The Entity/Relationship (E/R) Model & DB Design

Introduction to databases

CSC343, Winter 2016

Based on slides by Manos Papagelis

Thanks to Ryan Johnson, John Mylopoulos, Arnold Rosenbloom and Renee Miller for material in these slides

Overview

- Using the Entity/Relationship (ER) Model to model the real world

- From there, designing a database schema
  - Restructuring of an E/R model
 - Translating an E/R model into a logical model (DB Schema)

THE ENTITY/RELATIONSHIP (E/R) MODEL

Conceptualizing the real-world

- DB design begins with a boss or client who wants a database.

- We must map the entities and relationships of the world into the concepts of a database. This is called *modeling*.

- Sketching the key components is an efficient way to develop a design.

  - Sketch out (and debug) schema designs
  - Express as many constraints as possible
 - Convert to relational DB once the client is happy

Entity/Relationship Model

- Visual data model (diagram-based)
  - Quickly "chart out" a database design
  - Easier to "see" big picture
  - Comparable to class diagrams in UML

- Basic concept: *entities* and their *relationships*, along with the *attributes* describing them
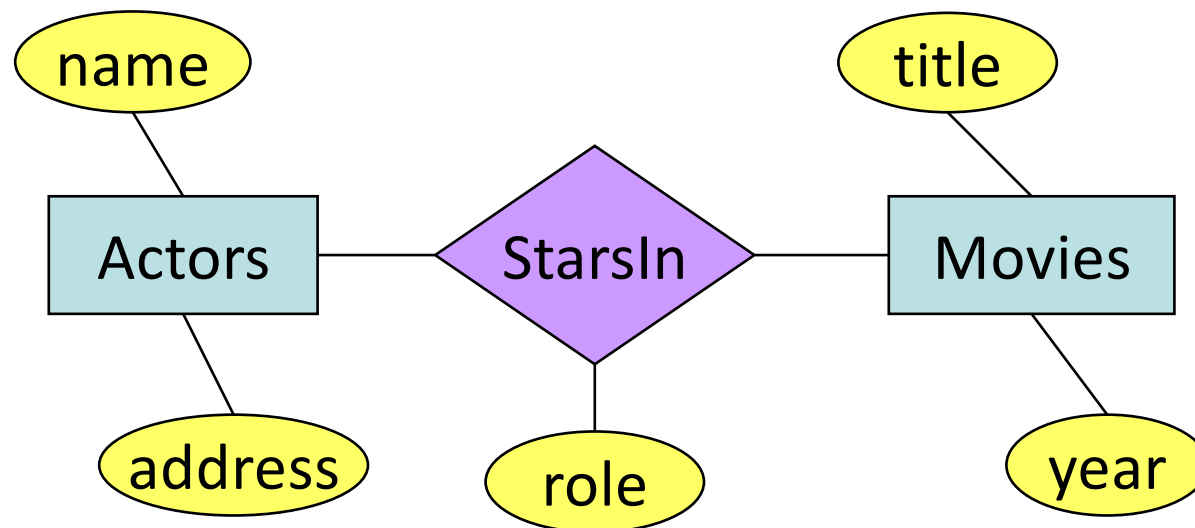
Entity Sets

- An entity set represents a *category* of objects that have properties in common and an autonomous existence (e.g., City, Department, Employee, Sale)
- An entity is an *instance* of an entity set (e.g., Stockholm is a City; Peterson is an Employee)
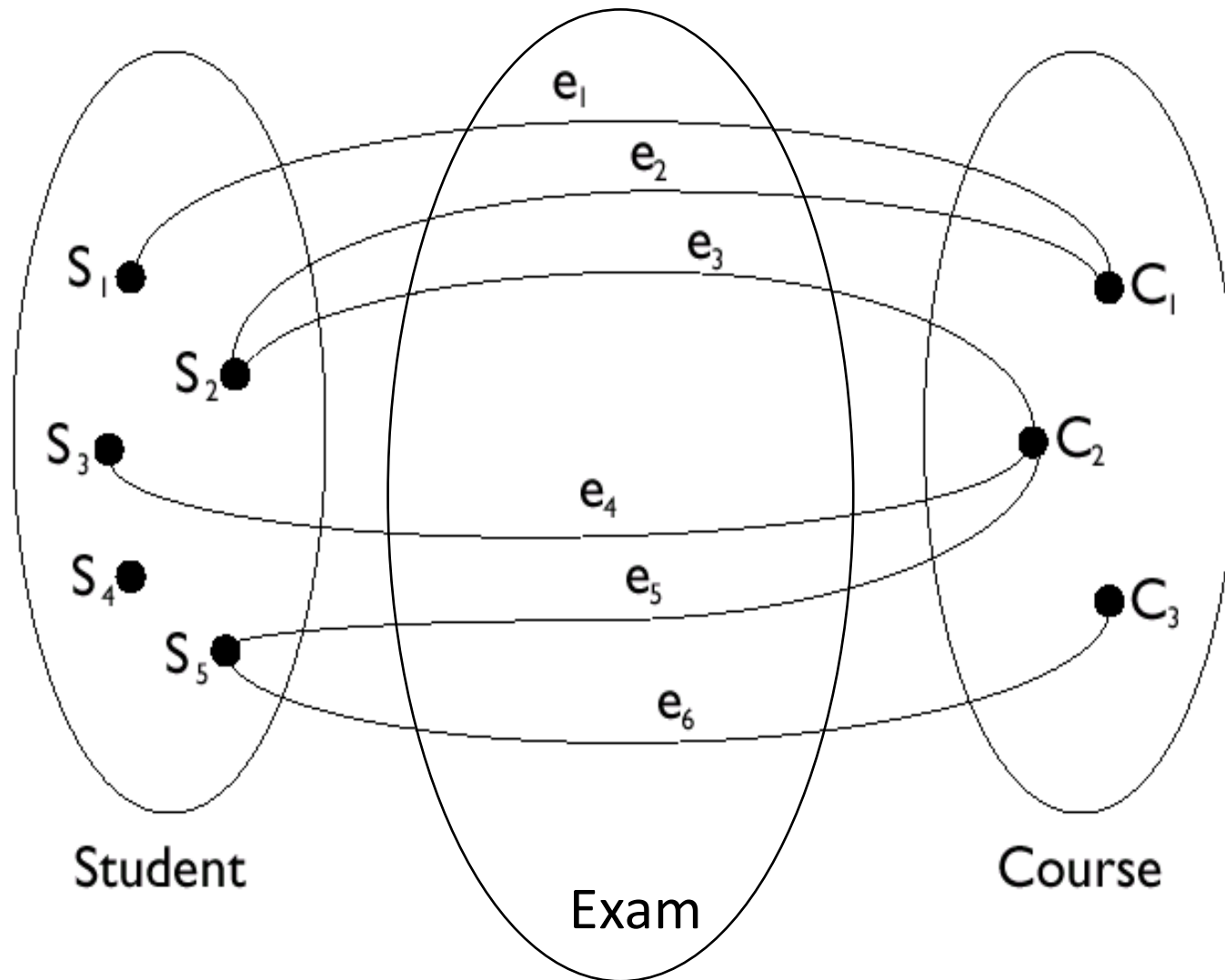
EMPLOYEE

DEPARTMENT

CITY

SALE
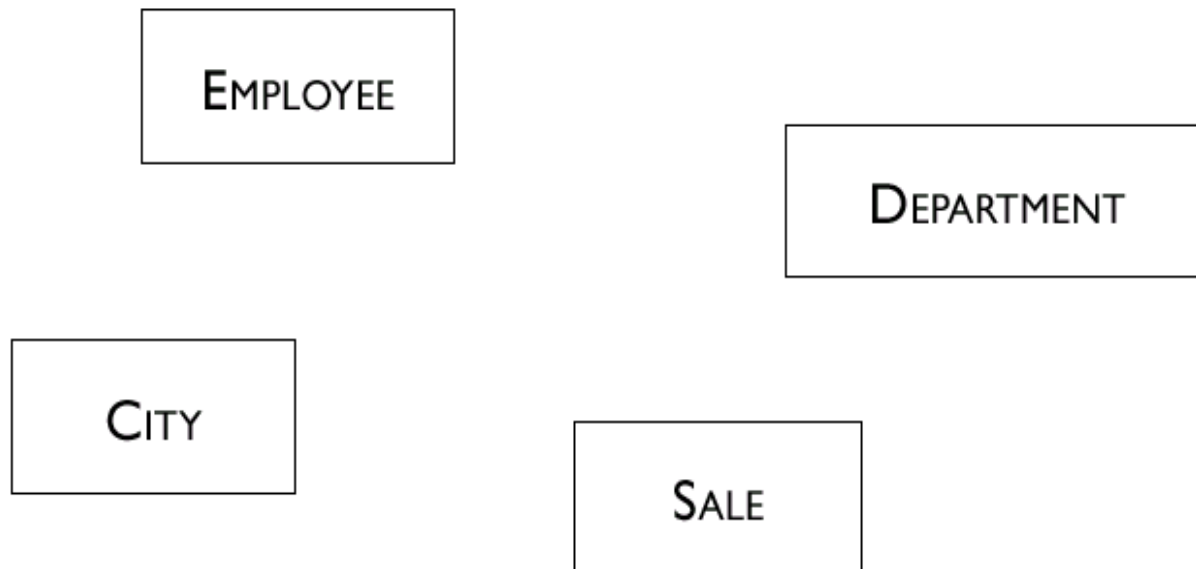
Relationship Sets

- A relationship set is an association between 2+ entity sets (e.g., Residence is a relationship set between entity sets City and Employee)

