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

csc343, Introduction to Databases
Winter 2019

Overview

- The Entity/Relationship (ER) Model (and its application to modeling the real world)
- Database schema design
  - Restructuring of an E/R model
  - Translating an E/R model into a logical model (DB Schema)

Conceptualizing the real-world

- DB design begins with a client who wants an information system.

- We must map the entities and relationships of the world (our client's domain) into the concepts of a database. This is called *modeling*.

- Sketching the key components is a first step of developing 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

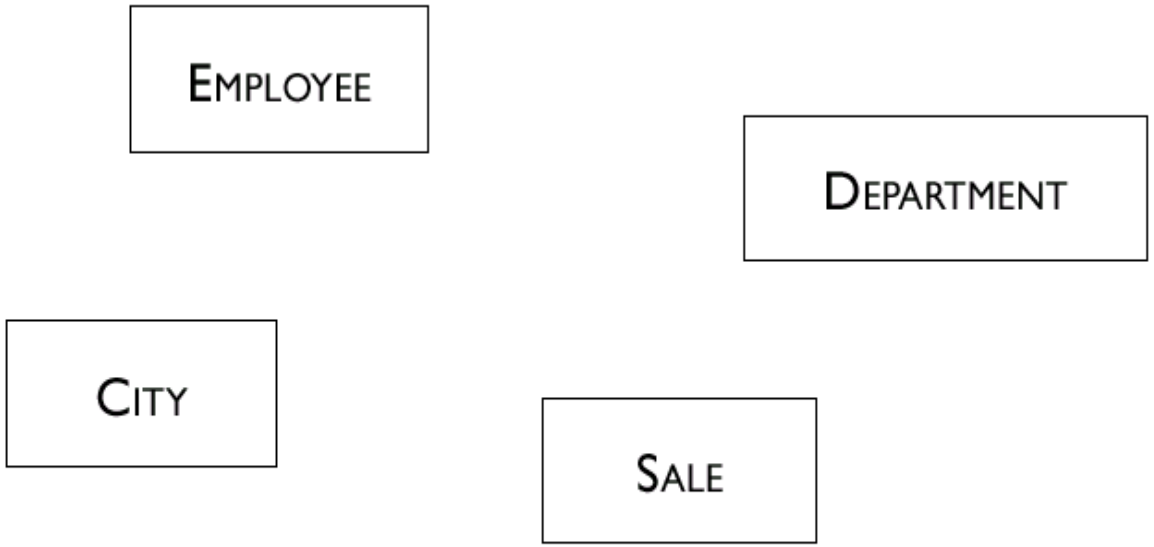
- Visual data model (diagram-based)
  - Quickly "chart out" a database design
  - Easier to "see" big picture
  - Comparable to class diagrams in UML

- Basic concepts/components:
  - *entities*
  - *relationships* among them
  - *attributes* describing the entities and relationships

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)

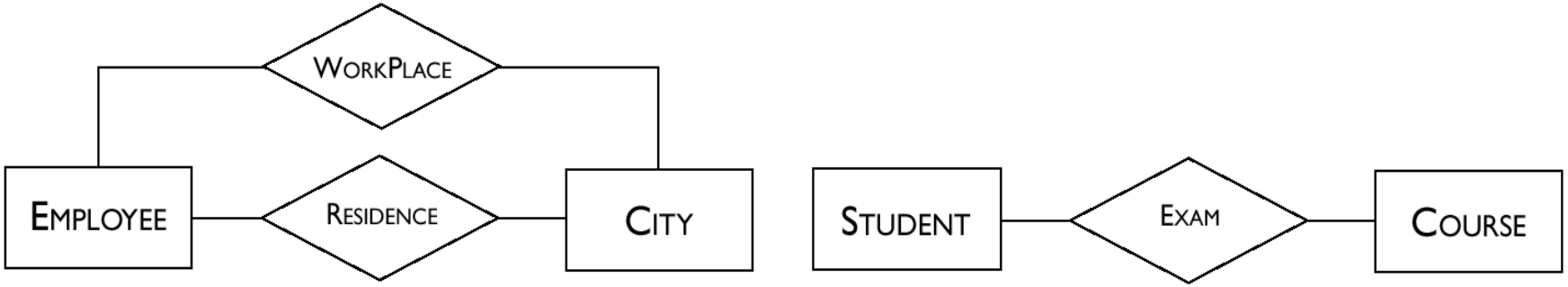
- An entity is an ***instance*** of an **entity set** (e.g., Stockholm is a City; Peterson is an Employee)



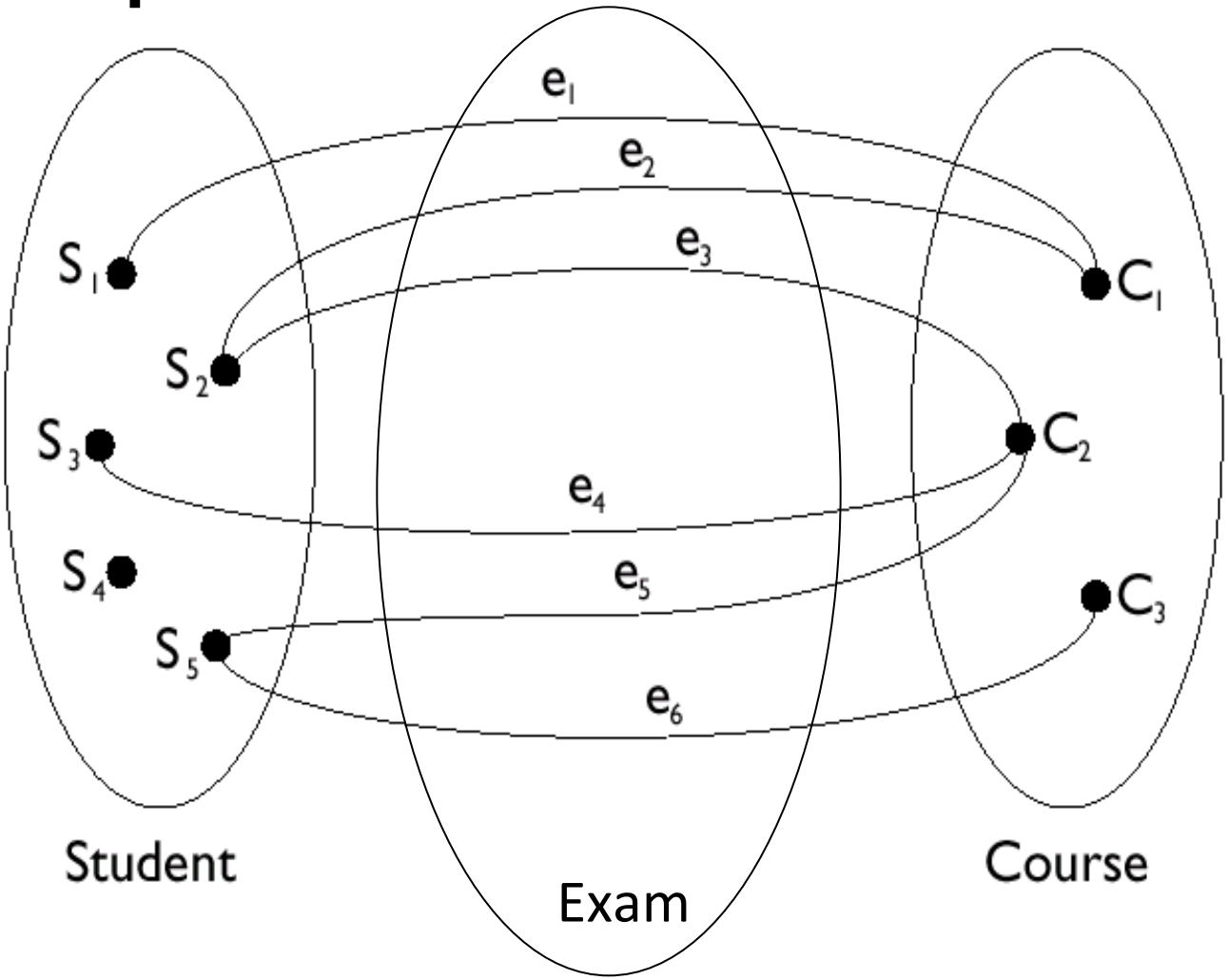
Relationship Sets

- 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)

