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Chapter 7. Conceptual Data Modeling Using Entities & Relationships

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chapter 7

Conceptual Data Modeling Using Entities and Relationships

Conceptual modeling is a very important phase in designing a successful database application. Generally, the term **database application** refers to a particular database and the associated programs that implement the database queries and updates. For example, a BANK database application that keeps track of customer accounts would include programs that implement database updates corresponding to customer deposits and withdrawals. These programs provide user-friendly graphical user interfaces (GUIs) utilizing forms and menus for the end users of the application—the bank tellers, in this example. Hence, a major part of the database application will require the design, implementation, and testing of these application programs. Traditionally, the design and testing of **application programs** has been considered to be part of *software engineering* rather than *database design*. In many software design tools, the database design methodologies and software engineering methodologies are intertwined since these activities are strongly related.

In this chapter, we follow the traditional approach of concentrating on the database structures and constraints during conceptual database design. The design of application programs is typically covered in software engineering courses. We present the modeling concepts of the **Entity-Relationship (ER) model**, which is a popular high-level conceptual data model. This model and its variations are frequently used for the conceptual design of database applications, and many database design tools employ its concepts. We describe the basic data-structuring concepts and constraints of the ER model and discuss their use in the design of conceptual schemas for database applications. We also present the diagrammatic notation associated with the ER model, known as **ER diagrams**.

Object modeling methodologies such as the **Unified Modeling Language** (**UML**) are becoming increasingly popular in both database and software design. These methodologies go beyond database design to specify detailed design of software modules and their interactions using various types of diagrams. An important part of these methodologies—namely, *class diagrams*[1]—are similar in many ways to the ER diagrams. In class diagrams, *operations* on objects are specified, in addition to specifying the database schema structure. Operations can be used to specify the *functional requirements* during database design, as we will discuss in Section 7.1. We present some of the UML notation and concepts for class diagrams that are particularly relevant to database design in Chapter 9, and briefly compare these to ER notation and concepts.

The basic ER modeling concepts are sufficient for representing many database schemas for traditional database applications, which include many data-processing applications in business and industry. Since the late 1970s, however, designers of database applications have tried to design more accurate database schemas that reflect the data properties and constraints more precisely. This was particularly important for newer applications of database technology, such as databases for engineering design and manufacturing (CAD/CAM),[2] telecommunications, complex software systems, and Geographic Information Systems (GIS), among many other applications. These types of databases have more complex requirements than do the more traditional applications. This led to the development of additional *semantic data modeling* concepts that were incorporated into conceptual data models such as the ER model. Various semantic data models have been proposed in the literature. Many of these concepts were also developed independently in related areas of computer science, such as the **knowledge representation** area of artificial intelligence and the **object modeling** area in software engineering. We shall describe features that have been proposed for semantic data models, and show how the ER model can be enhanced to include these concepts, leading to the **Enhanced ER** (**EER**) model. We will use the terms *object* and *entity* interchangeably in this chapter, because many of these concepts are commonly used in object-oriented models.[3]

This chapter is organized as follows: Section 7.1 discusses the role of high-level conceptual data models in database design. We introduce the requirements for a sample database application in Section 7.2 to illustrate the use of concepts from the ER model. This sample database is also used throughout the book. In Section 7.3 we present the concepts of entities and attributes, and we gradually introduce the diagrammatic technique for displaying an ER schema. In Section 7.4 we introduce the concepts of binary relationships and their roles and structural constraints. Section 7.5 introduces weak entity types. Section 7.6 shows how a schema design is refined to include relationships. Section 7.7 reviews the notation for ER diagrams,

[1] A **class** is similar to an *entity type* in many ways.

[2] CAD/CAM stands for computer-aided design/computer-aided manufacturing.

[3] EER has also been used to stand for Extended ER model.

summarizes the issues and common pitfalls that occur in schema design, and discusses how to choose the names for database schema constructs. Section 7.8 discusses more complex types of relationships. Section 7.9 incorporates the concepts of *class/subclass relationships* and *type inheritance* into the ER model. Then, in Section 7.10, we add the concepts of *specialization* and *generalization*. Section 7.11 discusses the various types of *constraints* on specialization/generalization, and Section 7.12 shows how the UNION construct can be modeled by including the concept of *category* in the EER model. Section 7.13 gives a sample UNIVERSITY database schema in the EER model and summarizes the EER model concepts by giving formal definitions. In Section 7.14, we discuss the fundamental abstractions that are used as the basis of many semantic data models. Section 7.15 summarizes the chapter. If only a basic introduction to ER modeling is desired, the reader may choose to skip some or all of the later sections of this chapter (Section 7.8, and Sections 7.12 through 7.14).

7.1 Using High-Level Conceptual Data Models for Database Design

Figure 7.1 shows a simplified overview of the database design process. The first step shown is **requirements collection and analysis**. During this step, the database designers interview prospective database users to understand and document their **data requirements**. The result of this step is a concisely written set of users' requirements. These requirements should be specified in as detailed and complete a form as possible. In parallel with specifying the data requirements, it is useful to specify the known **functional requirements** of the application. These consist of the user-defined **operations** (or **transactions**) that will be applied to the database, including both retrievals and updates. In software design, it is common to use *data flow diagrams*, *sequence diagrams*, *scenarios*, and other techniques to specify functional requirements. We will not discuss any of these techniques here; they are usually described in detail in software engineering texts. We give an overview of some of these techniques in Chapter 9.

Once the requirements have been collected and analyzed, the next step is to create a **conceptual schema** for the database, using a high-level conceptual data model. This step is called **conceptual design**. The conceptual schema is a concise description of the data requirements of the users and includes detailed descriptions of the entity types, relationships, and constraints; these are expressed using the concepts provided by the high-level data model. Because these concepts do not include implementation details, they are usually easier to understand and can be used to communicate with nontechnical users. The high-level conceptual schema can also be used as a reference to ensure that all users' data requirements are met and that the requirements do not conflict. This approach enables database designers to concentrate on specifying the properties of the data, without being concerned with storage and implementation details. This makes it is easier to create a good conceptual database design.

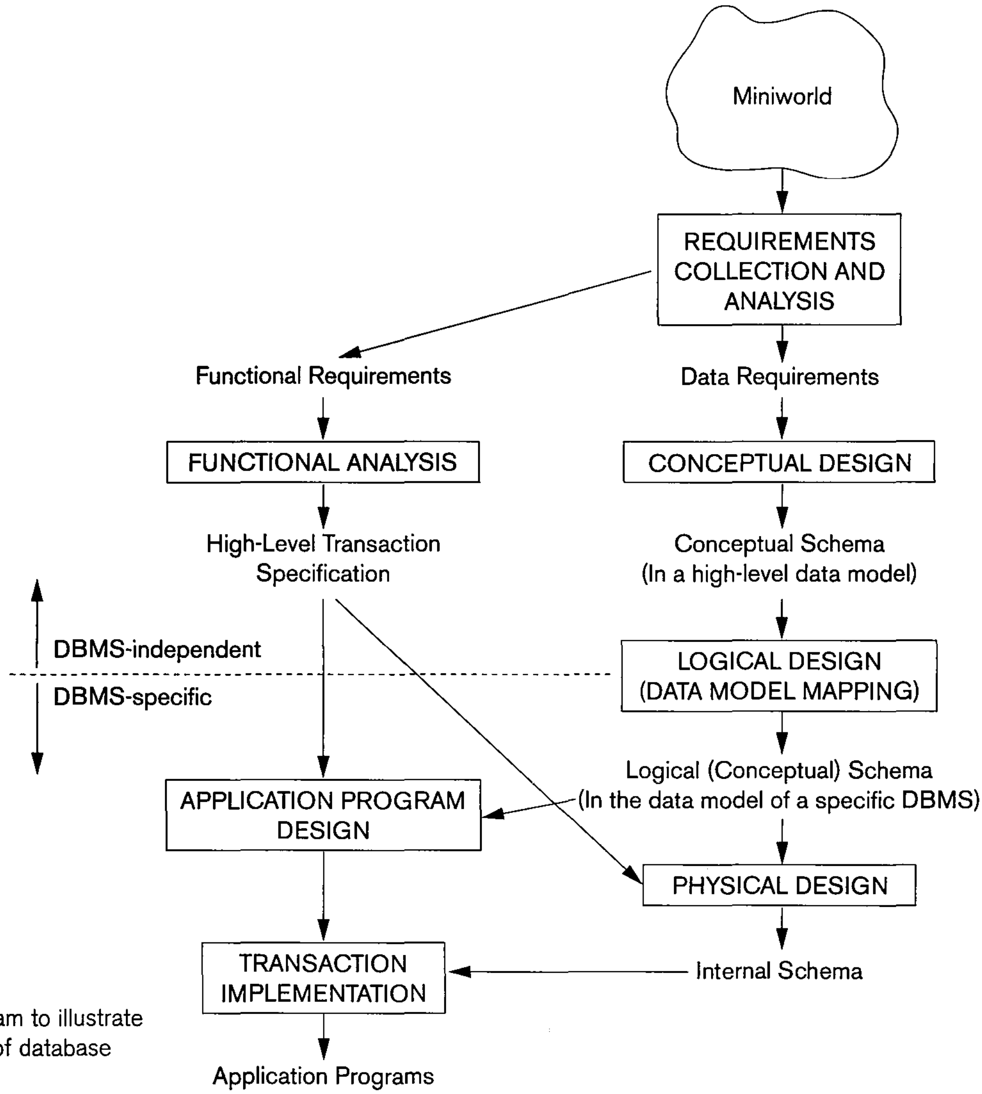

Figure 7.1
A simplified diagram to illustrate the main phases of database design.

During or after the conceptual schema design, the basic data model operations can be used to specify the high-level user queries and operations identified during functional analysis. This also serves to confirm that the conceptual schema meets all the identified functional requirements. Modifications to the conceptual schema can be introduced if some functional requirements cannot be specified using the initial schema.

The next step in database design is the actual implementation of the database, using a commercial DBMS. Most current commercial DBMSs use an implementation data model—such as the relational or the object-relational database model—so the conceptual schema is transformed from the high-level data model into the implementation data model. This step is called **logical design** or **data model mapping**; its result is a database schema in the implementation data model of the DBMS. Data model mapping is often automated or semiautomated within the database design tools.

The last step is the **physical design** phase, during which the internal storage structures, file organizations, indexes, access paths, and physical design parameters for the database files are specified. In parallel with these activities, application programs are designed and implemented as database transactions corresponding to the high-level transaction specifications. We discuss the database design process in more detail in Chapter 9.

We first present only the basic ER model concepts for conceptual schema design in this chapter. Additional modeling concepts are discussed in Sections 7.10 through 7.13, when we introduce the EER model.

7.2 A Sample Database Application

In this section we describe a sample database application, called COMPANY, which serves to illustrate the basic ER model concepts and their use in schema design. We list the data requirements for the database here, and then create its conceptual schema step-by-step as we introduce the modeling concepts of the ER model. The COMPANY database keeps track of a company's employees, departments, and projects. Suppose that after the requirements collection and analysis phase, the database designers provide the following description of the *miniworld*—the part of the company that will be represented in the database.

- The company is organized into departments. Each department has a unique name, a unique number, and a particular employee who manages the department. We keep track of the start date when that employee began managing the department. A department may have several locations.
- A department controls a number of projects, each of which has a unique name, a unique number, and a single location.
- We store each employee's name, Social Security number,[4] address, salary, sex (gender), and birth date. An employee is assigned to one department, but may work on several projects, which are not necessarily controlled by the same department. We keep track of the current number of hours per week that an employee works on each project. We also keep track of the direct supervisor of each employee (who is another employee).
- We want to keep track of the dependents of each employee for insurance purposes. We keep each dependent's first name, sex, birth date, and relationship to the employee.

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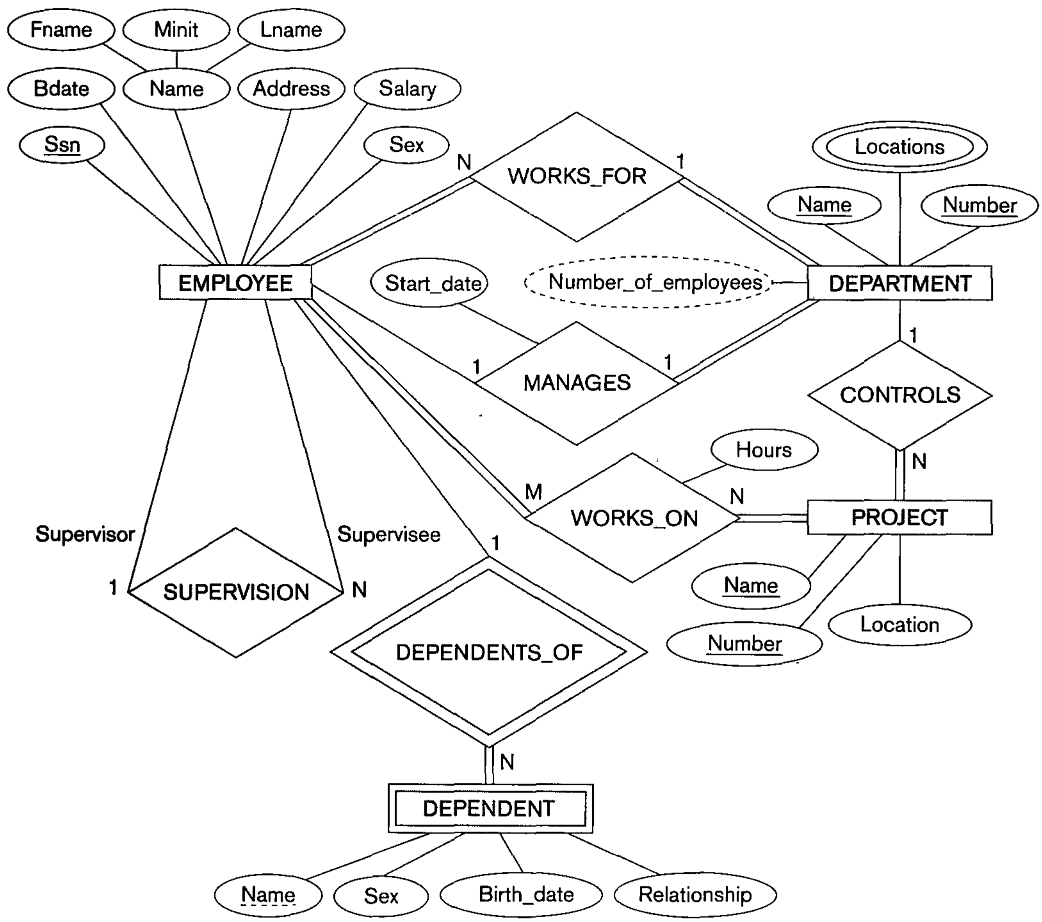
[4]The Social Security number, or SSN, is a unique nine-digit identifier assigned to each individual in the United States to keep track of his or her employment, benefits, and taxes. Other countries may have similar identification schemes, such as personal identification card numbers.

Figure 7.2 shows how the schema for this database application can be displayed by means of the graphical notation known as **ER diagrams**. This figure will be explained gradually as the ER model concepts are presented. We describe the step-by-step process of deriving this schema from the stated requirements—and explain the ER diagrammatic notation—as we introduce the ER model concepts.

7.3 Entity Types, Entity Sets, Attributes, and Keys

The ER model describes data as *entities, relationships,* and *attributes.* In Section 7.3.1 we introduce the concepts of entities and their attributes. We discuss entity types and key attributes in Section 7.3.2. Then, in Section 7.3.3, we specify the initial con-

Figure 7.2
An ER schema diagram for the COMPANY database. The diagrammatic notation is introduced gradually throughout this chapter and is summarized in Figure 7.14.



ceptual design of the entity types for the COMPANY database. Relationships are described in Section 7.4.

7.3.1 Entities and Attributes

Entities and Their Attributes. The basic object that the ER model represents is an **entity**, which is a *thing* in the real world with an independent existence. An entity may be an object with a physical existence (for example, a particular person, car, house, or employee) or it may be an object with a conceptual existence (for instance, a company, a job, or a university course). Each entity has **attributes**—the particular properties that describe it. For example, an EMPLOYEE entity may be described by the employee's name, age, address, salary, and job. A particular entity will have a value for each of its attributes. The attribute values that describe each entity become a major part of the data stored in the database.

Figure 7.3 shows two entities and the values of their attributes. The EMPLOYEE entity e_1 has four attributes: Name, Address, Age, and Home_phone; their values are 'John Smith,' '2311 Kirby, Houston, Texas 77001', '55', and '713-749-2630', respectively. The COMPANY entity c_1 has three attributes: Name, Headquarters, and President; their values are 'Sunco Oil', 'Houston', and 'John Smith', respectively.

Several types of attributes occur in the ER model: *simple* versus *composite*, *single-valued* versus *multivalued*, and *stored* versus *derived*. First we define these attribute types and illustrate their use via examples. Then we discuss the concept of a *NULL value* for an attribute.