- A relationship is an instance of a n-ary relationship set (e.g., the pair <Johanssen, Stockholm> is an instance of relationship Residence)
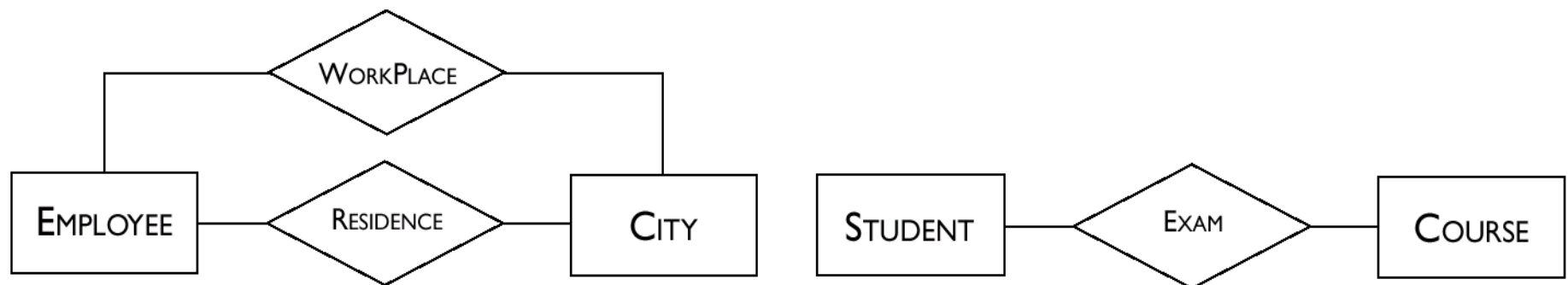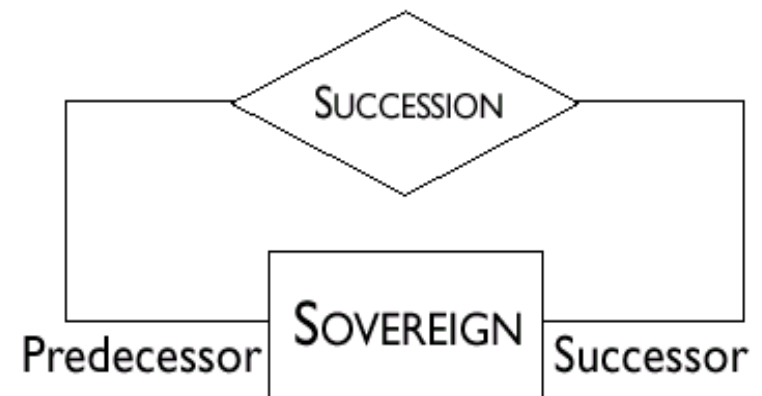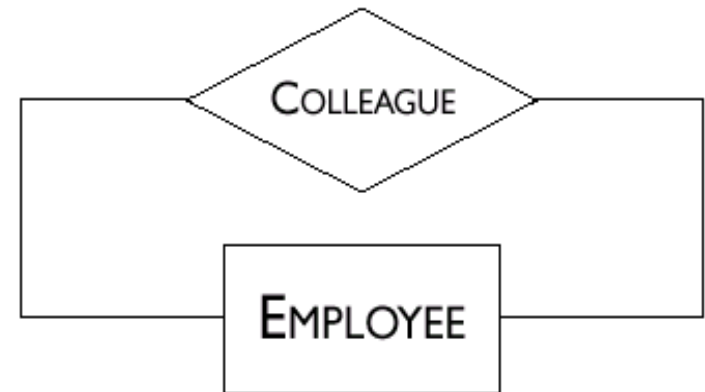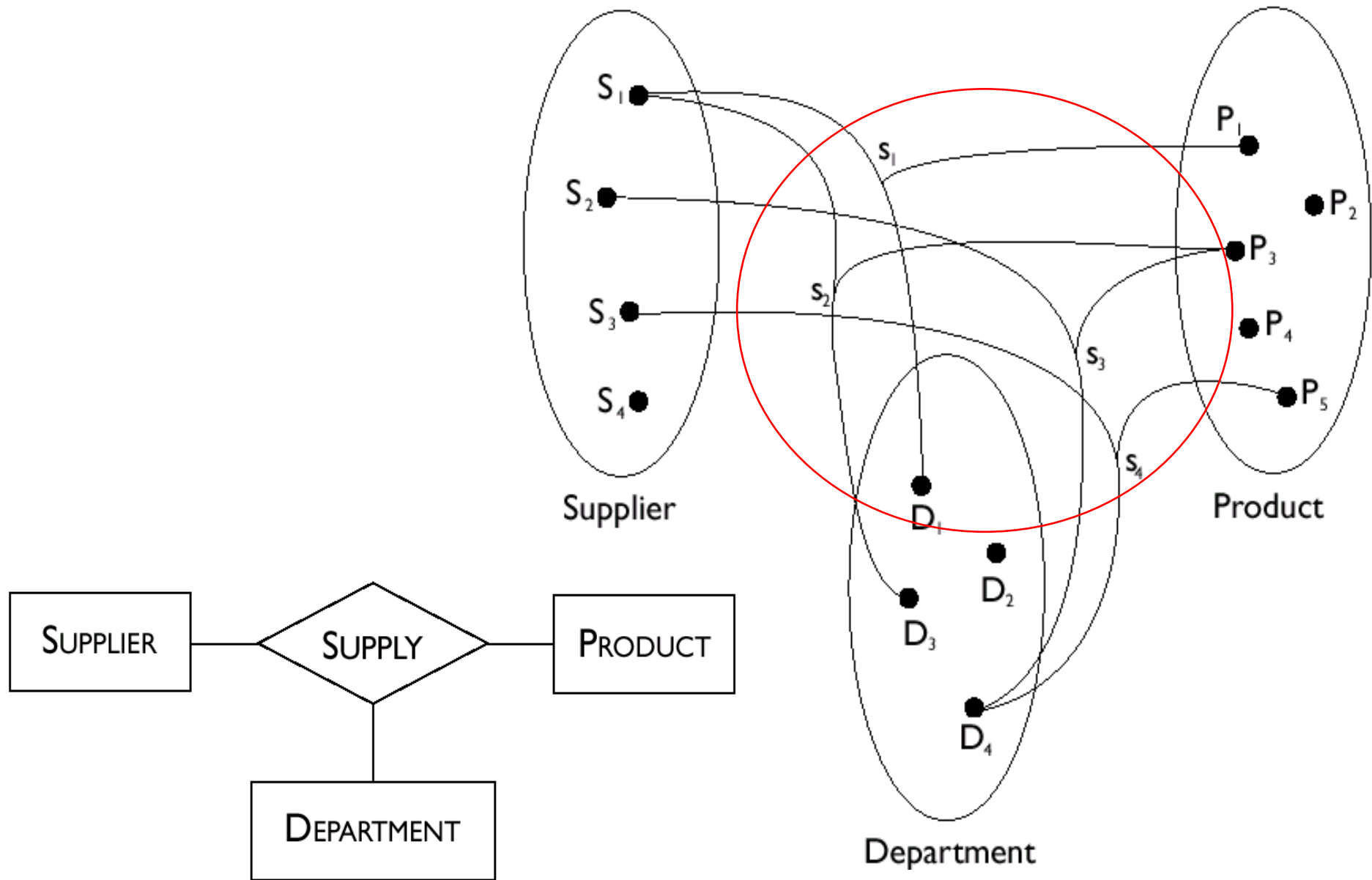
Example of Instances for Exam

Recursive Relationships

- Recursive relationships relate an entity set to itself

- The relationship may not be symmetric

  – If so, we indicate the two roles that the entity plays in the relationship
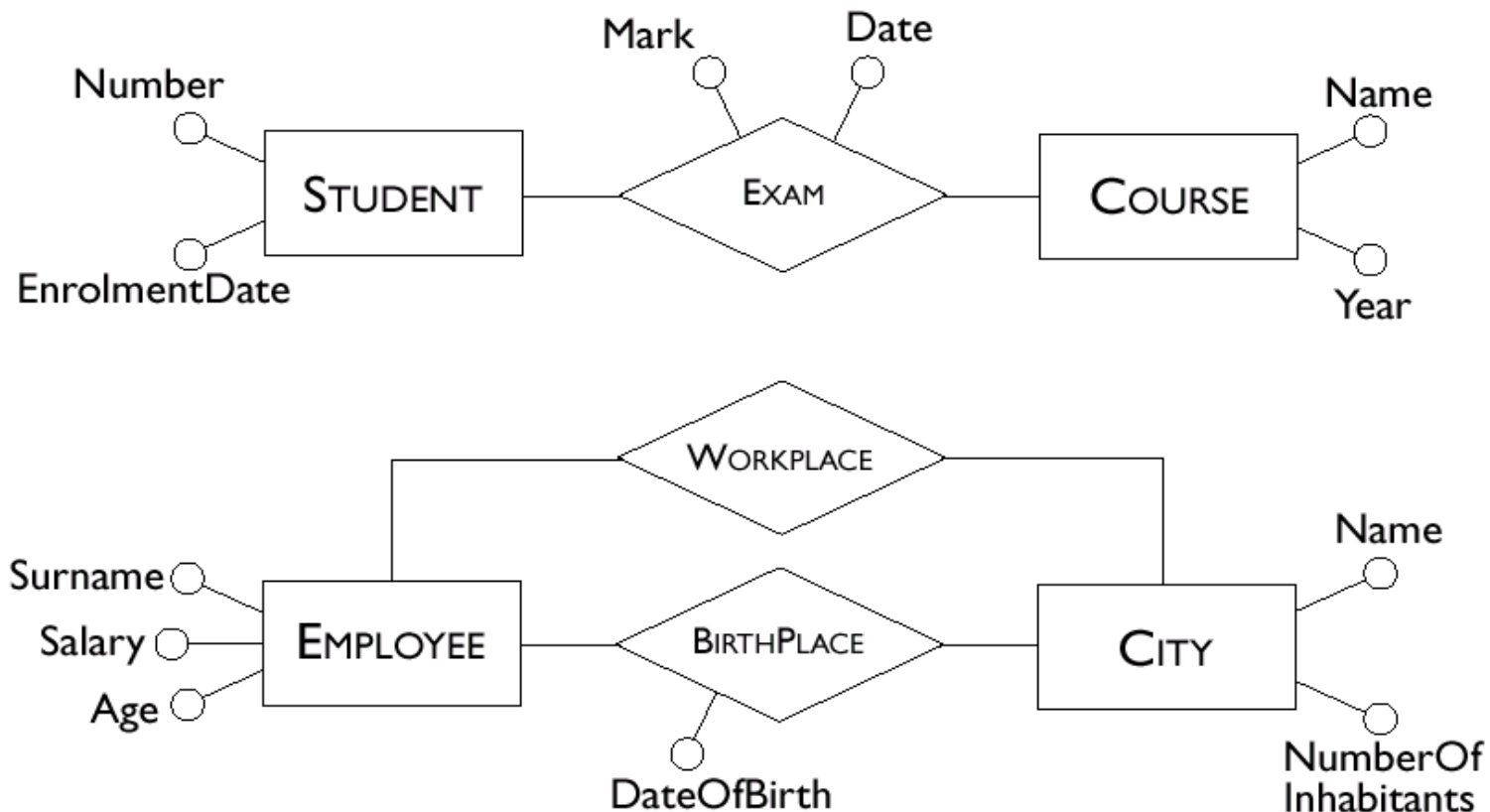
Ternary Relationships

