Dr Sophia Tsoka

Department of Informatics

Faculty of Natural and Mathematical Sciences

January 2021

4CCS1DBS – Database Systems

Week 2 – Data Modelling Using the Entity-Relationship Model

Topic: Conceptual Modelling for Database Systems

Overview of Week 2 Topics

- Overview of Database Design Process
- Recapping data models
- Entity-Relationship (ER) Model Concepts
    - Entities, Entity Types, Attributes
    - Relationships and Relationship Types
    - Weak Entity Types
    - Constraints and Attributes in Relationship Types
- ER Diagrams - Notation
- ER Diagram for COMPANY Schema

In this Recording

- Overview of Database Design Process
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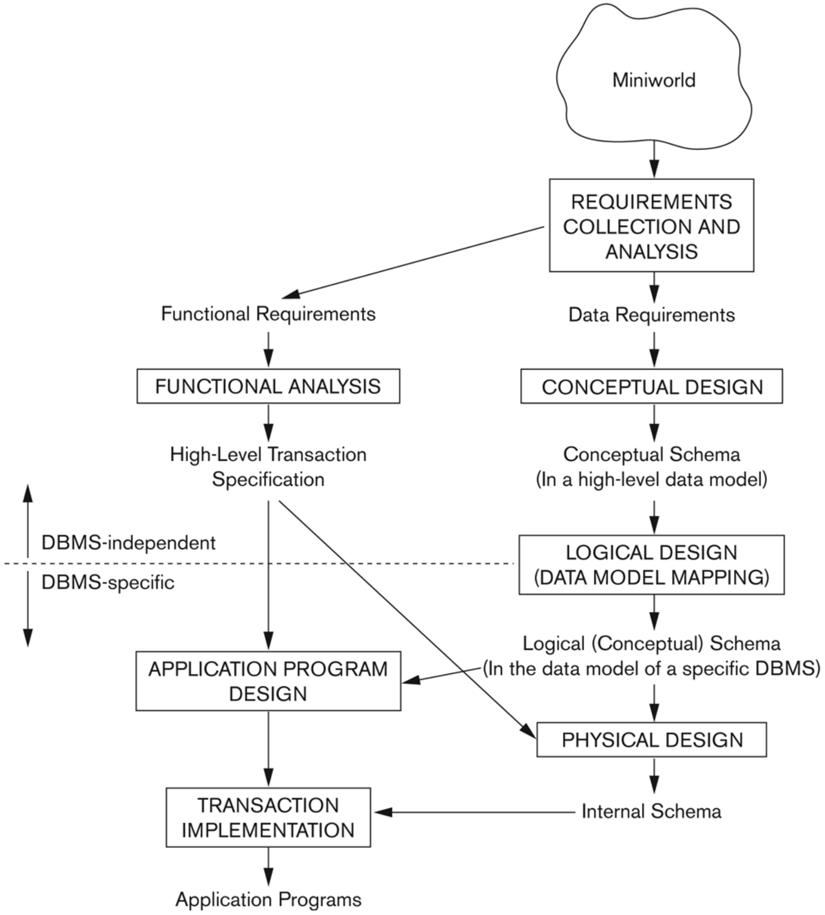
Overview of Database Design Process

- Two main activities:
  - Database design
  - Applications design
- Focus on database design here
  - 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

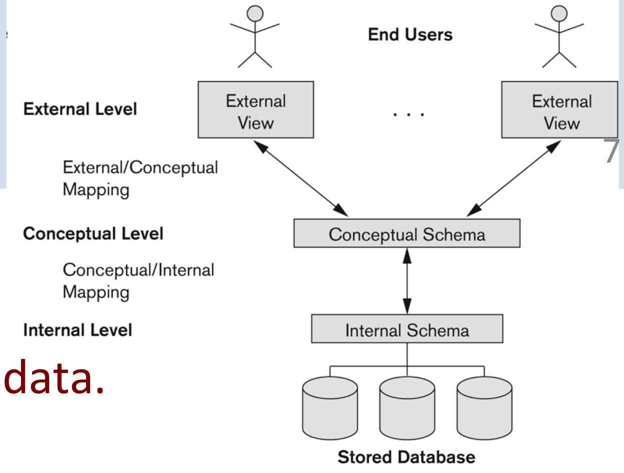
Overview of the Database Design Process


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)
APPLICATION PROGRAM DESIGN
Logical (Conceptual) Schema (In the data model of a specific DBMS)
PHYSICAL DESIGN
TRANSACTION IMPLEMENTATION
Internal Schema
Application Programs

Recap: Data Models

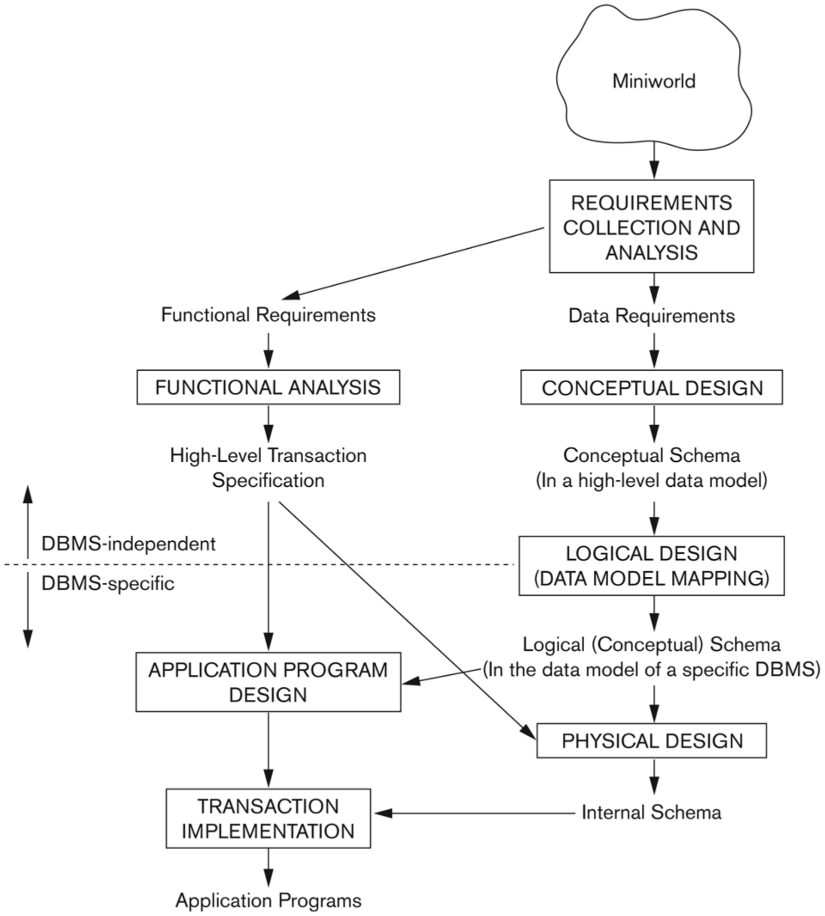
- **Data Model:**
  - A set of concepts to describe the ***structure*** of a database, the ***data types***, ***relationships*** and certain ***constraints*** that apply to the data. May include basic operations for retrievals or updates.
- **Data Model Structure and Constraints:**
  - Constructs are used to define the database structure
  - Constructs typically include ***elements*** (and their ***data types***) as well as groups of elements (e.g. ***entity, record, table***), and ***relationships*** among such groups
  - Constraints specify some restrictions on valid data; these constraints must be enforced at all times
- **Data Model Operations:**
  - Database retrievals and updates by referring to the constructs of the data model (basic model operations or user-defined operations)

Recap: Categories of Data Models



- **Conceptual (high-level, semantic) data models:**
  - Provide concepts that are close to the way many users perceive data.
  - (Also called ***entity-based*** or ***object-based*** data models.)
- **Physical (low-level, internal) data models:**
  - Provide concepts that describe details of how data is stored in the computer. These are usually specified in an ad-hoc manner through DBMS design and administration manuals
- **Implementation (representational) data models:**
  - Provide concepts that fall between the above two, used by many commercial DBMS implementations (e.g. relational data models used in many commercial systems).

Overview of the Database Design Process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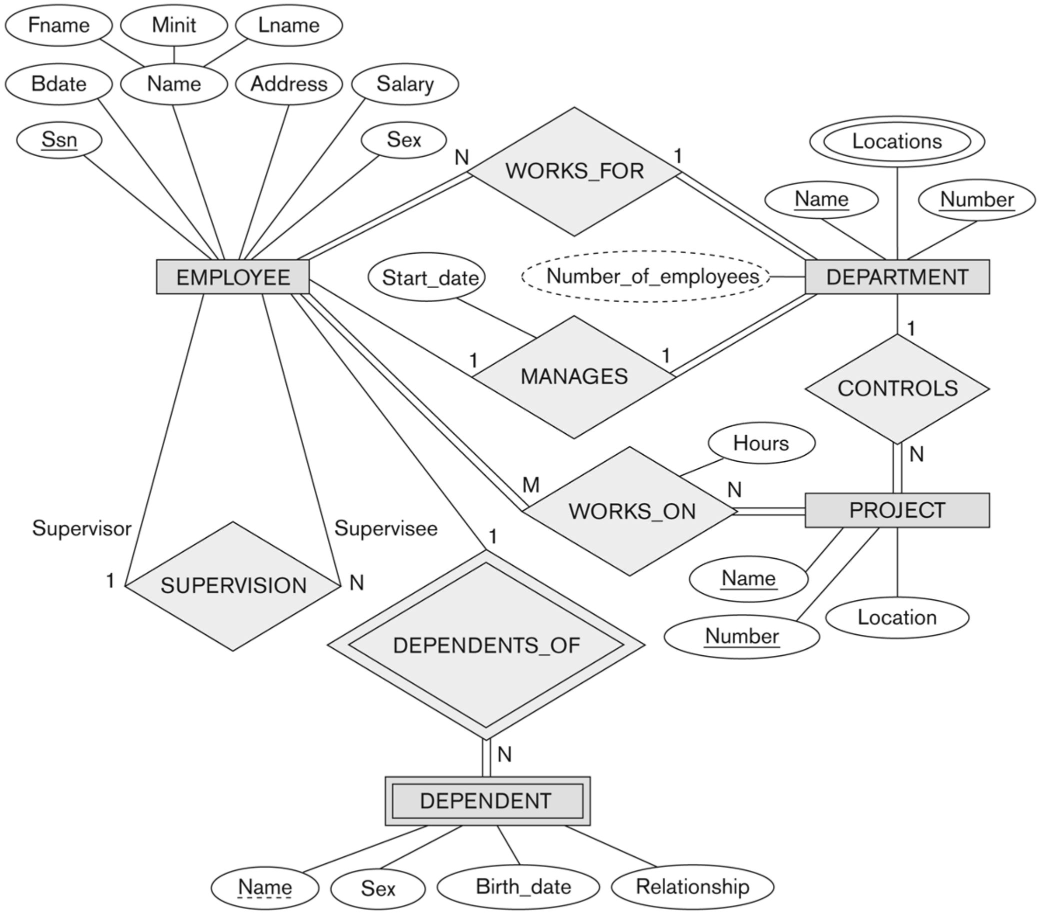
Example COMPANY Database

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

- We store each EMPLOYEE’s social security number, address, salary, gender and birthdate.
  - Each employee *works for* one department but may *work on* several projects.
  - We keep track of the number of hours per week that an employee currently works on each project.
  - We also keep track of the *direct supervisor* of each employee.
- Each employee may *have* a number of DEPENDENTs.
  - For each dependent, we keep track of their name, sex, birthdate, and relationship to the employee.