Composite versus Simple (Atomic) Attributes. Composite attributes can be divided into smaller subparts, which represent more basic attributes with independent meanings. For example, the Address attribute of the EMPLOYEE entity shown in Figure 7.3 can be subdivided into Street_address, City, State, and Zip,[5] with the values '2311 Kirby', 'Houston', 'Texas', and '77001.' Attributes that are not divisible are called **simple** or **atomic attributes.** Composite attributes can form a hierarchy;

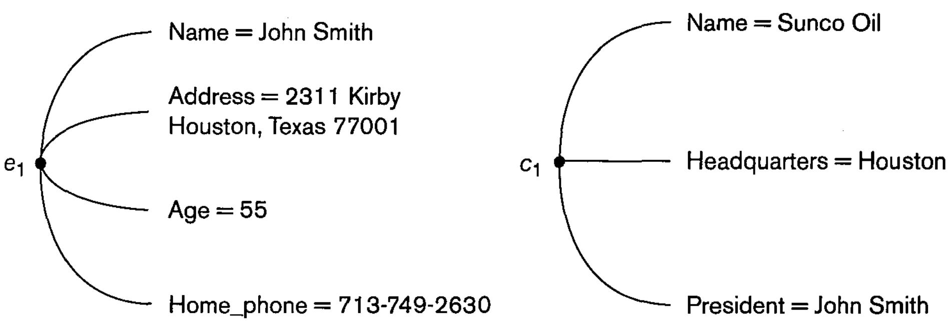


Figure 7.3
Two entities, EMPLOYEE e_1, and COMPANY c_1, and their attributes.

[5]Zip Code is the name used in the United States for a five-digit postal code, such as 76019, which can be extended to nine digits, such as 76019-0015. We use five-digit Zip Codes in our examples.

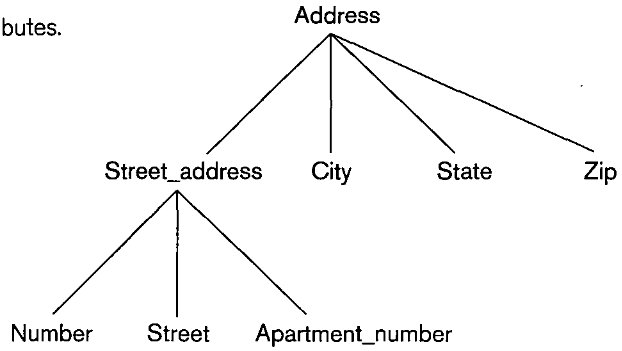
for example, Street_address can be further subdivided into three simple component attributes: Number, Street, and Apartment_number, as shown in Figure 7.4. The value of a composite attribute is the concatenation of the values of its component simple attributes.

Composite attributes are useful to model situations in which a user sometimes refers to the composite attribute as a unit but at other times refers specifically to its components. If the composite attribute is referenced only as a whole, there is no need to subdivide it into component attributes. For example, if there is no need to refer to the individual components of an address (Zip Code, street, and so on), then the whole address can be designated as a simple attribute.

Single-Valued versus Multivalued Attributes. Most attributes have a single value for a particular entity; such attributes are called **single-valued.** For example, Age is a single-valued attribute of a person. In some cases an attribute can have a set of values for the same entity—for instance, a Colors attribute for a car, or a College_degrees attribute for a person. Cars with one color have a single value, whereas two-tone cars have two color values. Similarly, one person may not have a college degree, another person may have one, and a third person may have two or more degrees; therefore, different people can have different *numbers* of *values* for the College_degrees attribute. Such attributes are called **multivalued.** A multivalued attribute may have lower and upper bounds to constrain the *number of values* allowed for each individual entity. For example, the Colors attribute of a car may be restricted to have between one and three values, if we assume that a car can have three colors at most.

Stored versus Derived Attributes. In some cases, two (or more) attribute values are related—for example, the Age and Birth_date attributes of a person. For a particular person entity, the value of Age can be determined from the current (today's) date and the value of that person's Birth_date. The Age attribute is hence called a **derived attribute** and is said to be **derivable from** the Birth_date attribute, which is called a **stored attribute.** Some attribute values can be derived from *related entities*; for example, an attribute Number_of_employees of a DEPARTMENT

Figure 7.4
A hierarchy of composite attributes.



entity can be derived by counting the number of employees related to (working for) that department.

NULL Values. In some cases, a particular entity may not have an applicable value for an attribute. For example, the Apartment_number attribute of an address applies only to addresses that are in apartment buildings and not to other types of residences, such as single-family homes. Similarly, a College_degrees attribute applies only to people with college degrees. For such situations, a special value called NULL is created. An address of a single-family home would have NULL for its Apartment_number attribute, and a person with no college degree would have NULL for College_degrees. NULL can also be used if we do not know the value of an attribute for a particular entity—for example, if we do not know the home phone number of 'John Smith' in Figure 7.3. The meaning of the former type of NULL is *not applicable*, whereas the meaning of the latter is *unknown*. The *unknown* category of NULL can be further classified into two cases. The first case arises when it is known that the attribute value exists but is *missing*—for instance, if the Height attribute of a person is listed as NULL. The second case arises when it is *not known* whether the attribute value exists—for example, if the Home_phone attribute of a person is NULL.

Complex Attributes. Notice that, in general, composite and multivalued attributes can be nested arbitrarily. We can represent arbitrary nesting by grouping components of a composite attribute between parentheses () and separating the components with commas, and by displaying multivalued attributes between braces { }. Such attributes are called **complex attributes**. For example, if a person can have more than one residence and each residence can have a single address and multiple phones, an attribute Address_phone for a person can be specified as shown in Figure 7.5.[6] Both Phone and Address are themselves composite attributes.

7.3.2 Entity Types, Entity Sets, Keys, and Value Sets

Entity Types and Entity Sets. A database usually contains groups of entities that are similar. For example, a company employing hundreds of employees may want to store similar information concerning each of the employees. These employee entities share the same attributes, but each entity has its *own value(s)* for each attribute. An **entity type** defines a *collection* (or *set*) of entities that have the same attributes. Each entity type in the database is described by its name and attributes. Figure 7.6 shows

{Address_phone({Phone(Area_code,Phone_number)},Address(Street_address (Number,Street,Apartment_number),City,State,Zip))}

Figure 7.5
A complex attribute: Address_phone.

[6]For those familiar with XML, we should note that complex attributes are similar to complex elements in XML (see Chapter 11).

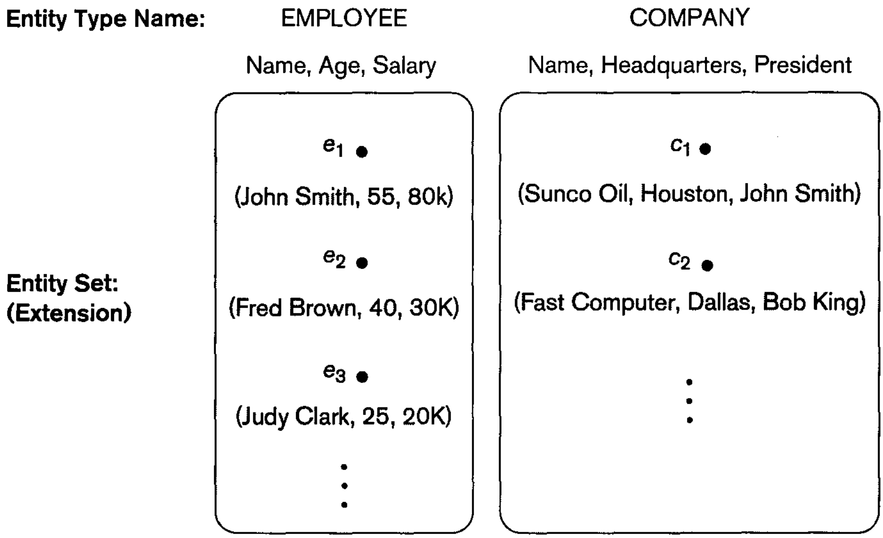


Figure 7.6
Two entity types, EMPLOYEE and COMPANY, and some member entities of each.

two entity types: EMPLOYEE and COMPANY, and a list of some of the attributes for each. A few individual entities of each type are also illustrated, along with the values of their attributes. The collection of all entities of a particular entity type in the database at any point in time is called an **entity set**; the entity set is usually referred to using the same name as the entity type. For example, EMPLOYEE refers to both a *type of entity* as well as the current set *of all employee entities* in the database.

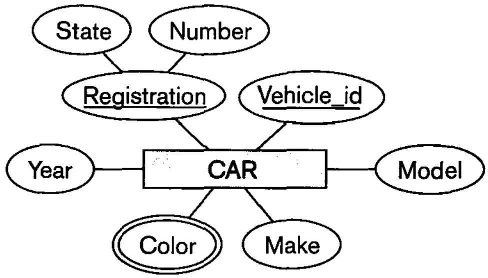
An entity type is represented in ER diagrams[7] (see Figure 7.2) as a rectangular box enclosing the entity type name. Attribute names are enclosed in ovals and are attached to their entity type by straight lines. Composite attributes are attached to their component attributes by straight lines. Multivalued attributes are displayed in double ovals. Figure 7.7(a) shows a CAR entity type in this notation.

An entity type describes the **schema** or **intension** for a *set of entities* that share the same structure. The collection of entities of a particular entity type is grouped into an entity set, which is also called the **extension** of the entity type.

Key Attributes of an Entity Type. An important constraint on the entities of an entity type is the **key** or **uniqueness constraint** on attributes. An entity type usually has one or more attributes whose values are distinct for each individual entity in the entity set. Such an attribute is called a **key attribute**, and its values can be used to identify each entity uniquely. For example, the Name attribute is a key of the COMPANY entity type in Figure 7.6 because no two companies are allowed to have the same name. For the PERSON entity type, a typical key attribute is Ssn (Social Security number). Sometimes several attributes together form a key, meaning that

[7]We use a notation for ER diagrams that is close to the original proposed notation (Chen 1976). Many other notations are in use; we illustrate some of them in Chapter 9 when we present UML class diagrams and in Appendix A.

(a)



(b)

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})

⋮

Figure 7.7
The CAR entity type with two key attributes, Registration and Vehicle_id. (a) ER diagram notation. (b) Entity set with three entities.

the *combination* of the attribute values must be distinct for each entity. If a set of attributes possesses this property, the proper way to represent this in the ER model that we describe here is to define a *composite attribute* and designate it as a key attribute of the entity type. Notice that such a composite key must be *minimal*; that is, all component attributes must be included in the composite attribute to have the uniqueness property. Superfluous attributes must not be included in a key. In ER diagrammatic notation, each key attribute has its name **underlined** inside the oval, as illustrated in Figure 7.7(a).

Specifying that an attribute is a key of an entity type means that the preceding uniqueness property must hold for *every entity set* of the entity type. Hence, it is a constraint that prohibits any two entities from having the same value for the key attribute at the same time. It is not the property of a particular entity set; rather, it is a constraint on *any entity set* of the entity type at any point in time. This key constraint (and other constraints we discuss later) is derived from the constraints of the miniworld that the database represents.

Some entity types have *more than one* key attribute. For example, each of the Vehicle_id and Registration attributes of the entity type CAR (Figure 7.7) is a key in its own right. The Registration attribute is an example of a composite key formed from two simple component attributes, State and Number, neither of which is a key on its own. An entity type may also have *no key*, in which case it is called a *weak entity type* (see Section 7.5).

In our diagrammatic notation, if two attributes are underlined separately, then *each is a key on its own*. Unlike the relational model (see Section 3.2.2), there is no concept of primary key in the ER model that we present here; the primary key will be chosen during mapping to a relational schema (see Chapter 8).

Value Sets (Domains) of Attributes. Each simple attribute of an entity type is associated with a **value set** (or **domain** of values), which specifies the set of values that may be assigned to that attribute for each individual entity. In Figure 7.6, if the range of ages allowed for employees is between 16 and 70, we can specify the value set of the Age attribute of EMPLOYEE to be the set of integer numbers between 16 and 70. Similarly, we can specify the value set for the Name attribute to be the set of strings of alphabetic characters separated by blank characters, and so on. Value sets are not displayed in ER diagrams, and are typically specified using the basic **data types** available in most programming languages, such as integer, string, Boolean, float, enumerated type, subrange, and so on. Additional data types to represent common database types such as date, time, and other concepts are also employed.

Mathematically, an attribute A of entity set E whose value set is V can be defined as a **function** from E to the power set[8] $P(V)$ of V:

$$A : E \rightarrow P(V)$$

We refer to the value of attribute A for entity e as $A(e)$. The previous definition covers both single-valued and multivalued attributes, as well as NULLs. A NULL value is represented by the *empty set*. For single-valued attributes, $A(e)$ is restricted to being a *singleton set* for each entity e in E, whereas there is no restriction on multivalued attributes.[9] For a composite attribute A, the value set V is the power set of the Cartesian product of $P(V_1), P(V_2), \ldots, P(V_n)$, where $V_1, V_2, \ldots, V_n$ are the value sets of the simple component attributes that form A:

$$V = P\ (P(V_1) \times P(V_2) \times \ldots \times P(V_n))$$

The value set provides all possible values. Usually only a small number of these values exist in the database at a particular time. Those values represent the data from the current state of the miniworld. They correspond to the data as it actually exists in the miniworld.

7.3.3 Initial Conceptual Design of the COMPANY Database

We can now define the entity types for the COMPANY database, based on the requirements described in Section 7.2. After defining several entity types and their attributes here, we refine our design in Section 7.4 after we introduce the concept of a relationship. According to the requirements listed in Section 7.2, we can identify

[8]The **power set** $P(V)$ of a set V is the set of all subsets of V.

[9]A **singleton** set is a set with only one element (value).

four entity types—one corresponding to each of the four items in the specification (see Figure 7.8):

1. An entity type DEPARTMENT with attributes Name, Number, Locations, Manager, and Manager_start_date. Locations is the only multivalued attribute. We can specify that both Name and Number are (separate) key attributes because each was specified to be unique.
2. An entity type PROJECT with attributes Name, Number, Location, and Controlling_department. Both Name and Number are (separate) key attributes.
3. An entity type EMPLOYEE with attributes Name, Ssn, Sex, Address, Salary, Birth_date, Department, and Supervisor. Both Name and Address may be composite attributes; however, this was not specified in the requirements. We

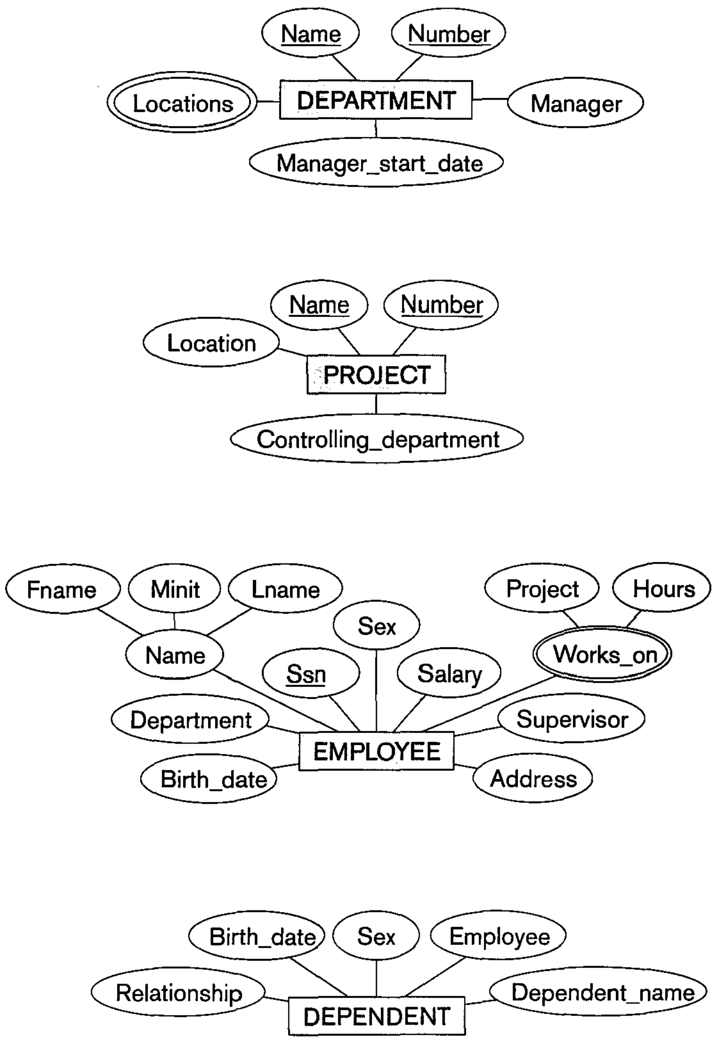


Figure 7.8
Preliminary design of entity types for the COMPANY database. Some of the shown attributes will be refined into relationships.

must go back to the users to see if any of them will refer to the individual components of Name—First_name, Middle_initial, Last_name—or of Address.

4. An entity type DEPENDENT with attributes Employee, Dependent_name, Sex, Birth_date, and Relationship (to the employee).

So far, we have not represented the fact that an employee can work on several projects, nor have we represented the number of hours per week an employee works on each project. This characteristic is listed as part of the third requirement in Section 7.2, and it can be represented by a multivalued composite attribute of EMPLOYEE called Works_on with the simple components (Project, Hours). Alternatively, it can be represented as a multivalued composite attribute of PROJECT called Workers with the simple components (Employee, Hours). We choose the first alternative in Figure 7.8, which shows each of the entity types just described. The Name attribute of EMPLOYEE is shown as a composite attribute, presumably after consultation with the users.