Attributes

- Describe elementary properties of entities or relationships (e.g., Surname, Salary and Age are attributes of Employee)

- May be single-valued, or multi-valued

Composite Attributes

- **composite attributes** are grouped attributes of the same entity or relationship that have closely connected meaning or uses
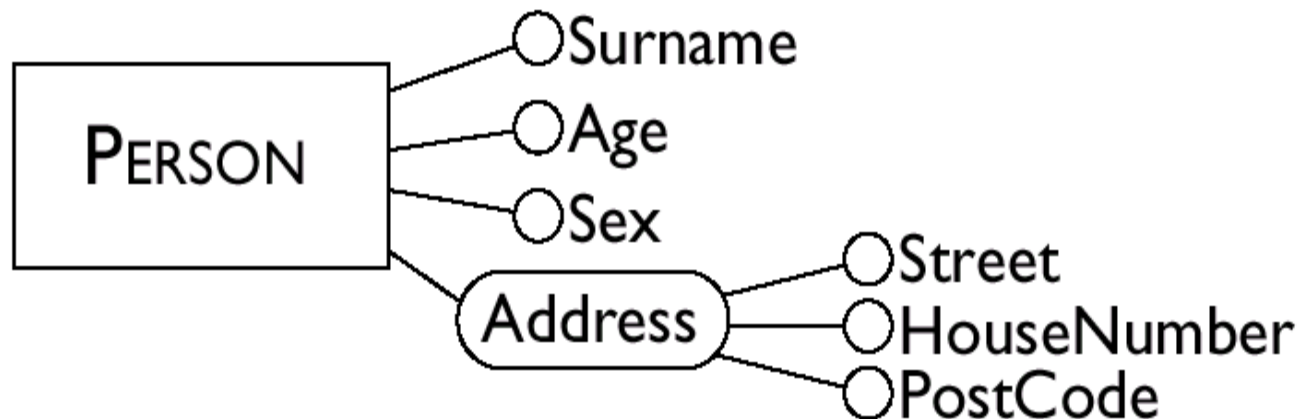
Example Schema with Attributes
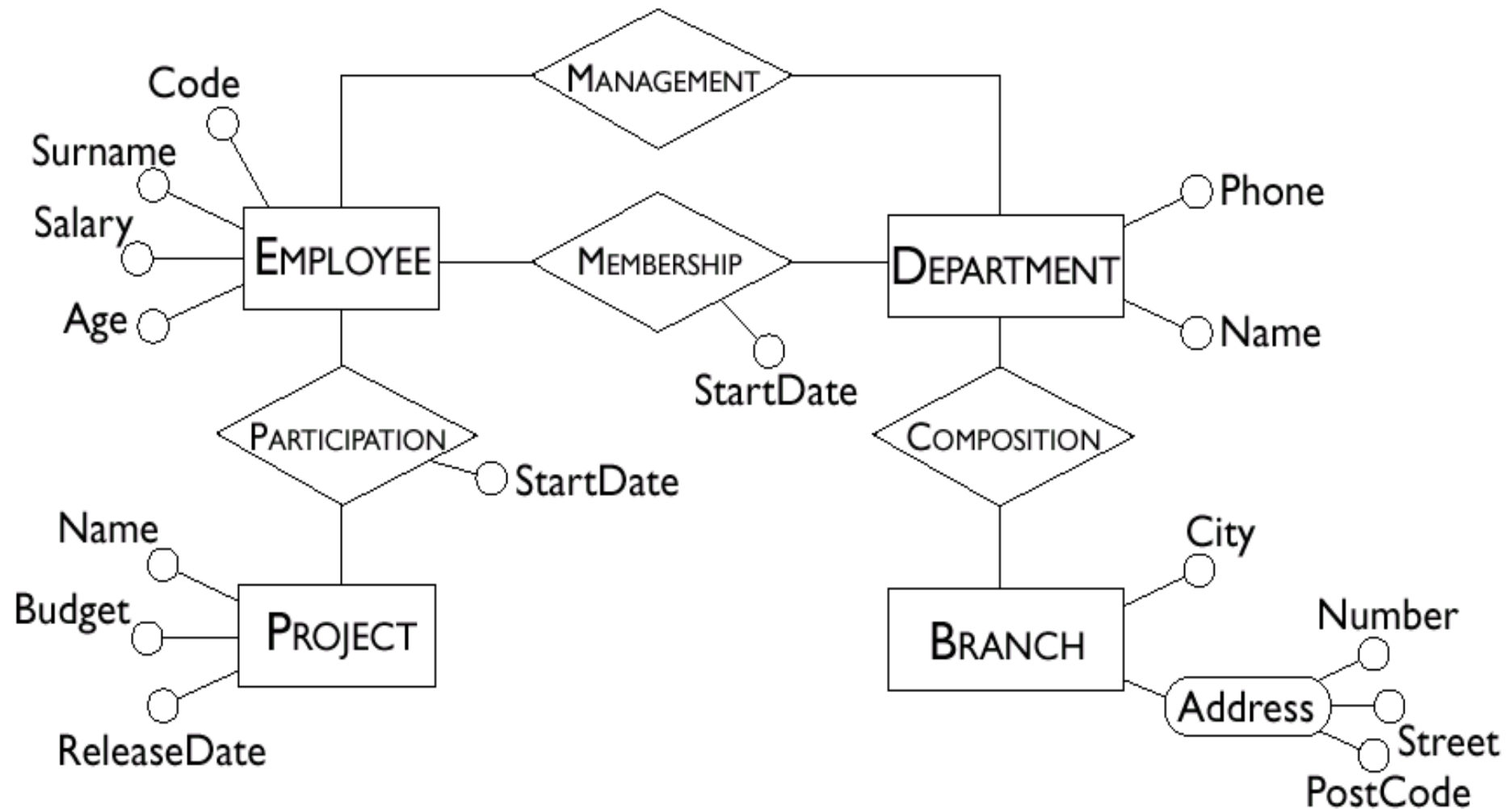
Keys in E/R

- Notation: solid circle
- If multi-attribute, connect with a line and a "knob"
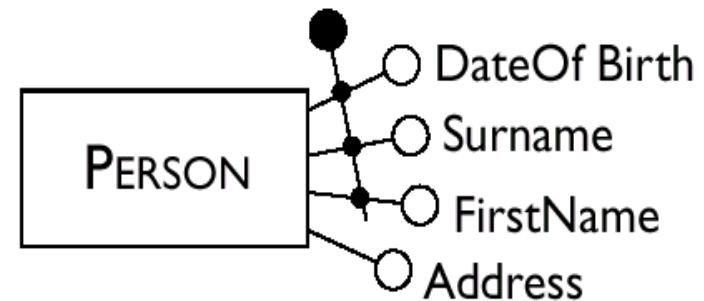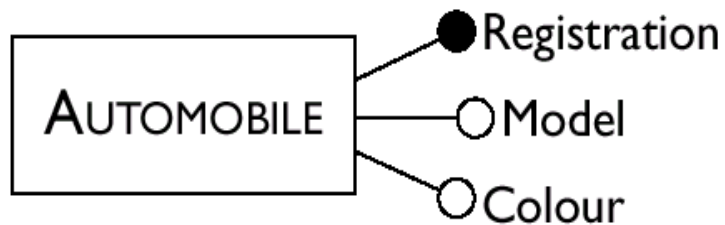
Cardinalities

- Each entity set participates in a relationship set with a minimum (min) and a maximum (max) cardinality

- Cardinalities constrain how entity instances participate in relationship instances

- Notation: pairs of (min, max) values for each entity set

An entity might not participate in any relationship

Cardinalities (cont.)

- In principle, cardinalities are pairs of non-negative integers (n, N) such that n ≤ N, where N means "any number"

- minimum cardinality n:
  - If 0, entity participation in a relationship is optional
  - If 1, entity participation in a relationship is mandatory

- maximum cardinality N:
  - If 1, each instance of the entity is associated at most with a single instance of the relationship
  - If N, then each instance of the entity is associated with many instances of the relationship

Cardinality Examples

ORDER —(0,1)— SALE —(1,1)— INVOICE

PERSON —(1,1)— RESIDENCE —(0,N)— CITY

TOURIST —(1,N)— RESERVATION —(0,N)— VOYAGE
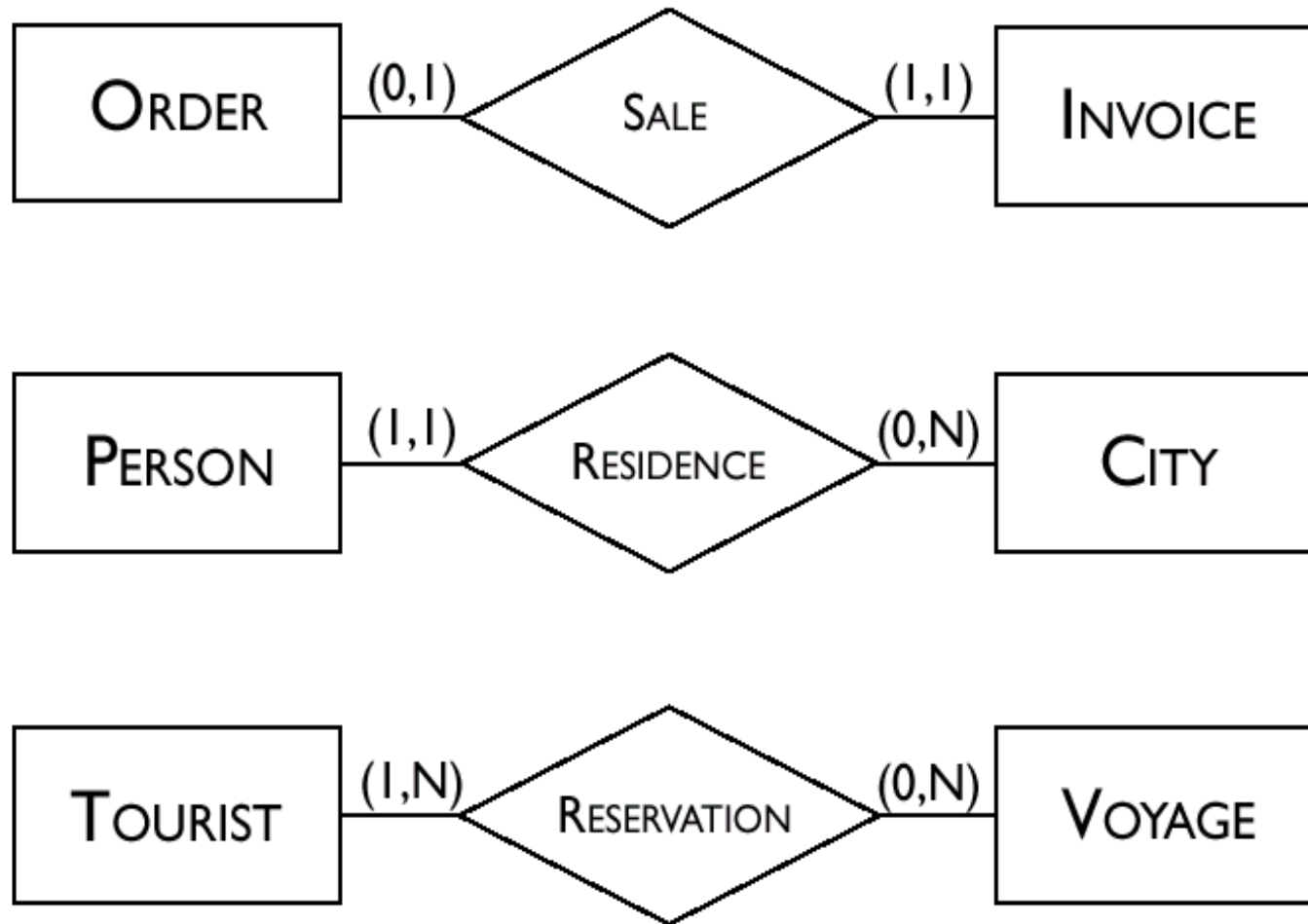
Multiplicity of relationships

