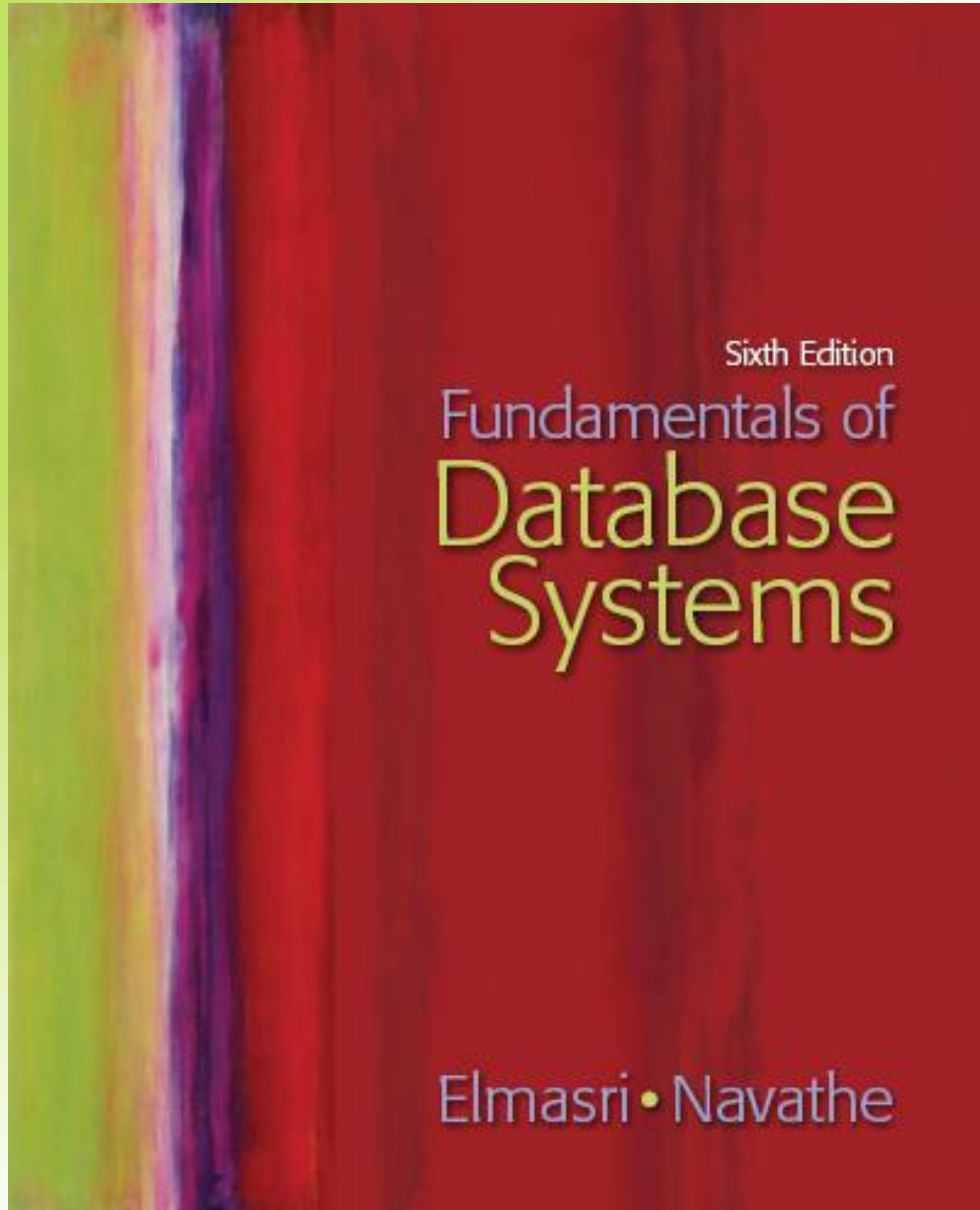
Chapter 9

Relational Database Design by ER- and EER-to-Relational Mapping



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Chapter 9

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Chapter 9 Outline

- **Schema Mapping (Logical Database Design) step of Database Design**
- **ER-to-Relational Mapping Algorithm**
  - Step 1: Mapping of Regular Entity Types
  - Step 2: Mapping of Weak Entity Types
  - Step 3: Mapping of Binary 1:1 Relation Types
  - Step 4: Mapping of Binary 1:N Relationship Types.
  - Step 5: Mapping of Binary M:N Relationship Types.
  - Step 6: Mapping of Multivalued attributes.
  - Step 7: Mapping of N-ary Relationship Types.
- **Mapping EER Model Constructs**
  - Step 8: Options for Mapping Specialization or Generalization.
  - Step 9: Mapping of Union Types (Categories).

Data Model Mapping Phase of Relational DB Design

- DB designers use ER/EER or other conceptual data model to produce a conceptual schema design (*independent* from any specific DBMS) during the *Conceptual Database Design* phase
- In *Logical Database Design* Phase (see Figure 7.1, next slide) conceptual schema design is converted (Mapped) to the data model of the DBMS
  - Typically relational model (see Chapters 3-6), or object/object-relational models (see Chapter 11)
  - Data model mapping is usually automated or semi-automated in many database design tools
- In this chapter, we study the various options for mapping ER/EER model constructs to relational model constructs
  - Object and object-relational mapping discussed in Chapter 11