7.4 Relationship Types, Relationship Sets, Roles, and Structural Constraints

In Figure 7.8 there are several *implicit relationships* among the various entity types. In fact, whenever an attribute of one entity type refers to another entity type, some relationship exists. For example, the attribute Manager of DEPARTMENT refers to an employee who manages the department; the attribute Controlling_department of PROJECT refers to the department that controls the project; the attribute Supervisor of EMPLOYEE refers to another employee (the one who supervises this employee); the attribute Department of EMPLOYEE refers to the department for which the employee works; and so on. In the ER model, these references should not be represented as attributes but as **relationships**, which are discussed in this section. The COMPANY database schema will be refined in Section 7.6 to represent relationships explicitly. In the initial design of entity types, relationships are typically captured in the form of attributes. As the design is refined, these attributes get converted into relationships between entity types.

This section is organized as follows: Section 7.4.1 introduces the concepts of relationship types, relationship sets, and relationship instances. We define the concepts of relationship degree, role names, and recursive relationships in Section 7.4.2, and then we discuss structural constraints on relationships—such as cardinality ratios and existence dependencies—in Section 7.4.3. Section 7.4.4 shows how relationship types can also have attributes.

7.4.1 Relationship Types, Sets, and Instances

A **relationship type** R among n entity types $E_1, E_2, \ldots, E_n$ defines a set of associations—or a **relationship set**—among entities from these entity types. As for the case of entity types and entity sets, a relationship type and its corresponding relationship set are customarily referred to by the *same name*, R. Mathematically, the relationship set R is a set of **relationship instances** r_i, where each r_i associates n individual entities $(e_1, e_2, ..., e_n)$, and each entity e_j in r_i is a member of entity set E_j, $1 \le j \le n$. Hence, a relationship set is a mathematical relation on $E_1, E_2, ..., E_n$; alternatively, it can be defined as a subset of the Cartesian product of the entity sets $E_1 \times E_2 \times ... \times E_n$. Each of the entity types $E_1, E_2, ..., E_n$ is said to participate in the relationship type R; similarly, each of the individual entities $e_1, e_2, ..., e_n$ is said to **participate** in the relationship instance $r_i = (e_1, e_2, ..., e_n)$.

Informally, each relationship instance r_i in R is an association of entities, where the association includes exactly one entity from each participating entity type. Each such relationship instance r_i represents the fact that the entities participating in r_i are related in some way in the corresponding miniworld situation. For example, consider a relationship type WORKS_FOR between the two entity types EMPLOYEE and DEPARTMENT, which associates each employee with the department for which the employee works in the corresponding entity set. Each relationship instance in the relationship set WORKS_FOR associates one EMPLOYEE entity and one DEPARTMENT entity. Figure 7.9 illustrates this example, where each relationship instance r_i is shown connected to the EMPLOYEE and DEPARTMENT entities that participate in r_i. In the miniworld represented by Figure 7.9, employees e_1, e_3, and e_6 work for department d_1; employees e_2 and e_4 work for department d_2; and employees e_5 and e_7 work for department d_3.

In ER diagrams, relationship types are displayed as diamond-shaped boxes, which are connected by straight lines to the rectangular boxes representing the participating

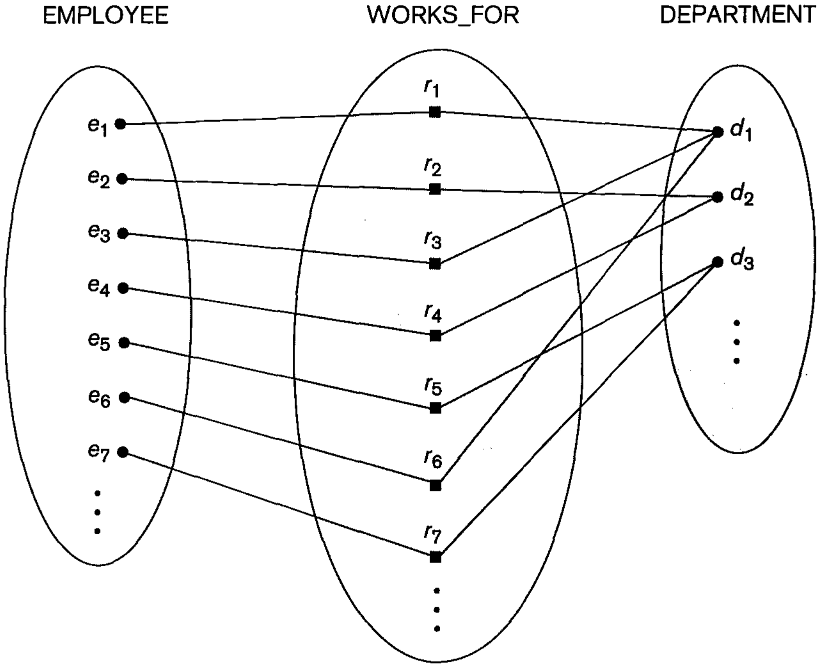


Figure 7.9
Some instances in the WORKS_FOR relationship set, which represents a relationship type WORKS_FOR between EMPLOYEE and DEPARTMENT.

entity types. The relationship name is displayed in the diamond-shaped box (see Figure 7.2).

7.4.2 Relationship Degree, Role Names, and Recursive Relationships

Degree of a Relationship Type. The **degree** of a relationship type is the number of participating entity types. Hence, the WORKS_FOR relationship is of degree two. A relationship type of degree two is called **binary**, and one of degree three is called **ternary**. An example of a ternary relationship is SUPPLY, shown in Figure 7.10, where each relationship instance r_i associates three entities—a supplier s, a part p, and a project j—whenever s supplies part p to project j. Relationships can generally be of any degree, but the ones most common are binary relationships. Higher-degree relationships are generally more complex than binary relationships; we characterize them further in Section 7.8.

Relationships as Attributes. It is sometimes convenient to think of a binary relationship type in terms of attributes, as we discussed in Section 7.3.3. Consider the WORKS_FOR relationship type in Figure 7.9. One can think of an attribute called Department of the EMPLOYEE entity type, where the value of Department for each EMPLOYEE entity is (a reference to) the DEPARTMENT entity for which that employee works. Hence, the value set for this Department attribute is the set of *all* DEPARTMENT entities, which is the DEPARTMENT entity set. This is what we did in

Figure 7.10
Some relationship instances in the SUPPLY ternary relationship set.

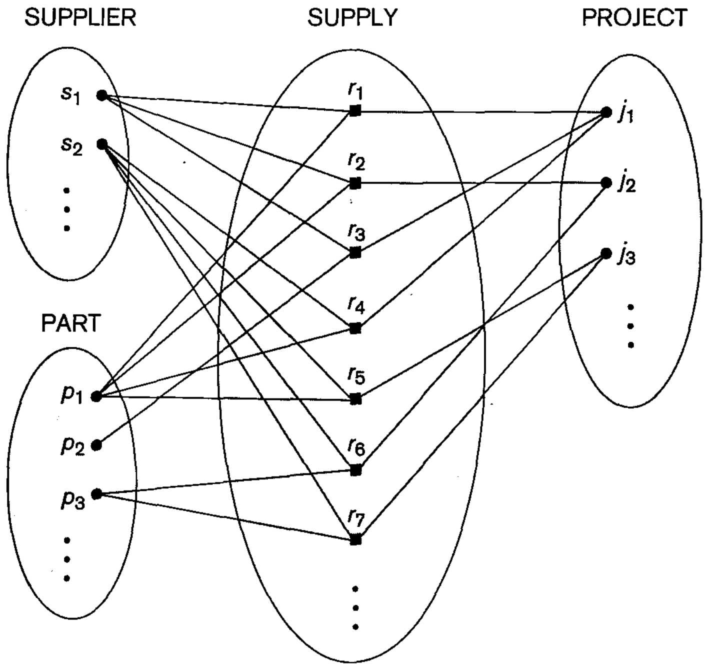


Figure 7.8 when we specified the initial design of the entity type EMPLOYEE for the COMPANY database. However, when we think of a binary relationship as an attribute, we always have two options. In this example, the alternative is to think of a multivalued attribute Employee of the entity type DEPARTMENT whose values for each DEPARTMENT entity is the set of EMPLOYEE entities who work for that department. The value set of this Employee attribute is the power set of the EMPLOYEE entity set. Either of these two attributes—Department of EMPLOYEE or Employee of DEPARTMENT—can represent the WORKS_FOR relationship type. If both are represented, they are constrained to be inverses of each other.[10]

Role Names and Recursive Relationships. Each entity type that participates in a relationship type plays a particular role in the relationship. The **role name** signifies the role that a participating entity from the entity type plays in each relationship instance, and helps to explain what the relationship means. For example, in the WORKS_FOR relationship type, EMPLOYEE plays the role of *employee* or *worker* and DEPARTMENT plays the role of *department* or *employer.*

Role names are not technically necessary in relationship types where all the participating entity types are distinct, since each participating entity type name can be used as the role name. However, in some cases the *same* entity type participates more than once in a relationship type in *different roles.* In such cases the role name becomes essential for distinguishing the meaning of the role that each participating entity plays. Such relationship types are called **recursive relationships**. Figure 7.11 shows an example. The SUPERVISION relationship type relates an employee to a supervisor, where both employee and supervisor entities are members of the same EMPLOYEE entity set. Hence, the EMPLOYEE entity type *participates twice* in SUPERVISION: once in the role of *supervisor* (or *boss*), and once in the role of *supervisee* (or *subordinate*). Each relationship instance r_i in SUPERVISION associates two employee entities e_j and e_k, one of which plays the role of supervisor and the other the role of supervisee. In Figure 7.11, the lines marked '1' represent the supervisor role, and those marked '2' represent the supervisee role; hence, e_1 supervises e_2 and e_3, e_4 supervises e_6 and e_7, and e_5 supervises e_1 and e_4. In this example, each relationship instance must be connected with two lines, one marked with '1' (supervisor) and the other with '2' (supervisee).

7.4.3 Constraints on Binary Relationship Types

Relationship types usually have certain constraints that limit the possible combinations of entities that may participate in the corresponding relationship set. These constraints are determined from the miniworld situation that the relationships represent. For example, in Figure 7.9, if the company has a rule that each employee must work for exactly one department, then we would like to describe this con-

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[10]This concept of representing relationship types as attributes is used in a class of data models called **functional data models**. In object databases (see Chapter 10), relationships can be represented by reference attributes, either in one direction or in both directions as inverses. In relational databases (see Chapter 3), foreign keys are a type of reference attribute used to represent relationships.

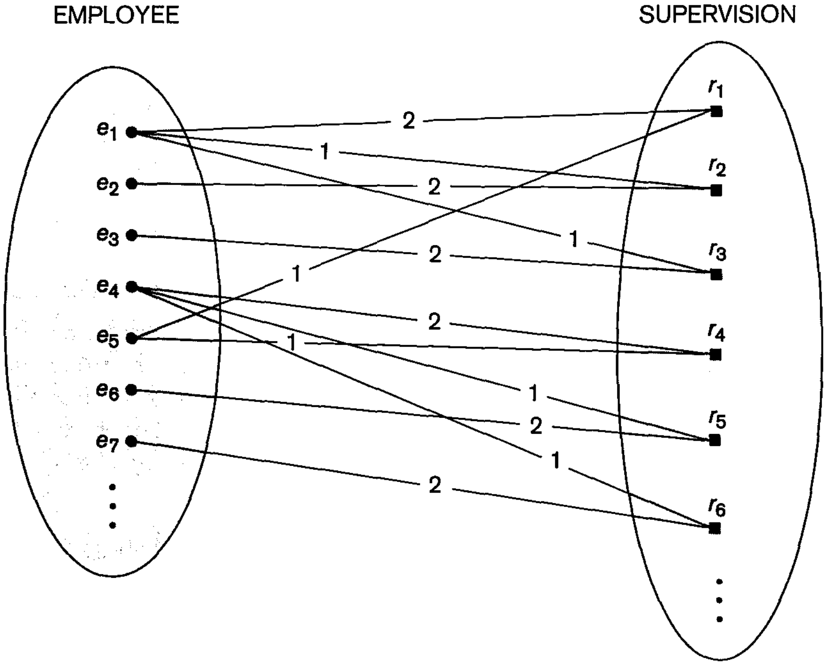

Figure 7.11
A recursive relationship SUPERVISION between EMPLOYEE in the *supervisor* role (1) and EMPLOYEE in the *subordinate* role (2).

straint in the schema. We can distinguish two main types of binary relationship constraints: *cardinality ratio* and *participation.*

Cardinality Ratios for Binary Relationships. The **cardinality ratio** for a binary relationship specifies the *maximum* number of relationship instances that an entity can participate in. For example, in the WORKS_FOR binary relationship type, DEPARTMENT:EMPLOYEE is of cardinality ratio 1:N, meaning that each department can be related to (that is, employs) any number of employees,[11] but an employee can be related to (work for) only one department. This means that for this particular relationship WORKS_FOR, a particular department entity can be related to any number of employees (N indicates there is no maximum number). On the other hand, an employee can be related to a maximum of one department. The possible cardinality ratios for binary relationship types are 1:1, 1:N, N:1, and M:N.

An example of a 1:1 binary relationship is MANAGES (Figure 7.12), which relates a department entity to the employee who manages that department. This represents the miniworld constraints that—at any point in time—an employee can manage one department only and a department can have one manager only. The relationship type WORKS_ON (Figure 7.13) is of cardinality ratio M:N, because the miniworld rule is that an employee can work on several projects and a project can have several employees.

[11]N stands for *any number* of related entities (zero or more).

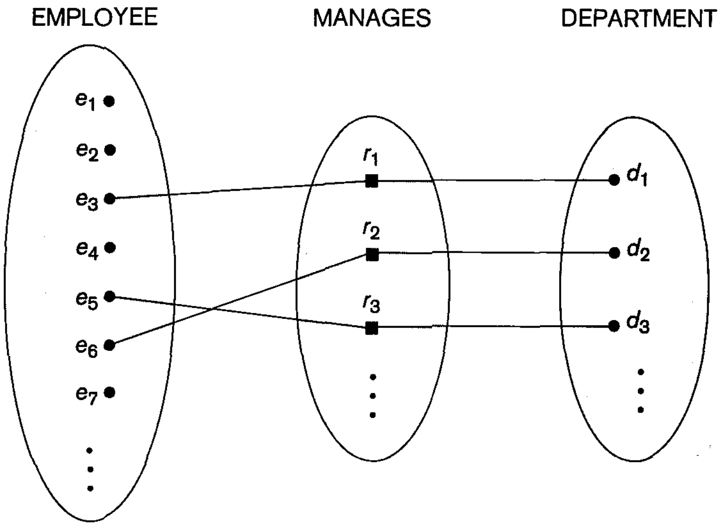

Figure 7.12
A 1:1 relationship, MANAGES.

Cardinality ratios for binary relationships are represented in ER diagrams by displaying 1, M, and N on the diamonds as shown in Figure 7.2. Notice that in this notation, we can either specify no maximum (N) or a maximum of one (1) on participation. An alternative notation (see Section 7.7.4) allows the designer to specify a specific *maximum number* on participation, such as 4 or 5.

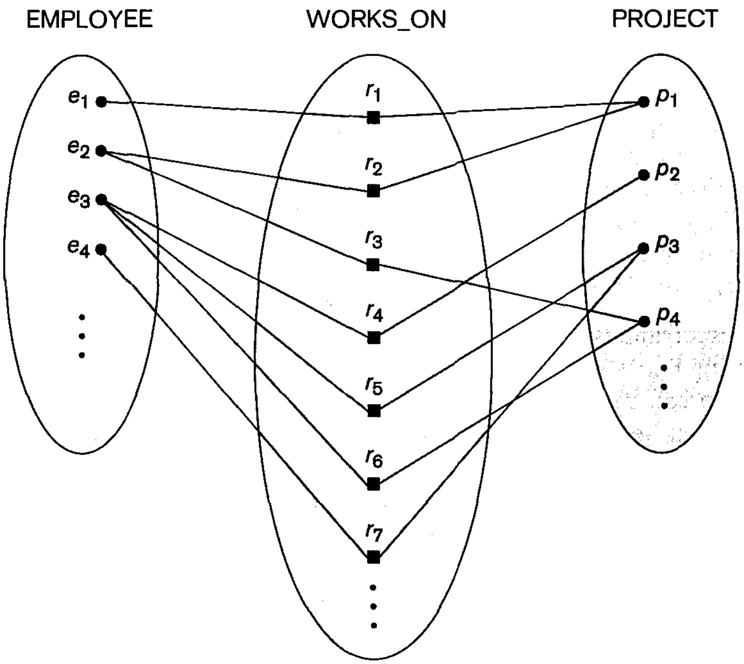

Figure 7.13
An M:N relationship, WORKS_ON.