An Entity-Relationship Diagram



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Week 2 – Data Modelling Using the Entity-Relationship Model

Topic: Entities and Attributes

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- Overview of Database Design Process
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- Entity-Relationship (ER) Model Concepts
  - Entities, Entity Types, Attributes
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  - Weak Entity Types
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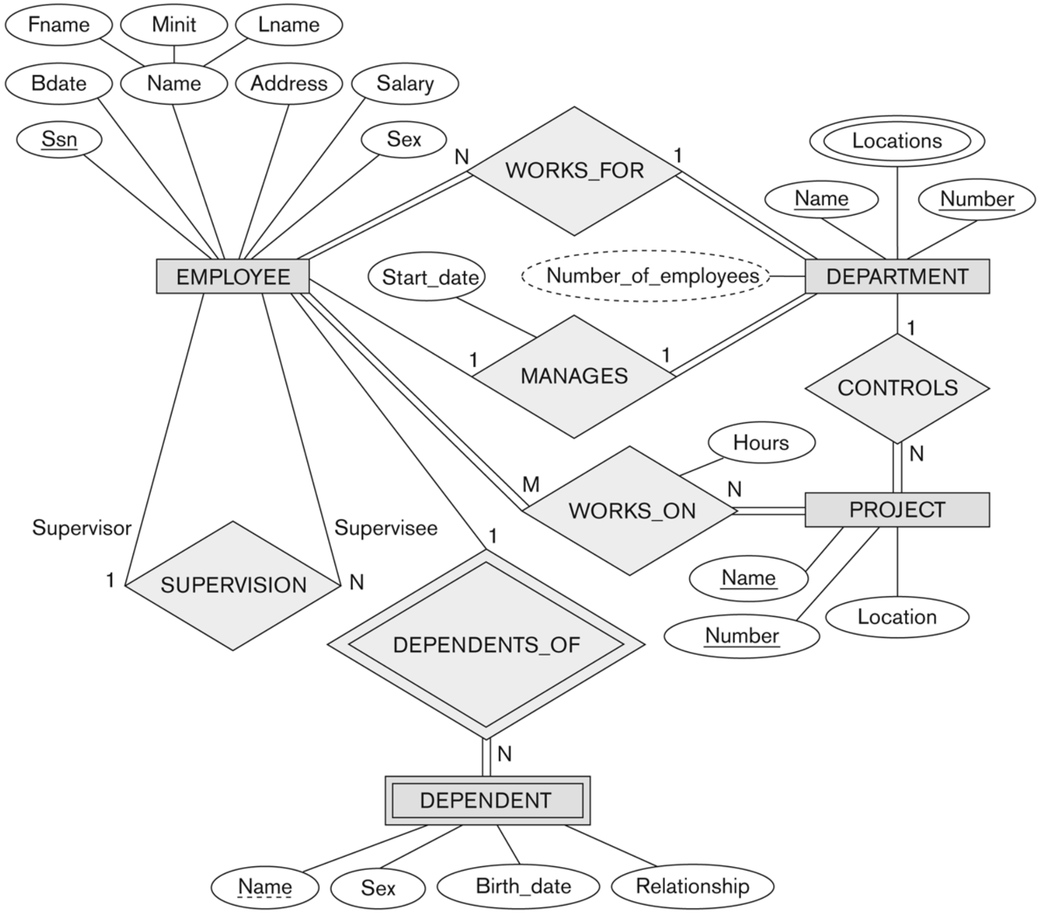
An Entity-Relationship Diagram for the COMPANY Database



The COMPANY Database

- The company is organised into **DEPARTMENTs**. Each department has a name, number and an employee who manages the department. We keep track of the start date of the department manager. A department may have several locations.
- Each department controls a number of **PROJECTs**. Each project has a unique name, unique number and is located at a single location.
- We store each **EMPLOYEE's** social security number, address, salary, gender and birthdate.
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Entity-Relationship (ER) Model Concepts

- Based on the previous specification of a mini-world, we define the conceptual model based on Entity-Relationship principles

- An Entity-Relationship model has three main concepts:
  - Entities (and their entity types and entity sets)
  - Attributes (simple, composite, single-valued, multi-valued)
  - Relationships (and their relationship types and relationship sets)

ER Model Concepts – Entities

- Entities are specific *objects* or *things* in the mini-world that are represented in the database
- For example:
  - the EMPLOYEE John Smith,
  - the Research DEPARTMENT,
  - the ProductX PROJECT
- Entities may be either physical (employees) or non-physical objects (projects)

ER Model Concepts – Attributes

- Attributes are properties used to describe an entity
    - For example an EMPLOYEE entity may have the attributes Name, SSN, Address, BirthDate etc.

- 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‘

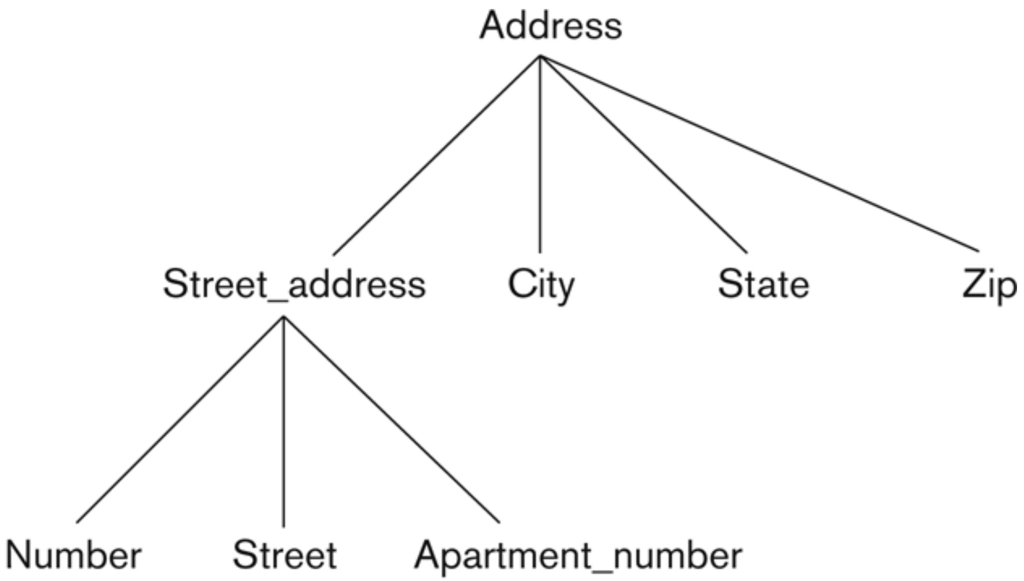
- Each attribute has a *value set* (or *data type*) associated with it – e.g. integer, string, date, etc.

Types of Attributes (1)

- Simple attribute
  - Each entity has an atomic (non-divisible) value for this attribute
  - For example: Employee Social Security Nnumber (SSN)

- 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.

Example of a Composite Attribute



Types of Attributes (2)

- Single-valued
  - Each entity can have a single value for this attribute
  - For example: the ‘Age’ attribute for each EMPLOYEE entity
- Multi-valued
  - An entity may have multiple values for that attribute.
  - For example: Colour of a CAR Entity or PreviousDegrees of a STUDENT.
  - Denoted as {Colour} or {PreviousDegrees}.

Types of Attributes (3)

- An attribute can be both composite and multi-valued

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

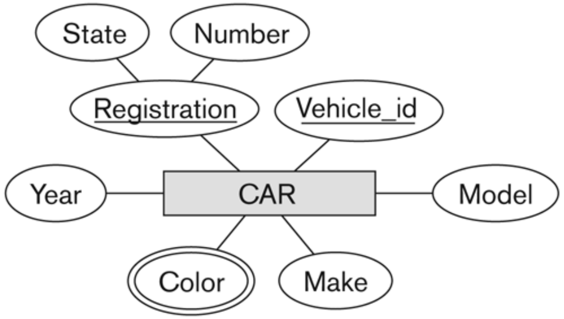
Entity Types and Key Attributes (1)

- 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 always have a unique value is called a **key attribute** of the entity type.
  - For example, SSN of EMPLOYEE.

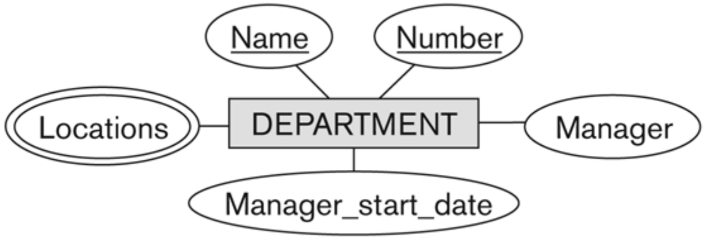
Entity Types and Key Attributes (2)

- A key attribute may be *composite*.
  - Example (from US car ids):
    - VehicleTagNumber is a key of the CAR entity type with components (Number, State).
- An entity type may have more than one key attribute.
  - The CAR entity type may have two keys:
    - VehicleIdentificationNumber (popularly called VIN)
    - VehicleTagNumber (Number, State) or license plate number.
- Each key attribute is underlined in the ER diagram



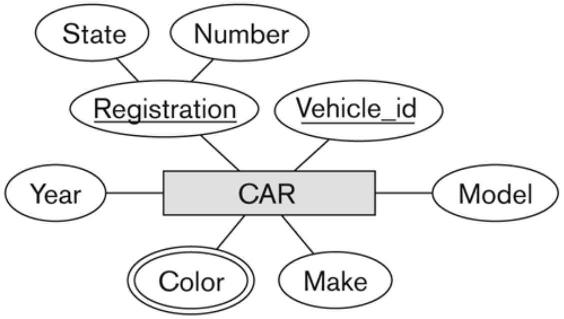
Displaying an Entity type

- 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

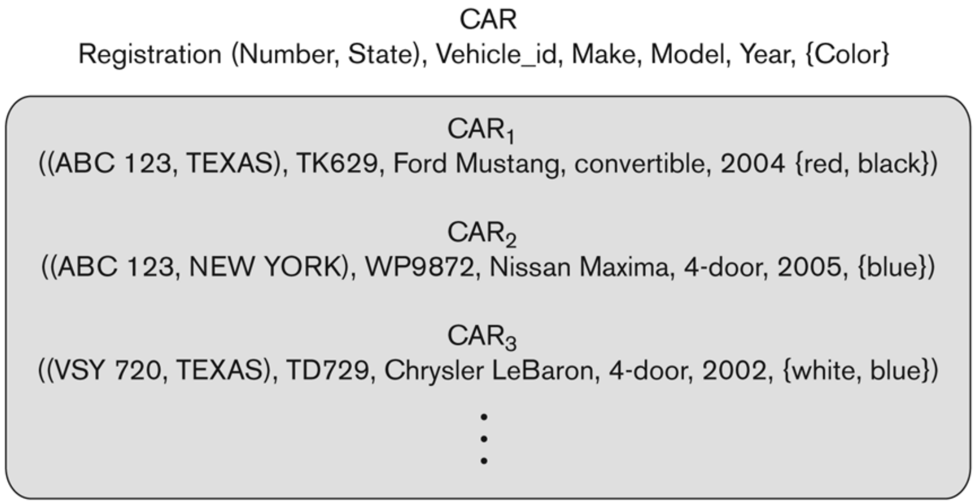


Entity Type CAR with Two Keys and a Corresponding Entity Set

- Entity type



- Entity set



CAR
Registration (Number, State), Vehicle_id, Make, Model, Year, {Color}

CAR$_1$
((ABC 123, TEXAS), TK629, Ford Mustang, convertible, 2004 {red, black})