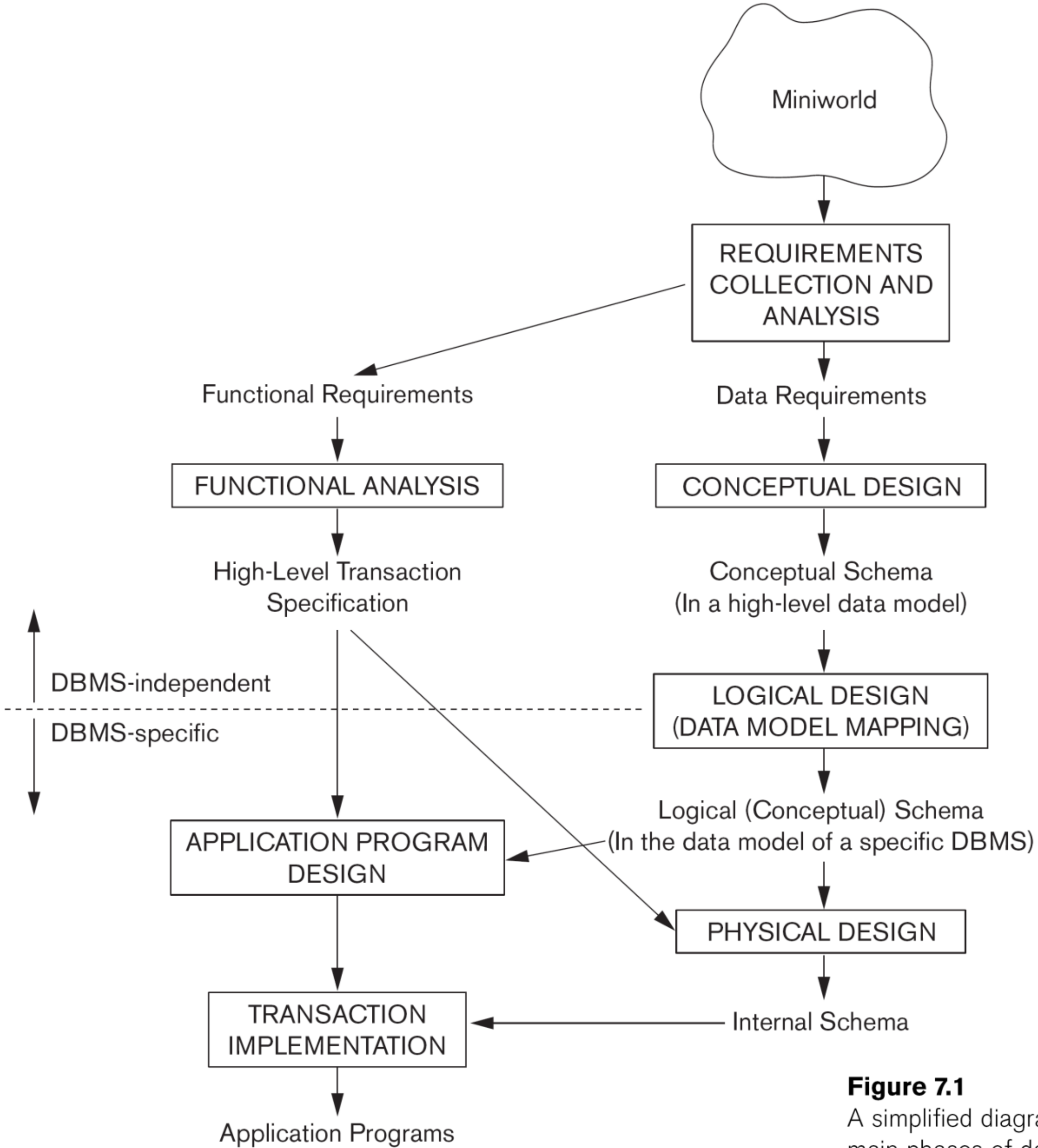
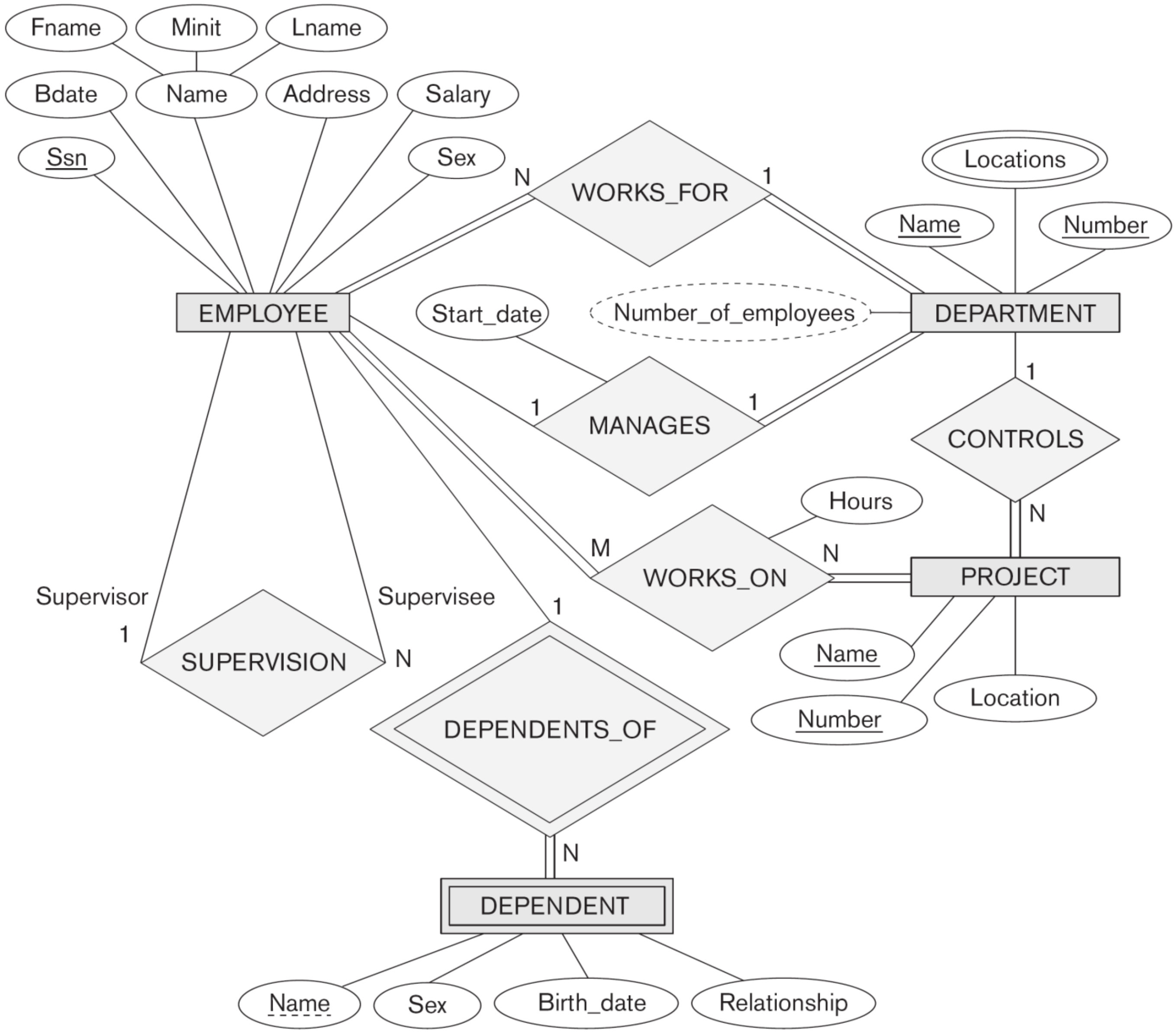


Figure 7.1
A simplified diagram to illustrate the main phases of database design.

Overview of ER-to-Relational Mapping Algorithm

- We present the concepts of a general mapping algorithm
- Algorithm has 7 steps:
  - Step 1: Mapping of regular (strong) entity types
  - Step 2: Mapping of weak (dependent) entity types
  - Steps 3, 4, 5: Mapping of binary relationship types of different cardinality ratios (1:1, 1:N, M:N)
  - Step 6: Mapping of multi-valued attributes
  - Step 7: Mapping of n-ary relationship types, n > 2
- Example: We use the COMPANY ER schema diagram (Figure 9.1, next slide) to illustrate the mapping steps
- Additional steps (Steps 8, 9) for mapping EER model constructs (specialization/generalization, UNION types) presented later

Figure 9.1
The ER conceptual schema diagram for the COMPANY database.



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ER-to-Relational Mapping Algorithm

- **Step 1: Mapping of Regular Entity Types**
  - For each regular (strong) entity type E in the ER schema, create a relation R that includes all the *simple* attributes (or simple components of composite attributes) of E.
  - Choose one of the key attributes of E as primary key for R.
  - If the chosen key of E is *composite*, the set of simple attributes that form it will together form the primary key of R.
- Example: We create the relations EMPLOYEE, DEPARTMENT, and PROJECT in the relational schema corresponding to the regular entity types in Figure 9.1
  - SSN, DNUMBER, and PNUMBER are chosen as primary keys for the relations EMPLOYEE, DEPARTMENT, and PROJECT (Figure 9.3(a), next slide).
  - <u>Note:</u> Additional attributes will be added to these tables in later mapping steps

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Figure 9.3
Illustration of some mapping steps.
a. *Entity* relations after step 1.
b. Additional *weak entity* relation after step 2.
c. *Relationship* relation after step 5.
d. Relation representing multivalued attribute after step 6.

(a) **EMPLOYEE**

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary

DEPARTMENT

Dname	Dnumber

PROJECT

Pname	Pnumber	Plocation

(b) **DEPENDENT**

Essn	Dependent_name	Sex	Bdate	Relationship

(c) **WORKS_ON**

Essn	Pno	Hours

(d) **DEPT_LOCATIONS**

Dnumber	Dlocation

ER-to-Relational Mapping Algorithm (cont.)