If entities E1 and E2 participate in relationship R with cardinalities (n1, N1) and (n2, N2) then the multiplicity of R is N1-to-N2 (which is the same as saying N2-to-N1)
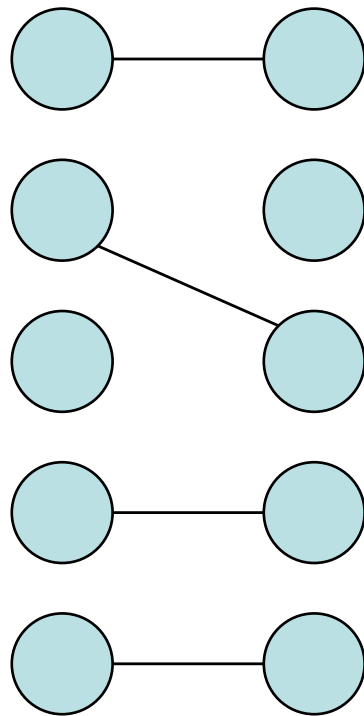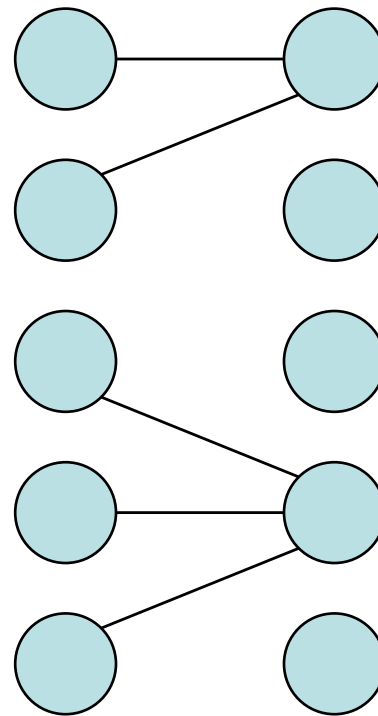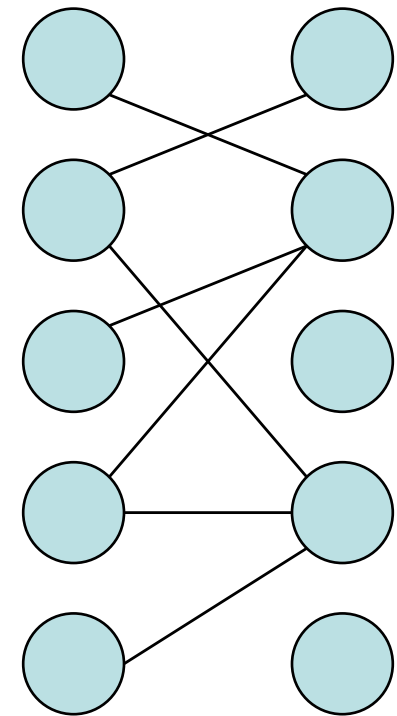
1-to-1   N-to-1 OR 1-to-N   N-to-N

Cardinalities of Attributes

- Describe min/max number of values an attribute can have
- When the cardinality of an attribute is (1, 1) it can be omitted (single-valued attributes)
- The value of an attribute, may also be null, or have several values (multi-valued attributes)

Surname

Person

(0,N)

CarRegistration#

(0,1)

License Number
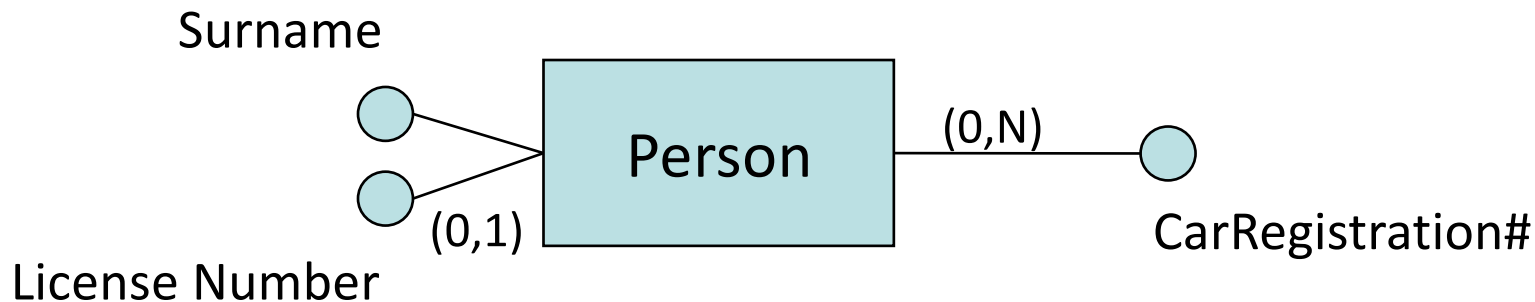
Cardinalities of Attributes (cont.)

- Multi-valued attributes often represent situations that can be modeled with additional entities. E.g., the ER schema of the previous slide can be revised into:

Surname

(0,1)

License Number

Person

(0,N)

Owns

(1,1)

Car

CarRegistration#
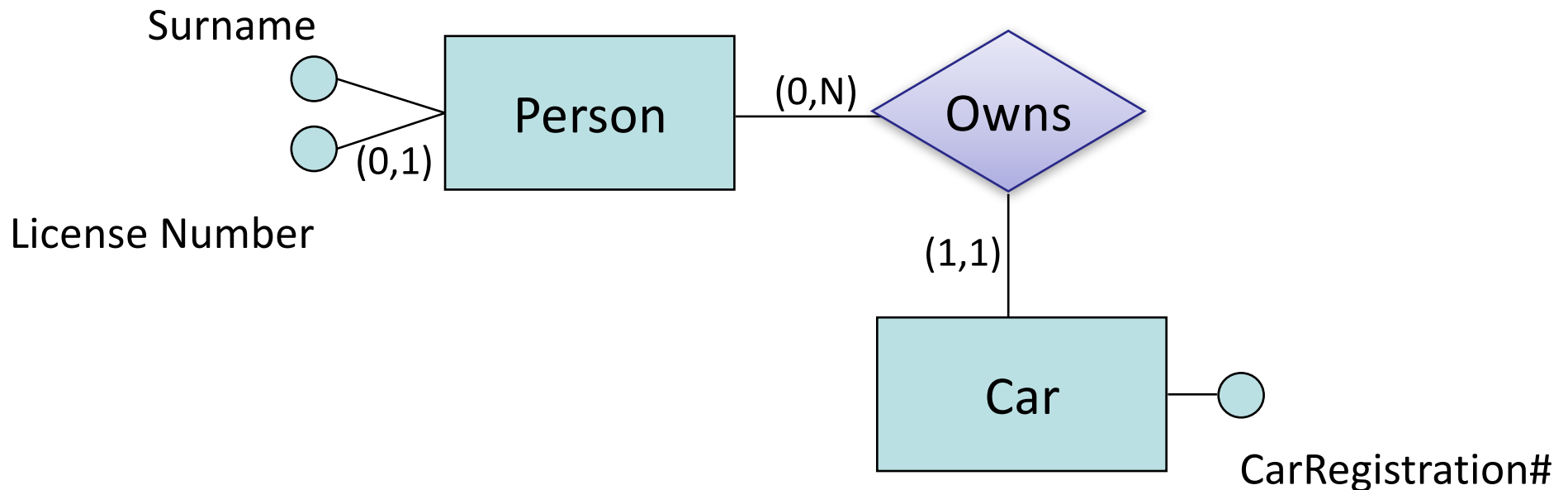
Keys in E/R

- Keys consist of minimal sets of attributes which uniquely identify instances of an entity set.

- Usually, a key is formed by one or more attributes of the entity itself (*internal* keys).

- Sometimes, an entity doesn't have a key among its attributes. This is called a *weak entity*.
  Solution: the keys of related entities brought in to help with identification (becoming *foreign keys*).