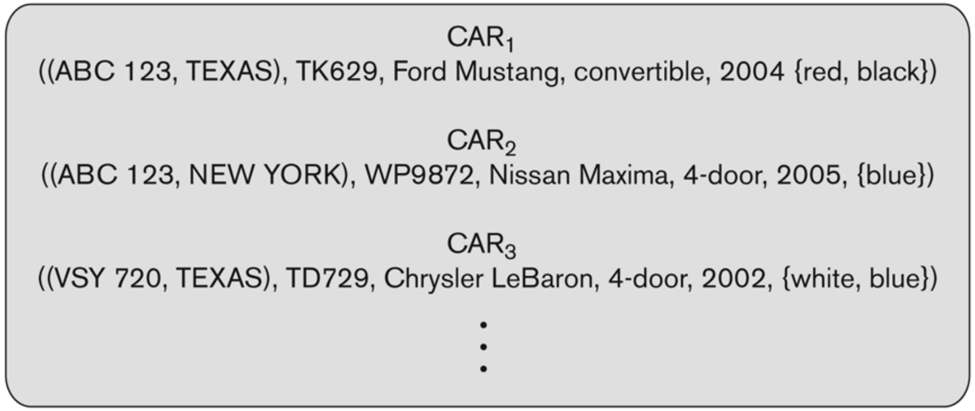
CAR$_2$
((ABC 123, NEW YORK), WP9872, Nissan Maxima, 4-door, 2005, {blue})

CAR$_3$
((VSY 720, TEXAS), TD729, Chrysler LeBaron, 4-door, 2002, {white, blue})

⋮

Entity Set

- Each entity type will have a collection of entities stored in the database
  - Called the *entity set*
- Three CAR entity instances in the entity set for CAR are shown
- Same name (CAR) used to refer to both the entity type and the entity set
- Entity set is the current *state* of the entities of that type that are stored in the database



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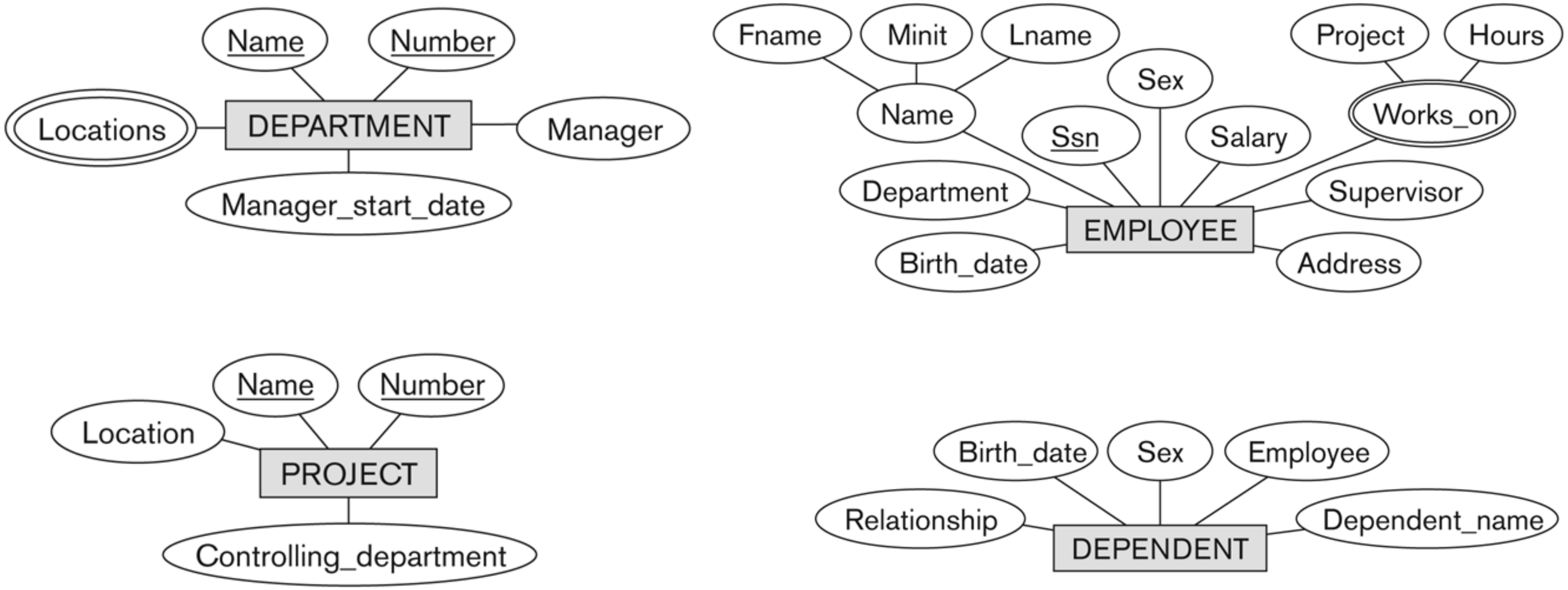
Initial Design of Entity Types for the COMPANY Database Schema

- Based on the requirements, we can identify four initial entity types in the COMPANY database:
  - DEPARTMENT
  - PROJECT
  - EMPLOYEE
  - DEPENDENT
- Their initial 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



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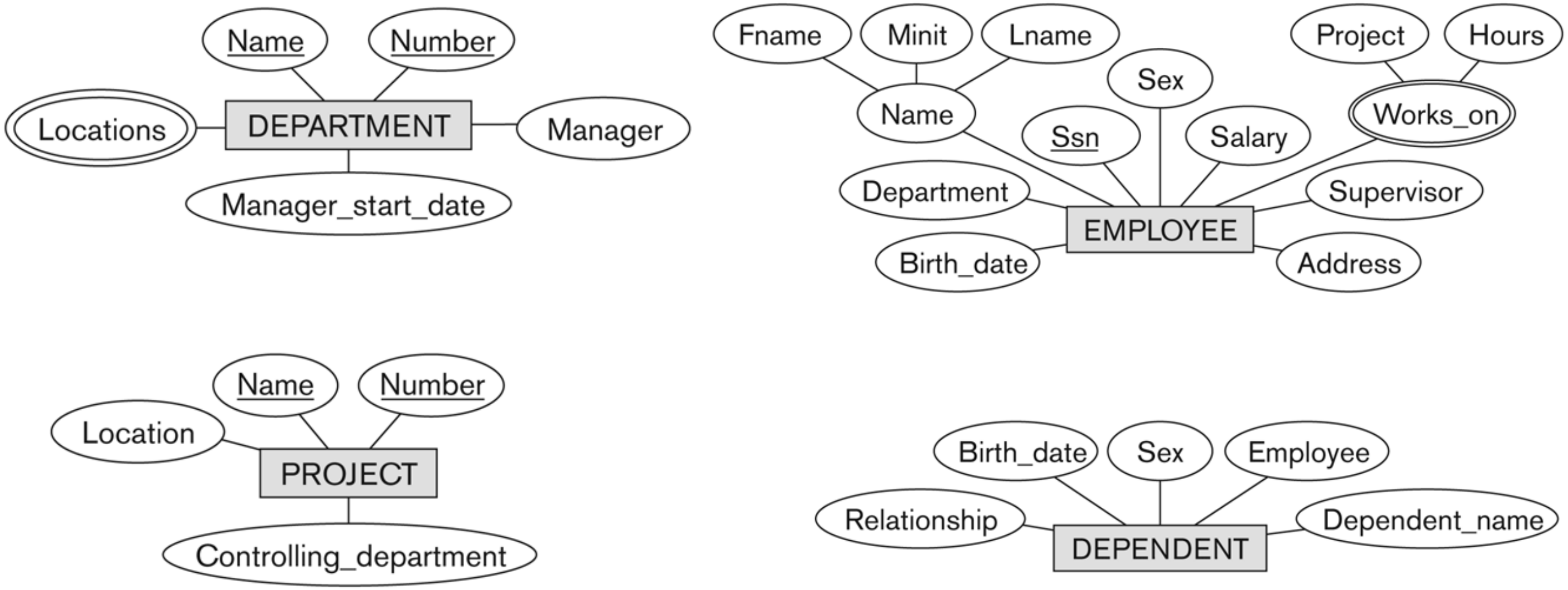

Refining the Initial Design by Introducing Relationships

- The initial design is typically not complete
- Some aspects in the requirements will be represented as **relationships**
- ER model has three main concepts:
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  - Attributes (simple, composite, single-valued, multi-valued)
  - Relationships (and their relationship types and relationship sets)

Relationships and Relationship Types (1)

- A **relationship** relates two or more distinct entities with a specific meaning
  - For example:
    - EMPLOYEE John Smith ***works on*** the ProductX PROJECT
    - 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

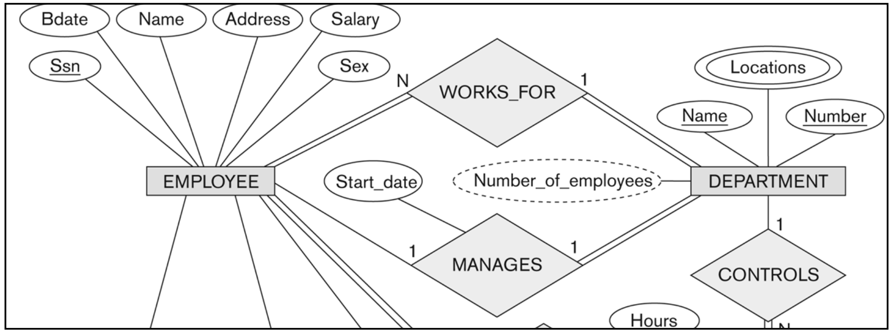
- The degree of a relationship type is the number of participating entity types
  - Both MANAGES and WORKS_ON are *binary* relationships

Relationship Type vs. Relationship Set

- Relationship Type:
  - A set of associations among entities
  - 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 (contd.)