- **Step 2: Mapping of Weak Entity Types**
  - For each weak entity type W with owner entity type E, create a relation R that includes all simple attributes (or simple components of composite attributes) of W as attributes of R.
  - Include as foreign key attribute(s) in R the primary key attribute(s) of the relation(s) that corresponds to the *owner* entity type(s).
  - The primary key of R is the *combination of* the primary key(s) of the owner(s) and the partial key of the weak entity type W, if any.
- Example: Create the relation DEPENDENT in this step to correspond to the weak entity type DEPENDENT.
  - see Figure 9.3(b)
  - Include the primary key SSN of the EMPLOYEE relation as a foreign key attribute of DEPENDENT (renamed to ESSN in Fig.).
  - The primary key of DEPENDENT is the combination {ESSN, DEPENDENT_NAME} because DEPENDENT_NAME is the partial key of DEPENDENT.

ER-to-Relational Mapping Algorithm (cont.)

- **Step 3: Mapping of Binary 1:1 Relationship Types**
  - For each binary 1:1 relationship type R in the ER schema, identify the relations S and T that correspond to the entity types participating in R.
- Three possible approaches:
  - **Foreign Key approach:** Choose one of the relations (say S) and include as *foreign key* in S the primary key of T (it is better to choose an entity type *with total participation in R* in the role of S).
    - Example (see Figure 9.2): 1:1 relationship MANAGES (Fig. 9.1) is mapped by choosing DEPARTMENT to serve in the role of S (because its participation in the MANAGES relationship type is total)
    - Mgr_SSN of DEPARTMENT is foreign key referencing EMPLOYEE
    - Attributes of MANAGES become attributes of DEPARTMENT
  - **Merged relation option:** Merge the two entity types and the relationship into a single relation (possible when *both participations are total*).
  - **Cross-reference or *relationship relation* option:** Set up a third relation R for cross-referencing the primary keys of the two relations S and T representing the entity types.

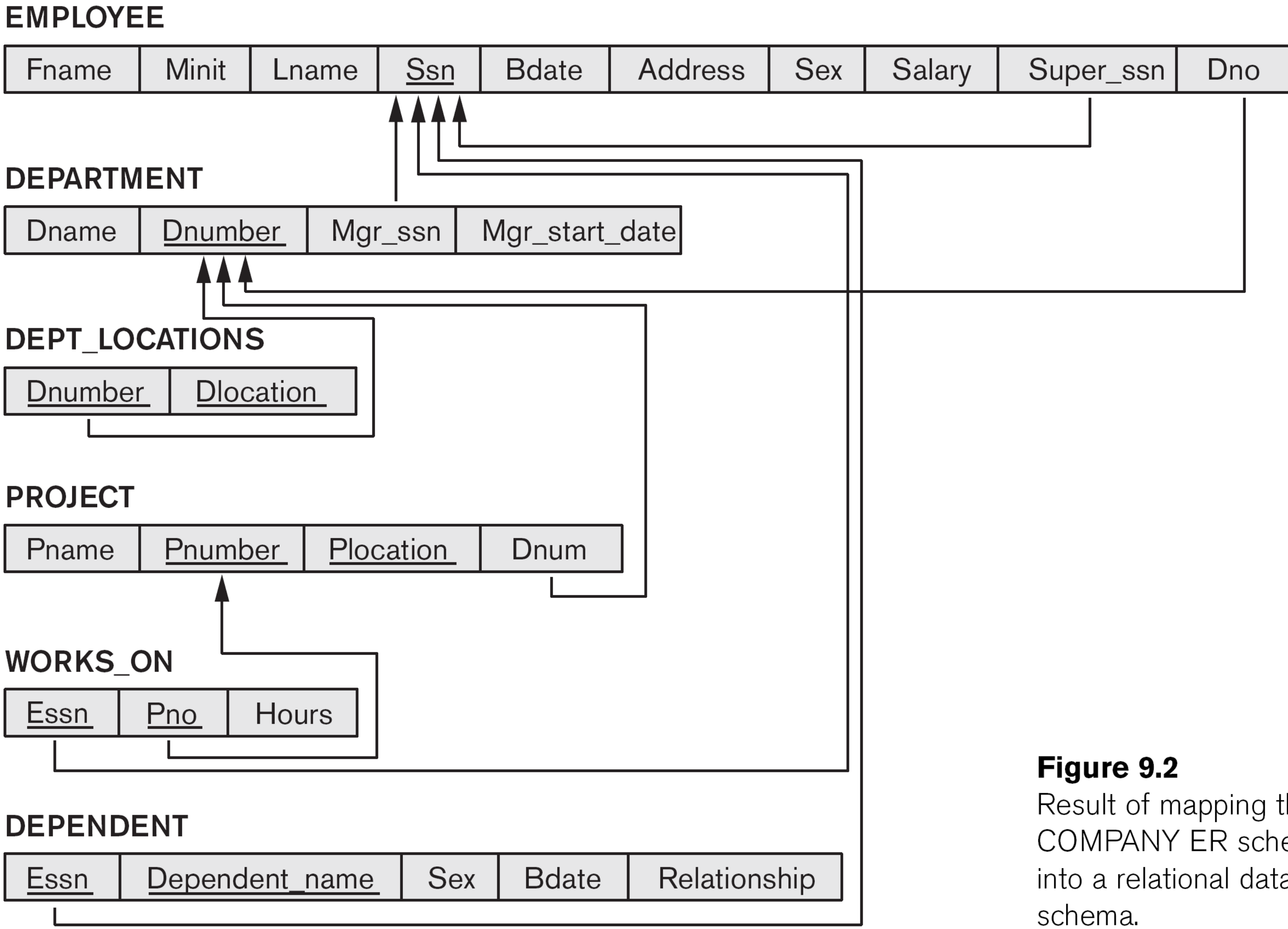

Figure 9.2
Result of mapping the COMPANY ER schema into a relational database schema.

ER-to-Relational Mapping Algorithm (cont.)

- **Step 4: Mapping of Binary 1:N Relationship Types**
  - For each regular binary 1:N relationship type R, identify the relation S that represent the participating entity type *at the N-side* of the relationship type.
  - Include as foreign key in S the primary key of the relation T that represents the other entity type participating in R.
  - Include any simple attributes of the 1:N relation type as attributes of S.
- Examples (Figures 9.1, 9.2): 1:N relationship types are WORKS_FOR, CONTROLS, and SUPERVISION.
  - For WORKS_FOR we include the primary key DNUMBER of the DEPARTMENT relation as foreign key in the EMPLOYEE relation and call it DNO
  - (cont. on next slide)

ER-to-Relational Mapping Algorithm (cont.)

- Examples (cont.):
  - For CONTROLS, we include the primary key DNUMBER of DEPARTMENT as foreign key in PROJECT and call it DNUM.
  - For SUPERVISION, we include the primary key SSN of EMPLOYEE as foreign key in EMPLOYEE itself and call it SuperSSN (this is a recursive relationship)
- All three 1:N relationship examples (Figures 9.1, WORKS_FOR, CONTROLS, and SUPERVISION) are mapped using the **foreign key** option in Figure 9.2
  - Can also use the **cross-reference** option (create a separate relation that has the primary keys of both relations as foreign keys).

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ER-to-Relational Mapping Algorithm (cont.)

- **Step 5: Mapping of Binary M:N Relationship Types**
  - For each regular binary M:N relationship type R, *create a new relation* S to represent R.
  - Include as foreign key attributes in S the primary keys of the relations that represent the participating entity types; *their combination will form the primary key* of S.
  - Also include any simple attributes of the M:N relationship type (or simple components of composite attributes) as attributes of S.
- Example: The M:N relationship type WORKS_ON (Figure 9.1) is mapped by creating a relation WORKS_ON in the relational database schema (Figure 9.3(c), Figure 9.2).
  - The primary keys of PROJECT and EMPLOYEE are foreign keys in WORKS_ON and renamed PNO and ESSN, respectively.
  - Attribute HOURS in WORKS_ON represents the HOURS attribute of the relation type.
  - The primary key of WORKS_ON is the combination {ESSN, PNO}.