- A key for a relationship consists of the keys of the entities it relates

Examples of Keys in E/R

internal, single-attribute

Registration
Model
Colour

AUTOMOBILE
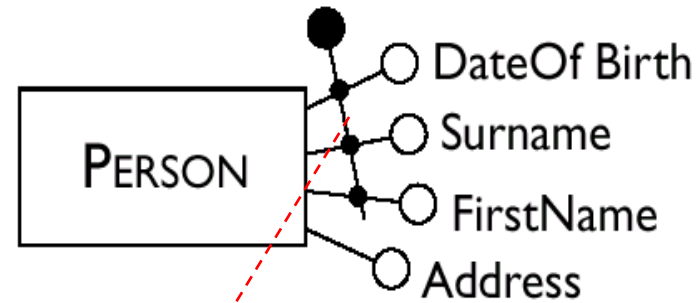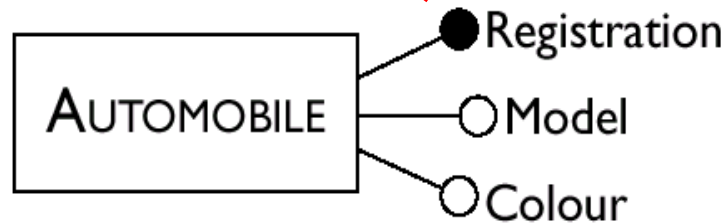
internal, multi-attribute

PERSON
DateOf Birth
Surname
FirstName
Address

foreign, multi-attribute

Registration
Year
Surname

STUDENT
(1,1)
ENROLMENT
(1,N)
UNIVERSITY
Name
City
Address
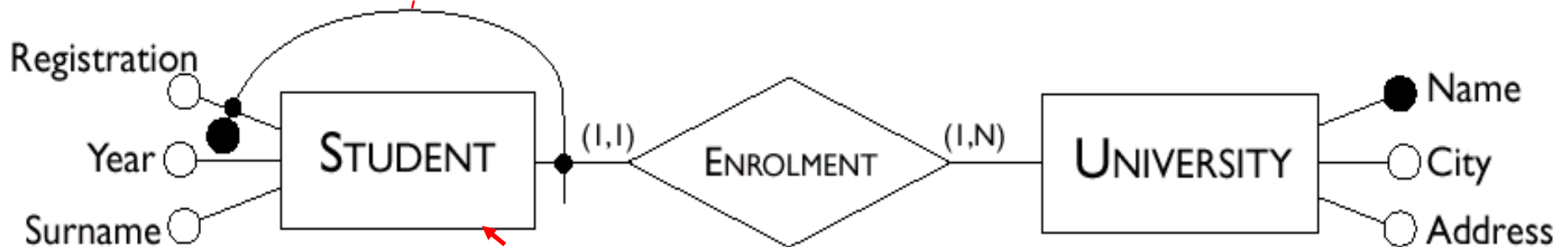
Weak entity

General Observations about Keys

- A key may consist of one or more attributes, provided that each of the attributes has (1,1) cardinality

- A foreign key can involve one or more entities, provided that each of them is member of a relationship to which the entity to be identified participates in the relationship with cardinality equal to (1,1)

- A foreign key may involve an entity that has itself a foreign key, as long as cycles are not generated

- Each entity set must have at least one (internal or foreign) key

Schema with Keys
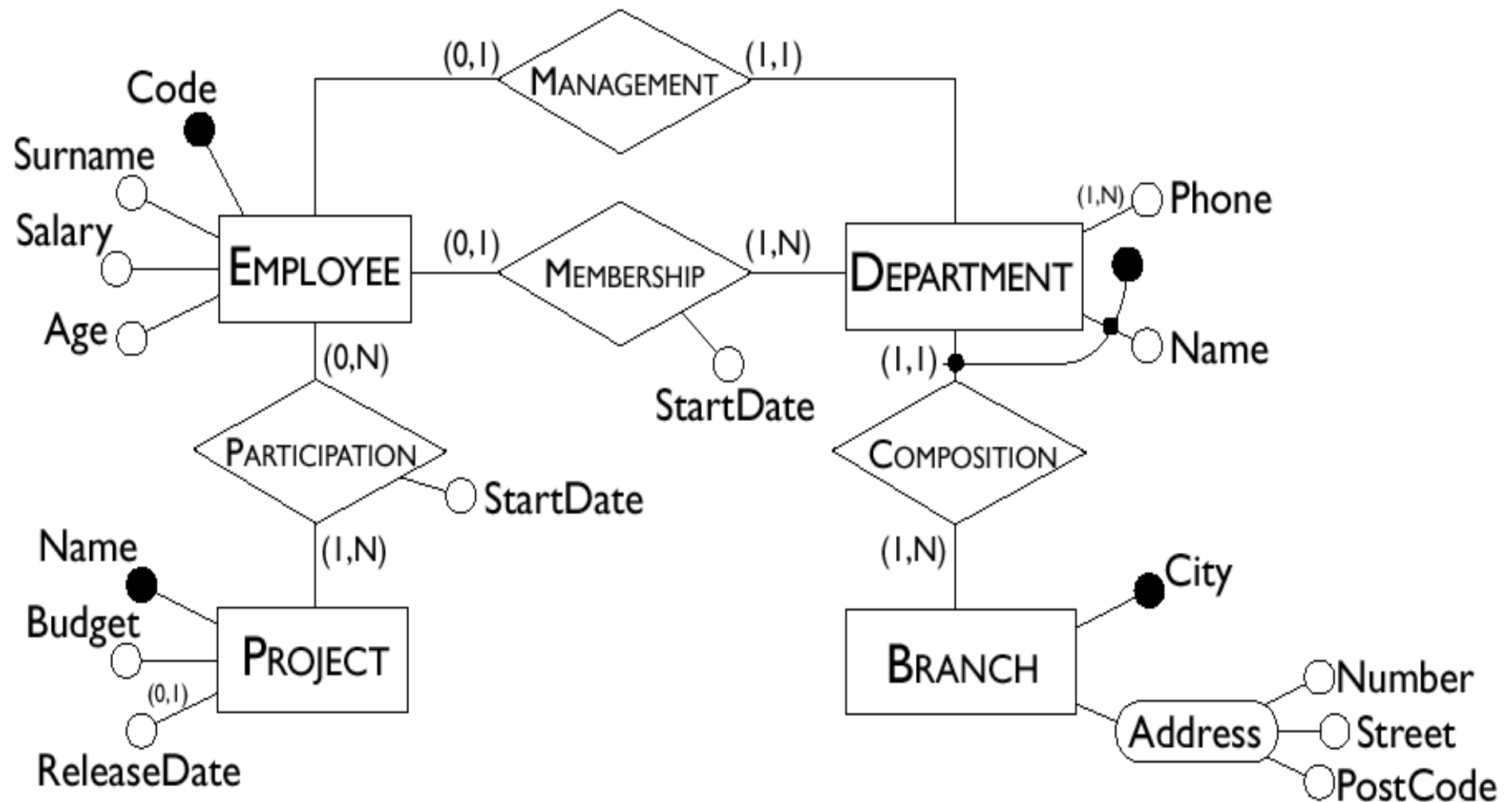
Challenge: modeling the "real world"

- Life is arbitrarily complex
  - Directors who are also actors? Actors who play multiple roles in one movie? Animal actors?

- Design choices: Should a concept be modeled as an entity, an attribute, or a relationship?

- Limitations of the ER Model: A lot of data semantics can be captured but some cannot

- Key to successful model: parsimony
  - As complex as necessary, but no more
  - Choose to represent only "relevant" things

EXAMPLE

From real world to E/R Model

We wish to create a database for a company that runs training courses. For this, we must store data about trainees and instructors. For each course participant (about 5,000 in all), identified by a code, we want to store her social security number, surname, age, sex, place of birth, employer's name, address and telephone number, previous employers (and periods employed), the courses attended (there are about 200 courses) and the final assessment for each course. We need also to represent the seminars that each participant is attending at present and, for each day, the places and times the classes are held.

Each course has a code and a title and any course can be given any number of times. Each time a particular course is given, we will call it an 'edition' of the course. For each edition, we represent the start date, the end date, and the number of participants. If a trainee is self-employed, we need to know her area of expertise, and, if appropriate, her title. For somebody who works for a company, we store the level and position held. For each instructor (about 300), we will show the surname, age, place of birth, the edition of the course taught, those taught in the past and the courses that the tutor is qualified to teach. All the instructors' telephone numbers are also stored. An instructor can be permanently employed by the training company or freelance.

From real world to E/R Model

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Glossary

Term	Description	Synonym	Links
Trainee	Participant in a course. Can be an employee or self-employed.	Participant	Course, Company
Instructor	Course tutor. Can be freelance.	Tutor	Course
Course	Course offered. Can have various editions.	Seminar	Instructor, Trainee
Company	Company by which a trainee is employed or has been employed.		Trainee

More Annotations

We wish to create a database for a company that runs training courses. For this, we must store data about *trainees* and *instructors*. For each *course participant* (about 5,000), identified by a code, we want to store her *social security number, surname, age, sex, place of birth, employer's name, address and telephone number, previous employers (and periods employed)*, courses attended (there are about 200 courses) and the final assessment for each course. We need also to represent *seminars* that each participant is attending at present and, *for each day, the places and times the classes are held.*

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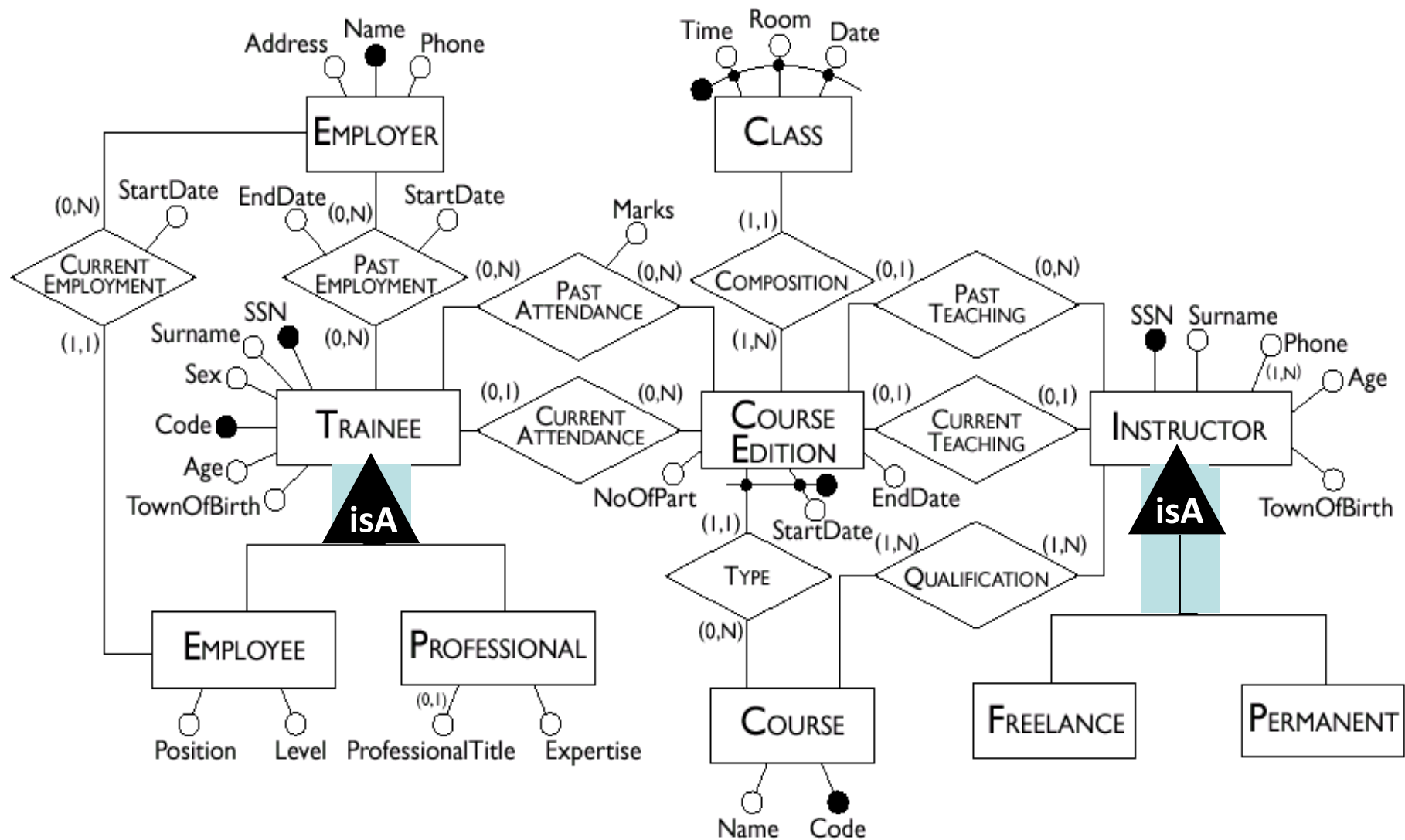
... the E/R model result