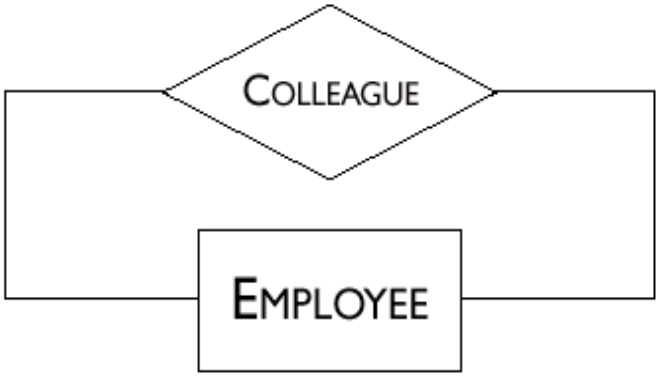


Example of Instances for Exam

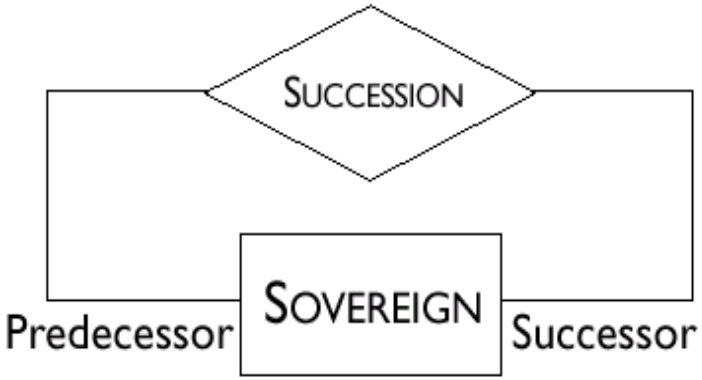


Recursive Relationships

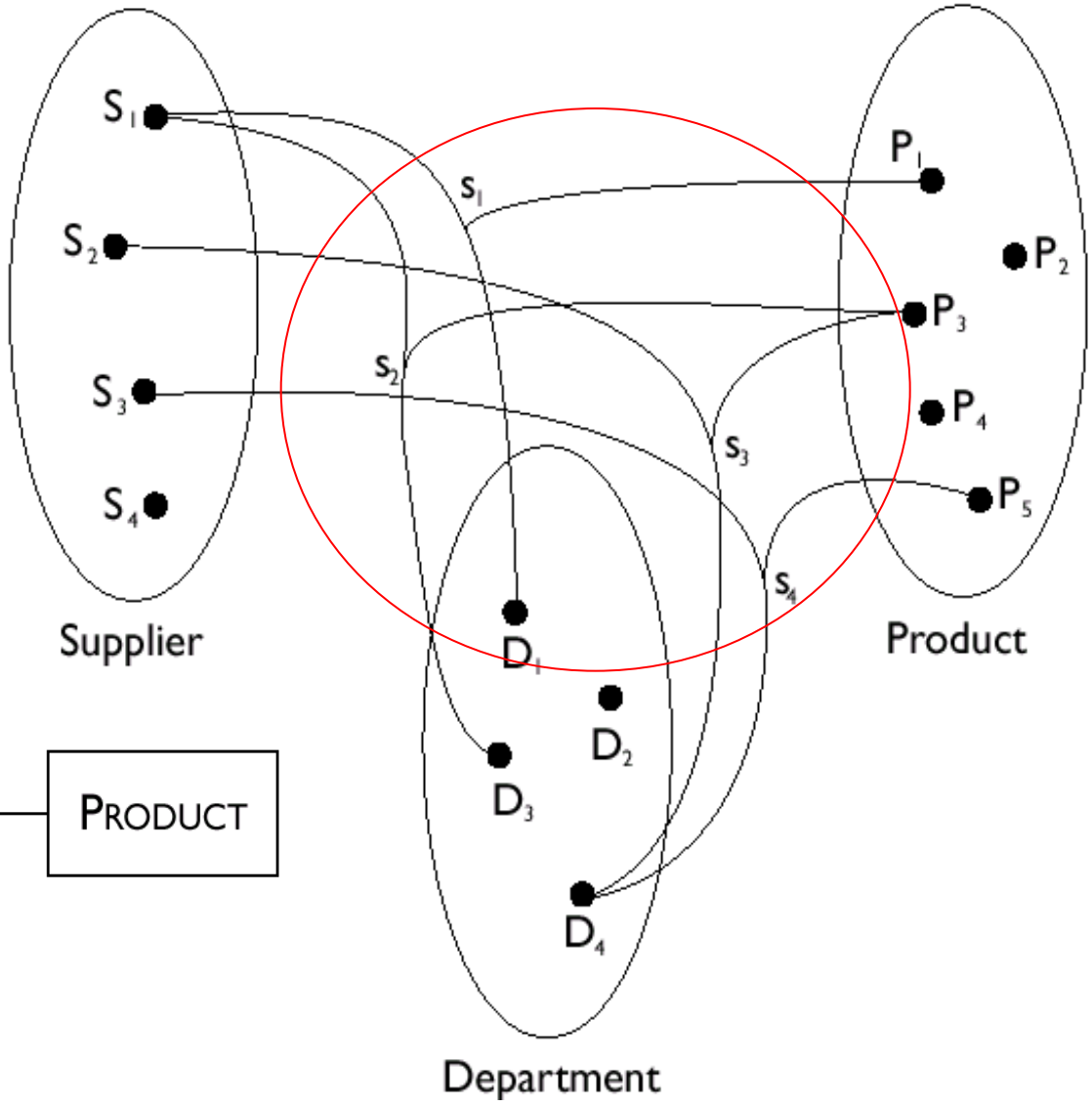
- Recursive relationships relate an entity set to itself

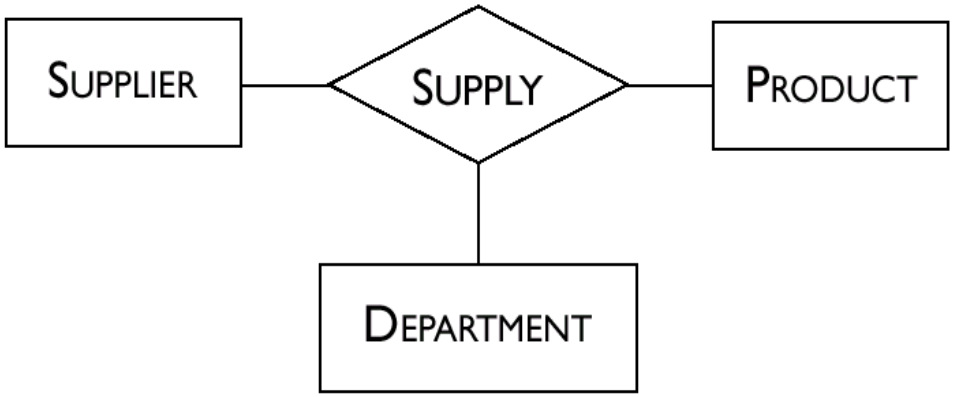


- The relationship may be asymmetric
  - If so, we indicate the two roles that the entity plays in the relationship



Ternary Relationships

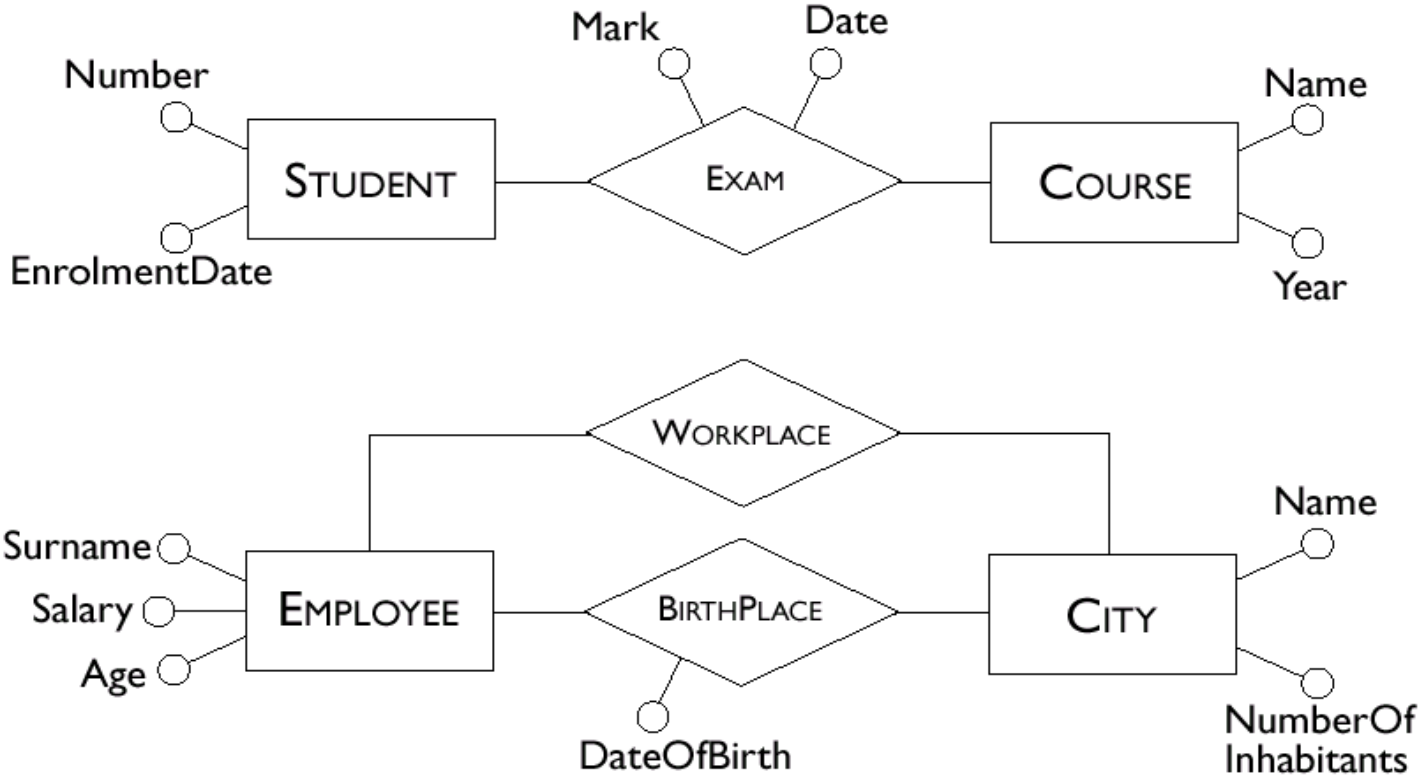




Attributes

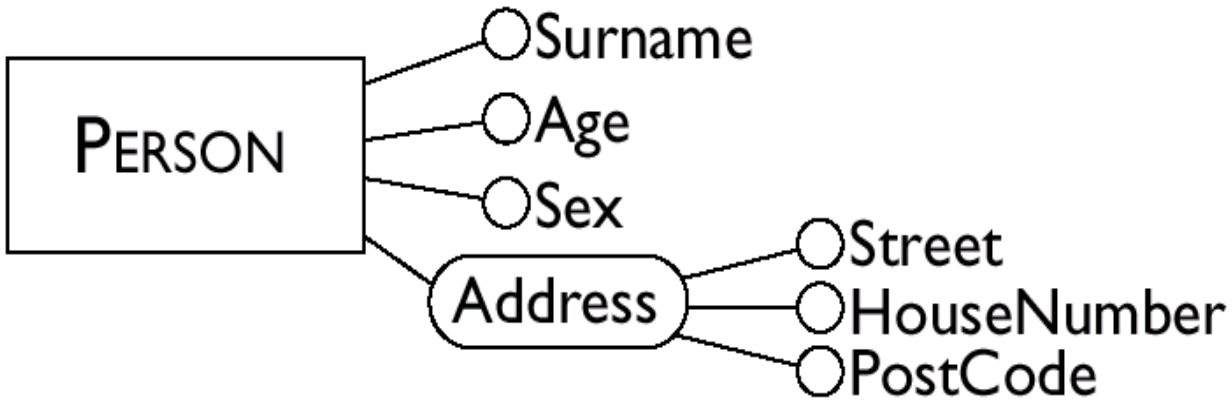
- Describe elementary properties of entities or relationships (e.g., Surname, Salary and Age are attributes of Employee)