ER-to-Relational Mapping Algorithm (cont.)

- **Discussion of Mapping of Binary Relationship Types (steps 3, 4, and 5):**
  - Foreign key option is preferred for 1:1 and 1:N relationships, but cannot be used for M:N relationships.
  - Relationship relation option can be used for any cardinality ratio, but the *primary key* will be different:
    - Combination of both foreign keys for M:N
    - Either foreign key for 1:1
    - Foreign key in the N-side relation for 1:N
  - Attributes of relationship type are included in the relationship relation (for cross-referencing option), or in the relation that includes the foreign key (for foreign key option).

ER-to-Relational Mapping Algorithm (cont.)

- **Step 6: Mapping of Multivalued attributes.**
  - For each multivalued attribute A, create a new relation R.
  - This relation R will include an attribute corresponding to A, plus the primary key attribute K (as a foreign key in R) of the relation that represents the entity type that has A as an attribute.
  - The primary key of R is the combination of A and K. If the multivalued attribute is composite, we include its simple components.
- Example (Figure 9.3(d)): The relation DEPT_LOCATIONS is created.
  - The attribute DLOCATION represents the multivalued attribute Locations of DEPARTMENT (Figure 9.1), while DNUMBER is foreign key to the DEPARTMENT relation (Figure 9.2).
  - The primary key of DEPT_LOCATIONS is the combination of {DNUMBER, DLOCATION}.

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ER-to-Relational Mapping Algorithm (cont.)

- **Step 7: Mapping of N-ary Relationship Types.**
  - For each n-ary relationship type R, where n>2, create a new *relationship relation* S to represent R.
  - Include as foreign key attributes in S the primary keys of the relations that represent the participating entity types.
  - Also include any simple attributes of the n-ary relationship type (or simple components of composite attributes) as attributes of S.
- Example: The relationship type SUPPLY (Figure 7.17(a), next slide)
  - This can be mapped to the relation SUPPLY (Figure 9.4, following slide), whose primary key is the combination of the three foreign keys {SNAME, PARTNO, PROJNAME}

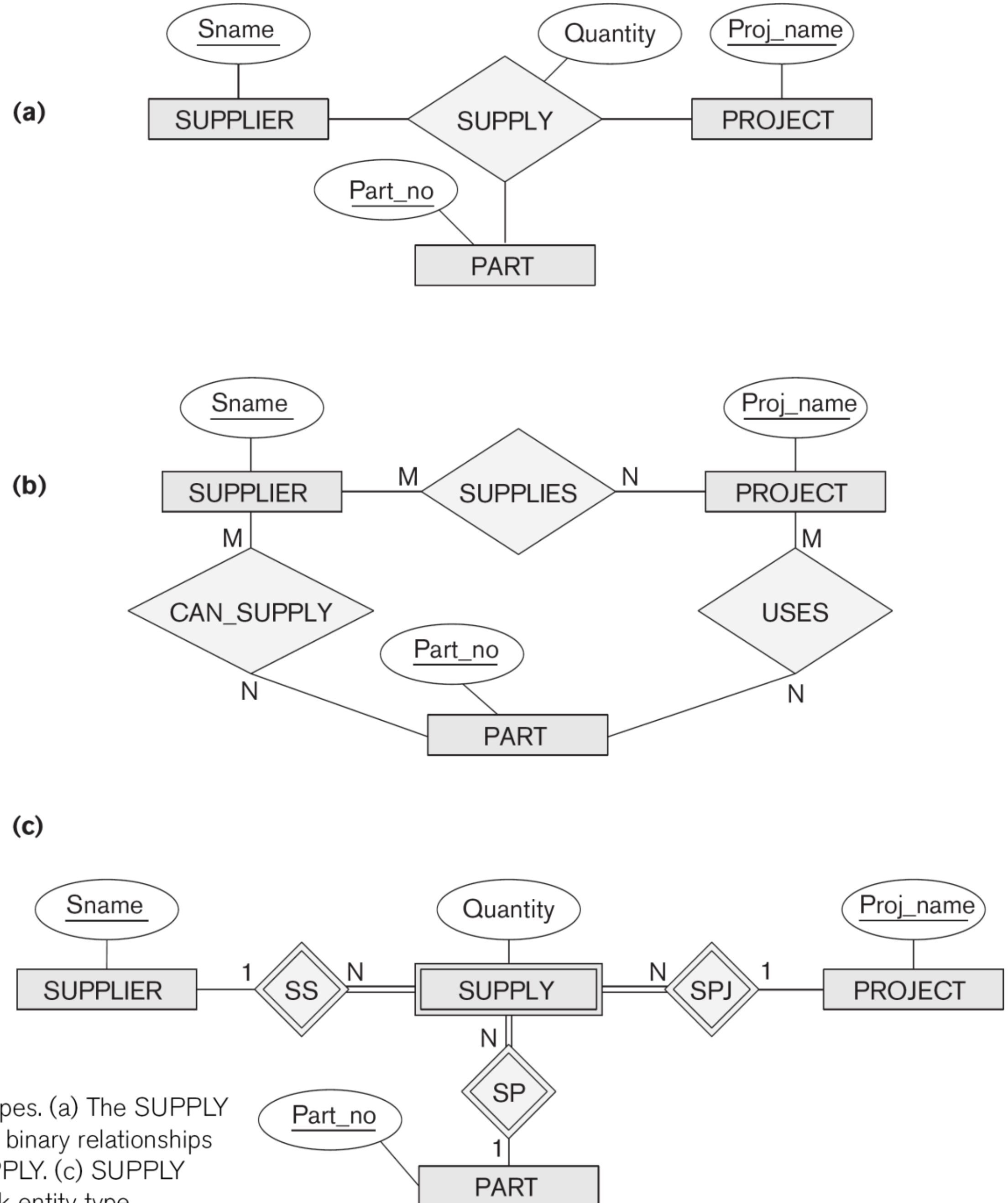


Figure 7.17
Ternary relationship types. (a) The SUPPLY relationship. (b) Three binary relationships not equivalent to SUPPLY. (c) SUPPLY represented as a weak entity type.

Figure 9.4
Mapping the *n*-ary relationship type SUPPLY from Figure 7.17(a).

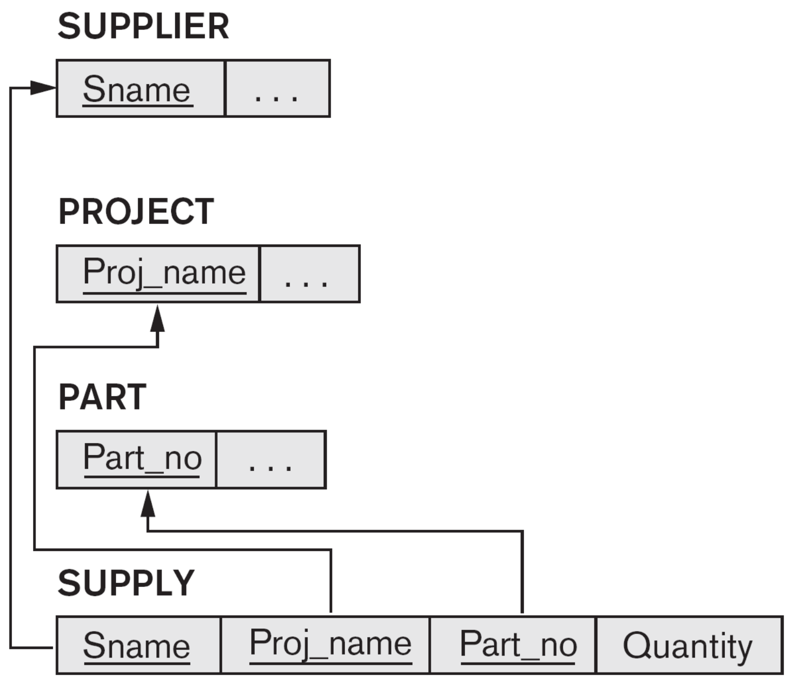


Table 9.1 Correspondence between ER and Relational Models

ER MODEL	RELATIONAL MODEL
Entity type	*Entity* relation
1:1 or 1:N relationship type	Foreign key (or *relationship* relation)
M:N relationship type	*Relationship* relation and *two* foreign keys
n-ary relationship type	*Relationship* relation and *n* foreign keys
Simple attribute	Attribute
Composite attribute	Set of simple component attributes
Multivalued attribute	Relation and foreign key
Value set	Domain
Key attribute	Primary (or secondary) key