FROM E/R MODEL TO DATABASE SCHEMA

Two Steps

- *Restructure* the ER schema to improve it, based on criteria

- *Translate* the schema into the relational model

1. RESTRUCTURING AN E/R MODEL

Restructuring Overview

Input: E/R Schema

Output: Restructured E/R Schema

Restructuring includes:

- Analysis of redundancies

- Choosing entity set vs attribute

- Limiting the use of weak entity sets

- Selection of keys

- Creating entity sets to replace attributes with cardinality greater than one
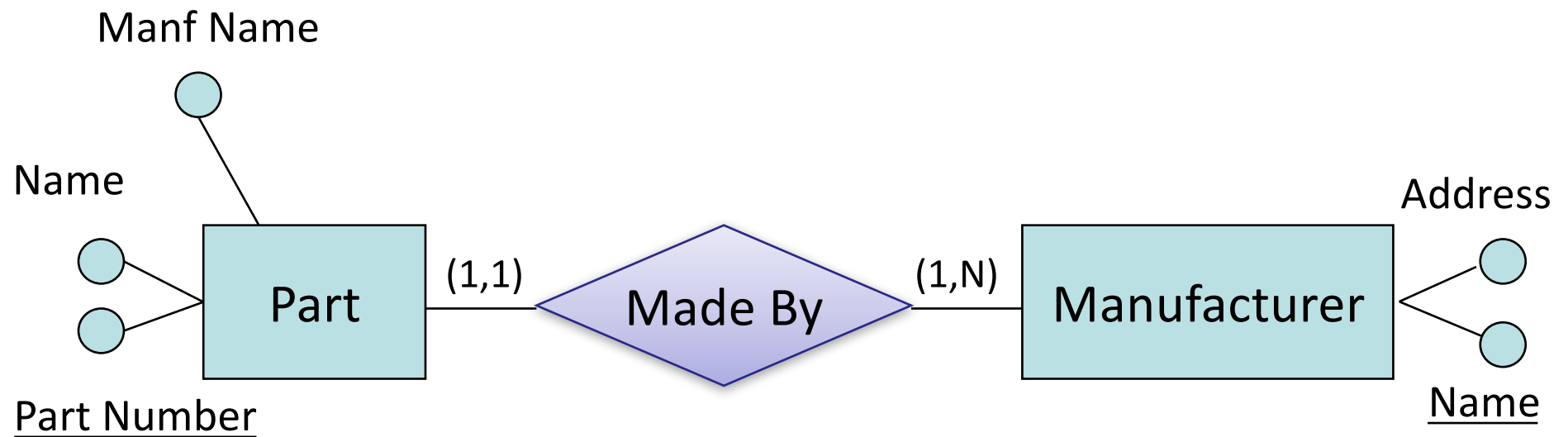
Example: no redundancy
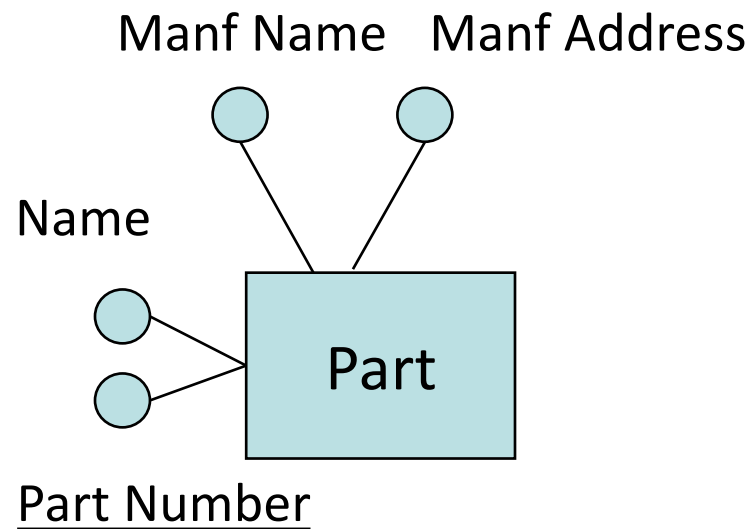
It is not redundant to have Name twice.

Name

Part

(1,1)

Made By

(1,N)

Manufacturer

Part Number

Address
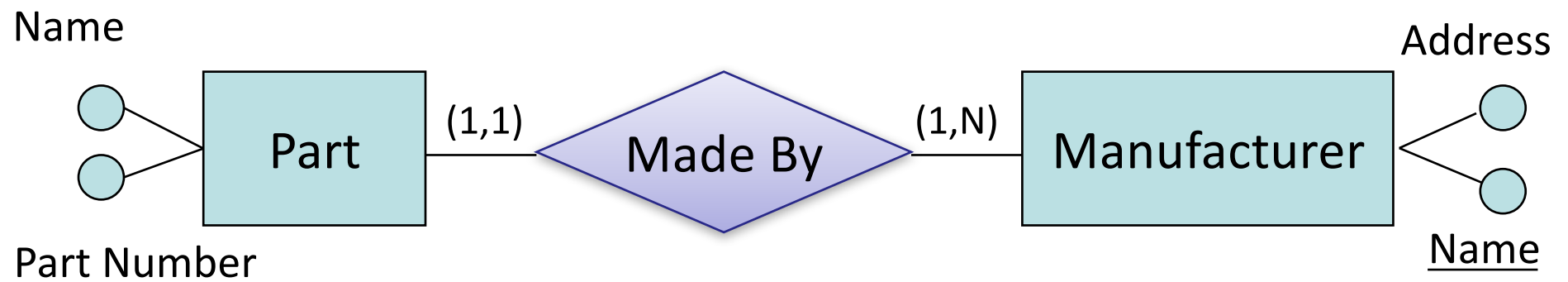
Name

Example: redundancy

What is redundant here?

Example: redundancy

What is redundant here?

Entity Sets Versus Attributes

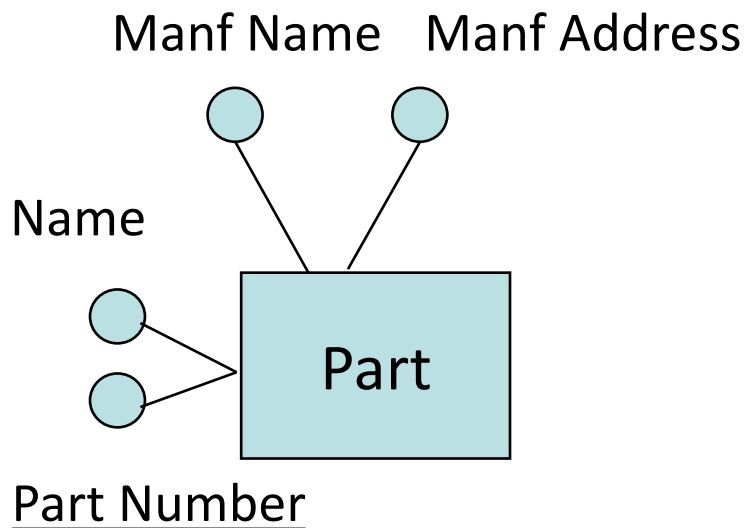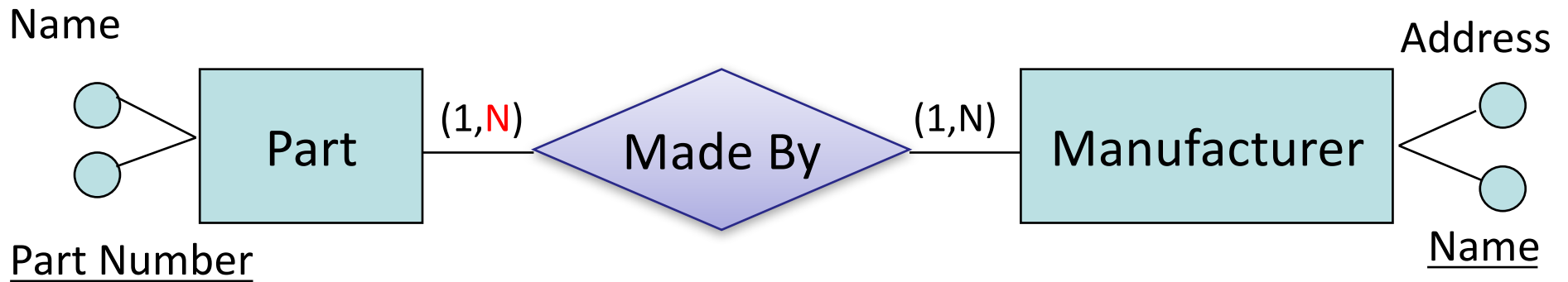- An entity set should satisfy at least one of the following conditions:

    - It is more than the name of something; it has at least one non-key attribute.

        or

    - It is the "many" in a many-one or many-many relationship.