- 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



COMPANY Database Requirements

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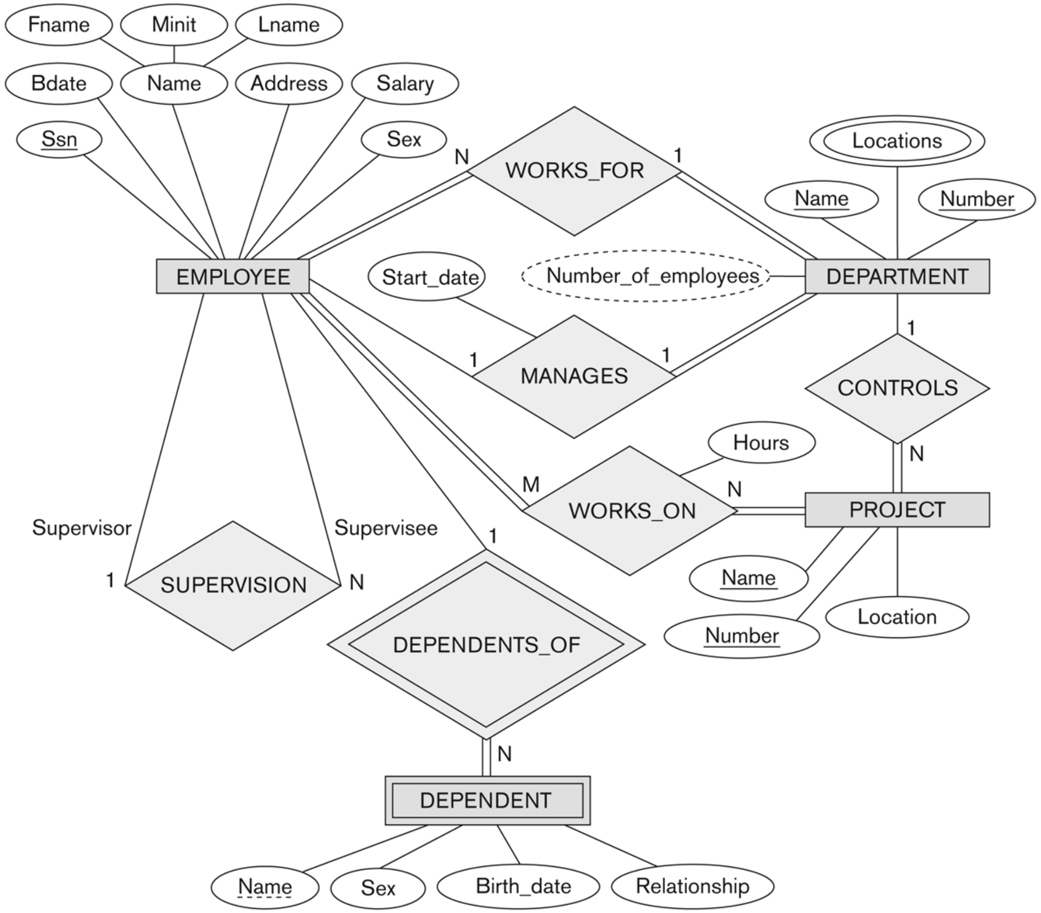
Refining the COMPANY Database Schema by Introducing Relationships

- By examining the requirements, six relationship types are identified
- 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)
- Most are *binary* relationships (degree of 2), apart from SUPERVISION that is *unary* (degree of 1)

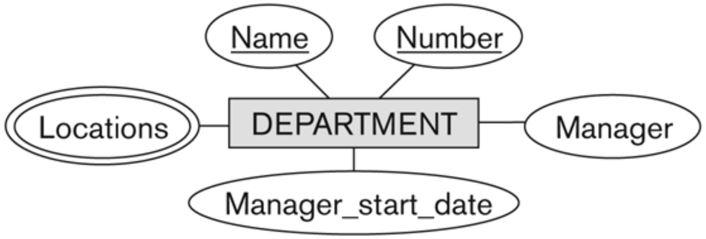
ER DIAGRAM – Relationship Types -

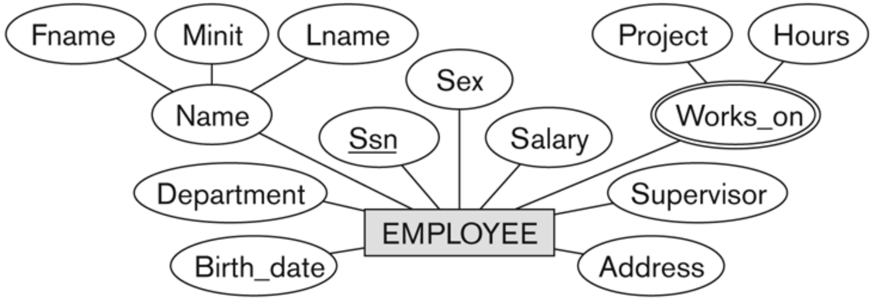
WORKS_FOR, MANAGES, WORKS_ON, CONTROLS, SUPERVISION, DEPENDENTS_OF



Discussion on Relationship Types

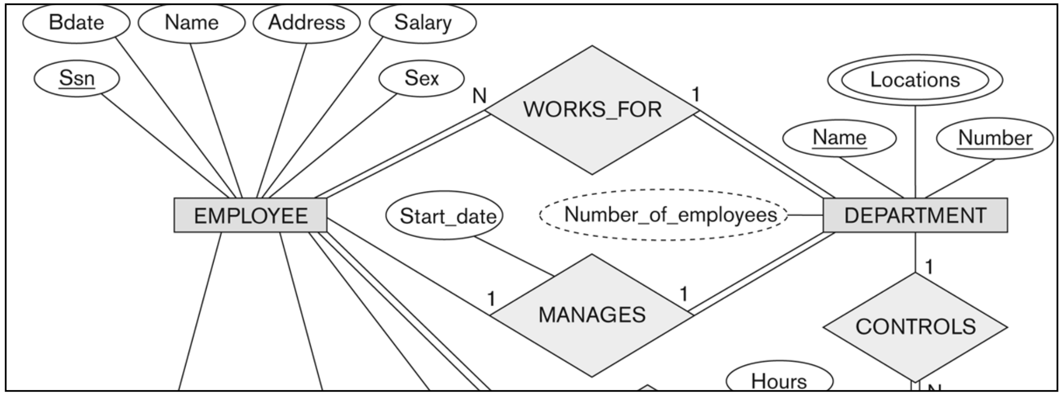
- In the refined design, some *attributes* from the initial entity types are refined into *relationships*:
  - Manager of DEPARTMENT → MANAGES
  - Works_on of EMPLOYEE → WORKS_ON
  - Department of EMPLOYEE → WORKS_FOR





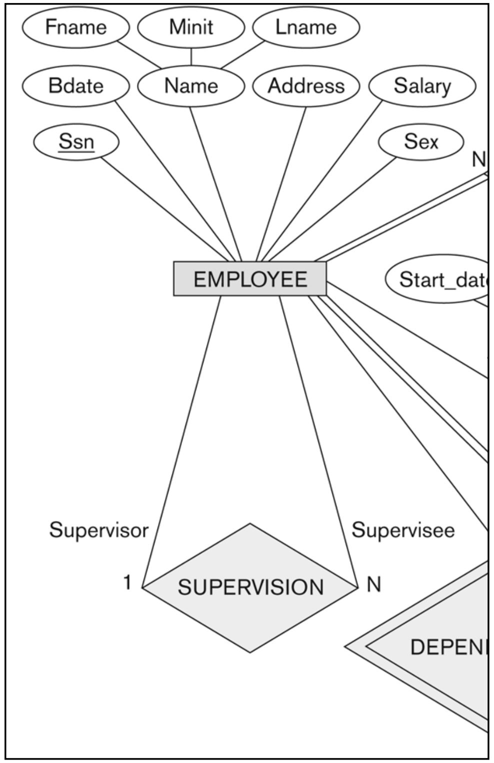
Discussion on Relationship Types (cont'd)

- 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.



Recursive Relationship Type

- A relationship type with the same participating entity type in distinct roles
- 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

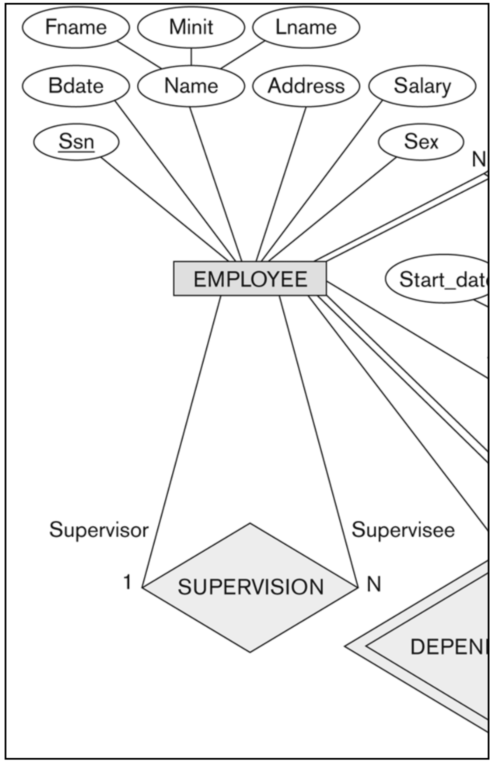


Displaying a Recursive Relationship

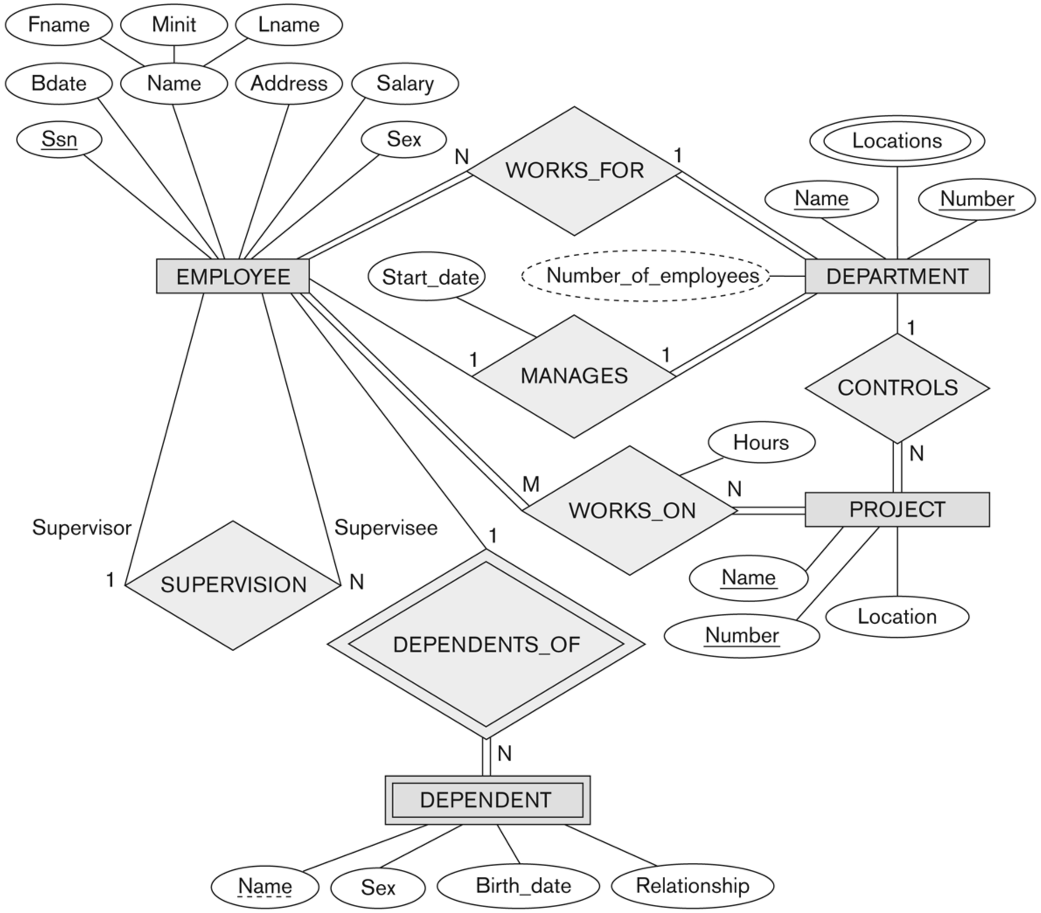
- In a recursive relationship type:
  - Both participations are same entity type in different roles
  - For example: SUPERVISION relationships between EMPLOYEE in role of *supervisor* or *boss* and another EMPLOYEE in role of *subordinate* or *worker*