Mapping EER Model Constructs to Relations

- We add two steps 8 and 9 to map EER model constructs
  - Step 8 is for mapping specialization/generalization and subclasses
  - Several options exist in step 8
  - Step 9 is for mapping categories (UNION types)
  - Step 9 can involve creating surrogate (artificial) key attributes for the relation representing the UNION type

Mapping EER Model Constructs to Relations (cont.)

- **Step8: Options for Mapping Specialization (or Generalization)**
  - Convert each specialization with m subclasses {S1, S2,….,Sm} and generalized superclass C, where the attributes of C are {k,a1,…an} and k is the (primary) key, into relational schemas using one of the four following options:
    - Option 8A: Multiple relations-Superclass and subclasses
    - Option 8B: Multiple relations-Subclass relations only
    - Option 8C: Single relation with one type attribute
    - Option 8D: Single relation with multiple type (or mapping) attributes

Mapping EER Model Constructs to Relations (cont.)

- **Option 8A: Multiple relations-Superclass and subclasses** (see Figure 9.5(a), next slide)
  - Create a relation L for superclass C with attributes Attrs(L) = {k,a1,…an} and PK(L) = k. Create a relation Li for each subclass Si, 1 $\leq$ i $\leq$ m, with the attributes Attrs(Li) = {k} U {attributes of Si} and PK(Li)=k. This option works for any specialization (total or partial, disjoint of over-lapping).
- **Option 8B: Multiple relations-Subclass relations only** (see Figure 9.5(b), next slide)
  - Create a relation Li for each subclass Si, 1 $\leq$ i $\leq$ m, with the attributes Attr(Li) = {attributes of Si} U {k,a1…,an} and PK(Li) = k. This option only works for a specialization whose subclasses are *total* (every entity in the superclass must belong to (at least) one of the subclasses)
  - Works best if subclasses are also *disjoint*

(a) EMPLOYEE

Ssn	Fname	Minit	Lname	Birth_date	Address	Job_type

SECRETARY

Ssn	Typing_speed

TECHNICIAN

Ssn	Tgrade

ENGINEER

Ssn	Eng_type

(b) CAR

Vehicle_id	License_plate_no	Price	Max_speed	No_of_passengers

TRUCK

Vehicle_id	License_plate_no	Price	No_of_axles	Tonnage

(c) EMPLOYEE

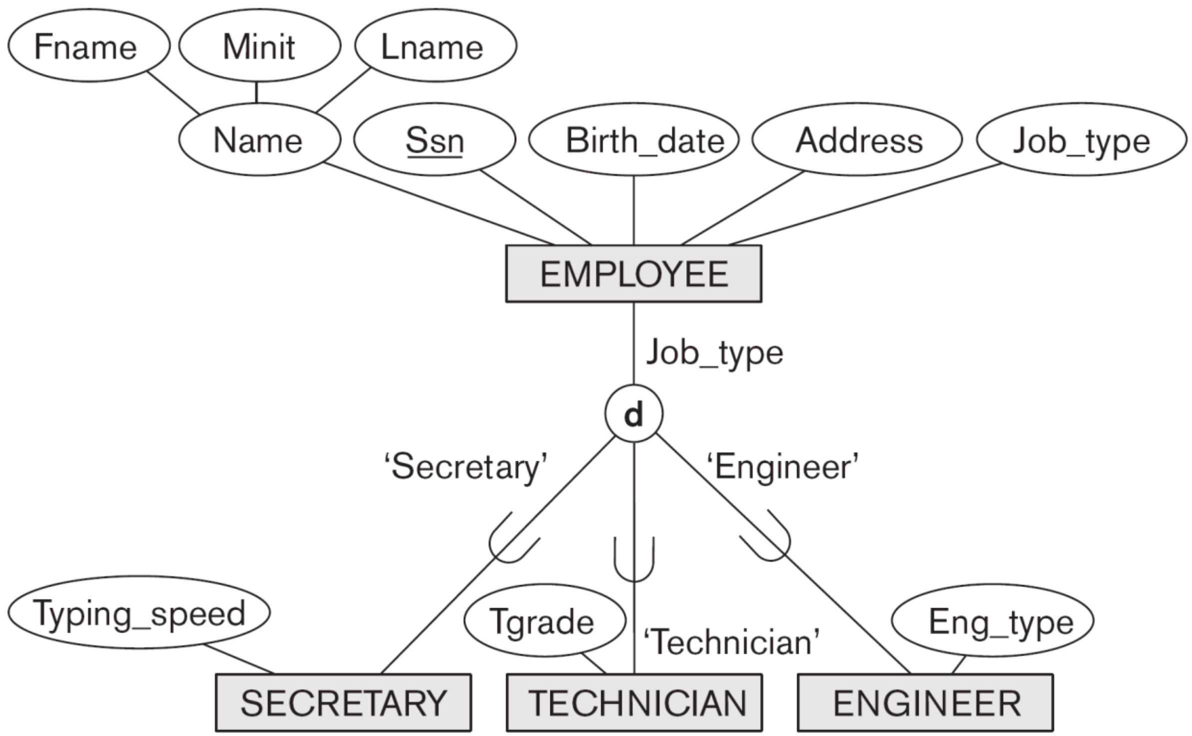
Ssn	Fname	Minit	Lname	Birth_date	Address	Job_type	Typing_speed	Tgrade	Eng_type

(d) PART

Part_no	Description	Mflag	Drawing_no	Manufacture_date	Batch_no	Pflag	Supplier_name	List_price

Figure 9.5
Options for mapping specialization or generalization. (a) Mapping the EER schema in Figure 8.4 using option 8A. (b) Mapping the EER schema in Figure 8.3(b) using option 8B. (c) Mapping the EER schema in Figure 8.4 using option 8C. (d) Mapping Figure 8.5 using option 8D with Boolean type fields Mflag and Pflag.

Figure 8.4
EER diagram notation for an attribute-defined specialization on Job_type.



[6]Such an attribute is called a *discriminator* in UML terminology.

