the type of mapping/relation



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Example: the Teaches relationship

- Want to model the info that each course is taught by one faculty.
  - Type of mapping ???
  - 1-to-1
    - Note: This is a Mapping and not a function!
- A student can take more than one course
  - 1 to Many
- Every course must have an instructor
  - Each element in the Course entity set must participate/appear in the Teaches relationship
- A faculty may teach zero or more courses

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Example: the Takes Course Relationship

- Student can be enrolled in many courses and each Course can have many students
  - Type of mapping:
    Many to Many
- Want to model the condition that every student must take at least one course
  - Each student must appear in Takes relationship
- How many courses can a student take ?
  - Do we want to specify a limit ?
- How many students must be enrolled in a course ?
  - Is there a minimum size for a class ?

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Mapping Cardinality, Participation Constraints, Structural constraints

- Type of mapping (**cardinality**)
  - 1-1, 1-many, many-many, many-1
  - Provides some information on relationship sets
- Participation constraints
  - *Total vs Partial*
    Total: Every student sid must appear in Takes relationship
    Partial: All faculty need not appear in Teaches relationship
- Structural constraints:
  - Minimum and maximum times they can appear in relationship
  - Syntax ??

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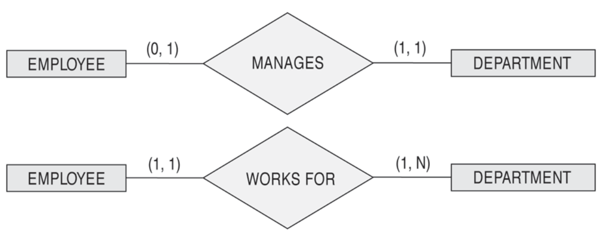
The (min,max) notation for relationship constraints



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

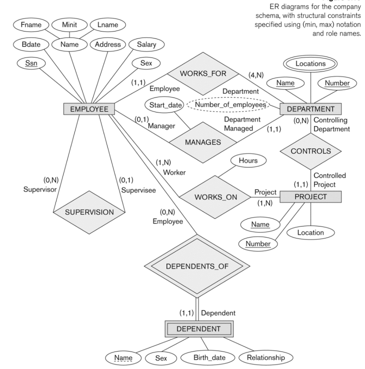

Figure 3.15
ER diagrams for the company schema, with structural constraints specified using (min, max) notation and role names.

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Conceptual Design Using the ER Model

- Design choices:
  - Should a concept be modeled as an entity or an attribute?
  - Should a concept be modeled as an entity or a relationship?
  - Identifying relationships: constraints, type, participation
- Constraints in the ER Model:
  - A lot of data semantics can (and should) be captured.
  - But some constraints cannot be captured in ER diagrams.

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Summary of Conceptual Design

- *Conceptual design* follows *requirements analysis*,
  - Yields a high-level description of data to be stored
  - Visual language – the diagram is the syntax!
- ER model popular for conceptual design
  - Constructs are expressive, close to the way people think about their applications.
  - There are additional constructs in a “real” ER model based tools.
- Can automate mapping of ER model to relational tables!

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A detailed example: The Company Database

- COMPANY database keeps track of Employees and Departments
  - Employees identified by SSN, Name, Location
  - Department specified byDepartment ID (did), Name, Budget
- Each department has a unique manager
  - Database must keep track of starting date
- Each employee works in a department
  - Database must keep track of starting date

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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

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

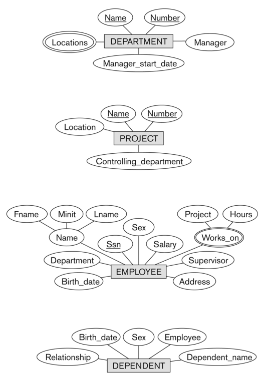

Figure 3.8
Preliminary design of entity types for the COMPANY database. Some of the shown attributes will be refined into relationships.

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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 (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.

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

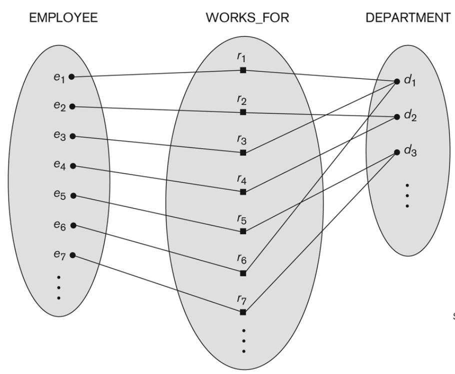

Figure 3.9
Some instances in the WORKS_FOR relationship set, which represents a relationship type WORKS_FOR between EMPLOYEE and DEPARTMENT.