- In figure, first role participation labeled with 'Supervisor' and second role participation labeled with 'Supervisee'

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

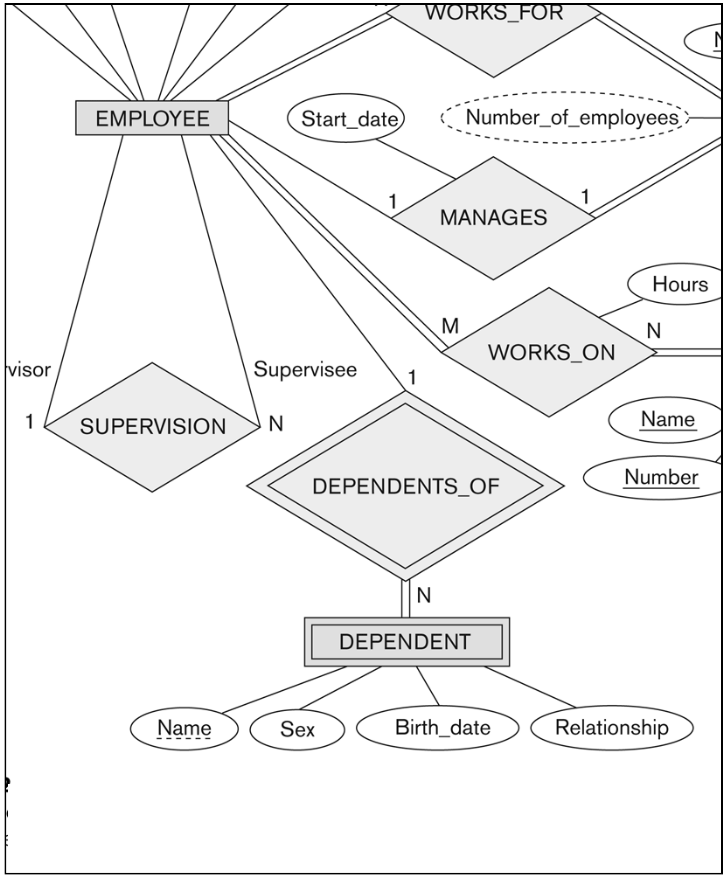


Recursive Relationship Type is: SUPERVISION (participation role names are shown)



Weak Entity Types

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



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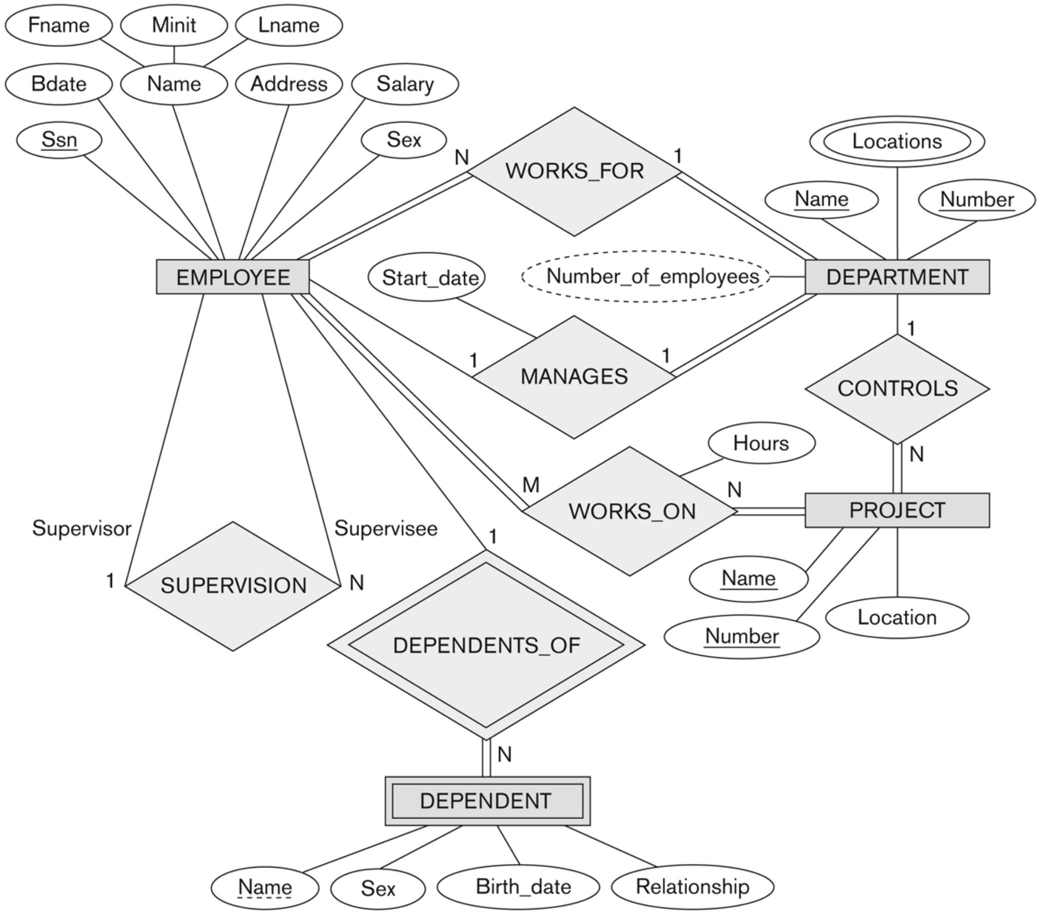

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Topic: Structural Constraints of Relationships

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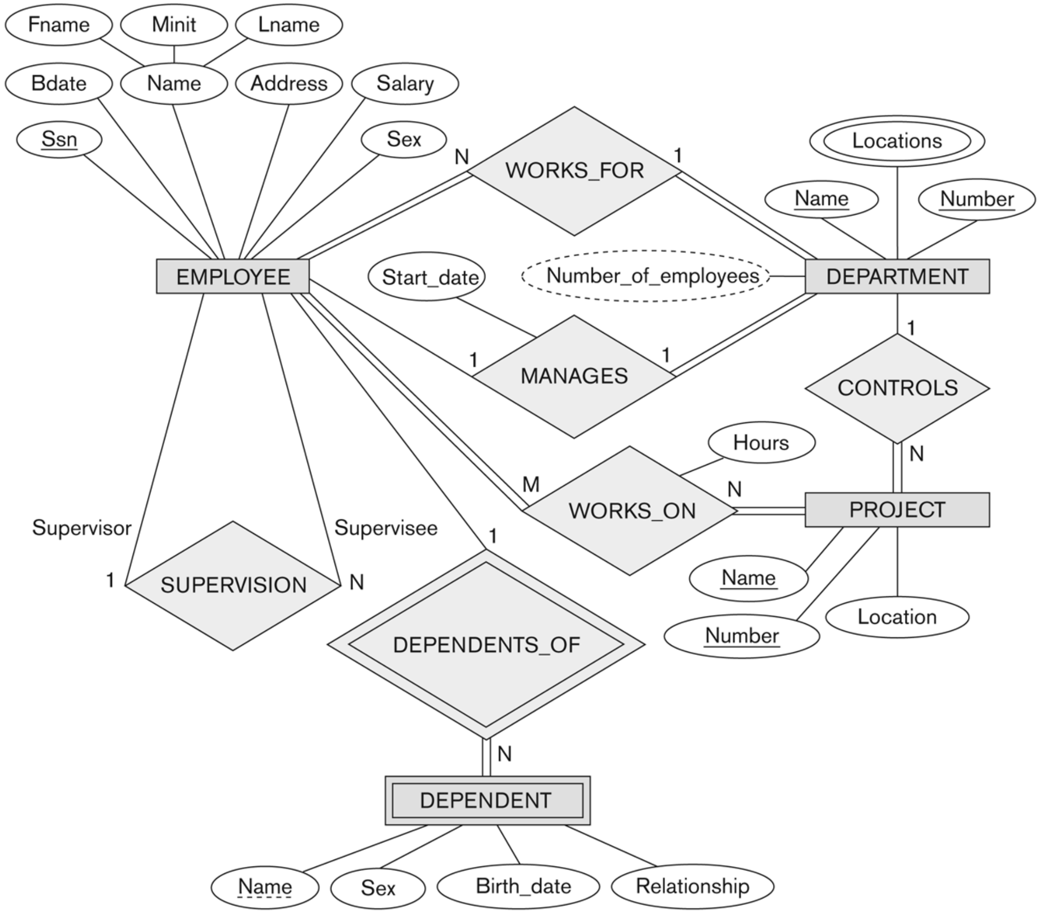
The COMPANY Database – ER diagram