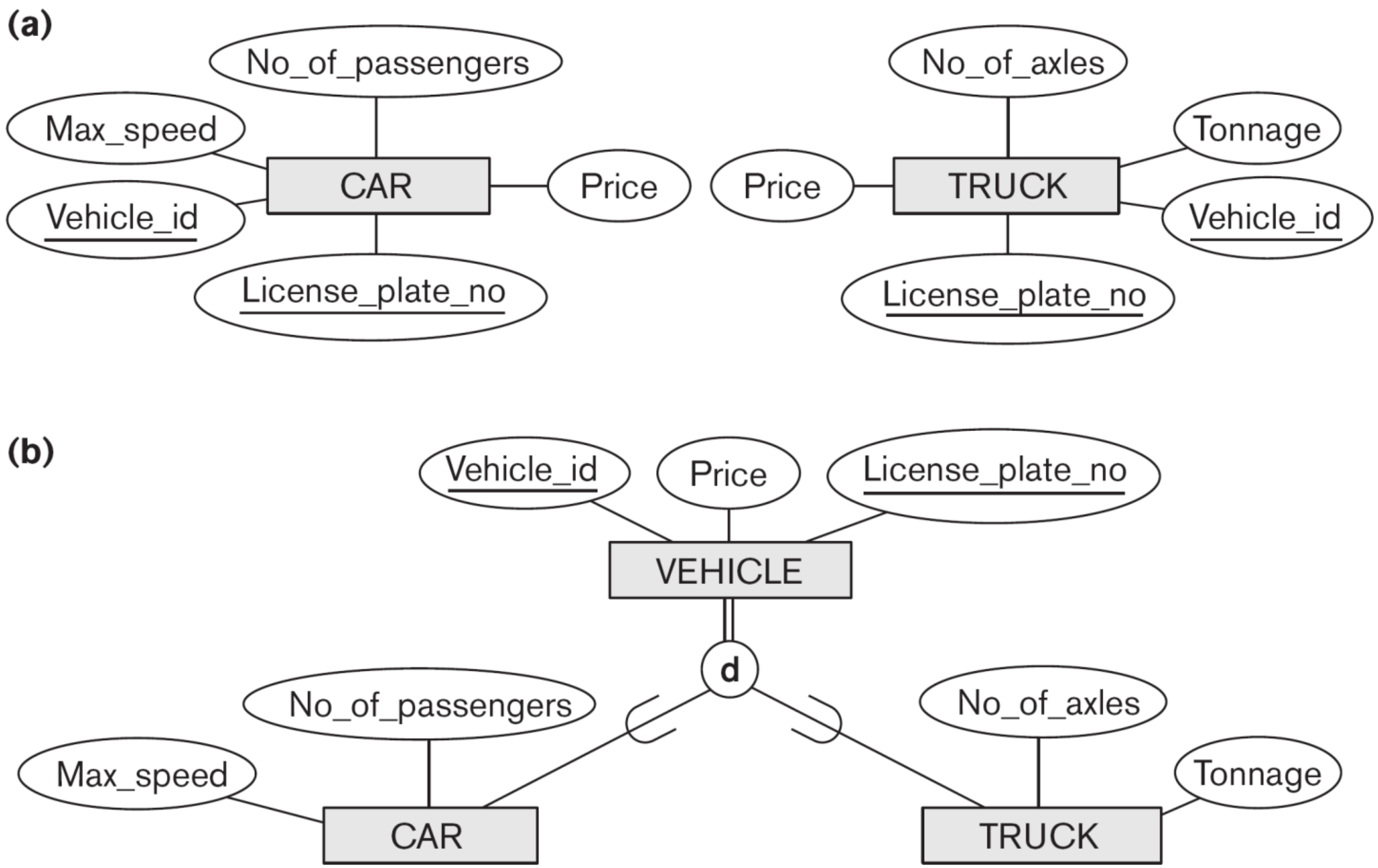


Figure 8.3
Generalization. (a) Two entity types, CAR and TRUCK. (b) Generalizing CAR and TRUCK into the superclass VEHICLE.

Mapping EER Model Constructs to Relations (cont.)

- **Option 8C: Single relation with one type attribute**
  - Create a single relation L with attributes Attrs(L) = {k,a_1,…a_n} U {attributes of S_1} U…U {attributes of S_m} U {t} and PK(L) = k. The attribute t is called a type (or **discriminating**) attribute that indicates the subclass to which each tuple belongs
  - Works for *disjoint* subclasses (see Figure 9.5(c))
- **Option 8D: Single relation with multiple type attributes**
  - Create a single relation schema L with attributes Attrs(L) = {k,a_1,…a_n} U {attributes of S_1} U…U {attributes of S_m} U {t_1, t_2,…,t_m} and PK(L) = k. Each t_i, $1 \le I \le m$, is a Boolean type attribute indicating whether or not a tuple belongs to the subclass S_i.
  - Works for *overlapping* subclasses (see Figure 9.5(d))

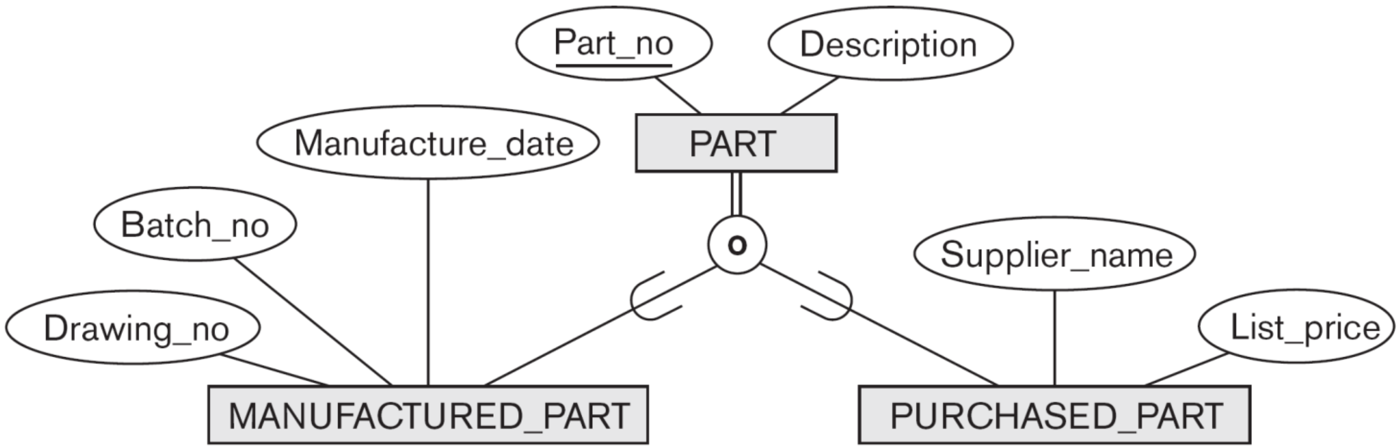


Figure 8.5
EER diagram notation for an overlapping (nondisjoint) specialization.

[7]The notation of using single or double lines is similar to that for partial or total participation of an entity type in a relationship type, as described in Chapter 7.

Mapping EER Model Constructs to Relations (cont.)

- Mapping of Shared Subclasses (Multiple Inheritance)
  - A shared subclass, such as STUDENT_ASSISTANT, is a subclass of several classes, indicating multiple inheritance.
  - These classes must all have the same key attribute; otherwise, the shared subclass would be a category.
  - We can apply any of the options discussed in Step 8 to a shared subclass, subject to the restriction discussed in Step 8 of the mapping algorithm.
  - In Figure 9.6 (next slide), option 8D is used for the shared subclass STUDENT_ASSISTANT (from Figure 8.7).