- May be single-valued, or multi-valued

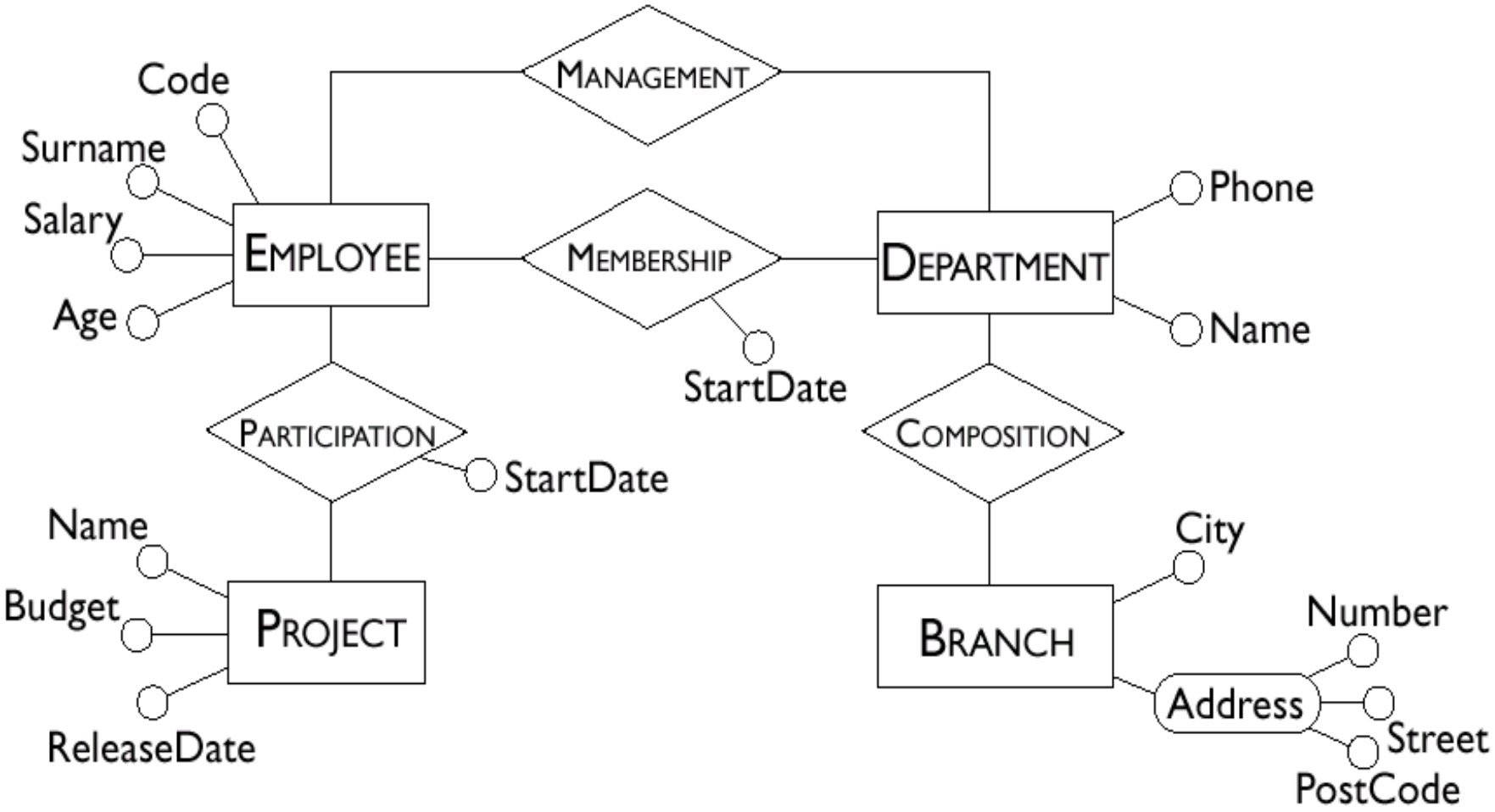


Composite Attributes

- composite attributes are grouped attributes of the same entity or relationship that have closely connected meaning or uses

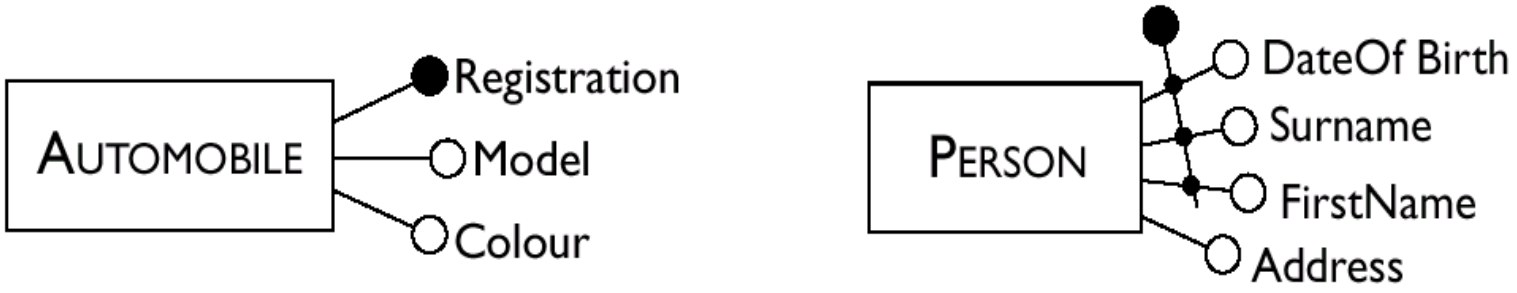


Example Schema with Attributes



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

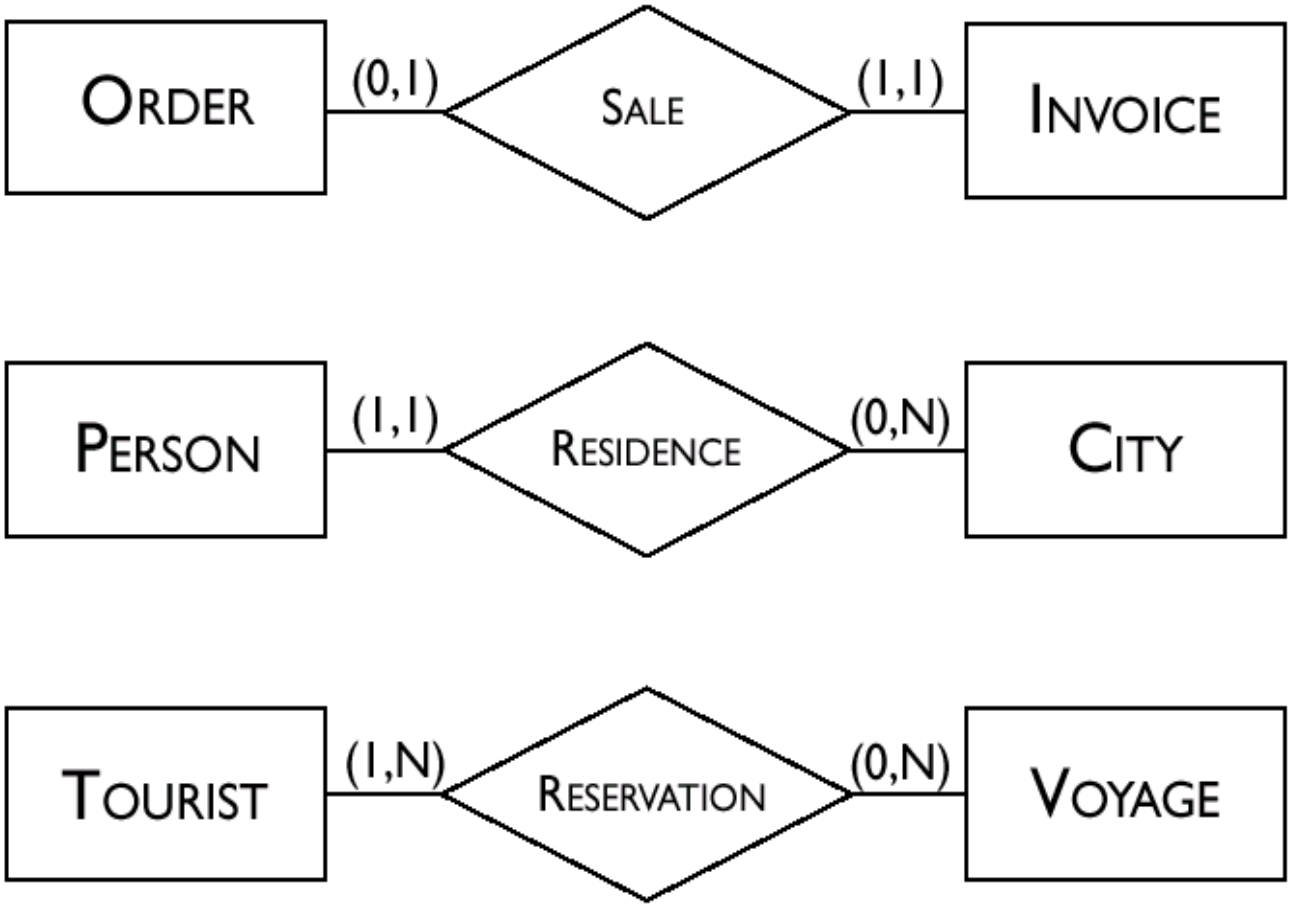
Cardinalities (cont.)