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

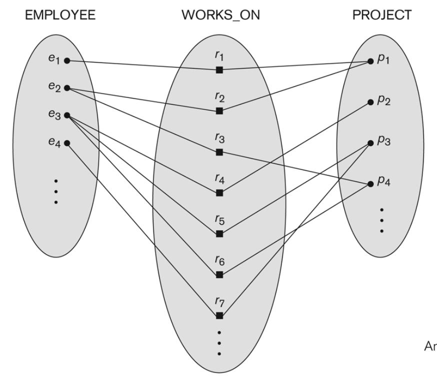

Figure 3.13
An M:N relationship, WORKS_ON.

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Relationship type vs. relationship set (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.

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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 are:

WORKS_FOR, MANAGES, WORKS_ON, CONTROLS, SUPERVISION, DEPENDENTS_OF

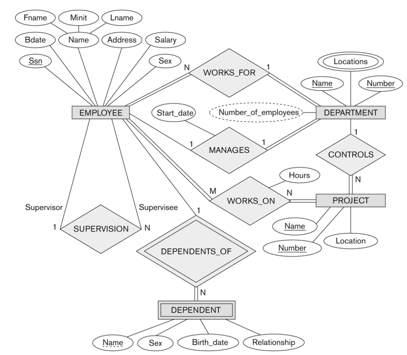

Figure 3.2
An ER schema diagram for the COMPANY database. The diagrammatic notation is introduced gradually throughout this chapter.

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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
  - 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.

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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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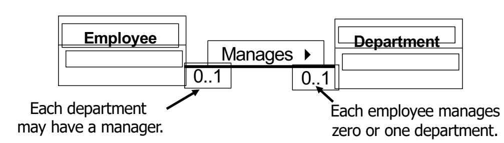
One-to-One Relationships

- In a one-to-one relationship, each instance of an entity class E1 can be associated with ***at most one*** instance of another entity class E2 and vice versa.
- Example: A department may have only one manager, and a manager may manage only one department.



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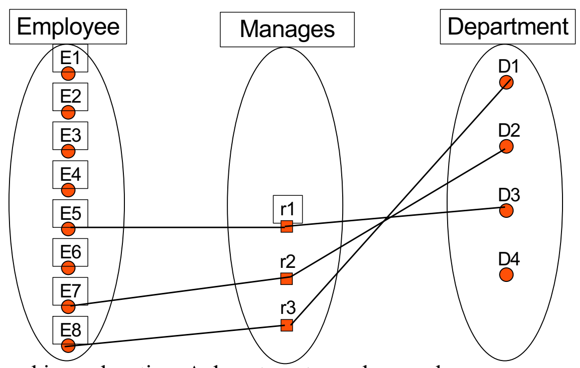
One-to-One Relationship Example



Relationship explanation: A department may have only one manager. A manager (employee) may manage only one department.

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Many-to-one (N:1) Relationship

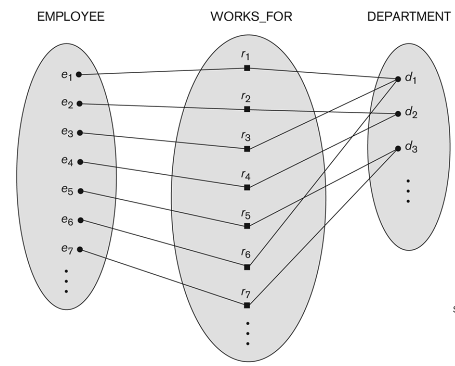

Figure 3.9
Some instances in the WORKS_FOR relationship set, which represents a relationship type WORKS_FOR between EMPLOYEE and DEPARTMENT.

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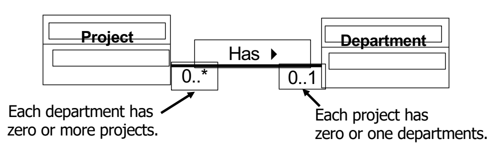
One-to-Many Relationships

- In a one-to-many relationship, each instance of an entity class E1 can be associated with ***more than one*** instance of another entity class E2. However, E2 can only be associated with ***at most one*** instance of entity class E1.
- Example: A department may have multiple projects, but a project may have only one department.



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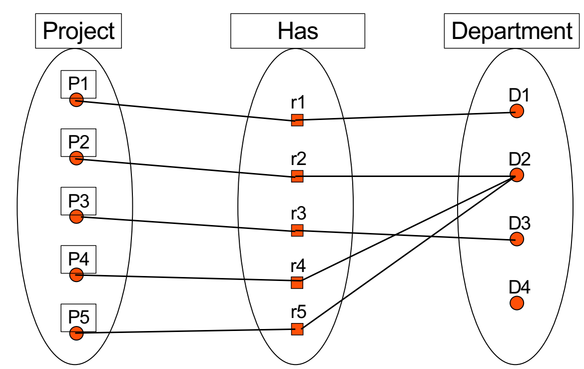
One-to-Many Relationship Example



Relationship: One-to-many relationship between department and project.