Participation Constraints and Existence Dependencies. The **participation constraint** specifies whether the existence of an entity depends on its being related to another entity via the relationship type. This constraint specifies the *minimum* number of relationship instances that each entity can participate in, and is sometimes called the **minimum cardinality constraint**. There are two types of participation constraints—total and partial—that we illustrate by example. If a company policy states that *every* employee must work for a department, then an employee entity can exist only if it participates in at least one WORKS_FOR relationship instance (Figure 7.9). Thus, the participation of EMPLOYEE in WORKS_FOR is called **total participation**, meaning that every entity in *the total set* of employee entities must be related to a department entity via WORKS_FOR. Total participation is also called **existence dependency**. In Figure 7.12 we do not expect every employee to manage a department, so the participation of EMPLOYEE in the MANAGES relationship type is **partial**, meaning that *some* or *part of the set of* employee entities are related to some department entity via MANAGES, but not necessarily all. We will refer to the cardinality ratio and participation constraints, taken together, as the **structural constraints** of a relationship type.

In ER diagrams, total participation (or existence dependency) is displayed as a *double line* connecting the participating entity type to the relationship, whereas partial participation is represented by a *single line* (see Figure 7.2). Notice that in this notation, we can either specify no minimum (partial participation) or a minimum of one (total participation). The alternative notation (see Section 7.7.4) allows the designer to specify a specific *minimum number* on participation in the relationship, such as 4 or 5.

We will discuss constraints on higher-degree relationships in Section 7.8.

7.4.4 Attributes of Relationship Types

Relationship types can also have attributes, similar to those of entity types. For example, to record the number of hours per week that an employee works on a particular project, we can include an attribute Hours for the WORKS_ON relationship type in Figure 7.13. Another example is to include the date on which a manager started managing a department via an attribute Start_date for the MANAGES relationship type in Figure 7.12.

Notice that attributes of 1:1 or 1:N relationship types can be migrated to one of the participating entity types. For example, the Start_date attribute for the MANAGES relationship can be an attribute of either EMPLOYEE or DEPARTMENT, although conceptually it belongs to MANAGES. This is because MANAGES is a 1:1 relationship, so every department or employee entity participates in *at most one* relationship instance. Hence, the value of the Start_date attribute can be determined separately, either by the participating department entity or by the participating employee (manager) entity.

For a 1:N relationship type, a relationship attribute can be migrated *only* to the entity type on the N-side of the relationship. For example, in Figure 7.9, if the

WORKS_FOR relationship also has an attribute Start_date that indicates when an employee started working for a department, this attribute can be included as an attribute of EMPLOYEE. This is because each employee works for only one department, and hence participates in at most one relationship instance in WORKS_FOR. In both 1:1 and 1:N relationship types, the decision where to place a relationship attribute—as a relationship type attribute or as an attribute of a participating entity type—is determined subjectively by the schema designer.

For M:N relationship types, some attributes may be determined by the *combination of participating entities* in a relationship instance, not by any single entity. Such attributes *must be specified as relationship attributes.* An example is the Hours attribute of the M:N relationship WORKS_ON (Figure 7.13); the number of hours per week an employee currently works on a project is determined by an employee-project combination and not separately by either entity.

7.5 Weak Entity Types

Entity types that do not have key attributes of their own are called **weak entity types.** In contrast, **regular entity types** that do have a key attribute—which include all the examples discussed so far—are called **strong entity types.** Entities belonging to a weak entity type are identified by being related to specific entities from another entity type in combination with one of their attribute values. We call this other entity type the **identifying** or **owner entity type,**[12] and we call the relationship type that relates a weak entity type to its owner the **identifying relationship** of the weak entity type.[13] A weak entity type always has a *total participation constraint* (existence dependency) with respect to its identifying relationship because a weak entity cannot be identified without an owner entity. However, not every existence dependency results in a weak entity type. For example, a DRIVER_LICENSE entity cannot exist unless it is related to a PERSON entity, even though it has its own key (License_number) and hence is not a weak entity.

Consider the entity type DEPENDENT, related to EMPLOYEE, which is used to keep track of the dependents of each employee via a 1:N relationship (Figure 7.2). In our example, the attributes of DEPENDENT are Name (the first name of the dependent), Birth_date, Sex, and Relationship (to the employee). Two dependents of *two distinct employees* may, by chance, have the same values for Name, Birth_date, Sex, and Relationship, but they are still distinct entities. They are identified as distinct entities only after determining the *particular employee entity* to which each dependent is related. Each employee entity is said to *own* the dependent entities related to it.

A weak entity type normally has a **partial key**, which is the attribute that can uniquely identify weak entities that are *related to the same owner entity.*[14] In our

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[12]The identifying entity type is also sometimes called the **parent entity type** or the **dominant entity type**.

[13]The weak entity type is also sometimes called the **child entity type** or the **subordinate entity type.**

[14]The partial key is sometimes called the **discriminator**.

example, if we assume that no two dependents of the same employee ever have the same first name, the attribute Name of DEPENDENT is the partial key. In the worst case, a composite attribute of *all the weak entity's attributes* will be the partial key.

In ER diagrams, both a weak entity type and its identifying relationship are distinguished by surrounding their boxes and diamonds with double lines (see Figure 7.2). The partial key attribute is underlined with a dashed or dotted line.

Weak entity types can sometimes be represented as complex (composite, multivalued) attributes. In the preceding example, we could specify a multivalued attribute Dependents for EMPLOYEE, which is a composite attribute with component attributes Name, Birth_date, Sex, and Relationship. The choice of which representation to use is made by the database designer. One criterion that may be used is to choose the weak entity type representation if there are many attributes. If the weak entity participates independently in relationship types other than its identifying relationship type, then it should not be modeled as a complex attribute.

In general, any number of levels of weak entity types can be defined; an owner entity type may itself be a weak entity type. In addition, a weak entity type may have more than one identifying entity type and an identifying relationship type of degree higher than two, as we illustrate in Section 7.8.

7.6 Refining the ER Design for the COMPANY Database

We can now refine the database design in Figure 7.8 by changing the attributes that represent relationships into relationship types. The cardinality ratio and participation constraint of each relationship type are determined from the requirements listed in Section 7.2. If some cardinality ratio or dependency cannot be determined from the requirements, the users must be questioned further to determine these structural constraints.

In our example, we specify the following relationship types:

- MANAGES, a 1:1 relationship type between EMPLOYEE and DEPARTMENT. EMPLOYEE participation is partial. DEPARTMENT participation is not clear from the requirements. We question the users, who say that a department must have a manager at all times, which implies total participation.[15] The attribute Start_date is assigned to this relationship type.
- WORKS_FOR, a 1:N relationship type between DEPARTMENT and EMPLOYEE. Both participations are total.
- CONTROLS, a 1:N relationship type between DEPARTMENT and PROJECT. The participation of PROJECT is total, whereas that of DEPARTMENT is determined to be partial, after consultation with the users indicates that some departments may control no projects.

[15]The rules in the miniworld that determine the constraints are sometimes called the *business rules*, since they are determined by the *business* or organization that will utilize the database.

- SUPERVISION, a 1:N relationship type between EMPLOYEE (in the supervisor role) and EMPLOYEE (in the supervisee role). Both participations are determined to be partial, after the users indicate that not every employee is a supervisor and not every employee has a supervisor.
- WORKS_ON, determined to be an M:N relationship type with attribute Hours, after the users indicate that a project can have several employees working on it. Both participations are determined to be total.
- DEPENDENTS_OF, a 1:N relationship type between EMPLOYEE and DEPENDENT, which is also the identifying relationship for the weak entity type DEPENDENT. The participation of EMPLOYEE is partial, whereas that of DEPENDENT is total.

After specifying the above six relationship types, we remove from the entity types in Figure 7.8 all attributes that have been refined into relationships. These include Manager and Manager_start_date from DEPARTMENT; Controlling_department from PROJECT; Department, Supervisor, and Works_on from EMPLOYEE; and Employee from DEPENDENT. It is important to have the least possible redundancy when we design the conceptual schema of a database. If some redundancy is desired at the storage level or at the user view level, it can be introduced later, as discussed in Section 1.6.1.

7.7 ER Diagrams, Naming Conventions, and Design Issues

7.7.1 Summary of Notation for ER Diagrams

Figures 7.9 through 7.13 illustrate examples of the participation of entity types in relationship types by displaying their sets or extensions—the individual entity instances in an entity set and the individual relationship instances in a relationship set. In ER diagrams the emphasis is on representing the schemas rather than the instances. This is more useful in database design because a database schema changes rarely, whereas the contents of the entity sets change frequently. In addition, the schema is obviously easier to display, because it is much smaller.

Figure 7.2 displays the COMPANY **ER database schema** as an **ER diagram.** We now review the full ER diagram notation. Entity types such as EMPLOYEE, DEPARTMENT, and PROJECT are shown in rectangular boxes. Relationship types such as WORKS_FOR, MANAGES, CONTROLS, and WORKS_ON are shown in diamond-shaped boxes attached to the participating entity types with straight lines. Attributes are shown in ovals, and each attribute is attached by a straight line to its entity type or relationship type. Component attributes of a composite attribute are attached to the oval representing the composite attribute, as illustrated by the Name attribute of EMPLOYEE. Multivalued attributes are shown in double ovals, as illustrated by the Locations attribute of DEPARTMENT. Key attributes have their names underlined. Derived attributes are shown in dotted ovals, as illustrated by the Number_of_employees attribute of DEPARTMENT.

Weak entity types are distinguished by being placed in double rectangles and by having their identifying relationship placed in double diamonds, as illustrated by the DEPENDENT entity type and the DEPENDENTS_OF identifying relationship type. The partial key of the weak entity type is underlined with a dotted line.

In Figure 7.2 the cardinality ratio of each *binary* relationship type is specified by attaching a 1, M, or N on each participating edge. The cardinality ratio of DEPARTMENT:EMPLOYEE in MANAGES is 1:1, whereas it is 1:N for DEPARTMENT: EMPLOYEE in WORKS_FOR, and M:N for WORKS_ON. The participation constraint is specified by a single line for partial participation and by double lines for total participation (existence dependency).

In Figure 7.2 we show the role names for the SUPERVISION relationship type because the same EMPLOYEE entity type plays two distinct roles in that relationship. Notice that the cardinality ratio is 1:N from supervisor to supervisee because each employee in the role of supervisee has at most one direct supervisor, whereas an employee in the role of supervisor can supervise zero or more employees.

Figure 7.14 summarizes the conventions for ER diagrams. It is important to note that there are many other alternative diagrammatic notations (see Section 7.7.4 and Appendix A).

7.7.2 Proper Naming of Schema Constructs

When designing a database schema, the choice of names for entity types, attributes, relationship types, and (particularly) roles is not always straightforward. One should choose names that convey, as much as possible, the meanings attached to the different constructs in the schema. We choose to use *singular names* for entity types, rather than plural ones, because the entity type name applies to each individual entity belonging to that entity type. In our ER diagrams, we will use the convention that entity type and relationship type names are uppercase letters, attribute names have their initial letter capitalized, and role names are lowercase letters. We have used this convention in Figure 7.2.

As a general practice, given a narrative description of the database requirements, the *nouns* appearing in the narrative tend to give rise to entity type names, and the *verbs* tend to indicate names of relationship types. Attribute names generally arise from additional nouns that describe the nouns corresponding to entity types.

Another naming consideration involves choosing binary relationship names to make the ER diagram of the schema readable from left to right and from top to bottom. We have generally followed this guideline in Figure 7.2. To explain this naming convention further, we have one exception to the convention in Figure 7.2—the DEPENDENTS_OF relationship type, which reads from bottom to top. When we describe this relationship, we can say that the DEPENDENT entities (bottom entity type) are DEPENDENTS_OF (relationship name) an EMPLOYEE (top entity type). To change this to read from top to bottom, we could rename the relationship type to HAS_DEPENDENTS, which would then read as follows: An EMPLOYEE entity (top

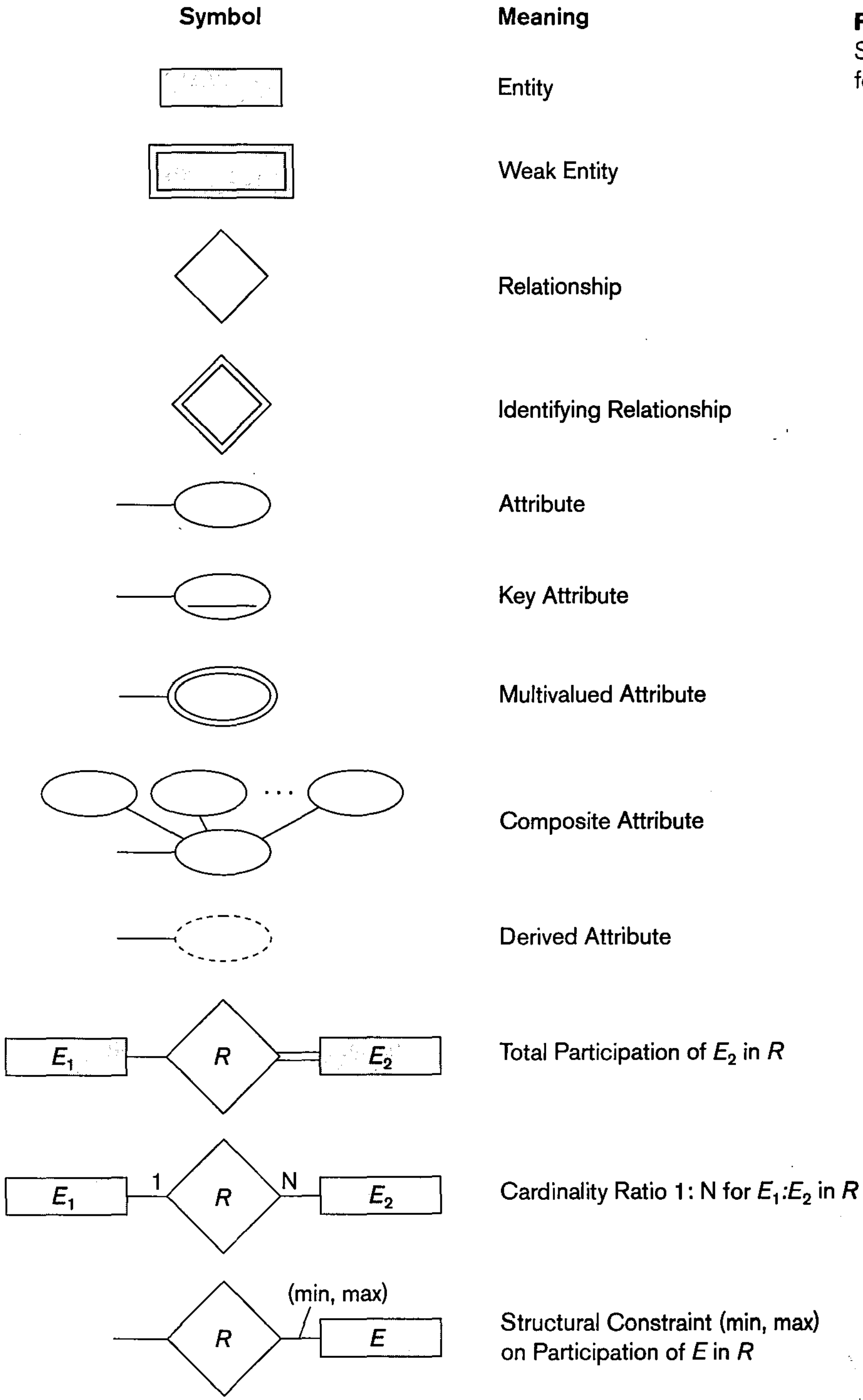


Figure 7.14
Summary of the notation for ER diagrams.

entity type) HAS_DEPENDENTS (relationship name) of type DEPENDENT (bottom entity type). Notice that this issue arises because each binary relationship can be described starting from either of the two participating entity types, as discussed in the beginning of Section 7.4.

7.7.3 Design Choices for ER Conceptual Design

It is occasionally difficult to decide whether a particular concept in the miniworld should be modeled as an entity type, an attribute, or a relationship type. In this section, we give some brief guidelines as to which construct should be chosen in particular situations.

In general, the schema design process should be considered an iterative refinement process, where an initial design is created and then iteratively refined until the most suitable design is reached. Some of the refinements that are often used include the following:

- A concept may be first modeled as an attribute and then refined into a relationship because it is determined that the attribute is a reference to another entity type. It is often the case that a pair of such attributes that are inverses of one another are refined into a binary relationship. We discussed this type of refinement in detail in Section 7.6. It is important to note that in our notation, once an attribute is replaced by a relationship, the attribute itself should be removed from the entity type to avoid duplication and redundancy.
- Similarly, an attribute that exists in several entity types may be elevated or promoted to an independent entity type. For example, suppose that several entity types in a UNIVERSITY database, such as STUDENT, INSTRUCTOR, and COURSE, each has an attribute Department in the initial design; the designer may then choose to create an entity type DEPARTMENT with a single attribute Dept_name and relate it to the three entity types (STUDENT, INSTRUCTOR, and COURSE) via appropriate relationships. Other attributes/relationships of DEPARTMENT may be discovered later.
- An inverse refinement to the previous case may be applied—for example, if an entity type DEPARTMENT exists in the initial design with a single attribute Dept_name and is related to only one other entity type, STUDENT. In this case, DEPARTMENT may be reduced or demoted to an attribute of STUDENT.
- Section 7.8 discusses choices concerning the degree of a relationship. Later in this chapter, we discuss other refinements concerning specialization/generalization. Chapter 9 discusses additional top-down and bottom-up refinements that are common in large-scale conceptual schema design.