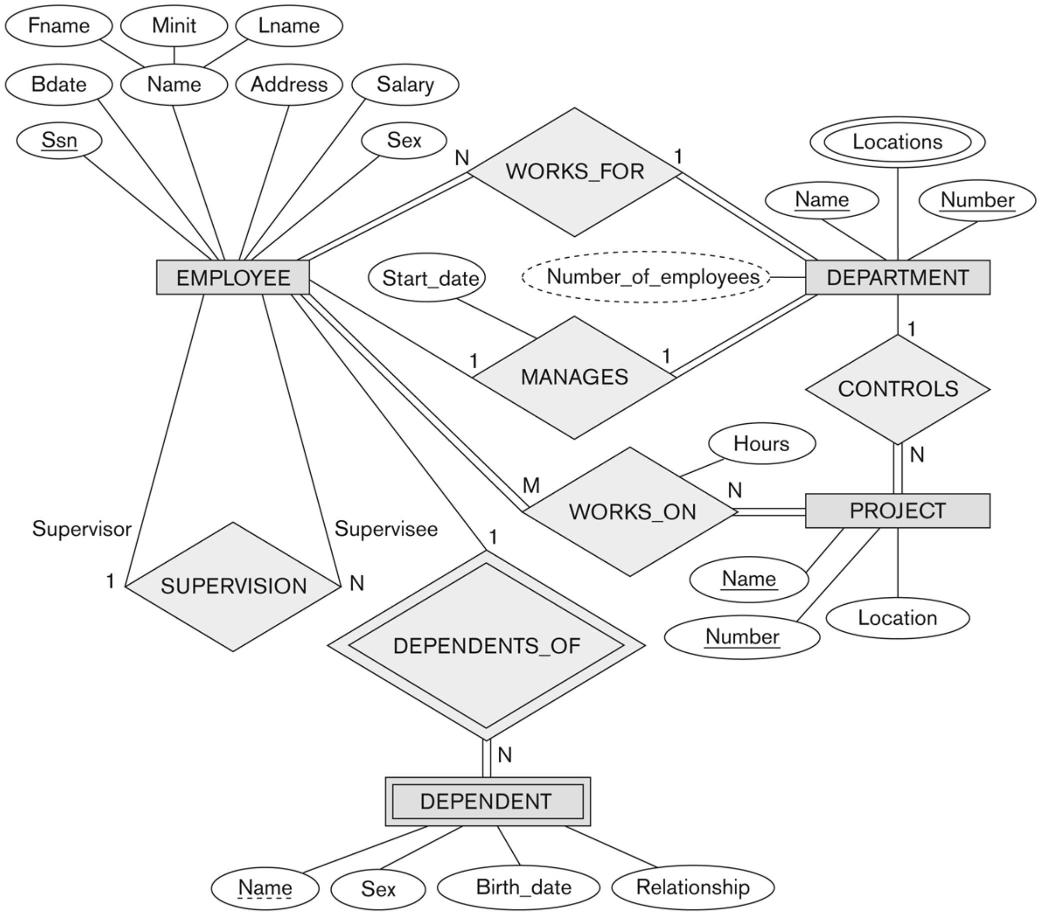


Constraints on Relationships

- Structural Constraints on Relationship Types
  - Also known as *ratio constraints.*
  - *Cardinality Ratio*: specifies *maximum* number of relationship instances that an entity can participate in.
    - 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 of an entity in a relationship, i.e. if existence of an entity depends on it being related to another entity via relationship type (also called *participation constraint*)
    - zero (optional participation, not existence-dependent)
    - one or more (mandatory participation, existence-dependent)

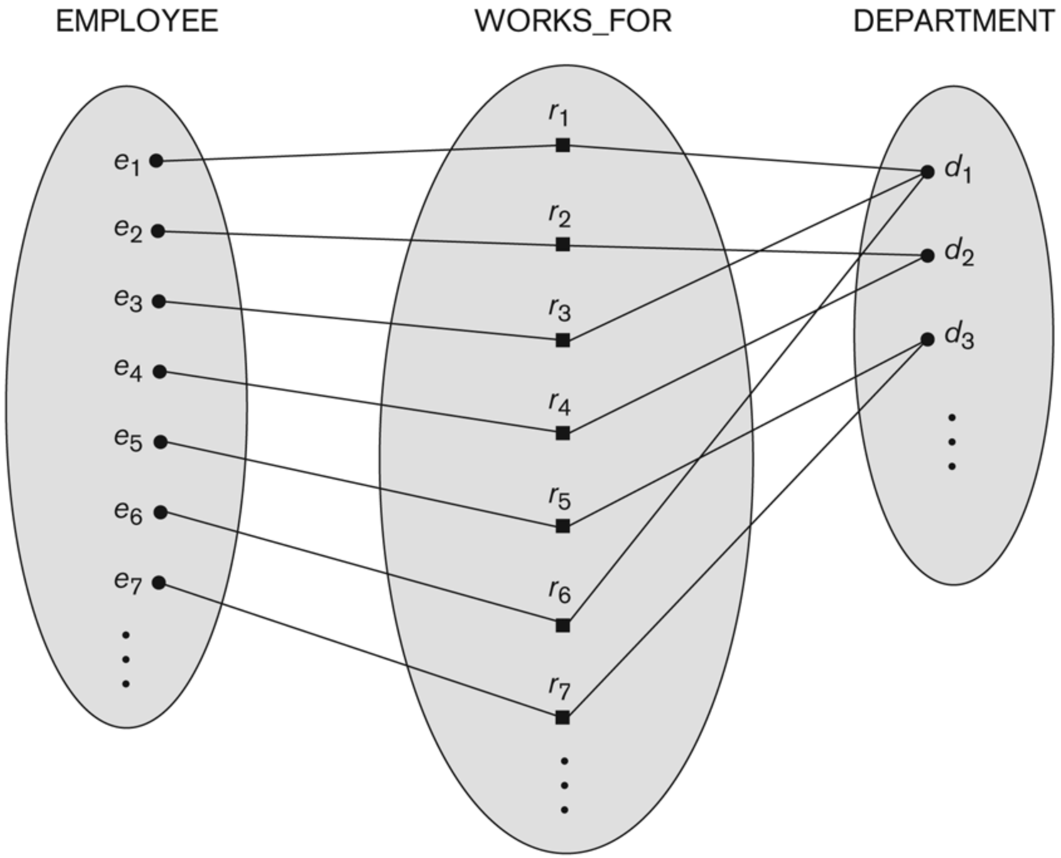
Notation for Constraints on Relationships

- 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*)
    - shown by double line
  - partial
    - shown by single line



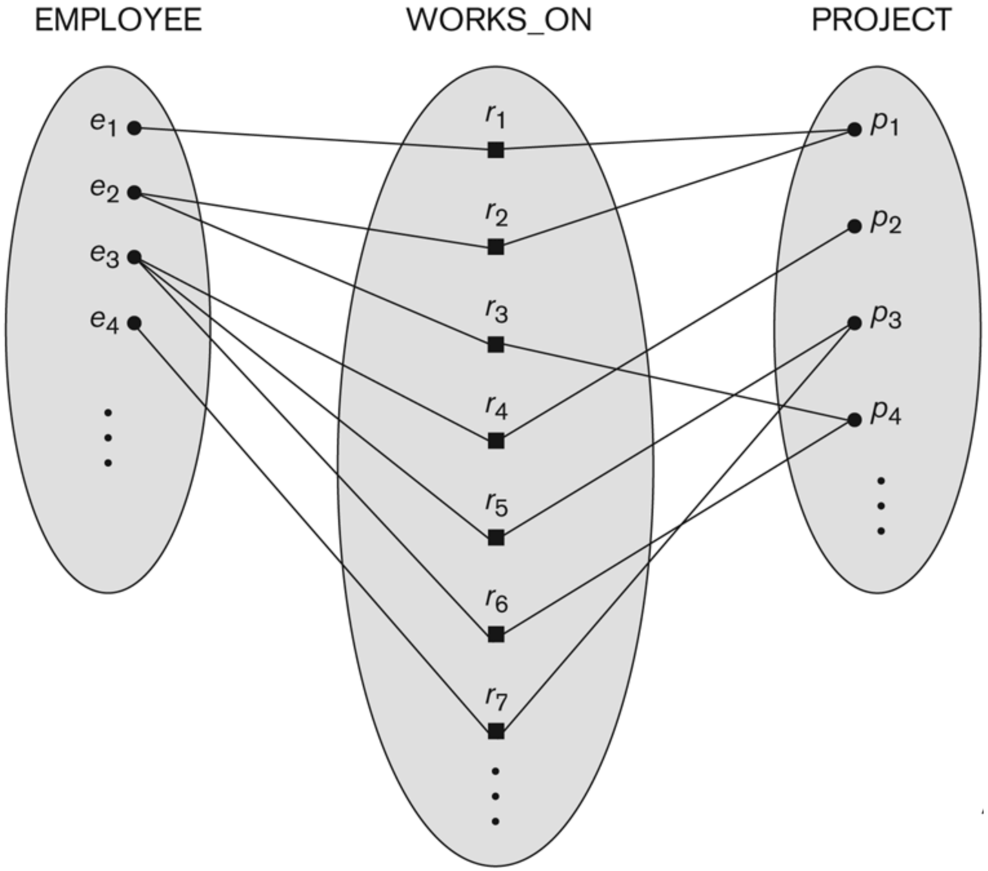
Relationship Instances of the WORKS_FOR Relationship Between EMPLOYEE and DEPARTMENT (N:1)

Each *instance of a relationship set* relates *individual participating entities*, one from each participating entity type



Many-to-one (N:1) Relationship

Relationship Instances of the WORKS_ON Relationship Between EMPLOYEE and PROJECT (M:N)

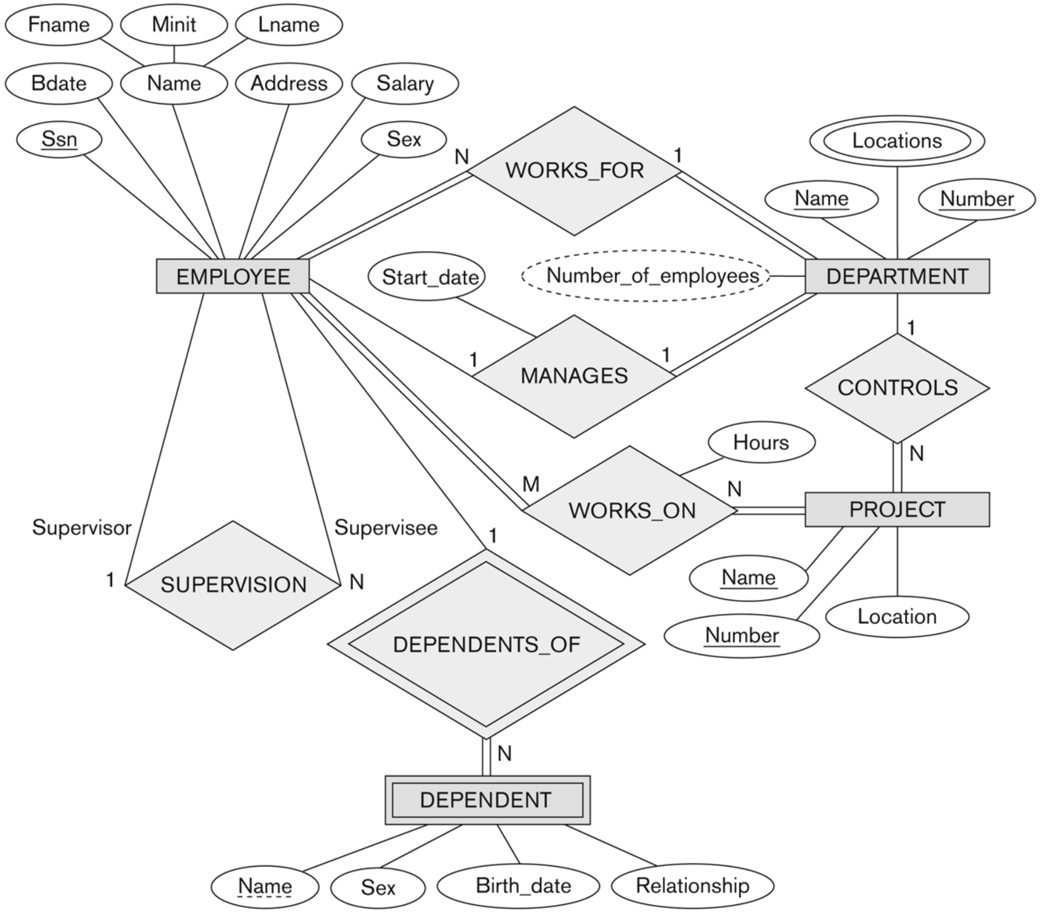


Many-to-many (M:N) Relationship

The COMPANY Database – Cardinality Ratios

Cardinality Ratio: specifies *maximum* number of relationship instances that an entity can participate in.