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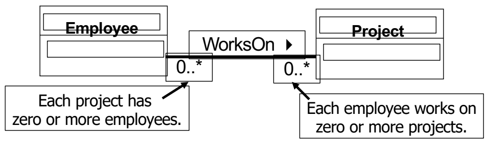
Many-to-Many Relationships

- In a many-to-many relationship, each instance of an entity class E1 can be associated with ***more than one*** instance of another entity class E2 and vice versa.
- Example: An employee may work on multiple projects, and a project may have multiple employees working on it.



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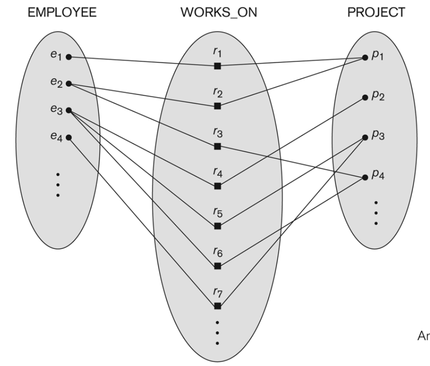
Many-to-many (M:N) Relationship



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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A Recursive Relationship Supervision`

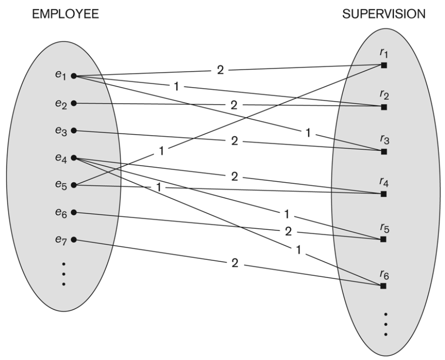

Figure 3.11
A recursive relationship SUPERVISION between EMPLOYEE in the *supervisor* role (1) and EMPLOYEE in the *subordinate* role (2).

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

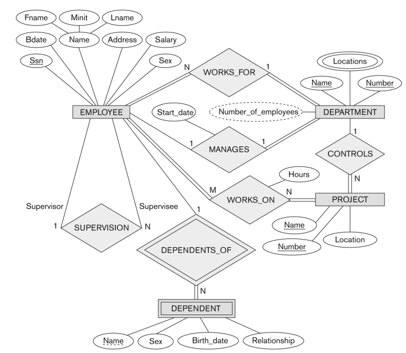

Figure 3.2
An ER schema diagram for the COMPANY database. The diagrammatic notation is introduced gradually throughout this chapter.

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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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Example Attribute of a Relationship Type: Hours of WORKS_ON

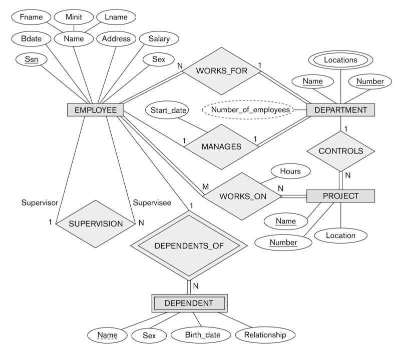

Figure 3.2
An ER schema diagram for the COMPANY database. The diagrammatic notation is introduced gradually throughout this chapter.

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Participation Constraints

- ***Cardinality*** is the *maximum* number of relationship instances for an entity participating in a relationship type.
- ***Participation*** is the *minimum* number of relationship instances for an entity participating in a relationship type.
  - Participation can be *optional* (zero) or *mandatory (1 or more)*.
- If an entity's participation in a relationship is mandatory (also called *total* participation), then the entity's existence depends on the relationship.
  - Called an *existence dependency*.

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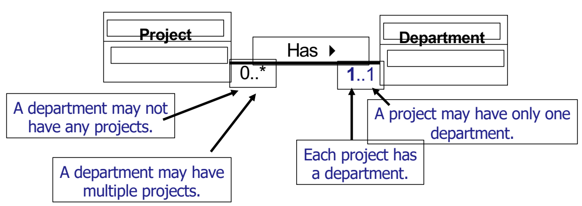
Participation Constraints Example

- Example: A project is associated with one department, and a department may have zero or more projects.



Note: Every project must participate in the relationship (mandatory).