7.7.4 Alternative Notations for ER Diagrams

There are many alternative diagrammatic notations for displaying ER diagrams. Appendix A gives some of the more popular notations. In Chapter 9, we introduce the Unified Modeling Language (UML) notation for class diagrams, which has been proposed as a standard for conceptual object modeling.

In this section, we describe one alternative ER notation for specifying structural constraints on relationships, which replaces the cardinality ratio (1:1, 1:N, M:N) and single/double line notation for participation constraints. This notation involves associating a pair of integer numbers (min, max) with each *participation* of an entity type E in a relationship type R, where $0 \le \text{min} \le \text{max}$ and $\text{max} \ge 1$. The numbers mean that for each entity e in E, e must participate in at least min and at most max relationship instances in R *at any point in time*. In this method, min = 0 implies partial participation, whereas min > 0 implies total participation.

Figure 7.15 displays the COMPANY database schema using the (min, max) notation.[16] Usually, one uses either the cardinality ratio/single-line/double-line notation *or* the (min, max) notation. The (min, max) notation is more precise, and we can use it to specify some structural constraints for relationship types of *higher degree*. However, it is not sufficient for specifying some key constraints on higher-degree relationships, as discussed in Section 7.8.

Figure 7.15 also displays all the role names for the COMPANY database schema.

7.8 Relationship Types of Degree Higher than Two

In Section 7.4.2 we defined the **degree** of a relationship type as the number of participating entity types and called a relationship type of degree two *binary* and a relationship type of degree three *ternary*. In this section, we elaborate on the differences between binary and higher-degree relationships, when to choose higher-degree versus binary relationships, and how to specify constraints on higher-degree relationships.

7.8.1 Choosing between Binary and Ternary (or Higher-Degree) Relationships

The ER diagram notation for a ternary relationship type is shown in Figure 7.16(a), which displays the schema for the SUPPLY relationship type that was displayed at the entity set/relationship set or instance level in Figure 7.10. Recall that the relationship set of SUPPLY is a set of relationship instances (s, j, p), where s is a SUPPLIER who is currently supplying a PART p to a PROJECT j. In general, a relationship type R of degree n will have n edges in an ER diagram, one connecting R to each participating entity type.

[16] In some notations, particularly those used in object modeling methodologies such as UML, the (min, max) is placed on the *opposite sides* to the ones we have shown. For example, for the WORKS_FOR relationship in Figure 7.15, the (1,1) would be on the DEPARTMENT side, and the (4,N) would be on the EMPLOYEE side. Here we used the original notation from Abrial (1974).

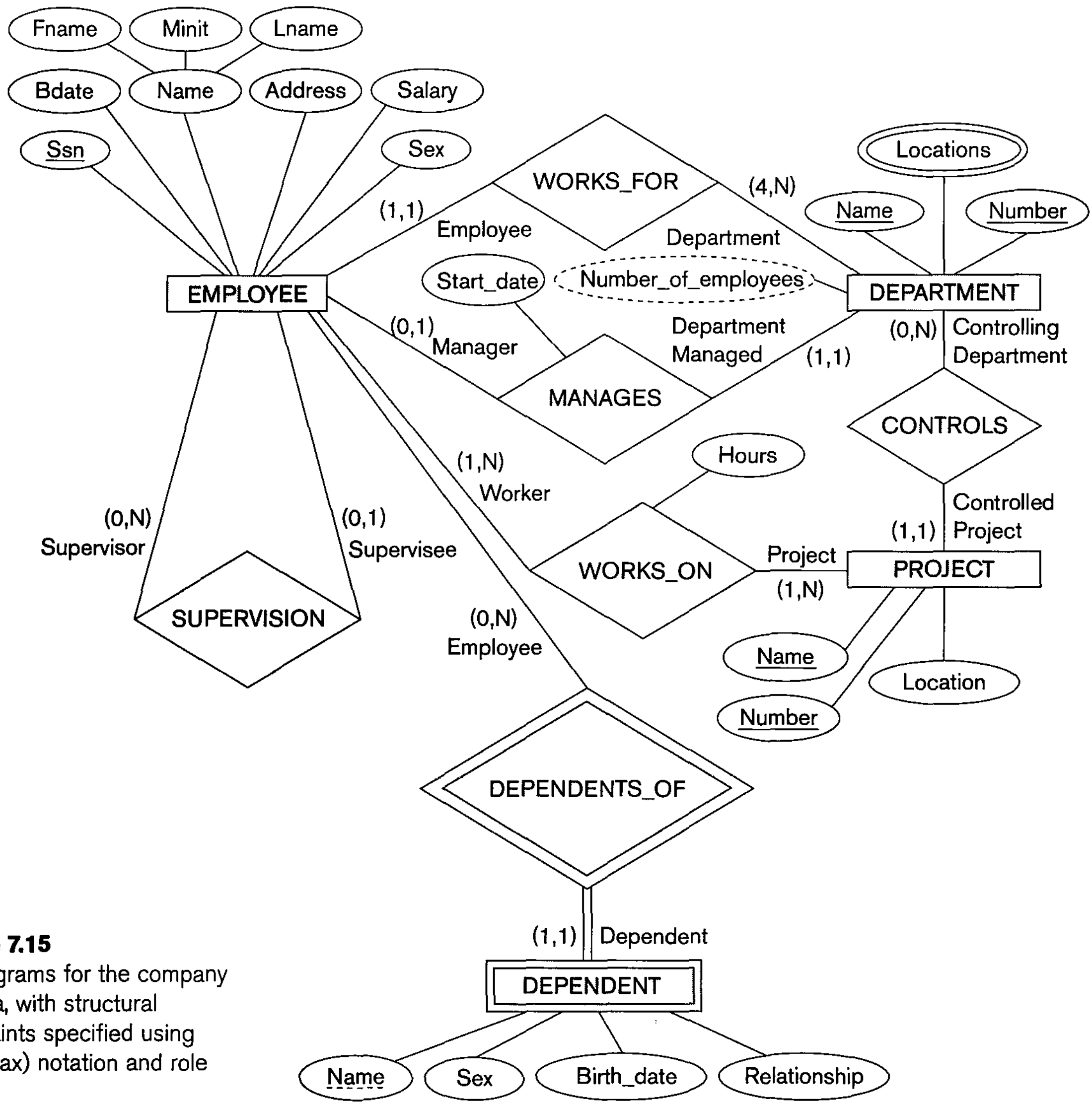


Figure 7.15
ER diagrams for the company schema, with structural constraints specified using (min, max) notation and role names.

Figure 7.16(b) shows an ER diagram for three binary relationship types CAN_SUPPLY, USES, and SUPPLIES. In general, a ternary relationship type represents different information than do three binary relationship types. Consider the three binary relationship types CAN_SUPPLY, USES, and SUPPLIES. Suppose that CAN_SUPPLY, between SUPPLIER and PART, includes an instance (s, p) whenever supplier s *can supply* part p (to any project); USES, between PROJECT and PART, includes an instance (j, p) whenever project j uses part p; and SUPPLIES, between SUPPLIER and PROJECT, includes an instance (s, j) whenever supplier s supplies *some part* to project j. The existence of three relationship instances (s, p), (j, p), and (s, j) in CAN_SUPPLY, USES, and SUPPLIES, respectively, does not necessarily imply

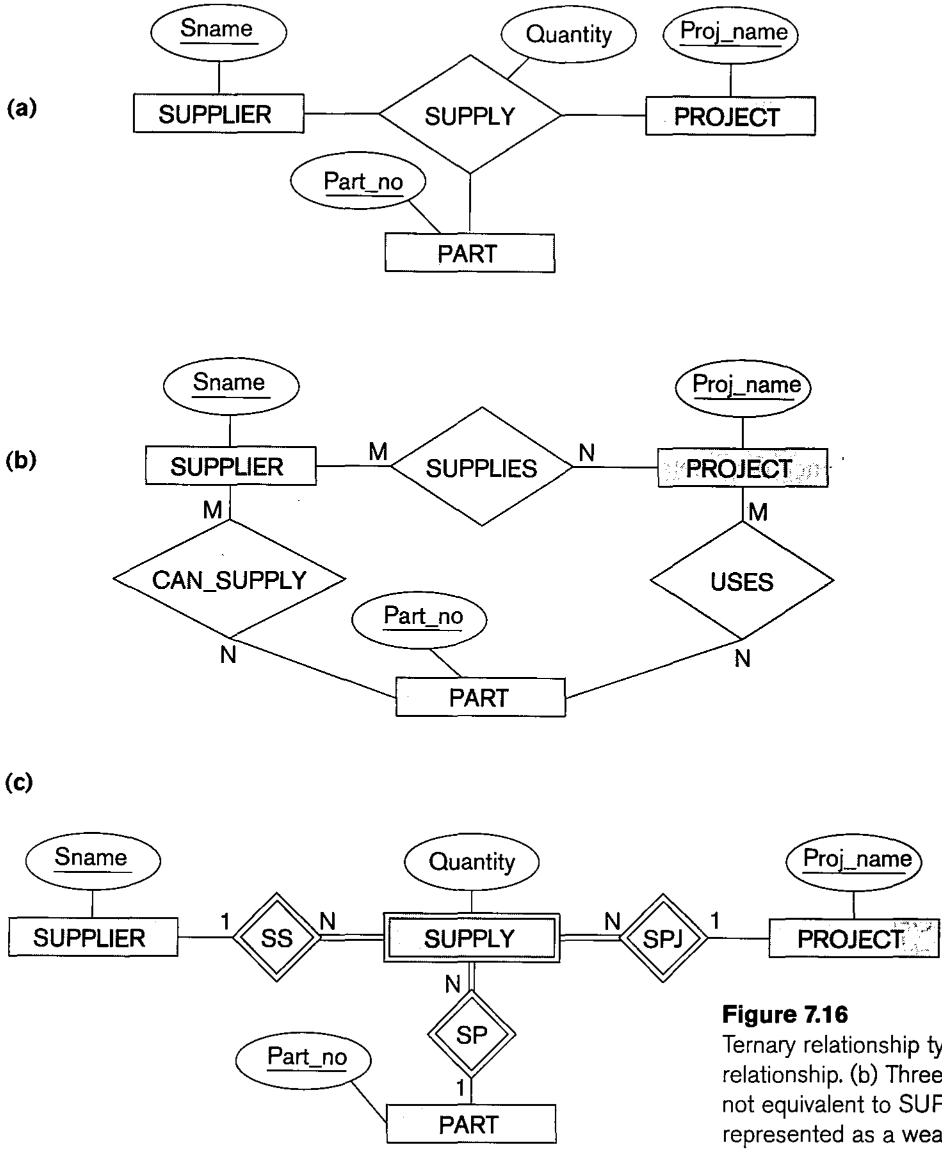


Figure 7.16
Ternary relationship types. (a) The SUPPLY relationship. (b) Three binary relationships not equivalent to SUPPLY. (c) SUPPLY represented as a weak entity type.

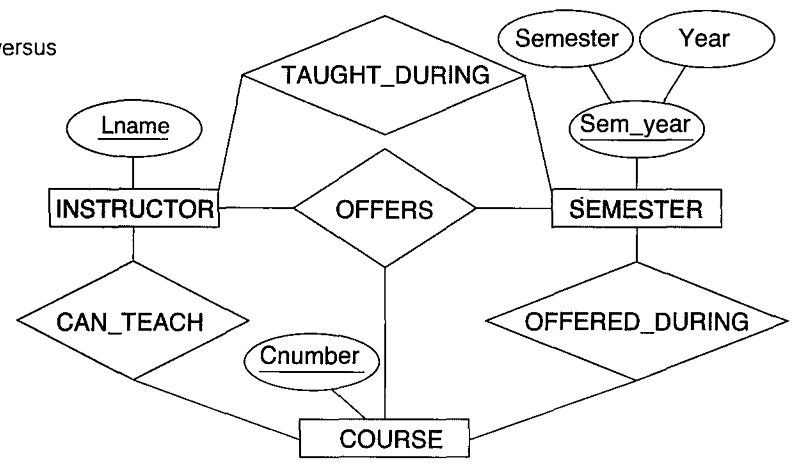
that an instance (s, j, p) exists in the ternary relationship SUPPLY, because the *meaning is different*. It is often tricky to decide whether a particular relationship should be represented as a relationship type of degree n or should be broken down into several relationship types of smaller degrees. The designer must base this decision on the semantics or meaning of the particular situation being represented. The typical solution is to include the ternary relationship *plus* one or more of the binary relationships, if they represent different meanings and if all are needed by the application.

Some database design tools are based on variations of the ER model that permit only binary relationships. In this case, a ternary relationship such as SUPPLY must be represented as a weak entity type, with no partial key and with three identifying relationships. The three participating entity types SUPPLIER, PART, and PROJECT are together the owner entity types (see Figure 7.16(c)). Hence, an entity in the weak entity type SUPPLY in Figure 7.16(c) is identified by the combination of its three owner entities from SUPPLIER, PART, and PROJECT.

It is also possible to represent the ternary relationship as a regular entity type by introducing an artificial or surrogate key. In this example, a key attribute Supply_id could be used for the supply entity type, converting it into a regular entity type. Three binary N:1 relationships relate SUPPLY to the three participating entity types.

Another example is shown in Figure 7.17. The ternary relationship type OFFERS represents information on instructors offering courses during particular semesters; hence it includes a relationship instance (*i*, *s*, *c*) whenever INSTRUCTOR *i* offers COURSE *c* during SEMESTER *s*. The three binary relationship types shown in Figure 7.17 have the following meanings: CAN_TEACH relates a course to the instructors who *can teach* that course, TAUGHT_DURING relates a semester to the instructors who *taught some course* during that semester, and OFFERED_DURING relates a semester to the courses offered during that semester *by any instructor*. These ternary and binary relationships represent different information, but certain constraints should hold among the relationships. For example, a relationship instance (*i*, *s*, *c*) should not exist in OFFERS *unless* an instance (*i*, *s*) exists in TAUGHT_DURING, an instance (*s*, *c*) exists in OFFERED_DURING, and an instance (*i*, *c*) exists in CAN_TEACH. However, the reverse is not always true; we may have instances (*i*, *s*), (*s*, *c*), and (*i*, *c*) in the three binary relationship types with no corresponding instance (*i*, *s*, *c*) in OFFERS. Note that in this example, based on the meanings of the relationships, we can infer the instances of TAUGHT_DURING and OFFERED_DURING from the instances in OFFERS, but we cannot infer the

Figure 7.17
Another example of ternary versus binary relationship types.



instances of CAN_TEACH; therefore, TAUGHT_DURING and OFFERED_DURING are redundant and can be left out.

Although in general three binary relationships *cannot* replace a ternary relationship, they may do so under certain *additional constraints*. In our example, if the CAN_TEACH relationship is 1:1 (an instructor can teach one course, and a course can be taught by only one instructor), then the ternary relationship OFFERS can be left out because it can be inferred from the three binary relationships CAN_TEACH, TAUGHT_DURING, and OFFERED_DURING. The schema designer must analyze the meaning of each specific situation to decide which of the binary and ternary relationship types are needed.

Notice that it is possible to have a weak entity type with a ternary (or *n*-ary) identifying relationship type. In this case, the weak entity type can have *several* owner entity types. An example is shown in Figure 7.18. This example shows part of a database that keeps track of candidates interviewing for jobs at various companies, and may be part of an employment agency database, for example. In the requirements, a candidate can have multiple interviews with the same company (for example, with different company departments or on separate dates), but a job offer is made based on one of the interviews. Here, INTERVIEW is represented as a weak entity with two owners CANDIDATE and COMPANY, and with the partial key Dept_date. An INTERVIEW entity is uniquely identified by a candidate, a company, and the combination of the date and department of the interview.

7.8.2 Constraints on Ternary (or Higher-Degree) Relationships

There are two notations for specifying structural constraints on *n*-ary relationships, and they specify different constraints. They should thus *both be used* if it is important to fully specify the structural constraints on a ternary or higher-degree relationship. The first notation is based on the cardinality ratio notation of binary relationships displayed in Figure 7.2. Here, a 1, M, or N is specified on each partici-

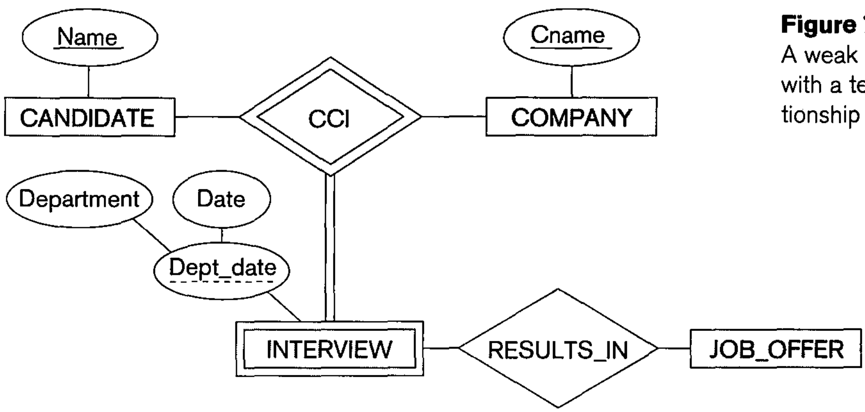


Figure 7.18
A weak entity type INTERVIEW with a ternary identifying relationship type.

pation arc (both M and N symbols stand for *many* or *any number*).[17] Let us illustrate this constraint using the SUPPLY relationship in Figure 7.16.