- In principle, cardinalities are pairs of non-negative integers (min, max) such that min ≤ max.

- minimum cardinality min:
  - If 0, entity participation in a relationship is optional
  - If 1, entity participation in a relationship is mandatory
  - Other values are possible

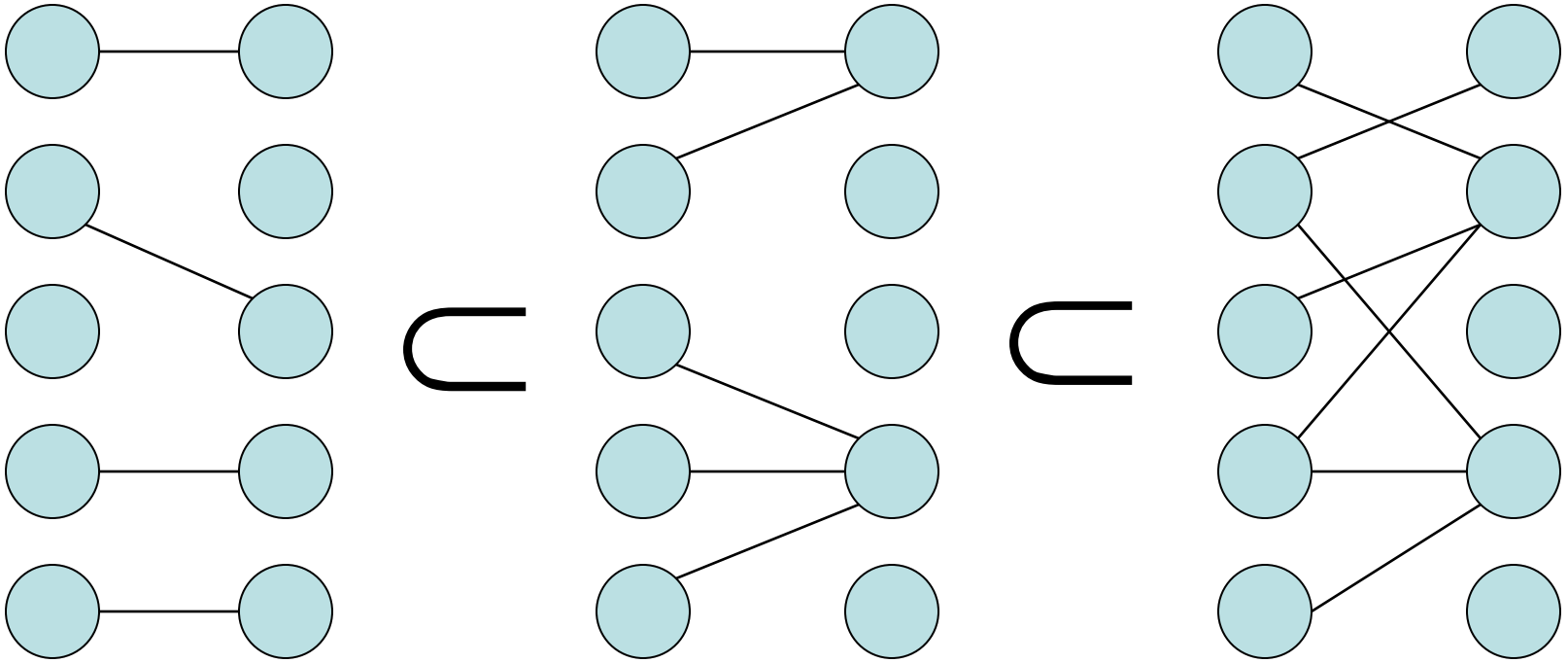
- maximum cardinality max:
  - If 1, each instance of the entity is associated at most with a single instance of the relationship
  - If > 1, then each instance of the entity can be associated multiple instances of the relationship
  - We write N to indicate no upper limit
  - Other values are possible

Cardinality Examples



Multiplicity of relationships

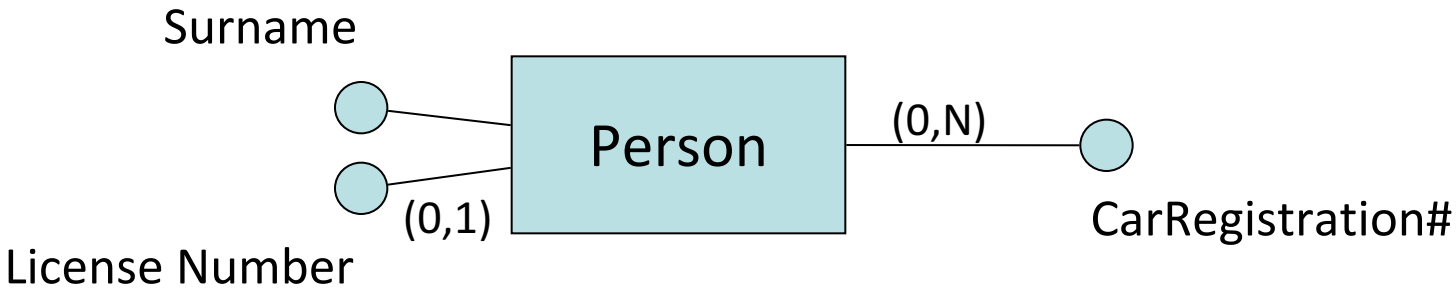
If entities E1 and E2 participate in relationship R with cardinalities (n1, N1) and (n2, N2) then the multiplicity of R is N1-to-N2 (which is the same as saying N2-to-N1)



1-to-1 N-to-1 OR 1-to-N N-to-N

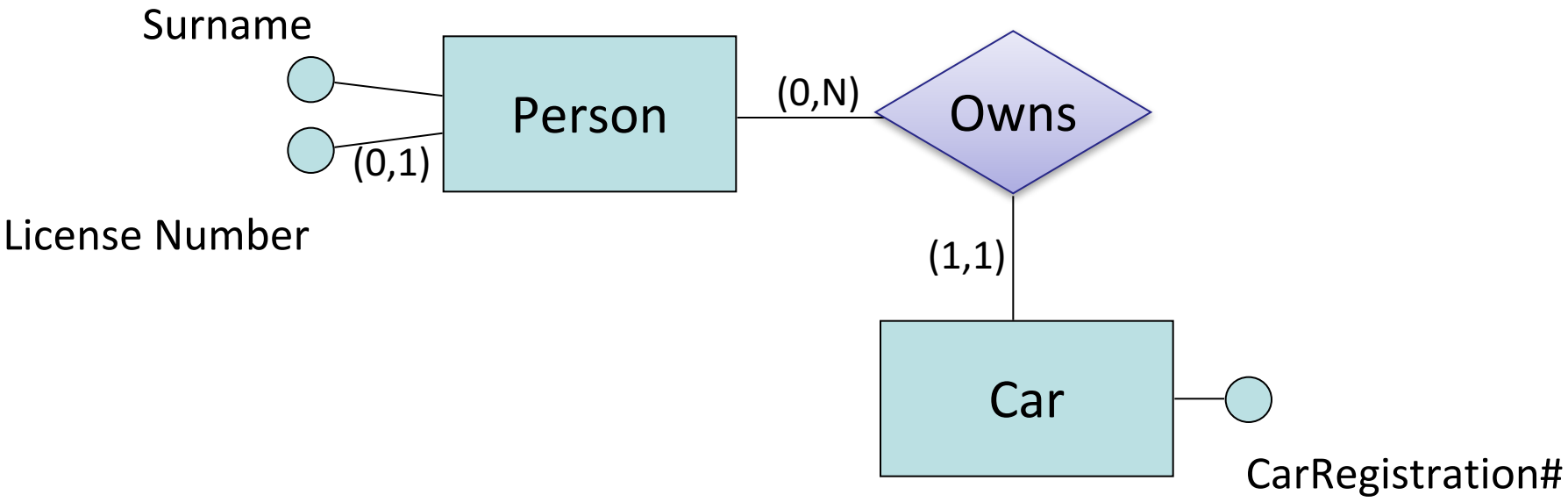
Cardinalities of Attributes

- 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)



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:



Keys in E/R

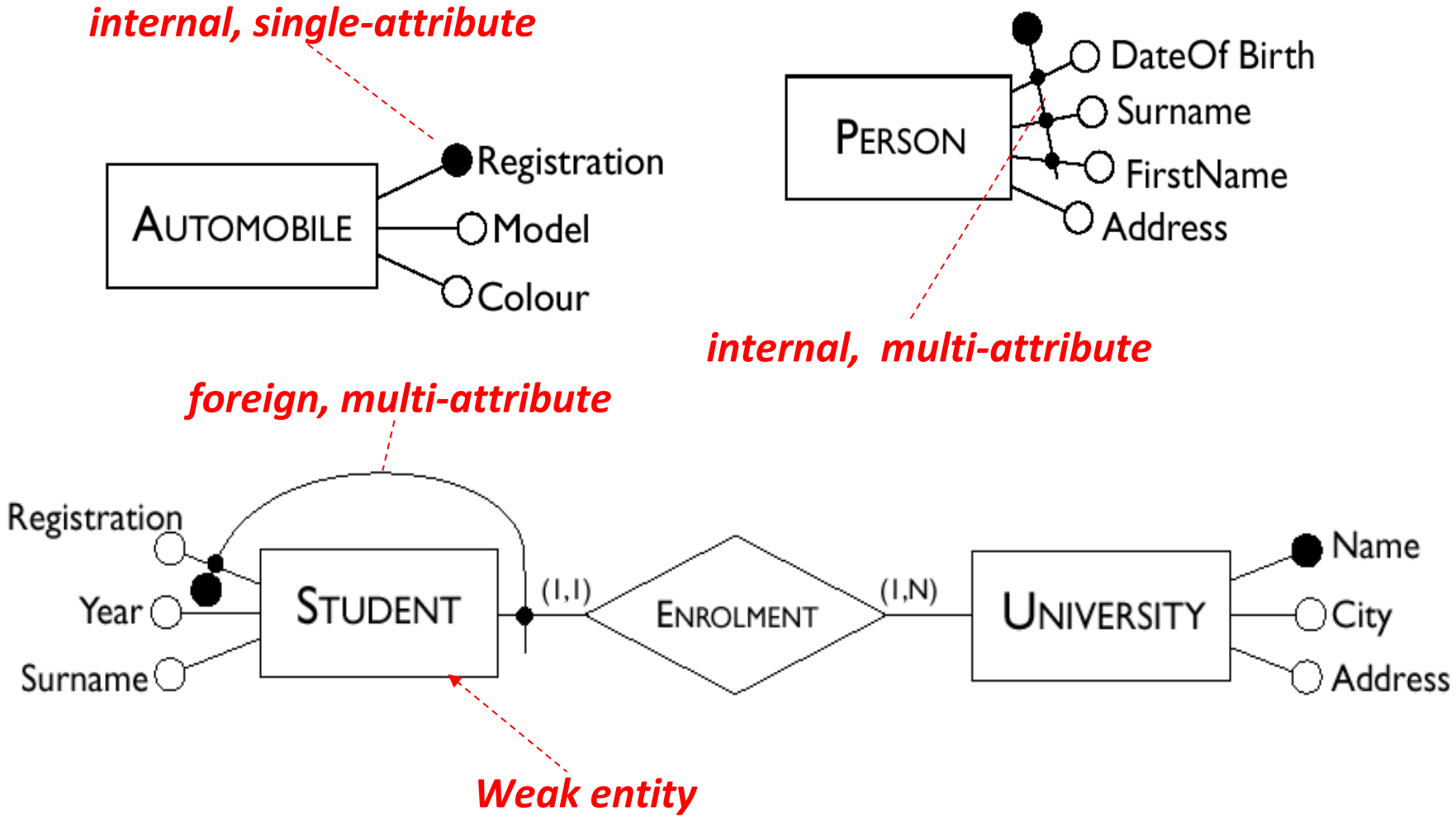
- Keys consist of minimal sets of attributes which uniquely identify instances of an entity set.

- 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

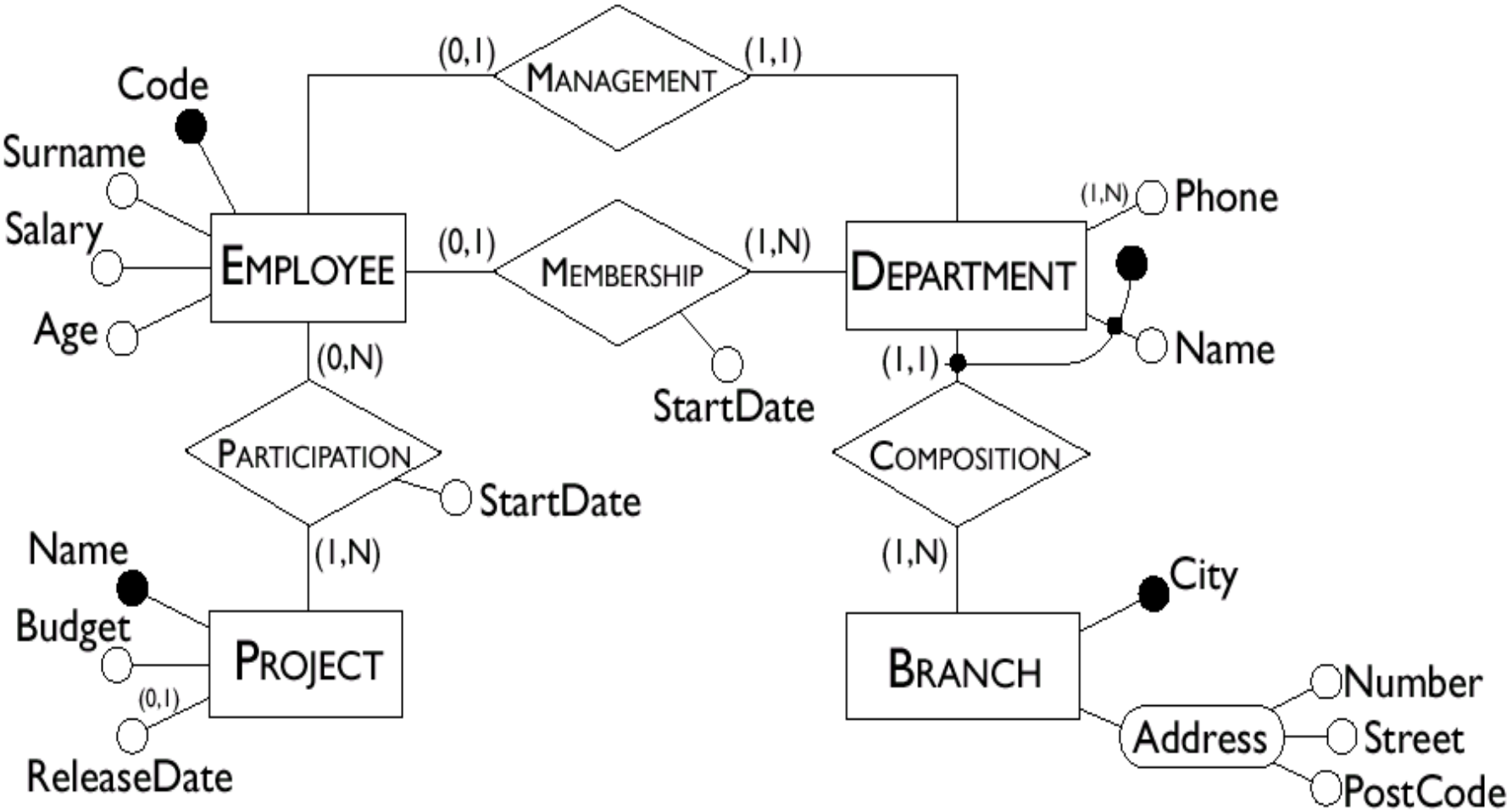
Examples of Keys in E/R



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 a 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 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

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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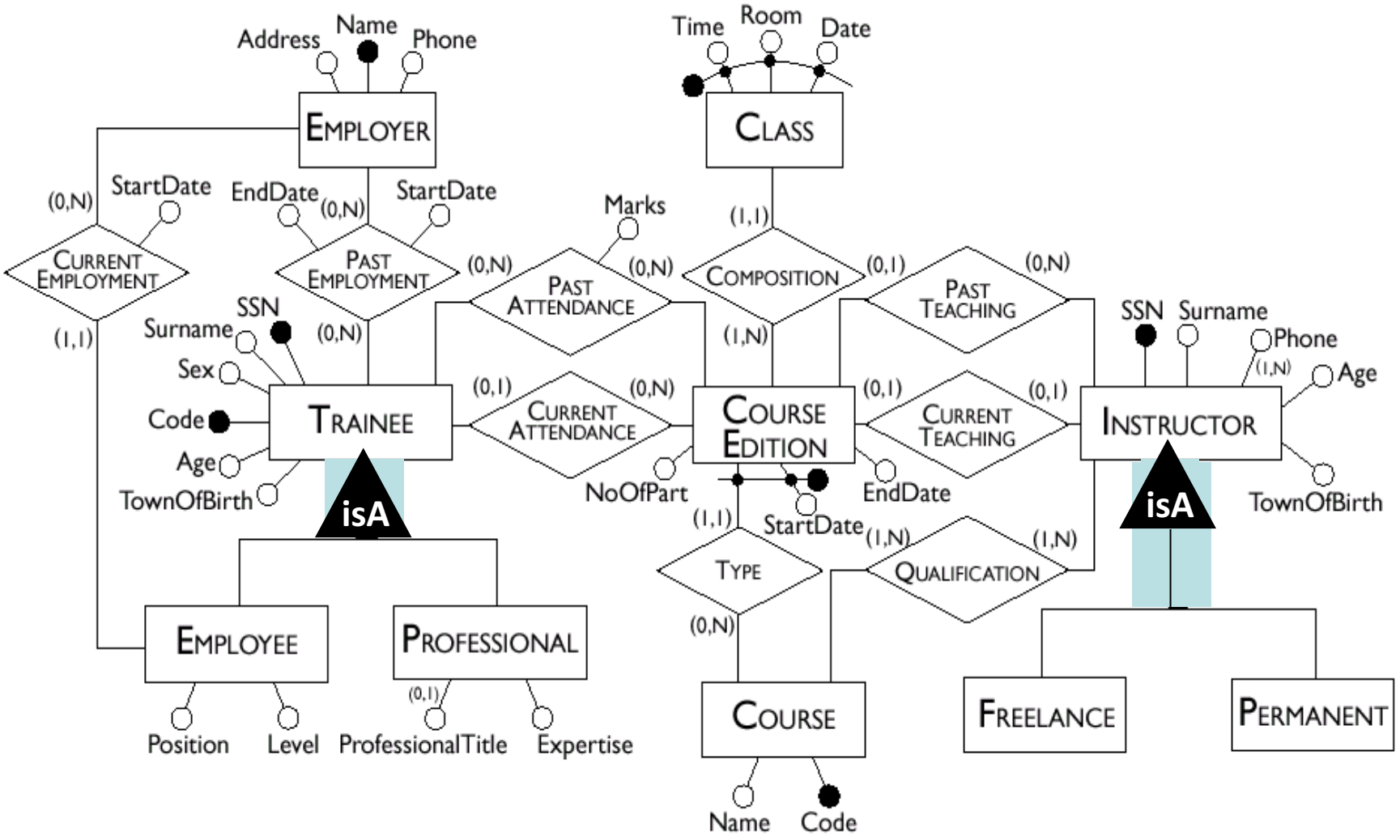
… the E/R model result