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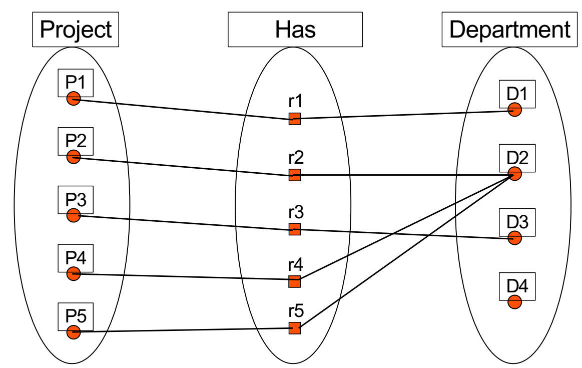
One-to-Many Participation Relationship Example



Relationship explanation: A project must be associated with one department. A department may have zero or more projects.

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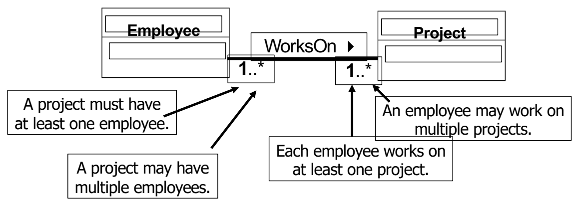
Participation Constraints Example 2

- Example: A project must have one or more employees, and an employee must work on one or more projects.



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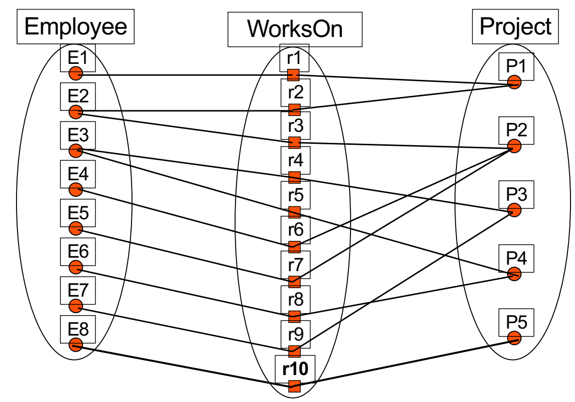
Many-to-Many Relationship Participation Example



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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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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

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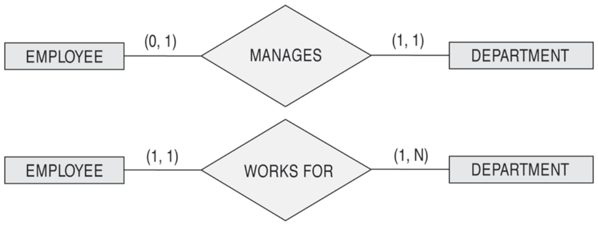
The (min,max) notation for relationship constraints



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

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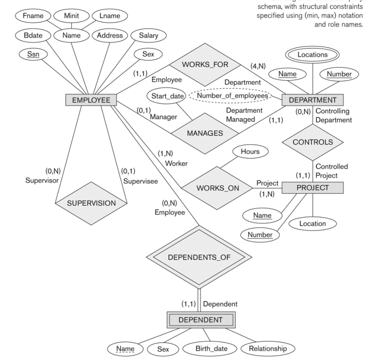
COMPANY ER Schema Diagram using (min, max) notation

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



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Alternate “syntax” for ER Model: UML Notation

- If you are familiar with UML, then ER database design can be expressed using Unified Modeling Language (UML) 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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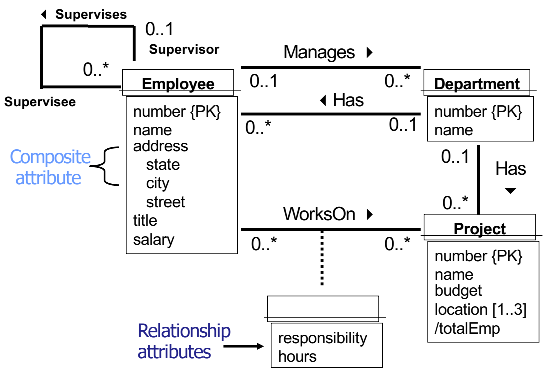
ER Model Example in UML notation



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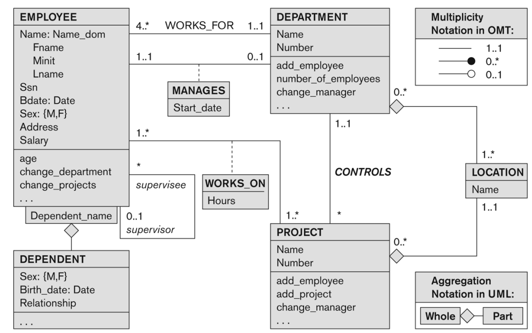
UML class diagram for COMPANY database schema

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



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