- Rules of thumb

    - A "thing" in its own right => Entity Set

    - A "detail" about some other "thing" => Attribute

Really this is just about avoiding redundancy

E.S. vs. attributes: examples

Domain fact change: A part can have more than one manufacturer …

Name

Part ── (1,N) ── Made By ── (1,N) ── Manufacturer

Part Number

Address

Name

Manf Name   Manf Address

Name

Part

Part Number

E.S. vs. attributes: examples

Domain fact change: Not representing Manufacturer address …

(No address attribute)

Name

Part Number

Part —(1,N)— Made By —(1,N)— Manufacturer

Name

Manf Name

(1,N)

Name

Part

Part Number
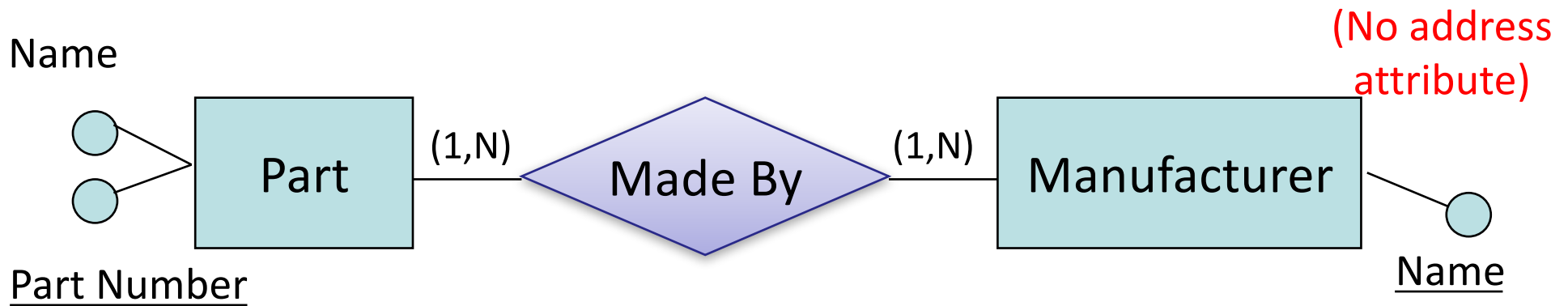
E.S. vs. attributes: examples

New domain

Name

Student number

Student — (0,1) — Mentored by — (1,1) — Mentor

Name
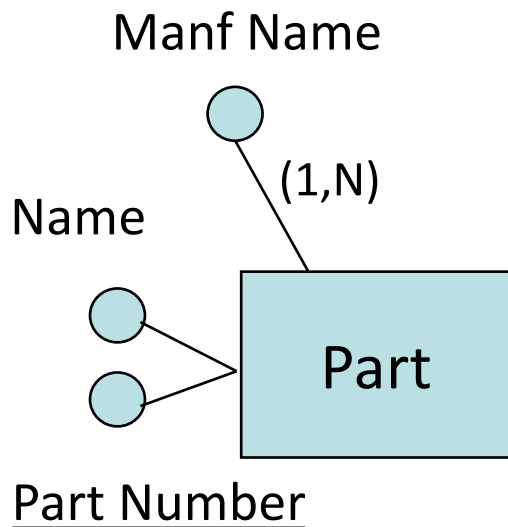
email

Mentor email   Mentor name

Name

Student

Student number
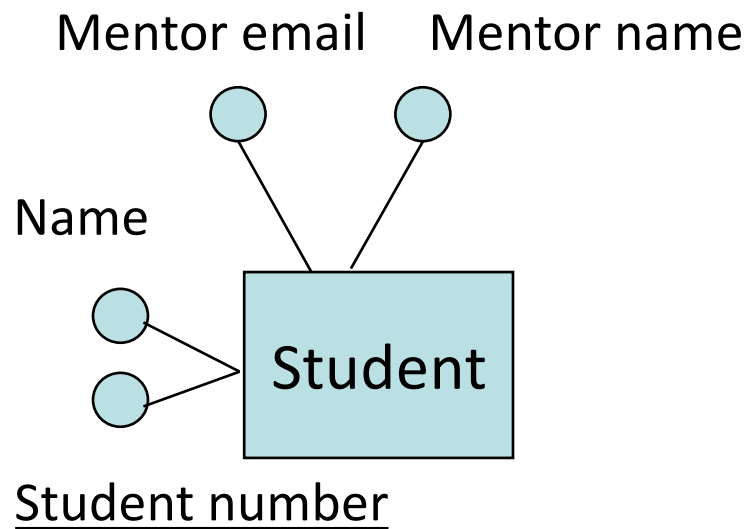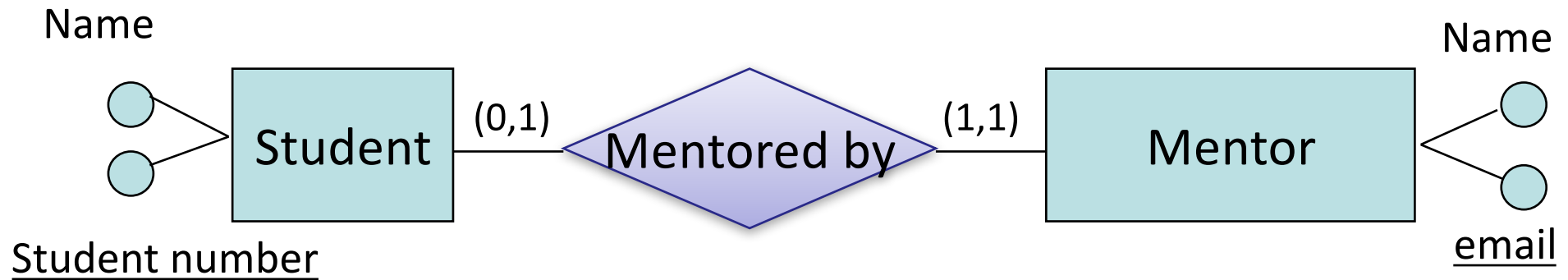
E.S. vs. attributes: examples

Domain fact change: A mentor can have more than one mentee …

Name

Student number

Student — (0,1) — Mentored by — (1,N) — Mentor

Name

email

Mentor email   Mentor name

Name

Student
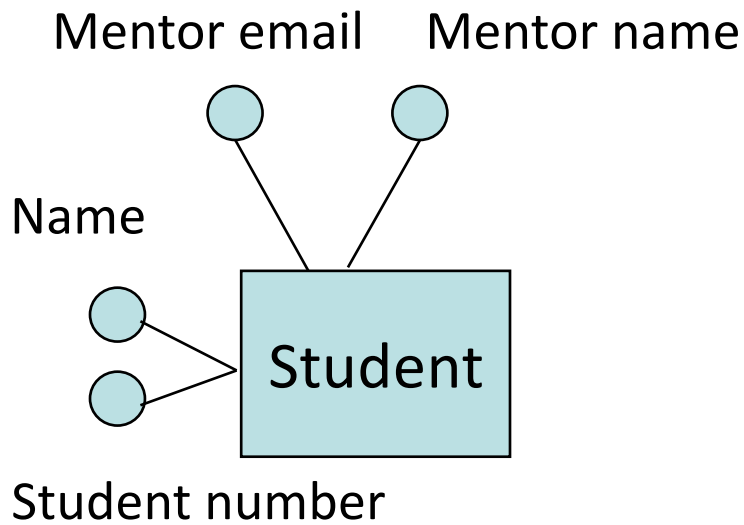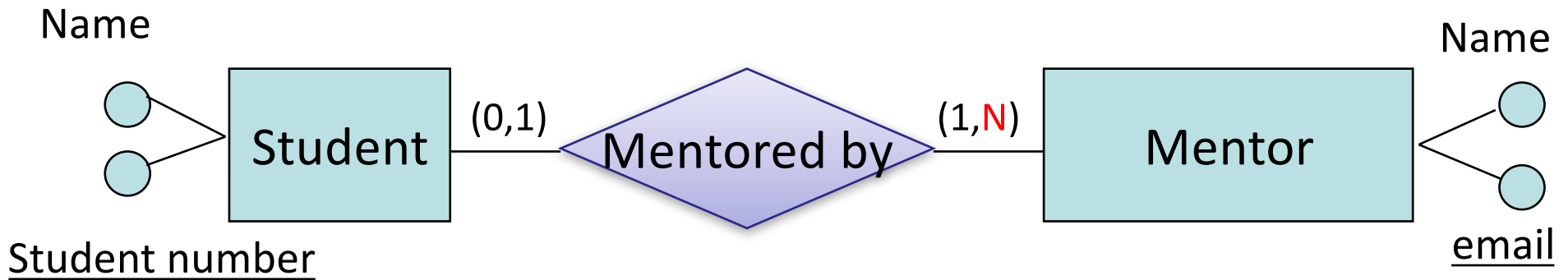
Student number

When to use weak entity sets?

- The usual reason is that there is no global authority capable of creating unique ID's

- Example: it is unlikely that there could be an agreement to assign unique student numbers across all students in the world

Don't Overuse Weak Entity Sets

- Beginning database designers often doubt that anything could be a key by itself
  - They make all entity sets weak, supported by all other entity sets to which they are linked

- It is usually better to create unique IDs
  - Social insurance number, automobile VIN, etc.
  - Useful for many reasons (next slide)

Selecting a Primary Key

- Every relation must have a primary key
- The criteria for this decision are as follows:
  - Attributes with null values cannot form primary keys
  - One/few attributes is preferable to many attributes
  - Internal keys preferable to external ones (weak entities depend for their existence on other entities)
  - A key that is used by many operations to access instances of an entity is preferable to others

Keeping keys simple

Multi-attribute and/or string keys…

- … are wasteful
  - e.g. Movies(<u>title</u>, <u>year</u>, …): 2 attributes, ~16 bytes
  - Number of movies ever made << 2^{32} (4 bytes)

  => Integer movieID key saves 75% space and a lot of typing

- … break encapsulation
  - e.g. Patient(<u>firstName</u>, <u>lastName</u>, <u>phone</u>, …)
  - Security/privacy hole

  => Integer patientID prevents information leaks

- … are brittle (nasty interaction of above two points)
  - Name or phone number change? Parent and child with same name?
  - Patient with no phone? Two movies with same title and year?