From an E/R model to a database schema

Two Steps

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

- *Translate* the schema into the relational model

Restructuring an E/R model

Restructuring Overview

Input: E/R Schema

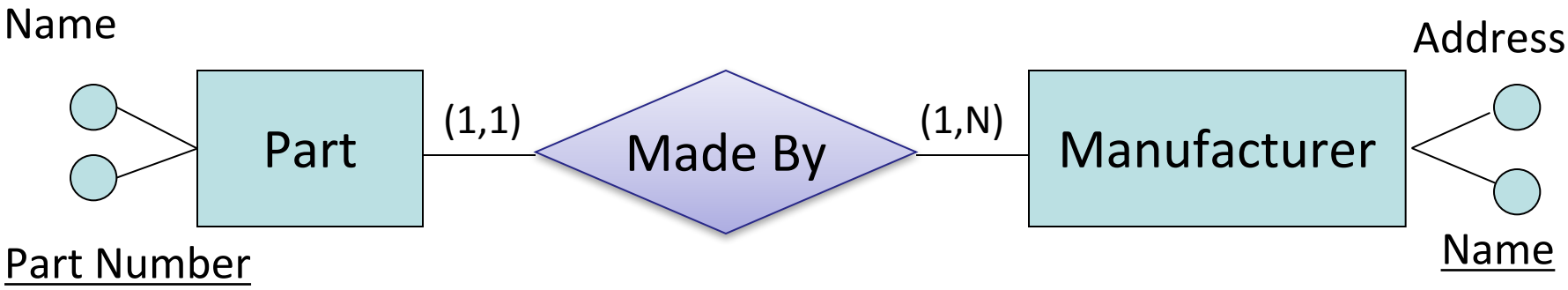
Output: Restructured E/R Schema

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

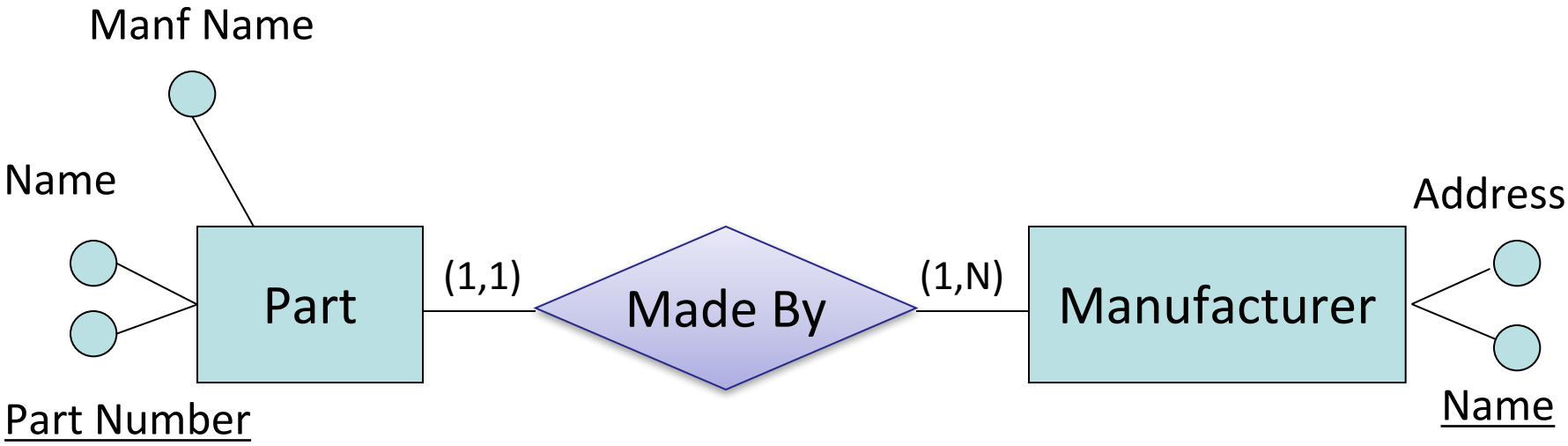
Example: no redundancy

It is not redundant to have Name twice.



Example: redundancy

What is redundant here?



Example: redundancy

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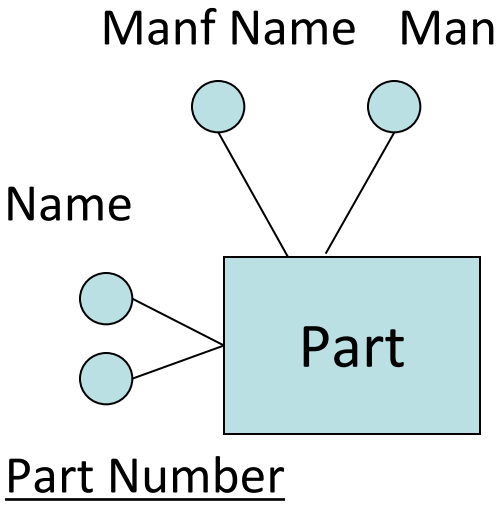


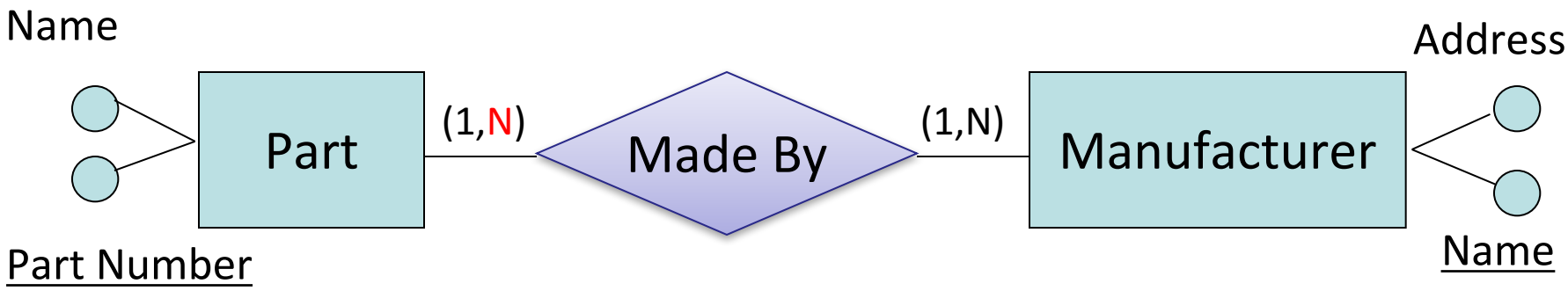
Entity Sets Versus Attributes

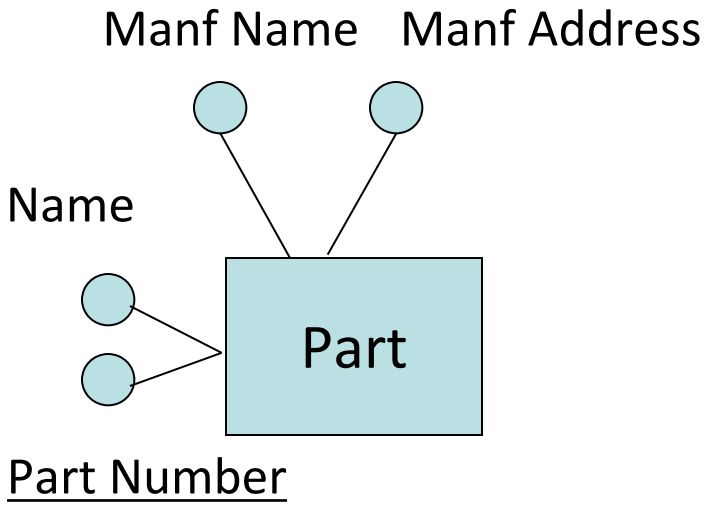
- An entity set should satisfy at least one of the following conditions:
  - It is more than the name of something; it has at least one non-key attribute.

    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

E.S. vs. attributes: examples

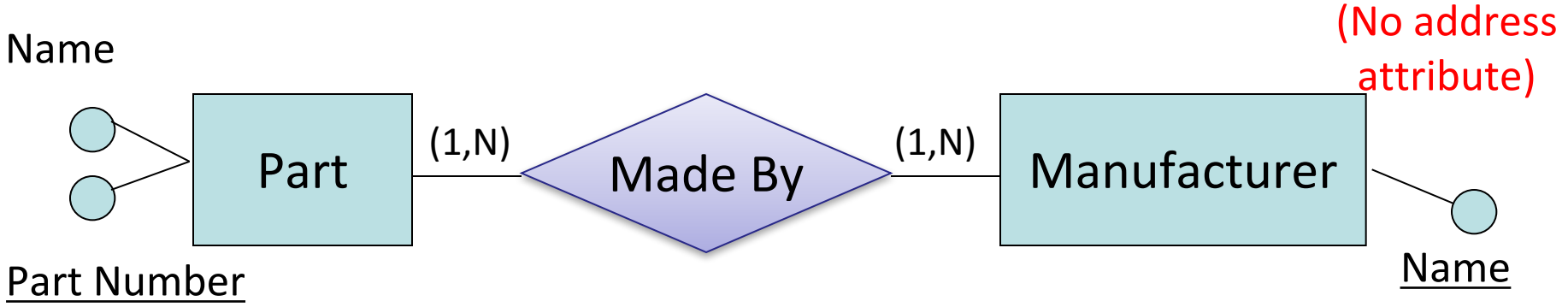
Domain fact change: A part can have more than one manufacturer …