Recall that the relationship set of SUPPLY is a set of relationship instances (s, j, p), where s is a SUPPLIER, j is a PROJECT, and p is a PART. Suppose that the constraint exists that for a particular project-part combination, only one supplier will be used (only one supplier supplies a particular part to a particular project). In this case, we place 1 on the SUPPLIER participation, and M, N on the PROJECT, PART participations in Figure 7.16. This specifies the constraint that a particular (j, p) combination can appear at most once in the relationship set because each such (PROJECT, PART) combination uniquely determines a single supplier. Hence, any relationship instance (s, j, p) is uniquely identified in the relationship set by its (j, p) combination, which makes (j, p) a key for the relationship set. In this notation, the participations that have a 1 specified on them are not required to be part of the identifying key for the relationship set.[18] If all three cardinalities are M or N, then the key will be the combination of all three participants.

The second notation is based on the (min, max) notation displayed in Figure 7.15 for binary relationships. A (min, max) on a participation here specifies that each entity is related to at least *min* and at most *max relationship instances* in the relationship set. These constraints have no bearing on determining the key of an n-ary relationship, where $n > 2$,[19] but specify a different type of constraint that places restrictions on how many relationship instances each entity can participate in.

7.9 Subclasses, Superclasses, and Inheritance

We now present the Enhanced ER (EER) model concepts. The EER model includes *all the modeling concepts of the ER model* that were presented earlier in this chapter. In addition, it includes the concepts of **subclass** and **superclass** and the related concepts of **specialization** and **generalization** (see Sections 7.10 and 7.11). Another concept included in the EER model is that of a **category** or **union type** (see Section 7.12), which is used to represent a collection of objects (entities) that is the *union* of objects of different entity types. Associated with these concepts is the important mechanism of **attribute and relationship inheritance.** Unfortunately, no standard terminology exists for these concepts, so we use the most common terminology. Alternative terminology is given in footnotes. We also describe a diagrammatic technique for displaying these concepts when they arise in an EER schema. We call the resulting schema diagrams **enhanced ER** or **EER diagrams.**

The first Enhanced ER (EER) model concept we take up is that of a **subtype** or **subclass** of an entity type. An entity type is used to represent both a *type of entity* and the *entity set* or *collection of entities of that type* that exist in the database. For example, the entity type EMPLOYEE describes the type (that is, the attributes and

[17]This notation allows us to determine the key of the *relationship relation*, as we discuss in Chapter 8.

[18]This is also true for cardinality ratios of binary relationships.

[19]The (min, max) constraints can determine the keys for binary relationships, though.

relationships) of each employee entity, and also refers to the current set of EMPLOYEE entities in the COMPANY database. In many cases an entity type has numerous subgroupings or subtypes of its entities that are meaningful and need to be represented explicitly because of their significance to the database application. For example, the entities that are members of the EMPLOYEE entity type may be distinguished further into SECRETARY, ENGINEER, MANAGER, TECHNICIAN, SALARIED_EMPLOYEE, HOURLY_EMPLOYEE, and so on. The set of entities in each of the latter groupings is a subset of the entities that belong to the EMPLOYEE entity set, meaning that every entity that is a member of one of these subgroupings is also an employee. We call each of these subgroupings a **subclass** or **subtype** of the EMPLOYEE entity type, and the EMPLOYEE entity type is called the **superclass** or **supertype** for each of these subclasses. Figure 7.19 shows how to represent these concepts diagramatically in EER diagrams. (The circle notation in Figure 7.19 will be explained in Section 7.10.)

We call the relationship between a superclass and any one of its subclasses a **superclass/subclass** or **supertype/subtype** or simply **class/subclass relationship.**[20] In our previous example, EMPLOYEE/SECRETARY and EMPLOYEE/TECHNICIAN are two class/subclass relationships. Notice that a member entity of the subclass represents the *same real-world entity* as some member of the superclass; for example, a

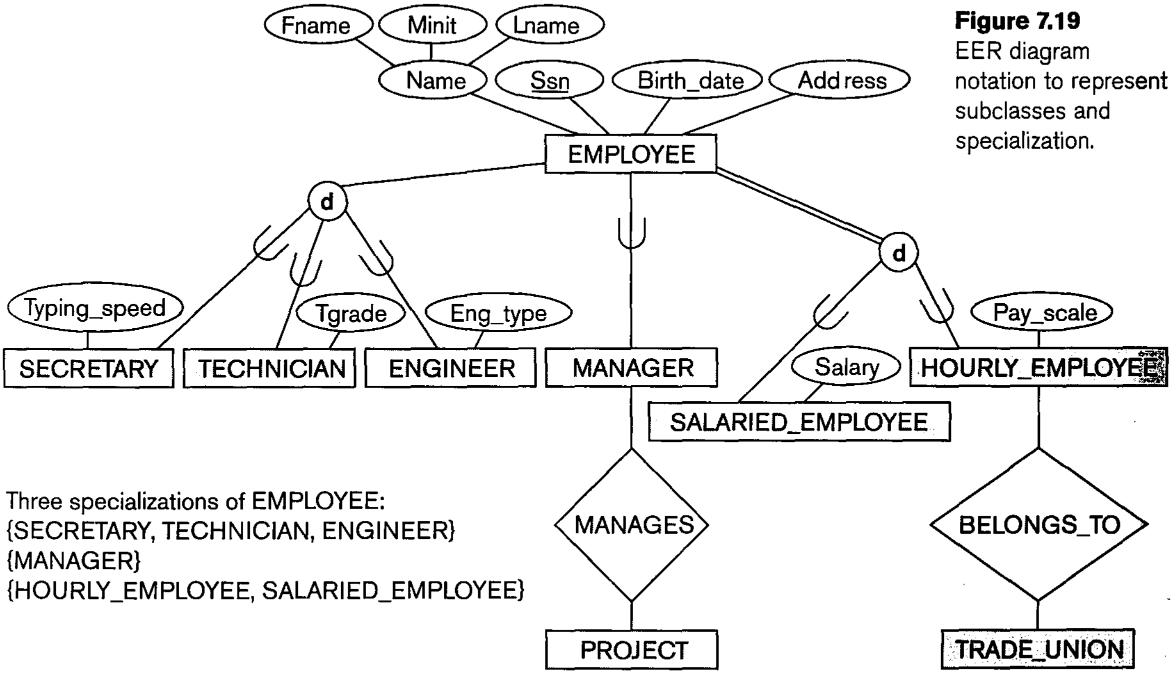


Figure 7.19
EER diagram notation to represent subclasses and specialization.

Three specializations of EMPLOYEE:
{SECRETARY, TECHNICIAN, ENGINEER}
{MANAGER}
{HOURLY_EMPLOYEE, SALARIED_EMPLOYEE}

[20]A class/subclass relationship is often called an **IS-A** (or **IS-AN**) **relationship** because of the way we refer to the concept. We say a SECRETARY *is an* EMPLOYEE, a TECHNICIAN *is an* EMPLOYEE, and so on.

SECRETARY entity 'Joan Logano' is also the EMPLOYEE 'Joan Logano.' Hence, the subclass member is the same as the entity in the superclass, but in a distinct *specific role.* When we implement a superclass/subclass relationship in the database system, however, we may represent a member of the subclass as a distinct database object—say, a distinct record that is related via the key attribute to its superclass entity. In Section 8.2, we discuss various options for representing superclass/subclass relationships in relational databases.

An entity cannot exist in the database merely by being a member of a subclass; it must also be a member of the superclass. Such an entity can be included optionally as a member of any number of subclasses. For example, a salaried employee who is also an engineer belongs to the two subclasses ENGINEER and SALARIED_EMPLOYEE of the EMPLOYEE entity type. However, it is not necessary that every entity in a superclass is a member of some subclass.

An important concept associated with subclasses (subtypes) is that of **type inheritance.** Recall that the *type* of an entity is defined by the attributes it possesses and the relationship types in which it participates. Because an entity in the subclass represents the same real-world entity from the superclass, it should possess values for its specific attributes *as well as* values of its attributes as a member of the superclass. We say that an entity that is a member of a subclass **inherits** all the attributes of the entity as a member of the superclass. The entity also inherits all the relationships in which the superclass participates. Notice that a subclass, with its own specific (or local) attributes and relationships together with all the attributes and relationships it inherits from the superclass, can be considered an *entity type* in its own right.[21]

7.10 Specialization and Generalization in EER

7.10.1 Specialization

Specialization is the process of defining a *set of subclasses* of an entity type; this entity type is called the **superclass** of the specialization. The set of subclasses that forms a specialization is defined on the basis of some distinguishing characteristic of the entities in the superclass. For example, the set of subclasses {SECRETARY, ENGINEER, TECHNICIAN} is a specialization of the superclass EMPLOYEE that distinguishes among employee entities based on the *job type* of each employee entity. We may have several specializations of the same entity type based on different distinguishing characteristics. For example, another specialization of the EMPLOYEE entity type may yield the set of subclasses {SALARIED_EMPLOYEE, HOURLY_EMPLOYEE}; this specialization distinguishes among employees based on the *method of pay.*

Figure 7.19 shows how we represent a specialization diagrammatically in an EER diagram. The subclasses that define a specialization are attached by lines to a circle

[21] In some object-oriented programming languages, a common restriction is that an entity (or object) has *only one type.* This is generally too restrictive for conceptual database modeling.

that represents the specialization, which is connected in turn to the superclass. The *subset symbol* on each line connecting a subclass to the circle indicates the direction of the superclass/subclass relationship.[22] Attributes that apply only to entities of a particular subclass—such as TypingSpeed of SECRETARY—are attached to the rectangle representing that subclass. These are called **specific attributes** (or **local attributes**) of the subclass. Similarly, a subclass can participate in **specific relationship types**, such as the HOURLY_EMPLOYEE subclass participating in the BELONGS_TO relationship in Figure 7.19. We will explain the **d** symbol in the circles in Figure 7.19 and additional EER diagram notation shortly.

Figure 7.20 shows a few entity instances that belong to subclasses of the {SECRETARY, ENGINEER, TECHNICIAN} specialization. Again, notice that an entity that belongs to a subclass represents *the same real-world entity* as the entity connected to it in the EMPLOYEE superclass, even though the same entity is shown twice; for example, e_1 is shown in both EMPLOYEE and SECRETARY in Figure 7.20.

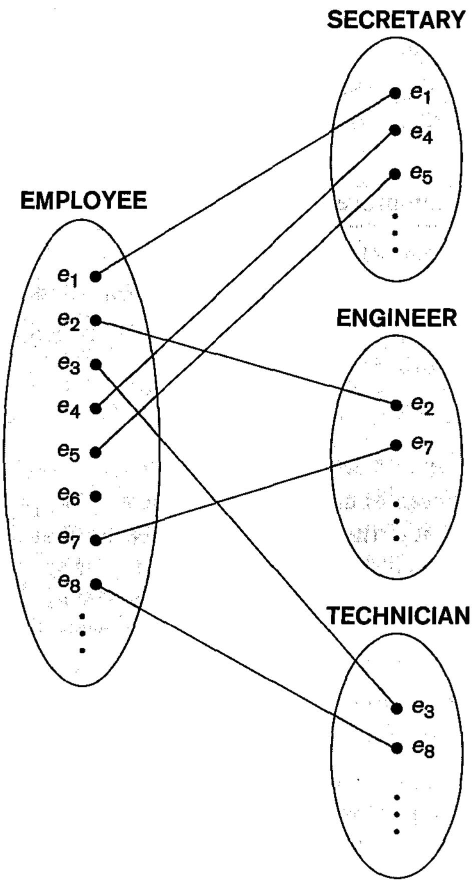


Figure 7.20
Instances of a specialization.

[22]There are many alternative notations for specialization; we present the UML notation in Chapter 9 and other proposed notations in Appendix A.

As the figure suggests, a superclass/subclass relationship such as EMPLOYEE/SECRETARY somewhat resembles a 1:1 relationship *at the instance level* (see Figure 7.12). The main difference is that in a 1:1 relationship two *distinct entities* are related, whereas in a superclass/subclass relationship the entity in the subclass is the same real-world entity as the entity in the superclass but is playing a *specialized role*—for example, an EMPLOYEE specialized in the role of SECRETARY, or an EMPLOYEE specialized in the role of TECHNICIAN.

There are two main reasons for including class/subclass relationships and specializations in a data model. The first is that certain attributes may apply to some but not all entities of the superclass. A subclass is defined in order to group the entities to which these attributes apply. The members of the subclass may still share the majority of their attributes with the other members of the superclass. For example, in Figure 7.19 the SECRETARY subclass has the specific attribute Typing_speed, whereas the ENGINEER subclass has the specific attribute Eng_type, but SECRETARY and ENGINEER share their other inherited attributes from the EMPLOYEE entity type.

The second reason for using subclasses is that some relationship types may be participated in only by entities that are members of the subclass. For example, if only HOURLY_EMPLOYEES can belong to a trade union, we can represent that fact by creating the subclass HOURLY_EMPLOYEE of EMPLOYEE and relating the subclass to an entity type TRADE_UNION via the BELONGS_TO relationship type, as illustrated in Figure 7.19.

In summary, the specialization process allows us to do the following:

- Define a set of subclasses of an entity type
- Establish additional specific attributes with each subclass
- Establish additional specific relationship types between each subclass and other entity types or other subclasses

7.10.2 Generalization

We can think of a *reverse process* of abstraction in which we suppress the differences among several entity types, identify their common features, and **generalize** them into a single **superclass** of which the original entity types are special **subclasses**. For example, consider the entity types CAR and TRUCK shown in Figure 7.21(a). Because they have several common attributes, they can be generalized into the entity type VEHICLE, as shown in Figure 7.21(b). Both CAR and TRUCK are now subclasses of the **generalized superclass** VEHICLE. We use the term **generalization** to refer to the process of defining a generalized entity type from the given entity types.

Notice that the generalization process can be viewed as being functionally the inverse of the specialization process. Hence, in Figure 7.21 we can view {CAR, TRUCK} as a specialization of VEHICLE, rather than viewing VEHICLE as a generalization of CAR and TRUCK. Similarly, in Figure 7.19 we can view EMPLOYEE as a generalization of SECRETARY, TECHNICIAN, and ENGINEER. A diagrammatic notation to distinguish

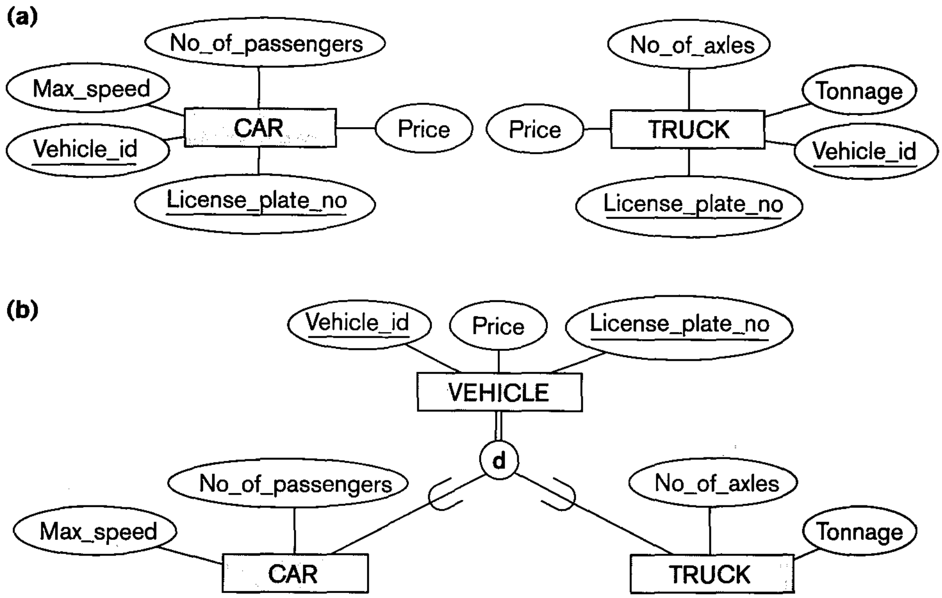


Figure 7.21
Generalization. (a) Two entity types, CAR and TRUCK. (b) Generalizing CAR and TRUCK into the superclass VEHICLE.

between generalization and specialization is used in some design methodologies. An arrow pointing to the generalized superclass represents a generalization, whereas arrows pointing to the specialized subclasses represent a specialization. We will *not* use this notation because the decision as to which process is followed in a particular situation is often subjective. Appendix A gives some of the suggested alternative diagrammatic notations for schema diagrams and class diagrams.

So far we have introduced the concepts of subclasses and superclass/subclass relationships, as well as the specialization and generalization processes. In general, a superclass or subclass represents a collection of entities of the same type and hence also describes an *entity type*; that is why superclasses and subclasses are all shown in rectangles in EER diagrams, like entity types. Next, we discuss the properties of specializations and generalizations in more detail.