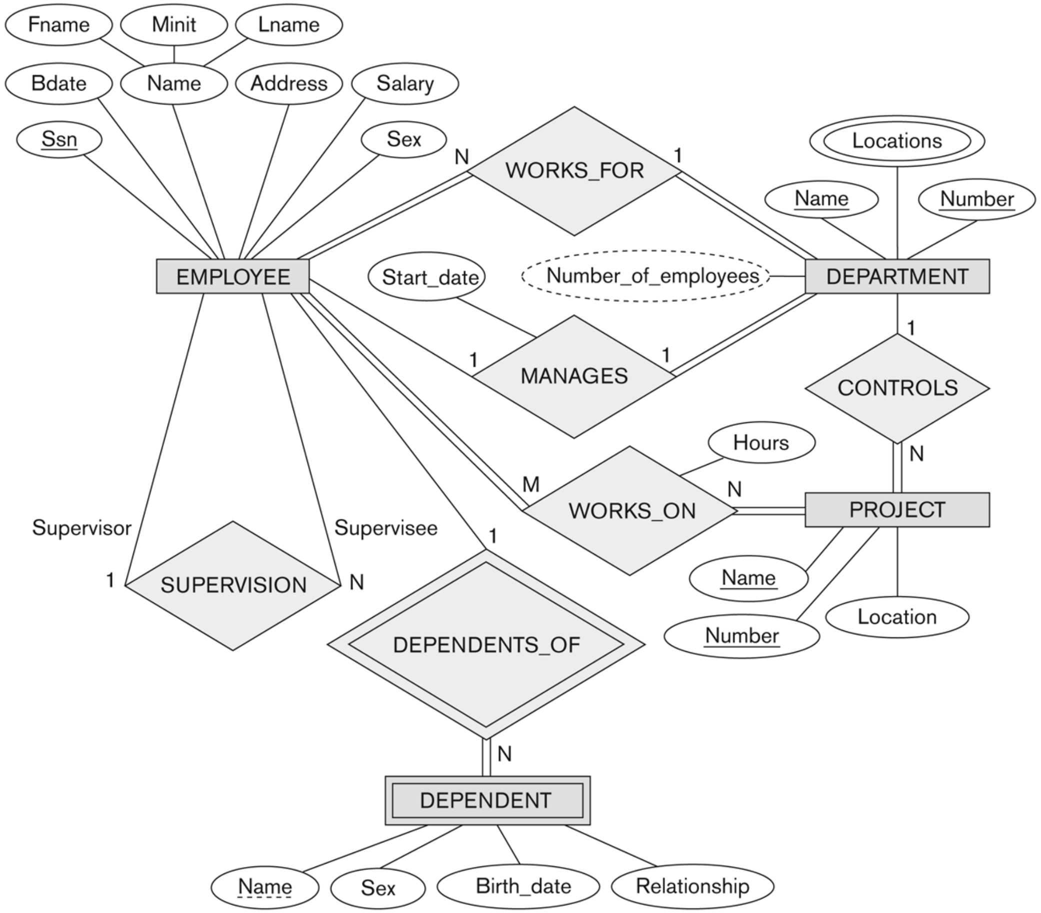
- One-to-one (1:1)
- One-to-many (1:N) or Many-to-one (N:1)
- Many-to-many (M:N)



The COMPANY Database – Existence Dependency Constraints

Existence Dependency Constraint: specifies *minimum* participation of an entity type

- Indicates if existence of an entity depends on it being related to another entity via relationship type
    - Zero: optional participation, not existence-dependent
    - One or more: mandatory participation, existence-dependent

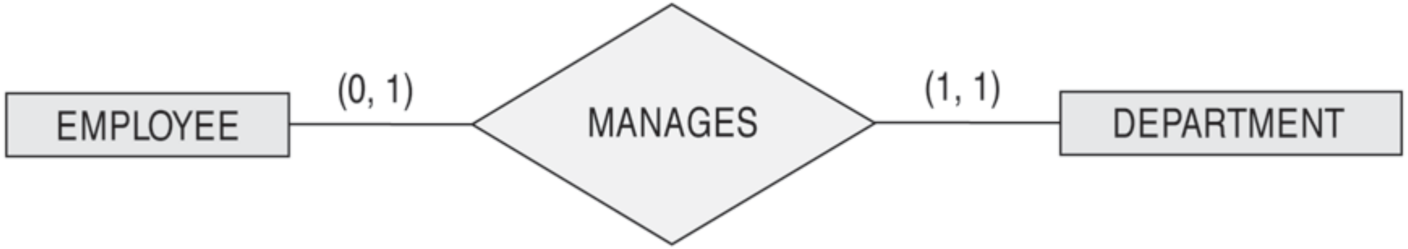


Alternative (min, max) Notation for Relationship (1)

- 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

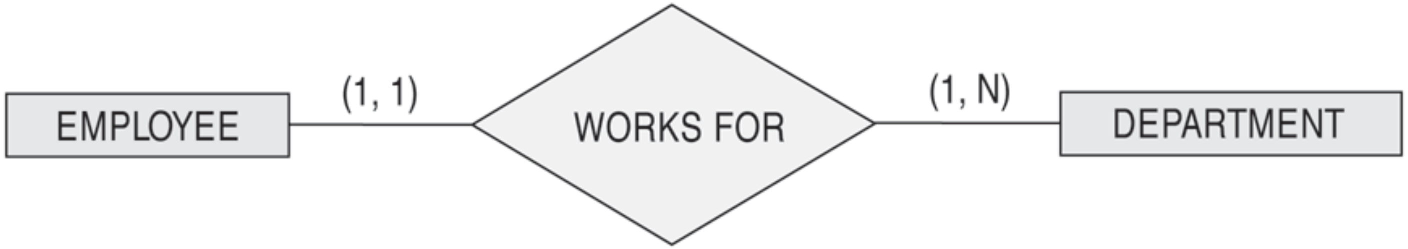
Alternative (min, max) Notation for Relationship (2)

- 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

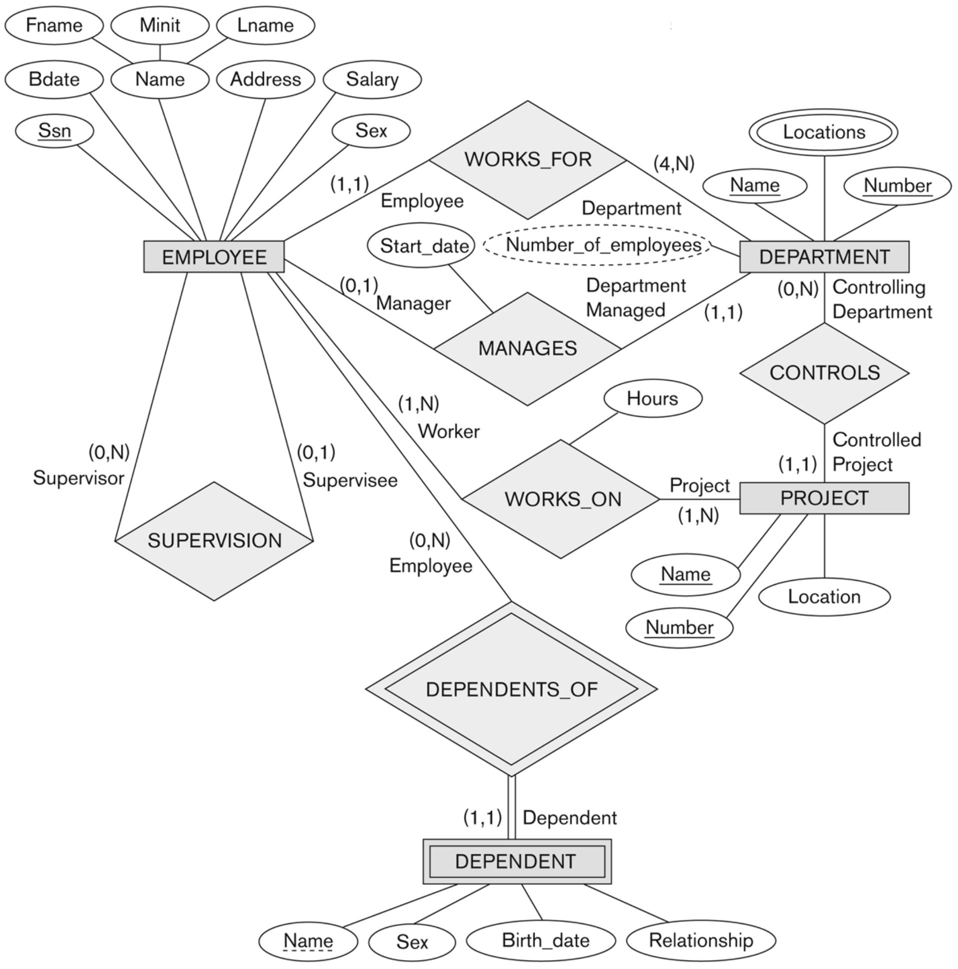


The (min,max) Notation for Relationship Constraints

- Examples:
  - 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 (1,N) for participation of DEPARTMENT in WORKS_FOR



COMPANY ER Schema Diagram using (min, max) notation

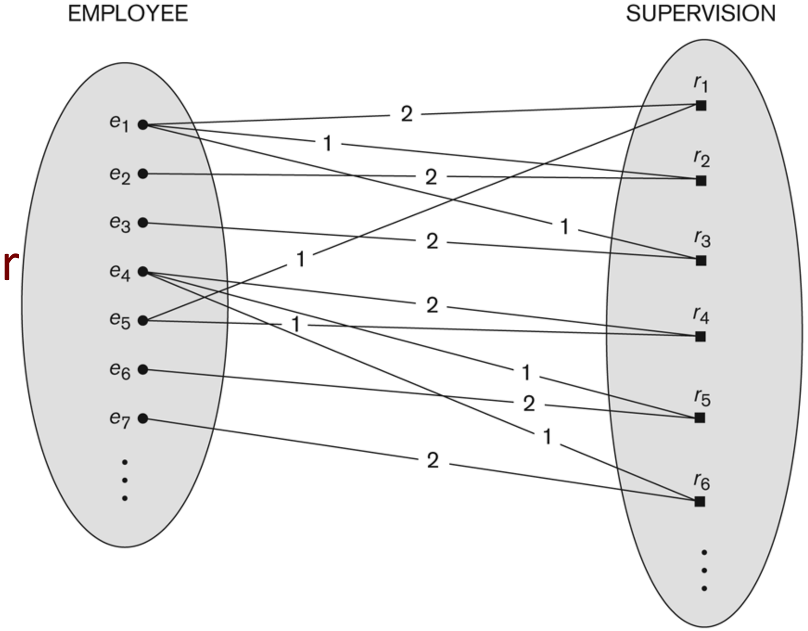


Displaying a Recursive Relationship

- 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 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.