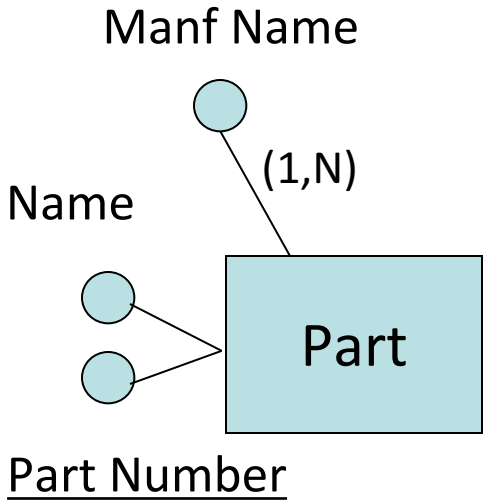




E.S. vs. attributes: examples

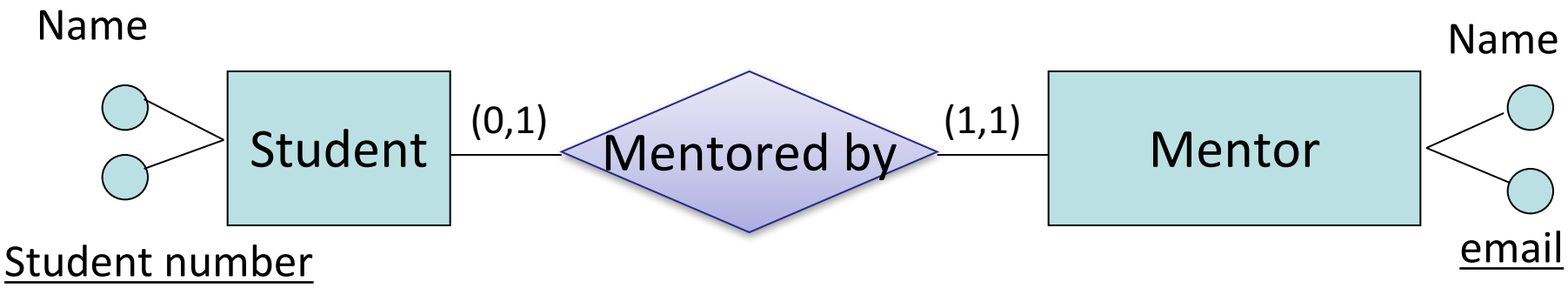
Domain fact change: Not representing Manufacturer address …

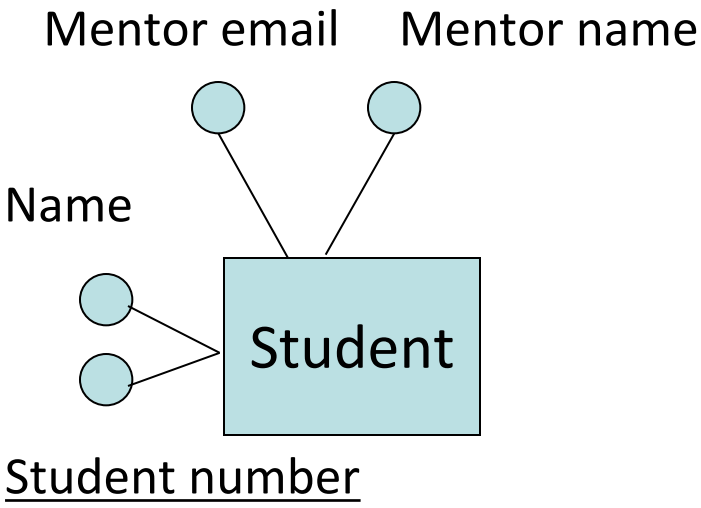




E.S. vs. attributes: examples

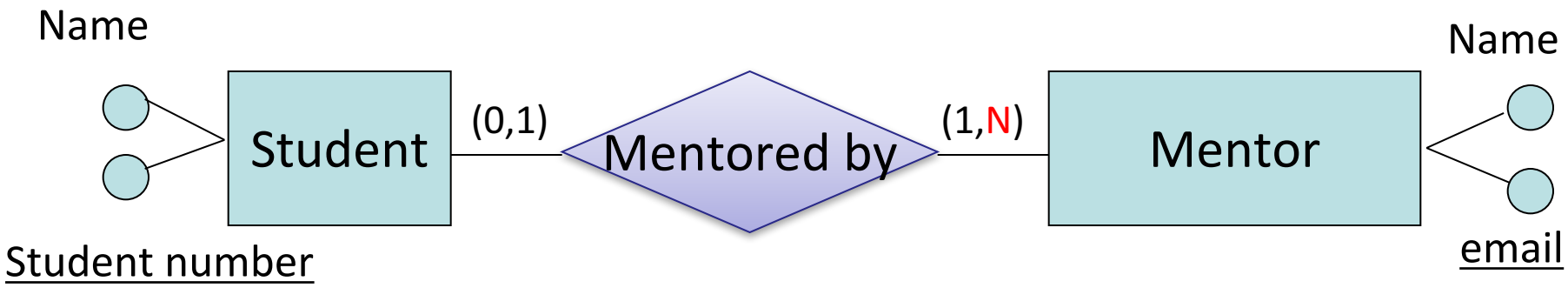
New domain

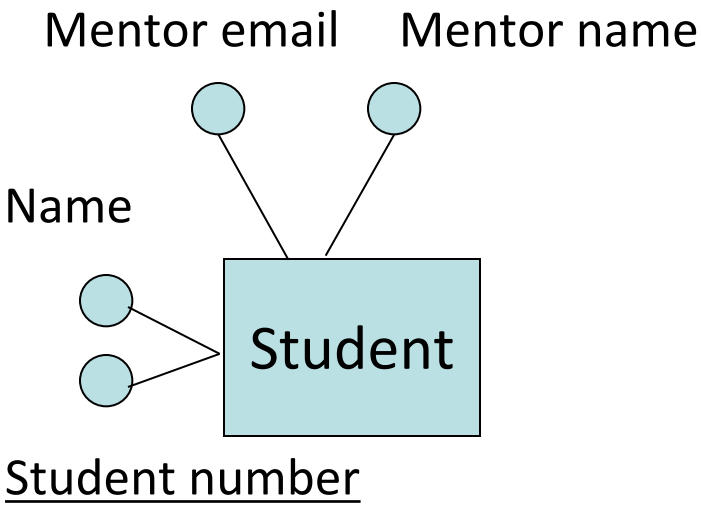




E.S. vs. attributes: examples

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





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

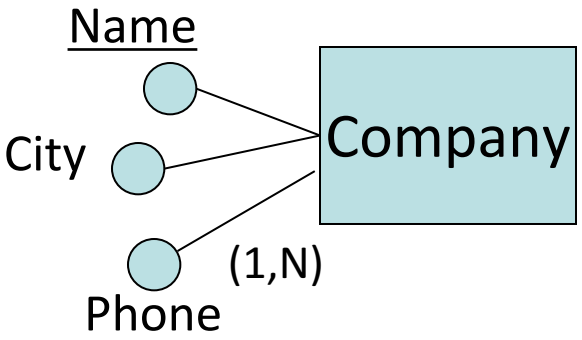
Multi-attribute and/or string keys…

- … **break encapsulation:** e.g. Patient(firstName, lastName, phone, …) => Security/privacy hole
  - Integer patientID can prevent information leaks

- … are brittle: name or phone number change? parent and child with same name? patient with no phone? two movies with same title and year?
  - use internal IDs: always exist, are immutable, and unique

Attributes with cardinality > 1

- The traditional relational model doesn't allow multi-valued attributes => convert these to entity sets.



Translating an E/R model into a Database Schema (i.e., Relational Model)

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 can become a relation and it's attributes are:
  - the keys of the entity sets that it connects
    +
  - the attributes of the relationship itself.

  - **There are opportunities to simplify the translation!**

Many-to-Many Binary Relationships Foreign Key constraints

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

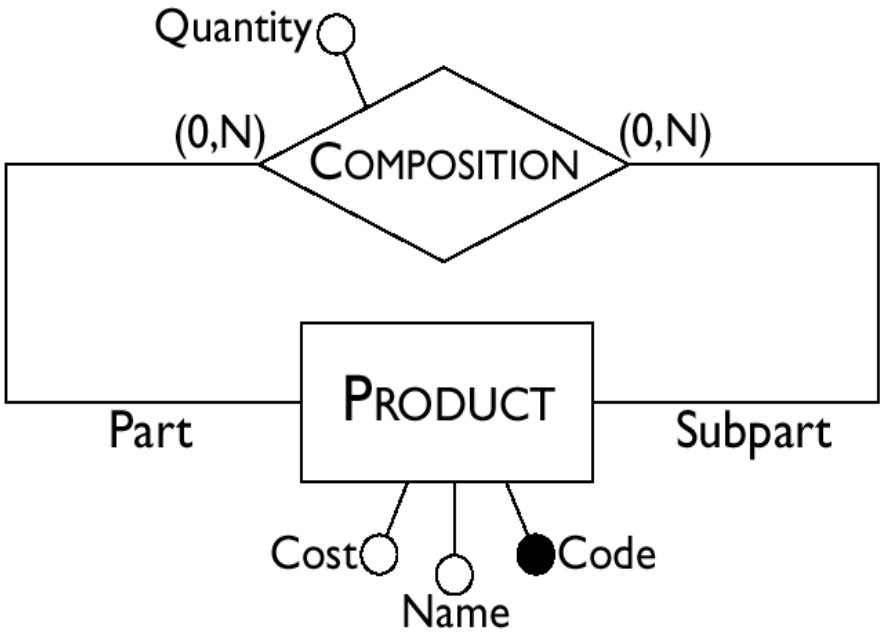
Project(<u>Code</u>, Name, Budget)

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

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

Participation[Number] $\subseteq$ Project[Number]