7.11 Constraints and Characteristics of Specialization and Generalization Hierarchies

First, we discuss constraints that apply to a single specialization or a single generalization. For brevity, our discussion refers only to *specialization* even though it applies to *both* specialization and generalization. Then, we discuss differences between specialization/generalization *lattices* (*multiple inheritance*) and *hierarchies* (*single inheritance*), and elaborate on the differences between the specialization and generalization processes during conceptual database schema design.

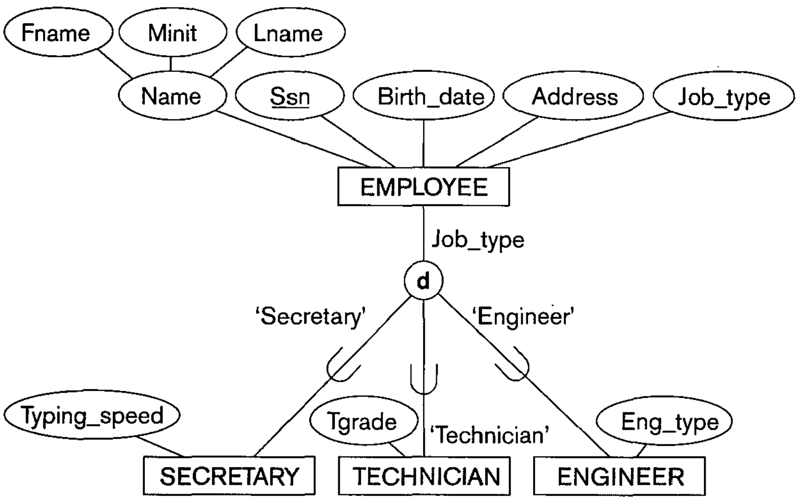
7.11.1 Constraints on Specialization and Generalization

In general, we may have several specializations defined on the same entity type (or superclass), as shown in Figure 7.19. In such a case, entities may belong to subclasses in each of the specializations. However, a specialization may also consist of a *single* subclass only, such as the {MANAGER} specialization in Figure 7.19; in such a case, we do not use the circle notation.

In some specializations we can determine exactly the entities that will become members of each subclass by placing a condition on the value of some attribute of the superclass. Such subclasses are called **predicate-defined** (or **condition-defined**) **subclasses.** For example, if the EMPLOYEE entity type has an attribute Job_type, as shown in Figure 7.22, we can specify the condition of membership in the SECRETARY subclass by the condition (Job_type = 'Secretary'), which we call the **defining predicate** of the subclass. This condition is a *constraint* specifying that exactly those entities of the EMPLOYEE entity type whose attribute value for Job_type is 'Secretary' belong to the subclass. We display a predicate-defined subclass by writing the predicate condition next to the line that connects the subclass to the specialization circle.

If *all* subclasses in a specialization have their membership condition on the *same* attribute of the superclass, the specialization itself is called an **attribute-defined specialization,** and the attribute is called the **defining attribute** of the specialization.[23] In this case, all the entities with the same value for the attribute belong to the same sub-

Figure 7.22
EER diagram notation for an attribute-defined specialization on Job_type.



[23]Such an attribute is called a *discriminator* in UML terminology (see Chapter 9).

class. We display an attribute-defined specialization by placing the defining attribute name next to the arc from the circle to the superclass, as shown in Figure 7.22.

When we do not have a condition for determining membership in a subclass, the subclass is called **user-defined.** Membership in such a subclass is determined by the database users when they apply the operation to add an entity to the subclass; hence, membership is *specified individually for each entity by the user*, not by any condition that may be evaluated automatically.

Two other constraints may apply to a specialization. The first is the **disjointness** (or **disjointedness**) **constraint,** which specifies that the subclasses of the specialization must be disjoint. This means that an entity can be a member of *at most* one of the subclasses of the specialization. A specialization that is attribute-defined implies the disjointness constraint (if the attribute used to define the membership predicate is single-valued). Figure 7.22 illustrates this case, where the **d** in the circle stands for *disjoint.* The **d** notation also applies to user-defined subclasses of a specialization that must be disjoint, as illustrated by the specialization {HOURLY_EMPLOYEE, SALARIED_EMPLOYEE} in Figure 7.19. If the subclasses are not constrained to be disjoint, their sets of entities may be **overlapping**; that is, the same (real-world) entity may be a member of more than one subclass of the specialization. This case, which is the default, is displayed by placing an **o** in the circle, as shown in Figure 7.23.

The second constraint on specialization is called the **completeness** (or **totalness**) **constraint,** which may be total or partial. A **total specialization** constraint specifies that *every* entity in the superclass must be a member of at least one subclass in the specialization. For example, if every EMPLOYEE must be either an HOURLY_EMPLOYEE or a SALARIED_EMPLOYEE, then the specialization {HOURLY_EMPLOYEE, SALARIED_EMPLOYEE} in Figure 7.19 is a total specialization of EMPLOYEE. This is shown in EER diagrams by using a double line to connect the superclass to the circle. A single line is used to display a **partial specialization,** which allows an entity not to belong to any of the subclasses. For example, if some EMPLOYEE entities do not belong to any of the subclasses {SECRETARY, ENGINEER, TECHNICIAN} in Figures 7.19 and 7.22, then that specialization is partial.[24]

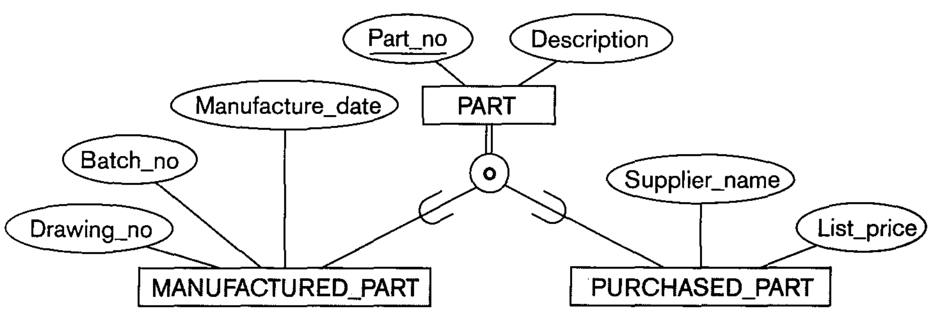


Figure 7.23
EER diagram notation for an overlapping (nondisjoint) specialization.

[24]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 earlier in this chapter.

Notice that the disjointness and completeness constraints are *independent.* Hence, we have the following four possible constraints on specialization:

- Disjoint, total
- Disjoint, partial
- Overlapping, total
- Overlapping, partial

Of course, the correct constraint is determined from the real-world meaning that applies to each specialization. In general, a superclass that was identified through the *generalization* process usually is **total**, because the superclass is *derived from* the subclasses and hence contains only the entities that are in the subclasses.

Certain insertion and deletion rules apply to specialization (and generalization) as a consequence of the constraints specified earlier. Some of these rules are as follows:

- Deleting an entity from a superclass implies that it is automatically deleted from all the subclasses to which it belongs.
- Inserting an entity in a superclass implies that the entity is mandatorily inserted in all *predicate-defined* (or *attribute-defined*) subclasses for which the entity satisfies the defining predicate.
- Inserting an entity in a superclass of a *total specialization* implies that the entity is mandatorily inserted in at least one of the subclasses of the specialization.

The reader is encouraged to make a complete list of rules for insertions and deletions for the various types of specializations.

7.11.2 Specialization and Generalization Hierarchies and Lattices

A subclass itself may have further subclasses specified on it, forming a hierarchy or a lattice of specializations. For example, in Figure 7.24 ENGINEER is a subclass of

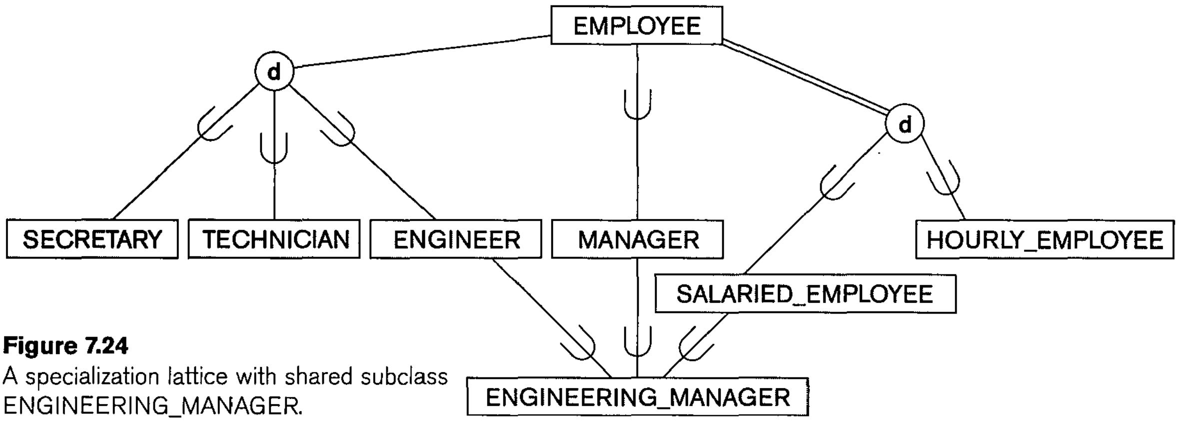


Figure 7.24
A specialization lattice with shared subclass ENGINEERING_MANAGER.

EMPLOYEE and is also a superclass of ENGINEERING_MANAGER; this represents the real-world constraint that every engineering manager is required to be an engineer. A **specialization hierarchy** has the constraint that every subclass participates *as a subclass* in *only one* class/subclass relationship; that is, each subclass has only one parent, which results in a **tree structure** or **strict hierarchy**. In contrast, for a **specialization lattice**, a subclass can be a subclass in *more than one* class/subclass relationship. Hence, Figure 7.24 is a lattice.

Figure 7.25 shows another specialization lattice of more than one level. This may be part of a conceptual schema for a UNIVERSITY database. Notice that this arrangement would have been a hierarchy except for the STUDENT_ASSISTANT subclass, which is a subclass in two distinct class/subclass relationships.

The requirements for the part of the UNIVERSITY database shown in Figure 7.25 are the following:

1. The database keeps track of three types of persons: employees, alumni, and students. A person can belong to one, two, or all three of these types. Each person has a name, SSN, sex, address, and birth date.

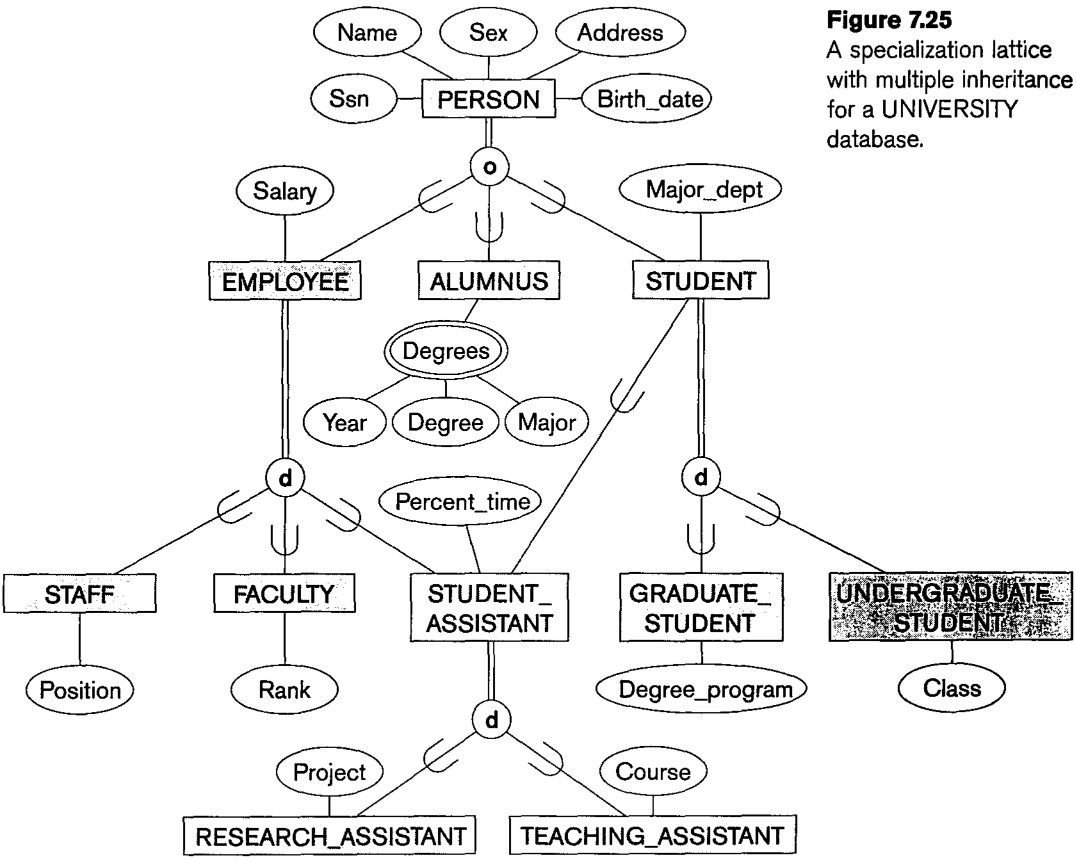


Figure 7.25
A specialization lattice with multiple inheritance for a UNIVERSITY database.

2. Every employee has a salary, and there are three types of employees: faculty, staff, and student assistants. Each employee belongs to exactly one of these types. For each alumnus, a record of the degree or degrees that he or she earned at the university is kept, including the name of the degree, the year granted, and the major department. Each student has a major department.
3. Each faculty has a rank, whereas each staff member has a staff position. Student assistants are classified further as either research assistants or teaching assistants, and the percent of time that they work is recorded in the database. Research assistants have their research project stored, whereas teaching assistants have the current course they work on.
4. Students are further classified as either graduate or undergraduate, with the specific attributes degree program (M.S., Ph.D., M.B.A., and so on) for graduate students and class (freshman, sophomore, and so on) for undergraduates.

In Figure 7.25, all person entities represented in the database are members of the PERSON entity type, which is specialized into the subclasses {EMPLOYEE, ALUMNUS, STUDENT}. This specialization is overlapping; for example, an alumnus may also be an employee and may also be a student pursuing an advanced degree. The subclass STUDENT is the superclass for the specialization {GRADUATE_STUDENT, UNDERGRADUATE_STUDENT}, while EMPLOYEE is the superclass for the specialization {STUDENT_ASSISTANT, FACULTY, STAFF}. Notice that STUDENT_ASSISTANT is also a subclass of STUDENT. Finally, STUDENT_ASSISTANT is the superclass for the specialization into {RESEARCH_ASSISTANT, TEACHING_ASSISTANT}.

In such a specialization lattice or hierarchy, a subclass inherits the attributes not only of its direct superclass, but also of all its predecessor superclasses *all the way to the root* of the hierarchy or lattice if necessary. For example, an entity in GRADUATE_STUDENT inherits all the attributes of that entity as a STUDENT *and* as a PERSON. Notice that an entity may exist in several *leaf nodes* of the hierarchy, where a **leaf node** is a class that has *no subclasses of its own.* For example, a member of GRADUATE_STUDENT may also be a member of RESEARCH_ASSISTANT.

A subclass with *more than one* superclass is called a **shared subclass**, such as ENGINEERING_MANAGER in Figure 7.24. This leads to the concept known as **multiple inheritance**, where the shared subclass ENGINEERING_MANAGER directly inherits attributes and relationships from multiple classes. Notice that the existence of at least one shared subclass leads to a lattice (and hence to *multiple inheritance*); if no shared subclasses existed, we would have a hierarchy rather than a lattice and only **single inheritance** would exist. An important rule related to multiple inheritance can be illustrated by the example of the shared subclass STUDENT_ASSISTANT in Figure 7.25, which inherits attributes from both EMPLOYEE and STUDENT. Here, both EMPLOYEE and STUDENT inherit *the same attributes* from PERSON. The rule states that if an attribute (or relationship) originating in the *same superclass* (PERSON) is inherited more than once via different paths (EMPLOYEE and STUDENT) in the lattice, then it should be included only once in the shared subclass

(STUDENT_ASSISTANT). Hence, the attributes of PERSON are inherited *only once* in the STUDENT_ASSISTANT subclass in Figure 7.25.

It is important to note here that some models and languages are limited to **single inheritance** and *do not allow* multiple inheritance (shared subclasses). It is also important to note that some models do not allow an entity to have multiple types, and hence an entity can be a member *of only one leaf class.*[25] In such a model, it is necessary to create additional subclasses as leaf nodes to cover all possible combinations of classes that may have some entity that belongs to all these classes simultaneously. For example, in the overlapping specialization of PERSON into {EMPLOYEE, ALUMNUS, STUDENT} (or {E, A, S} for short), it would be necessary to create seven subclasses of PERSON in order to cover all possible types of entities: E, A, S, E_A, E_S, A_S, and E_A_S. Obviously, this can lead to extra complexity.