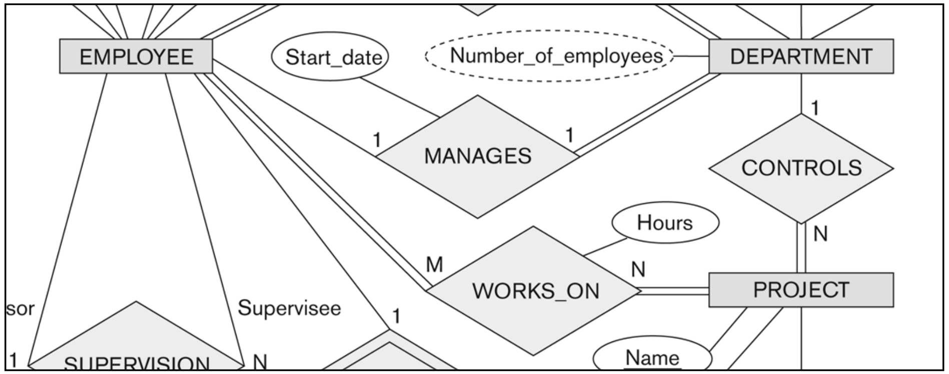


1: supervisor role

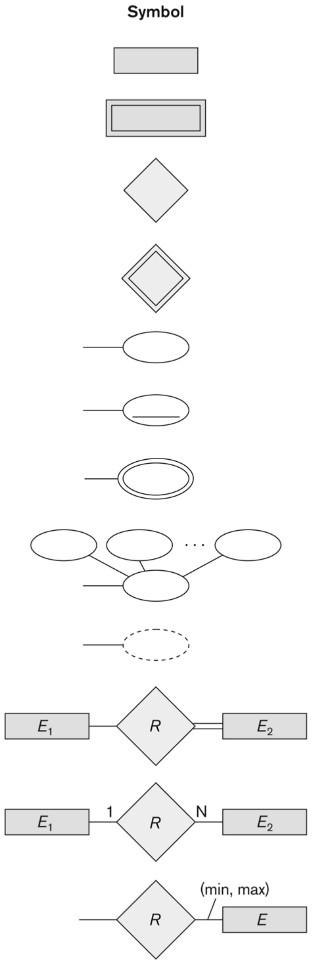
2: supervisee role

Attributes of Relationship Types
Example: Hours of Relationship WORKS_ON

- 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



Summary of Notation for ER Diagrams



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

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

Alternative Diagrammatic Notation

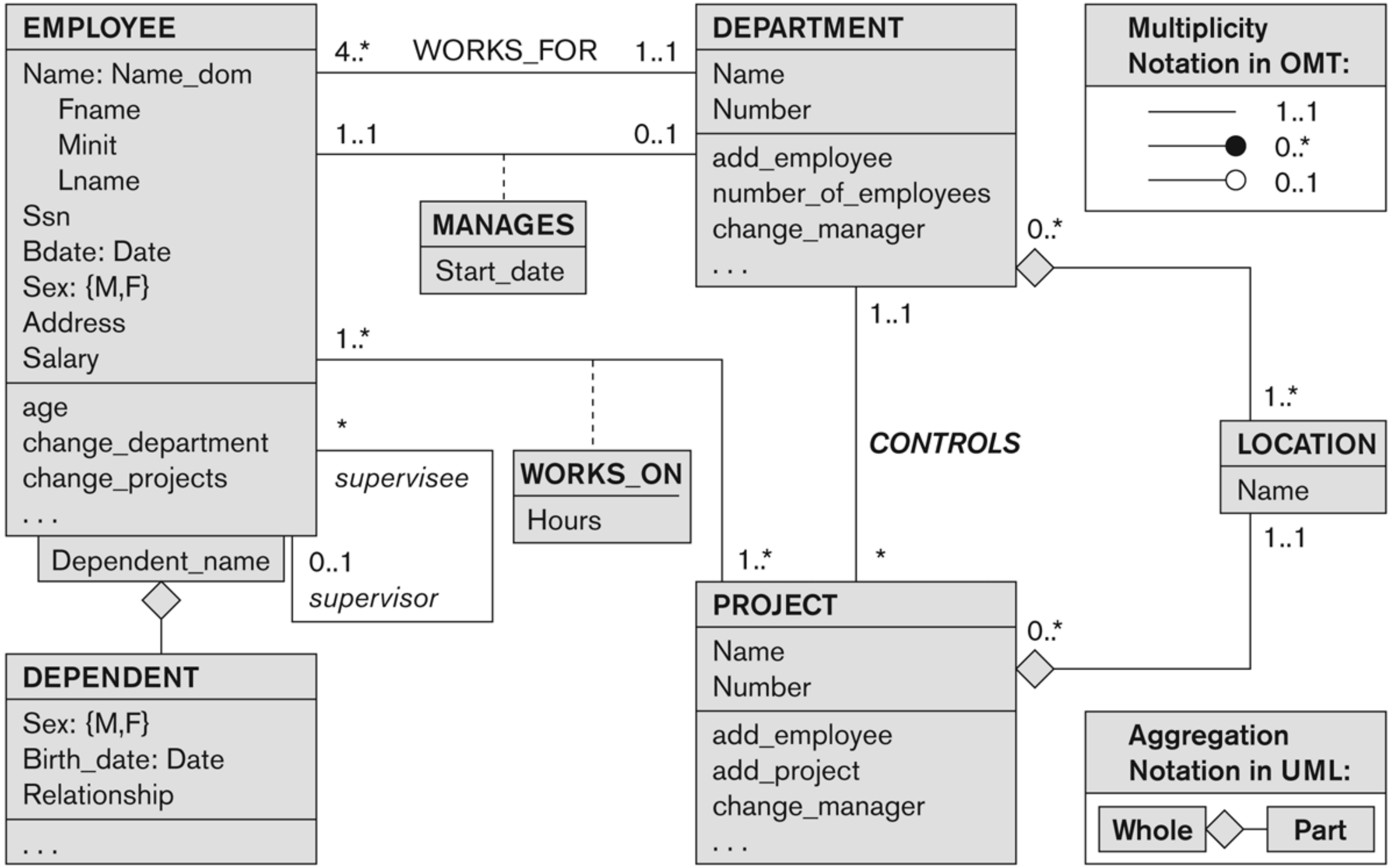
- ER diagrams is a popular means for displaying database schemas
- Many other notations exist in the literature and in various database design and modeling tools
- UML class diagrams is representative of another way of displaying ER concepts that is used in several commercial design tools

- Please note that this module will only focus on ER diagrams

UML Class Diagrams

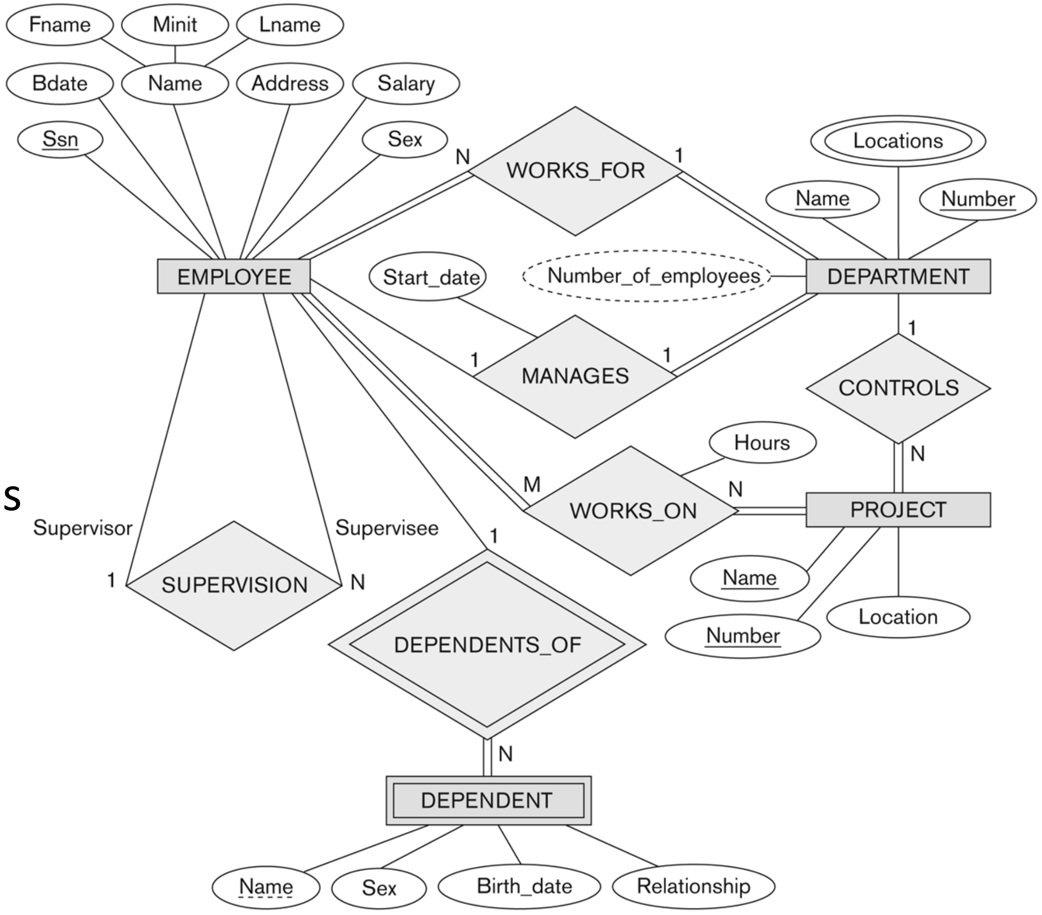
- Represent *classes* (similar to entity types) as large boxes with three sections:
  - Top section includes entity type (class) name
  - Second section includes attributes
  - Third section includes class operations (operations are not in basic ER model)
- Relationships (called *associations*) represented 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



Summary of Week 2 Topics

- Overview of Database Design Process
- Recapping data models
- Entity-Relationship (ER) Model Concepts
  - Entities, Entity Types, Attributes
  - Relationships and Relationship Types
  - Weak Entity Types
  - Constraints and Attributes in Relationship Types
- ER Diagrams - Notation
- ER Diagram for COMPANY Schema


Fname
Minit
Lname
Bdate
Name
Address
Salary
Ssn
Sex
N
WORKS_FOR
1
Locations
Name
Number
EMPLOYEE
Start_date
Number_of_employees
DEPARTMENT
1
1
MANAGES
1
CONTROLS
Hours
N
M
N
WORKS_ON
PROJECT
Supervisor
Supervisee
1
1
SUPERVISION
N
Name
Location
Number
DEPENDENTS_OF
N
DEPENDENT
Name
Sex
Birth_date
Relationship