Many-to-Many Recursive Relationships



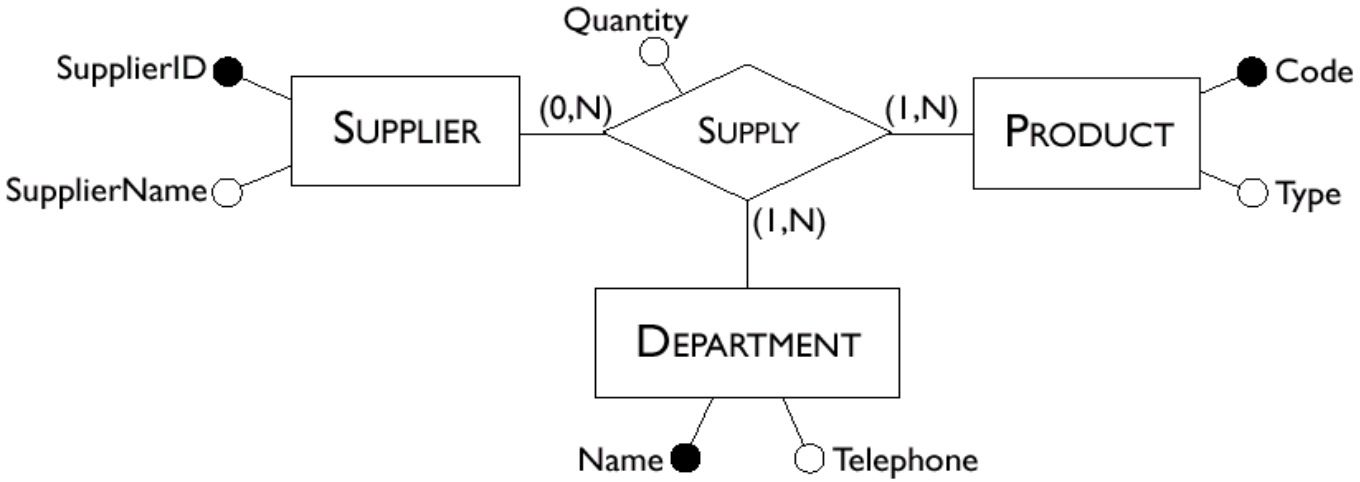
Product(<u>Code</u>, Name, Cost)

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)

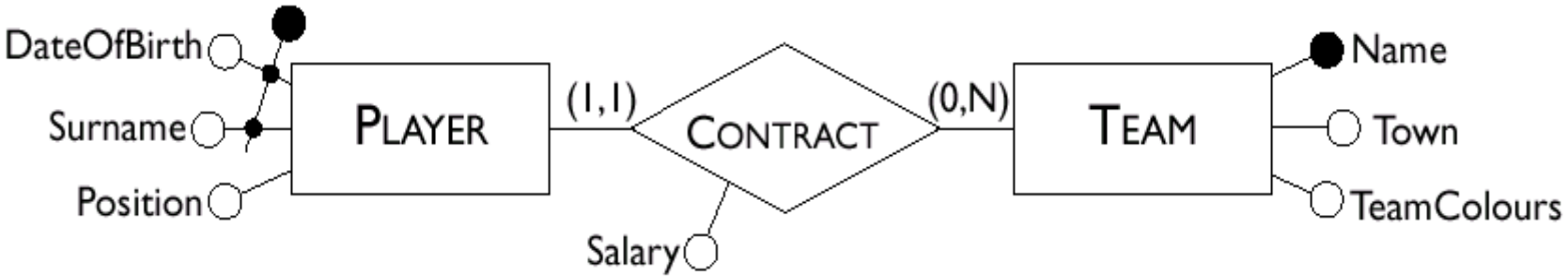
Supply[Supplier] $\subseteq$ Supplier[SupplierID]

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

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

One-to-Many Relationships

with mandatory participation on the "one" side



Player(Surname, DOB, Position)
Team(Name, Town, TeamColours)
Contract(PlayerSurname, PlayerDOB, Team, Salary)
Contract[PlayerSurname, PlayerDOB] ⊆ Player[Surname, DOB]
Contract[Team] ⊆ Team[Name]

OR

Player(Surname, DOB, Position, TeamName, Salary)
Team(Name, Town, TeamColors)
Player[TeamName] ⊆ Team[Name]

One-to-One Relationships
with mandatory participation for both

Head(<u>Number</u>, Name, Salary, Department)
Department(<u>Name</u>, Telephone, Branch)
Management(<u>Number, Name</u>, StartDate)
Management[Name] ⊆ Department[Name]
Management[Number] ⊆ Head[Number]

Or

Head(<u>Number</u>, Name, Salary, StartDate)
Department(<u>Name</u>, Telephone, HeadNumber, Branch)
Department[HeadNumber] ⊆ Head[Number]

Or

Head(<u>Number</u>, Name, Salary)
Department(<u>Name</u>, Telephone, Branch, HeadNumber, StartDate)
Department[HeadNumber] ⊆ Head[Number]

One-to-One Relationships
with mandatory participation for both

Or

Head(Number, Name, Salary, Department, StartDate)

Department(Name, Telephone, Branch)

Head[Department] ⊆ Department[Name]

Or

Head(Number, Name, Salary, Department)

Department(Name, Telephone, Branch, StartDate)

Head[Department] ⊆ Department[Name]

It is a possible translation, but not as intuitive as the other ones

One-to-One Relationships

with optional participation for one

Employee(Number, Name, Salary)
Department(Name, Telephone, Branch)
Management(Head, Department, StartDate)

Management[Head] ⊆ Employee[Number]

Management[Department] ⊆ Department[Name]

Or

Employee(Number, Name, Salary)
Department(Name, Telephone, Branch, Head, StartDate)

Department[Head] ⊆ 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 (with respect to what the E/R diagram represents).
- Crucial thing we might be missing: the full set of functional dependencies.
- => we still need the FD-based DB design theory.

Redundancy can sometimes be *desirable*

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

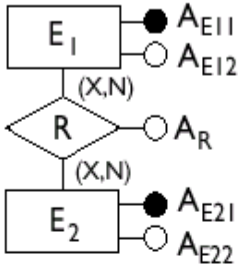
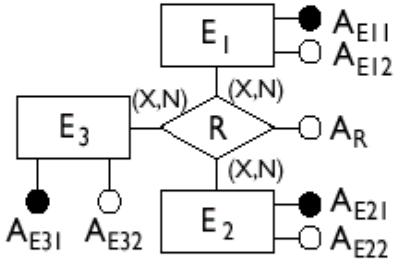
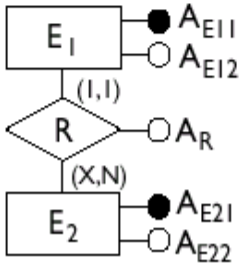
- Advantages of redundancy:
  - Speed: Fewer accesses necessary to obtain information

- 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

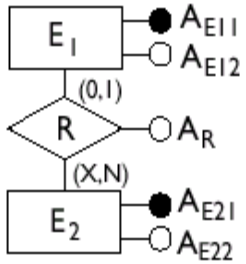
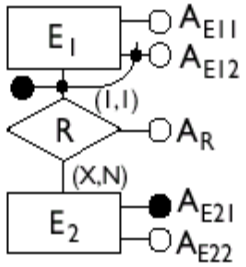
  with and without the redundancy.

Performance analysis is required to decide about redundancy !

Summary of Transformation Rules

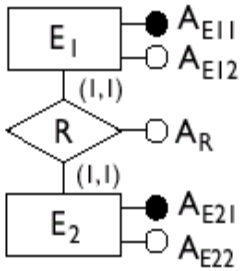
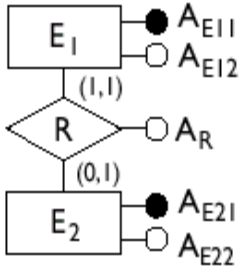
Type	Initial schema	Possible translation
Binary many-to-many relationship		$E_1(\underline{A_{E11}}, A_{E12})$ $E_2(\underline{A_{E21}}, A_{E22})$ $R(\underline{A_{E11}}, \underline{A_{E21}}, A_R)$
Ternary many-to-many relationship		$E_1(\underline{A_{E11}}, A_{E12})$ $E_2(\underline{A_{E21}}, A_{E22})$ $E_3(\underline{A_{E31}}, A_{E32})$ $R(\underline{A_{E11}}, \underline{A_{E21}}, \underline{A_{E31}}, A_R)$
One-to-many relationship with mandatory participation		$E_1(\underline{A_{E11}}, A_{E12}, A_{E21}, A_R)$ $E_2(\underline{A_{E21}}, A_{E22})$

...More Rules...

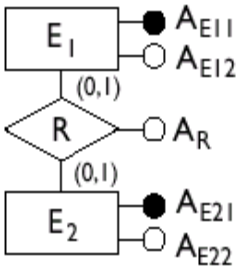
Type	Initial schema	Possible translation
One-to-many relationship with optional participation		$E_1(\underline{A_{E11}}, A_{E12})$ $E_2(\underline{A_{E21}}, A_{E22})$ $R(\underline{A_{E11}}, \underline{A_{E21}}, A_R)$ Alternatively: $E_1(\underline{A_{E11}}, A_{E21}, A^*_{E21}, A^*_R)$ $E_2(\underline{A_{E21}}, A_{E22})$
Relationship with external identifiers		$E_1(\underline{A_{E12}}, \underline{A_{E21}}, A_{E11}, A_R)$ $E_2(\underline{A_{E21}}, A_{E22})$

✲ Indicates that nulls are allowed

…Even More Rules…

Type	Initial schema	Possible translation
One-to-one relationship with mandatory participation for both entities		$E_1(\underline{A_{E11}}, A_{E12}, \underline{A_{E21}}, A_R)$ $E_2(\underline{A_{E21}}, A_{E22})$ Alternatively: $E_2(\underline{A_{E21}}, A_{E22}, \underline{A_{E11}}, A_R)$ $E_1(\underline{A_{E11}}, A_{E12})$
One-to-one relationship with optional participation for one entity		$E_1(\underline{A_{E11}}, A_{E12}, \underline{A_{E21}}, A_R)$ $E_2(\underline{A_{E21}}, A_{E22})$

...and the Last One...

Type	Initial schema	Possible translation
One-to-one relationship with optional participation for both entities		$E_1(\underline{A_{E11}}, A_{E21})$ $E_2(\underline{A_{E21}}, A_{E22}, A^*_{E11}, A^*_R)$ Alternatively: $E_1(\underline{A_{E11}}, A_{E12}, A^*_{E21}, A^*_R)$ $E_2(\underline{A_{E21}}, A_{E22})$ Alternatively: $E_1(\underline{A_{E11}}, A_{E12})$ $E_2(\underline{A_{E21}}, A_{E22})$ $R(\underline{A_{E11}}, \underline{A_{E21}}, A_R)$