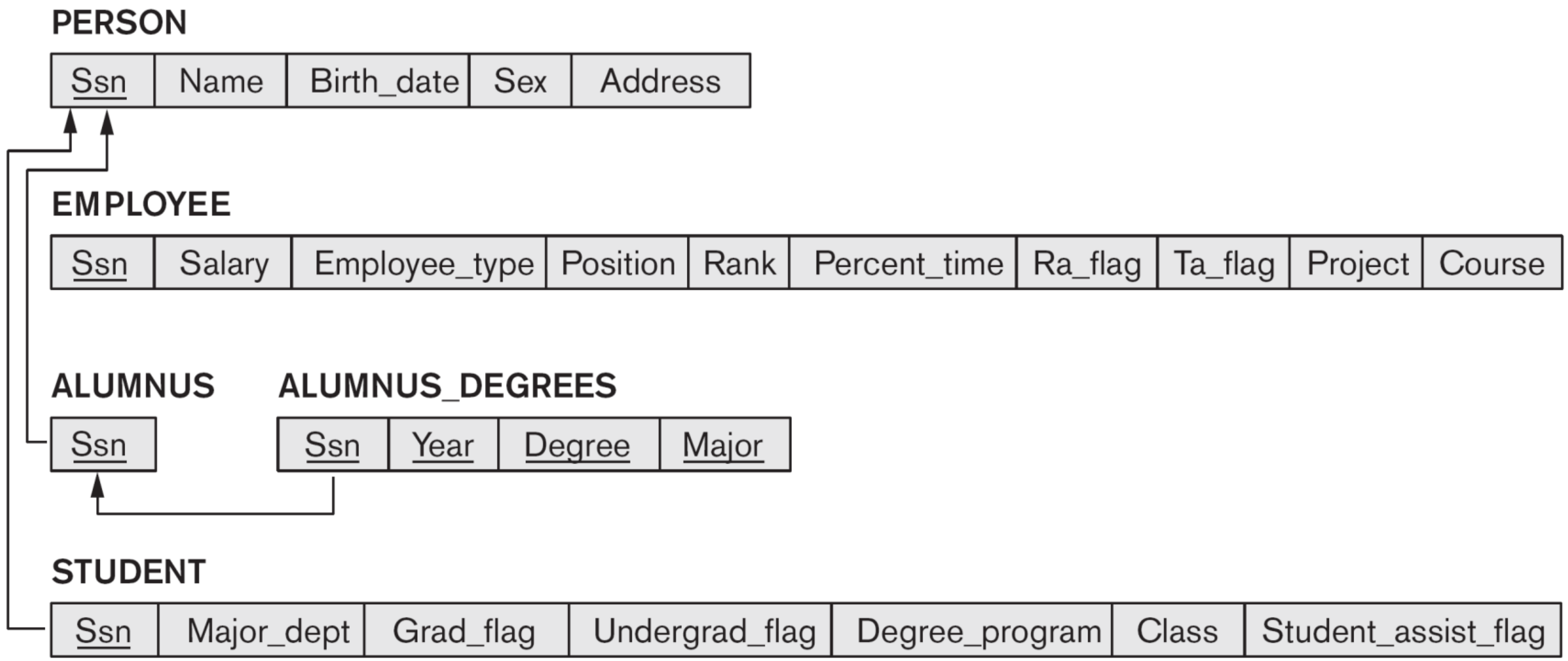


Figure 9.6
Mapping the EER specialization lattice in Figure 8.8 using multiple options.

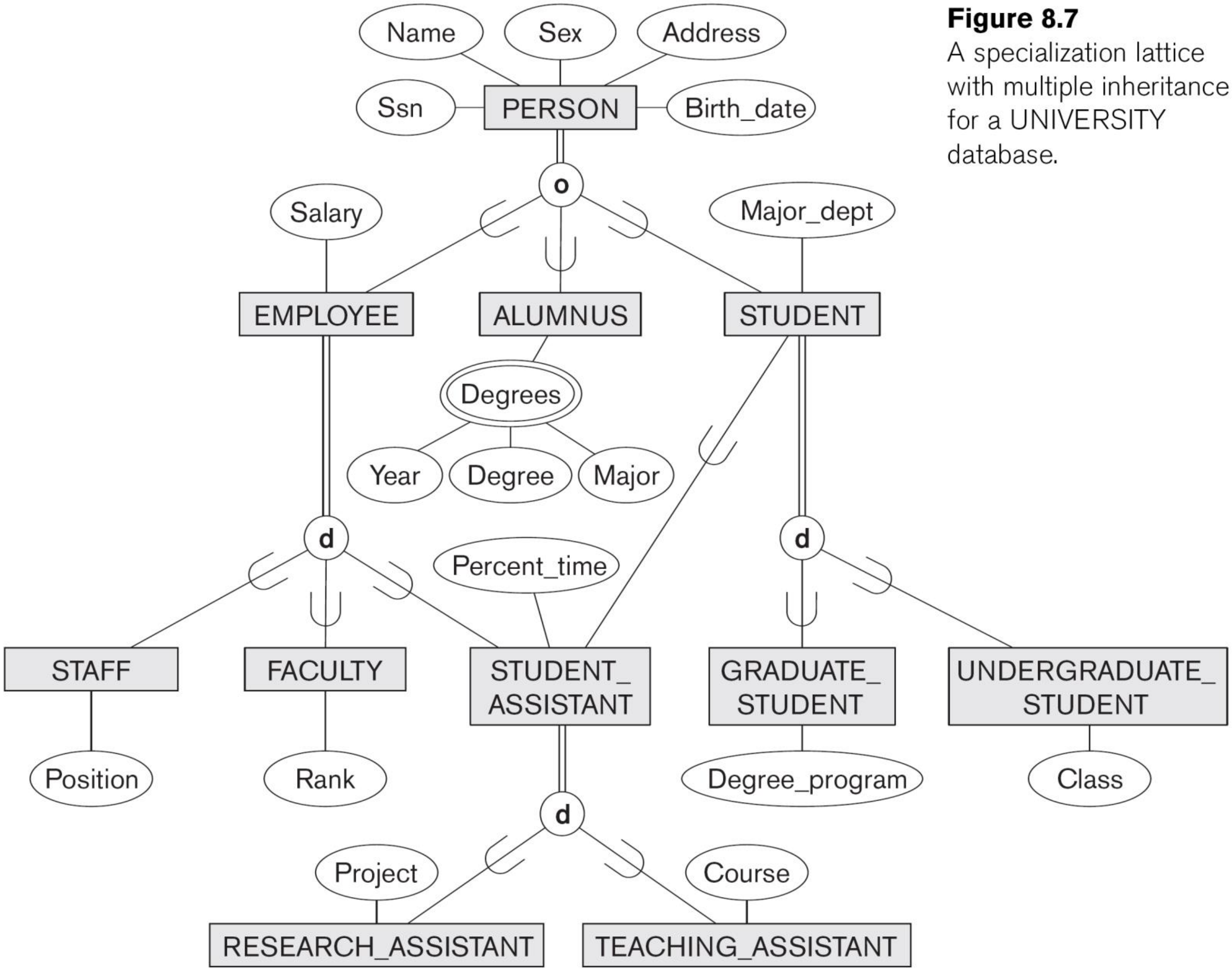
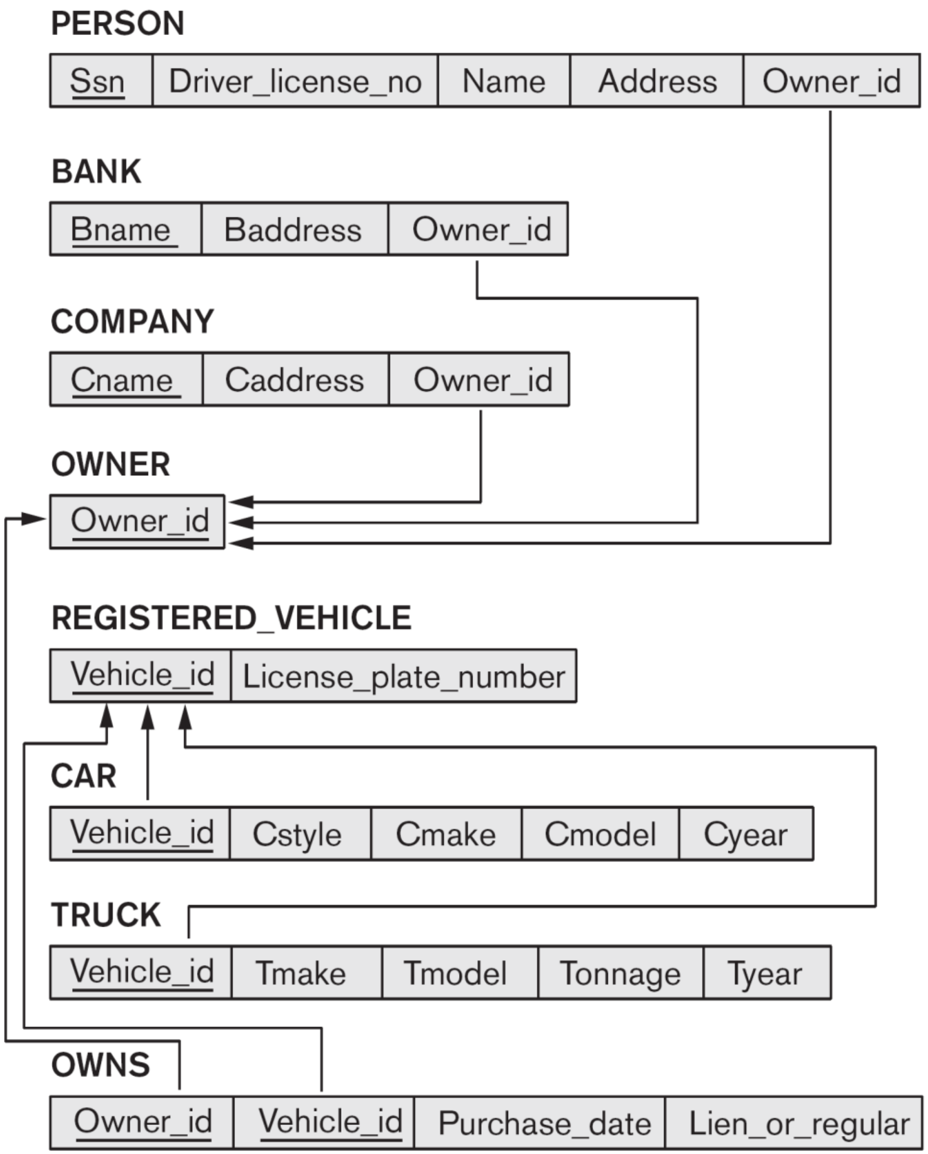