  => Internal ID always exist, are immutable, unique

Also: computers are really good at integers…

Attributes with cardinality > 1

- The relational model doesn't allow multi-valued attributes. We must convert these to entity sets.
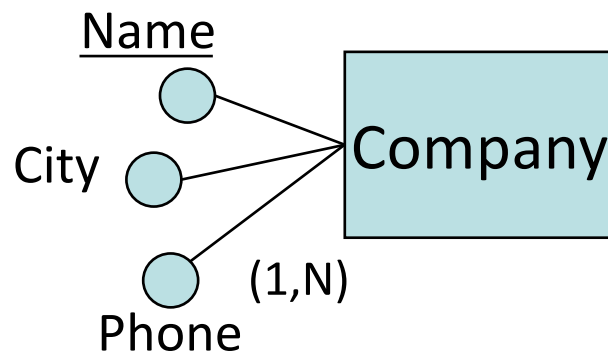
2. TRANSLATING AN E/R MODEL INTO A DB SCHEMA

Translation into a Logical Schema

Input: E/R Schema

Output: Relational Schema

- Starting from an E/R schema, an equivalent relational schema is constructed
  - "equivalent": a schema capable of representing the same information

- A good translation should also:
  - not allow redundancy
  - not invite unnecessary null values

The general idea

- Each entity set becomes a relation.
  Its attributes are

  - the attributes of the entity set.

- Each relationship becomes a relation.
  It's attributes are

  - the keys of the entity sets that it connects, plus

  - the attributes of the relationship itself.

- We'll see opportunities to simplify.

Many-to-Many Binary Relationships
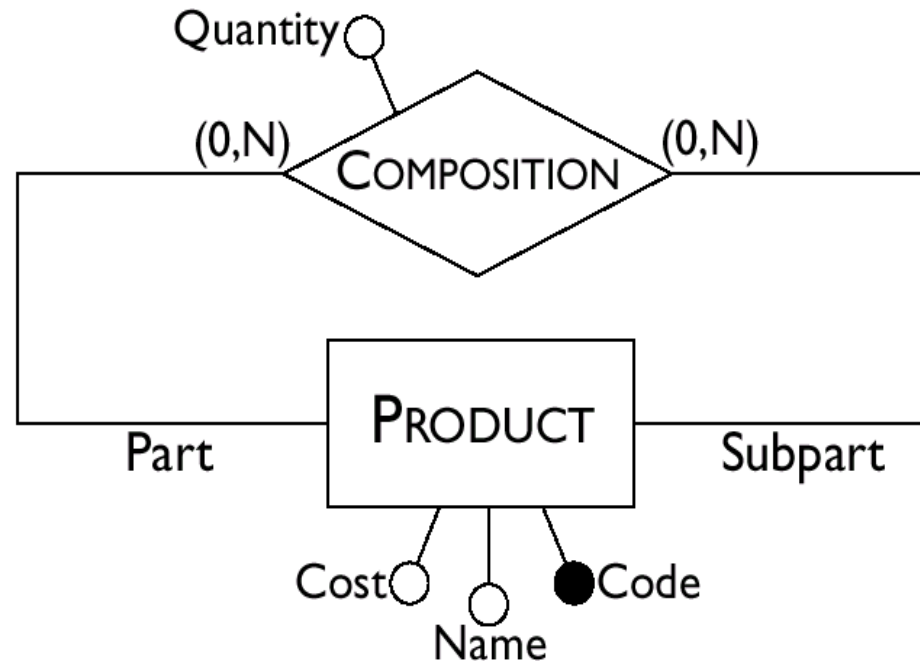

Employee(<u>Number</u>, Surname, Salary)

Project(<u>Code</u>, Name, Budget)

Participation(<u>Number, Code</u>, StartDate)

        Participation[Number] $\subseteq$ Employee[Number]

        Participation[Code] $\subseteq$ Project[Code]

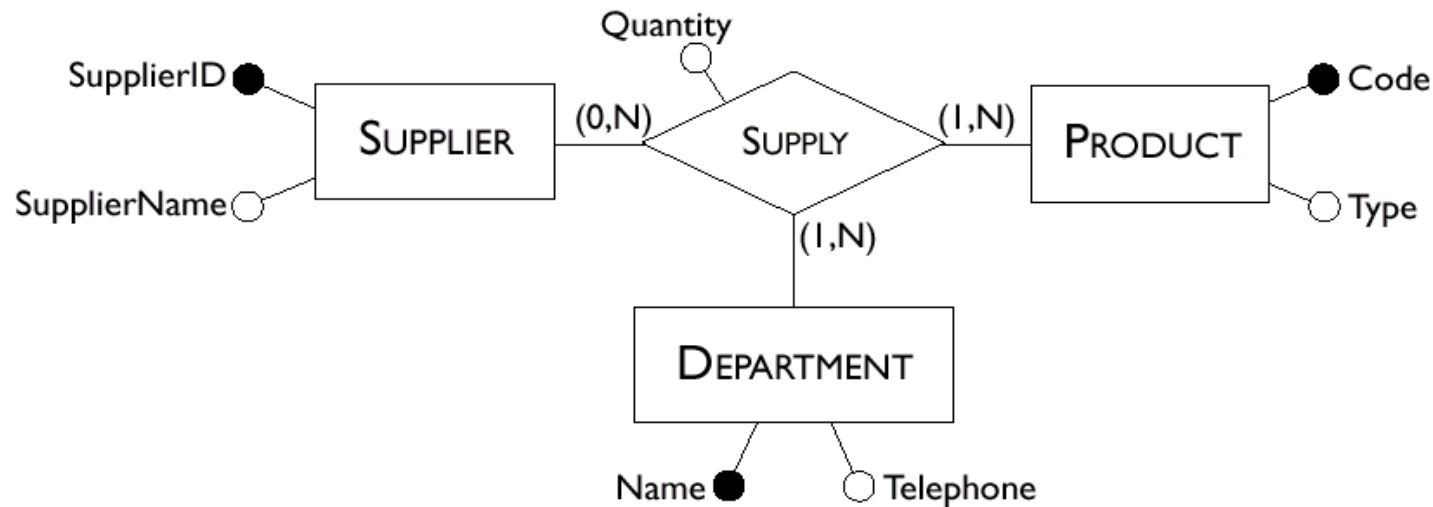# Many-to-Many Recursive Relationships

Product(<u>Code</u>, Name, Cost)

Composition(<u>Part, SubPart</u>, Quantity)

Composition[Part] ⊆ Product[Code]

Composition[SubPart] ⊆ Product[Code]

Many-to-Many Ternary Relationships

Supplier(<u>SupplierID</u>, SupplierName)

Product(<u>Code</u>, Type)

Department(<u>Name</u>, Telephone)

Supply(<u>Supplier, Product, Department</u>, Quantity)

$\quad\quad\quad$ Supply[Supplier] $\subseteq$ Supplier[SupplierID]

$\quad\quad\quad$ Supply[Product] $\subseteq$ Product[Code]

$\quad\quad\quad$ Supply[Department] $\subseteq$ Department[Name]

One-to-Many Relationships
with mandatory participation on the "one" side
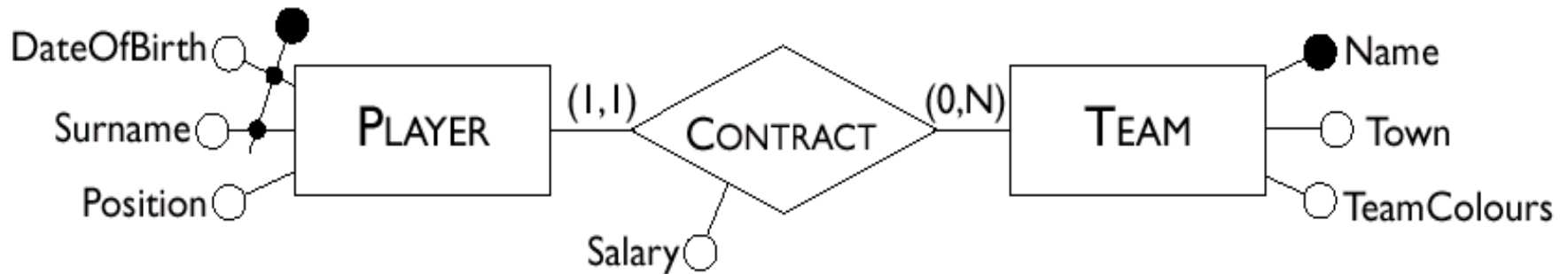
Player(<u>Surname, DateOfBirth</u>, Position)

Team(<u>Name</u>, Town, TeamColours)

Contract(<u>PlayerSurname, PlayerDateOfBirth</u>, Team, Salary)

OR

Player(<u>Surname, DateOfBirth</u>, Position, TeamName, Salary)

Team(<u>Name</u>, Town, TeamColours)

Player[TeamName] ⊆ Team[Name]

One-to-One Relationships
with mandatory participation for both

The standard translation, with 3 relations

Or

Head(<u>Number</u>, Name, Salary, Department, StartDate)

Department(<u>Name</u>, Telephone, Branch)

$\qquad$ Head[Department] $\subseteq$ Department[Name]

Or

Head(<u>Number</u>, Name, Salary, StartDate)

Department(<u>Name</u>, Telephone, HeadNumber, Branch)

$\qquad$ Department[HeadNumber] $\subseteq$ Head[Number]

One-to-One Relationships
with optional participation for one

Employee(<u>Number</u>, Name, Salary)
Department(<u>Name</u>, Telephone, Branch, Head, StartDate)

Management(Head, Department, StartDate)

Management[Head] $\subseteq$ Employee[Number]

Management[Department] $\subseteq$ Department[Name]

Or

Employee(<u>Number</u>, Name, Salary)
Department(<u>Name</u>, Telephone, Branch, Head, StartDate)

Department[Head] $\subseteq$ Employee[Number]

Summary of Types of Relationship

- many-to-many (binary or ternary)
- one-to-many
  - mandatory: (1,1) on the "one" side
  - optional: (0,1) on the "one" side
- one-to-one
  - both mandatory: (1,1) on both sides
  - one mandatory, one optional:
    (1,1) on one side and (0,1) on other side
  - both optional: (0,1) on both sides

Will the schema be "good"?

- If we use this process, will the schema we get be a good one?

- The process should ensure that there is no redundancy.

- But only with respect to what the E/R diagram represents.

- Crucial thing we are missing: functional dependencies. (We only have keys, not other FDs.)

- So we still need FD theory.

Redundancy can be *desirable*

- **Disadvantages** of redundancy:
  - More storage (but usually at negligible cost)
  - Additional operations to keep the data consistent

- **Advantages** of redundancy:
  - Speed: Fewer accesses necessary to obtain information

- How to decide to maintain or eliminate a redundancy? Examine:
  - the cost of operations that involve the redundant information and
  - the storage needed for the redundant information

  with and without the redundancy.

Performance analysis is required to decide about redundancy