Figure 8.7
A specialization lattice with multiple inheritance for a UNIVERSITY database.

Mapping EER Model Constructs to Relations (cont.)

- **Step 9: Mapping of Union Types (Categories).**
  - For mapping a category whose defining superclasses have different keys, it is customary to specify a new (artificial) key attribute, called a *surrogate key*, when creating a relation to correspond to the category.
  - In Figure 9.7 (next slide), the relation OWNER corresponds to the OWNER category (from Figure 8.8). The primary key of the OWNER relation is the surrogate key, which we called OwnerId.
  - Unique values of OwnerId can be created by the system (similar to ObjectId in Object databases, see Chapter 11)
  - Useful to add an attribute OwnerType to OWNER relation to indicate if a record represents a BANK, COMPANY, or PERSON (not shown in Figure 9.7)

Figure 9.7
Mapping the EER categories (union types) in Figure 8.8 to relations.



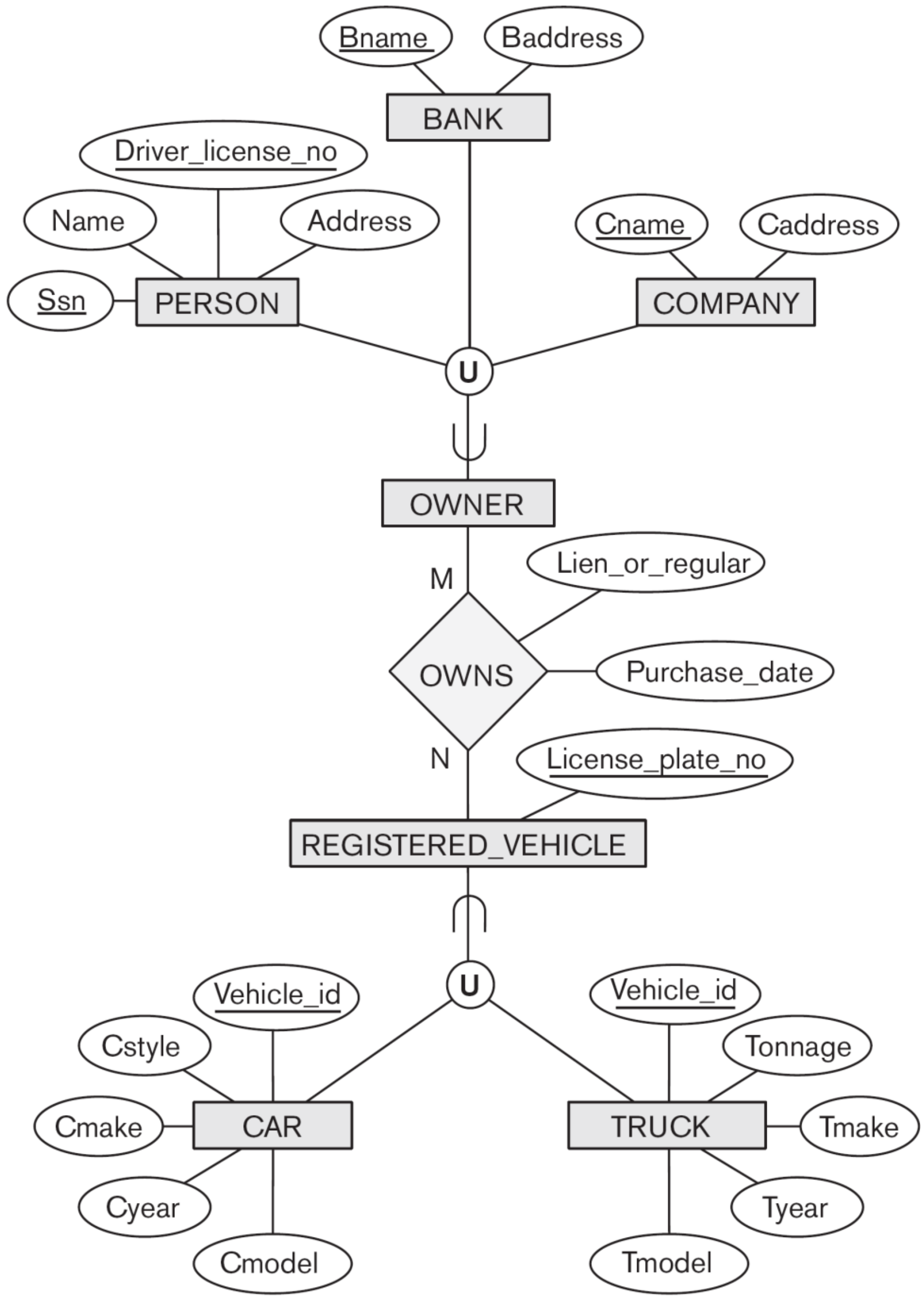


Figure 8.8
Two categories (union types): OWNER and REGISTERED_VEHICLE.

Chapter Summary

- **ER-to-Relational Mapping Algorithm**
  - Step 1: Mapping of Regular Entity Types
  - Step 2: Mapping of Weak Entity Types
  - Step 3: Mapping of Binary 1:1 Relation Types
  - Step 4: Mapping of Binary 1:N Relationship Types.
  - Step 5: Mapping of Binary M:N Relationship Types.
  - Step 6: Mapping of Multivalued attributes.
  - Step 7: Mapping of N-ary Relationship Types.

- **Mapping EER Model Constructs to Relations**
  - Step 8: Options for Mapping Specialization or Generalization.
  - Step 9: Mapping of Union Types (Categories).

Possible In-Class Exercises

- **Apply the ER-to-Relational Mapping Algorithm to the SHIP_TRACKING ER Schema in Figure 9.8 (next slide)**
- **Apply the ER and EER Mapping Algorithm to the UNIVERSITY EER database schema in Figure 8. (following slide)**

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