Although we have used specialization to illustrate our discussion, similar concepts *apply equally* to generalization, as we mentioned at the beginning of this section. Hence, we can also speak of **generalization hierarchies** and **generalization lattices.**

7.11.3 Utilizing Specialization and Generalization in Refining Conceptual Schemas

Now we elaborate on the differences between the specialization and generalization processes, and how they are used to refine conceptual schemas during conceptual database design. In the specialization process, we typically start with an entity type and then define subclasses of the entity type by successive specialization; that is, we repeatedly define more specific groupings of the entity type. For example, when designing the specialization lattice in Figure 7.25, we may first specify an entity type PERSON for a university database. Then we discover that three types of persons will be represented in the database: university employees, alumni, and students. We create the specialization {EMPLOYEE, ALUMNUS, STUDENT} for this purpose and choose the overlapping constraint, because a person may belong to more than one of the subclasses. We specialize EMPLOYEE further into {STAFF, FACULTY, STUDENT_ASSISTANT}, and specialize STUDENT into {GRADUATE_STUDENT, UNDERGRADUATE_STUDENT}. Finally, we specialize STUDENT_ASSISTANT into {RESEARCH_ASSISTANT, TEACHING_ASSISTANT}. This successive specialization corresponds to a **top-down conceptual refinement process** during conceptual schema design. So far, we have a hierarchy; then we realize that STUDENT_ASSISTANT is a shared subclass, since it is also a subclass of STUDENT, leading to the lattice.

It is possible to arrive at the same hierarchy or lattice from the other direction. In such a case, the process involves generalization rather than specialization and corresponds to a **bottom-up conceptual synthesis.** For example, the database designers may first discover entity types such as STAFF, FACULTY, ALUMNUS, GRADUATE_STUDENT, UNDERGRADUATE_STUDENT, RESEARCH_ASSISTANT,

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[25]In some models, the class is further restricted to be a *leaf node* in the hierarchy or lattice.

TEACHING_ASSISTANT, and so on; then they generalize {GRADUATE_STUDENT, UNDERGRADUATE_STUDENT} into STUDENT; then they generalize {RESEARCH_ASSISTANT, TEACHING_ASSISTANT} into STUDENT_ASSISTANT; then they generalize {STAFF, FACULTY, STUDENT_ASSISTANT} into EMPLOYEE; and finally they generalize {EMPLOYEE, ALUMNUS, STUDENT} into PERSON.

In structural terms, hierarchies or lattices resulting from either process may be identical; the only difference relates to the manner or order in which the schema superclasses and subclasses were created during the design process. In practice, it is likely that neither the generalization process nor the specialization process is followed strictly, but that a combination of the two processes is employed. New classes are continually incorporated into a hierarchy or lattice as they become apparent to users and designers. Notice that the notion of representing data and knowledge by using superclass/subclass hierarchies and lattices is quite common in knowledge-based systems and expert systems, which combine database technology with artificial intelligence techniques. For example, frame-based knowledge representation schemes closely resemble class hierarchies. Specialization is also common in software engineering design methodologies that are based on the object-oriented paradigm.

7.12 Modeling of UNION Types Using Categories in EER

All of the superclass/subclass relationships we have seen thus far have a *single superclass.* A shared subclass such as ENGINEERING_MANAGER in the lattice in Figure 7.24 is the subclass in three *distinct* superclass/subclass relationships, where each of the three relationships has a *single* superclass. However, it is sometimes necessary to represent a single superclass/subclass relationship with *more than one* superclass, where the superclasses represent different entity types. In this case, the subclass will represent a collection of objects that is a subset of the UNION of distinct entity types; we call such a *subclass* a **union type** or a **category**.[26]

For example, suppose that we have three entity types: PERSON, BANK, and COMPANY. In a database for motor vehicle registration, an owner of a vehicle can be a person, a bank (holding a lien on a vehicle), or a company. We need to create a class (collection of entities) that includes entities of all three types to play the role of *vehicle owner.* A category (union type) OWNER that is a *subclass of the UNION* of the three entity sets of COMPANY, BANK, and PERSON can be created for this purpose. We display categories in an EER diagram as shown in Figure 7.26. The superclasses COMPANY, BANK, and PERSON are connected to the circle with the ∪ symbol, which stands for the *set union operation.* An arc with the subset symbol connects the circle to the (subclass) OWNER category. If a defining predicate is needed, it is displayed next to the line from the superclass to which the predicate applies. In Figure 7.26 we have two categories: OWNER, which is a subclass of the union of PERSON,

[26]Our use of the term *category* is based on the ECR (Entity-Category-Relationship) model (Elmasri et al. 1985).

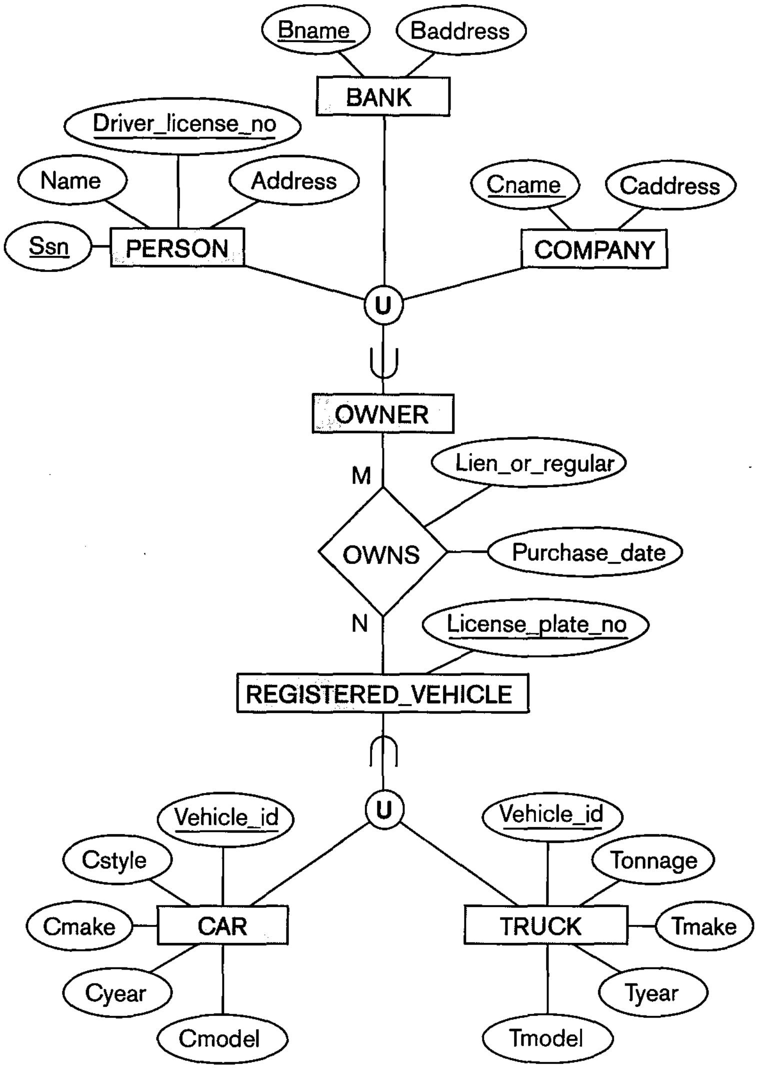


Figure 7.26
Two categories (union types): OWNER and REGISTERED_VEHICLE.

BANK, and COMPANY; and REGISTERED_VEHICLE, which is a subclass of the union of CAR and TRUCK.

A category has two or more superclasses that may represent *distinct entity types,* whereas other superclass/subclass relationships always have a single superclass. To better understand the difference, we can compare a category, such as OWNER in Figure 7.26, with the ENGINEERING_MANAGER shared subclass in Figure 7.26. The latter is a subclass of *each of* the three superclasses ENGINEER, MANAGER, and SALARIED_EMPLOYEE, so an entity that is a member of ENGINEERING_MANAGER must exist in *all three.* This represents the constraint that an engineering manager must be an ENGINEER, a MANAGER, *and* a SALARIED_EMPLOYEE; that is, ENGINEERING_MANAGER is a subset of the *intersection* of the three classes (sets of entities). On the other hand, a category is a subset of the *union* of its superclasses. Hence, an entity that is a member of OWNER must exist in *only one* of the superclasses. This represents the constraint that an OWNER may be a COMPANY, a BANK, *or* a PERSON in Figure 7.26.

Attribute inheritance works more selectively in the case of categories. For example, in Figure 7.26 each OWNER entity inherits the attributes of a COMPANY, a PERSON, or a BANK, depending on the superclass to which the entity belongs. On the other hand, a shared subclass such as ENGINEERING_MANAGER (Figure 7.24) inherits *all* the attributes of its superclasses SALARIED_EMPLOYEE, ENGINEER, and MANAGER.

It is interesting to note the difference between the category REGISTERED_VEHICLE (Figure 7.26) and the generalized superclass VEHICLE (Figure 7.21(b)). In Figure 7.21(b), every car and every truck is a VEHICLE; but in Figure 7.26, the REGISTERED_VEHICLE category includes some cars and some trucks but not necessarily all of them (for example, some cars or trucks may not be registered). In general, a specialization or generalization such as that in Figure 7.21(b), if it were *partial*, would not preclude VEHICLE from containing other types of entities, such as motorcycles. However, a category such as REGISTERED_VEHICLE in Figure 7.26 implies that only cars and trucks, but not other types of entities, can be members of REGISTERED_VEHICLE.

A category can be **total** or **partial.** A total category holds the *union* of all entities in its superclasses, whereas a partial category can hold a *subset of the union.* A total category is represented diagrammatically by a double line connecting the category and the circle, whereas a partial category is indicated by a single line.

The superclasses of a category may have different key attributes, as demonstrated by the OWNER category in Figure 7.26, or they may have the same key attribute, as demonstrated by the REGISTERED_VEHICLE category. Notice that if a category is total (not partial), it may be represented alternatively as a total specialization (or a total generalization). In this case, the choice of which representation to use is subjective. If the two classes represent the same type of entities and share numerous attributes, including the same key attributes, specialization/generalization is preferred; otherwise, categorization (union type) is more appropriate.

It is important to note that some modeling methodologies do not have union types. In these models, a union type must be represented in a roundabout way (see Section 8.2).

7.13 A Sample UNIVERSITY EER Schema, Design Choices, and Formal Definitions

In this section, we first give an example of a database schema in the EER model to illustrate the use of the various concepts discussed here. Then, we discuss design choices for conceptual schemas, and finally we summarize the EER model concepts and define them formally in the same manner in which we formally defined the concepts of the basic ER model.

7.13.1 The UNIVERSITY Database Example

For our sample database application, consider a UNIVERSITY database that keeps track of students and their majors, transcripts, and registration as well as of the university's course offerings. The database also keeps track of the sponsored research projects of faculty and graduate students. This schema is shown in Figure 7.27. A discussion of the requirements that led to this schema follows.

For each person, the database maintains information on the person's Name [Name], Social Security number [Ssn], address [Address], sex [Sex], and birth date [Bdate]. Two subclasses of the PERSON entity type are identified: FACULTY and STUDENT. Specific attributes of FACULTY are rank [Rank] (assistant, associate, adjunct, research, visiting, and so on), office [Foffice], office phone [Fphone], and salary [Salary]. All faculty members are related to the academic department(s) with which they are affiliated [BELONGS] (a faculty member can be associated with several departments, so the relationship is M:N). A specific attribute of STUDENT is [Class] (freshman=1, sophomore=2, ..., graduate student=5). Each STUDENT is also related to his or her major and minor departments (if known) [MAJOR] and [MINOR], to the course sections he or she is currently attending [REGISTERED], and to the courses completed [TRANSCRIPT]. Each TRANSCRIPT instance includes the grade the student received [Grade] in a section of a course.

GRAD_STUDENT is a subclass of STUDENT, with the defining predicate Class = 5. For each graduate student, we keep a list of previous degrees in a composite, multivalued attribute [Degrees]. We also relate the graduate student to a faculty advisor [ADVISOR] and to a thesis committee [COMMITTEE], if one exists.

An academic department has the attributes name [Dname], telephone [Dphone], and office number [Office] and is related to the faculty member who is its chairperson [CHAIRS] and to the college to which it belongs [CD]. Each college has attributes college name [Cname], office number [Coffice], and the name of its dean [Dean].

A course has attributes course number [C#], course name [Cname], and course description [Cdesc]. Several sections of each course are offered, with each section having the attributes section number [Sec#] and the year and quarter in which the section was offered ([Year] and [Qtr]).[27] Section numbers uniquely identify each section. The sections being offered during the current quarter are in a subclass CURRENT_SECTION of SECTION, with the defining predicate Qtr = Current_qtr and Year = Current_year. Each section is related to the instructor who taught or is teaching it ([TEACH]), if that instructor is in the database.

The category INSTRUCTOR_RESEARCHER is a subset of the union of FACULTY and GRAD_STUDENT and includes all faculty, as well as graduate students who are supported by teaching or research. Finally, the entity type GRANT keeps track of research grants and contracts awarded to the university. Each grant has attributes grant title [Title], grant number [No], the awarding agency [Agency], and the starting date [St_date]. A grant is related to one principal investigator [PI] and to all

[27]We assume that the *quarter* system rather than the *semester* system is used in this university.

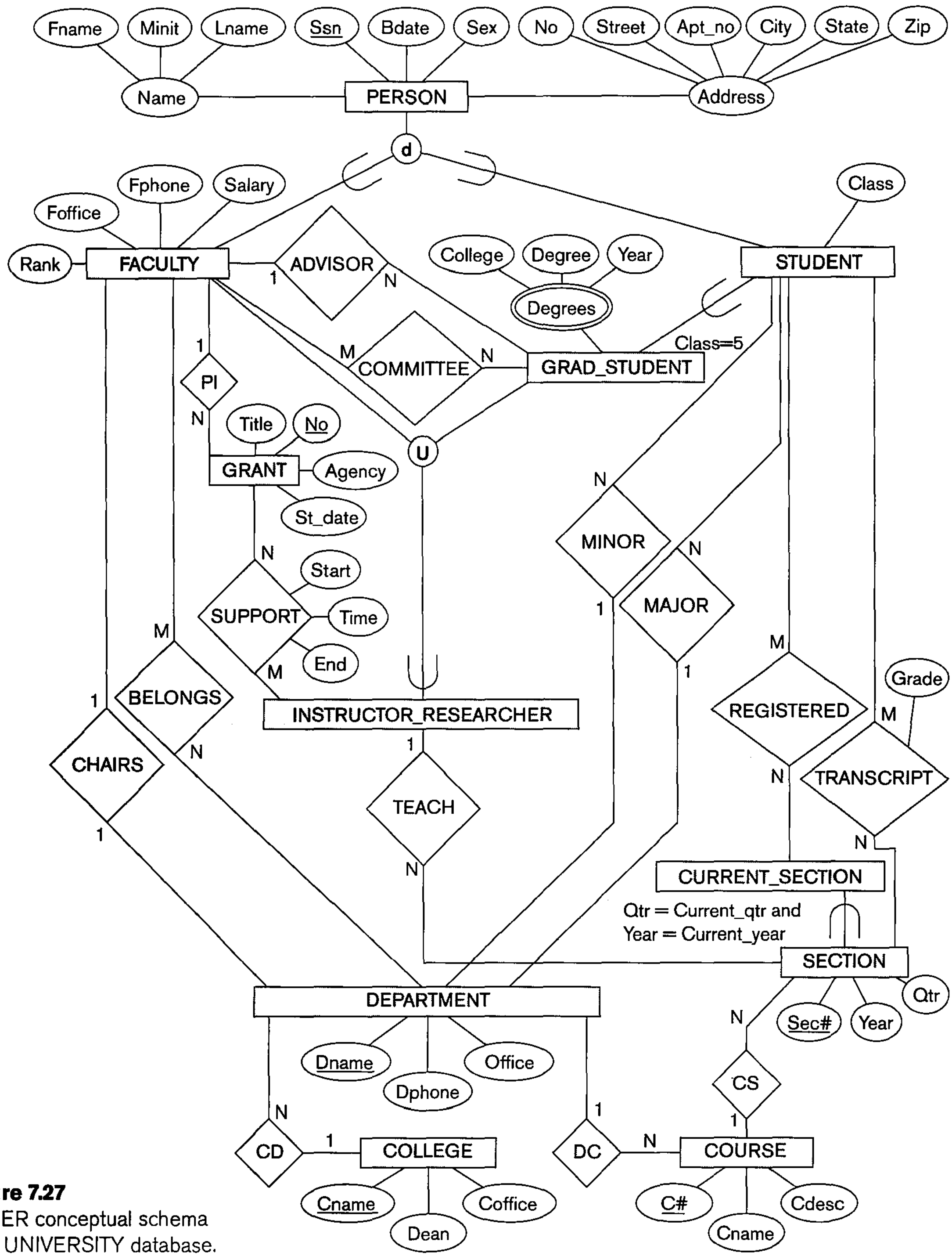


Figure 7.27
An EER conceptual schema for a UNIVERSITY database.

researchers it supports [SUPPORT]. Each instance of support has as attributes the starting date of support [Start], the ending date of the support (if known) [End], and the percentage of time being spent on the project [Time] by the researcher being supported.

7.13.2 Design Choices for Specialization/Generalization

It is not always easy to choose the most appropriate conceptual design for a database application. In Section 7.7.3, we presented some of the typical issues that confront a database designer when choosing among the concepts of entity types, relationship types, and attributes to represent a particular miniworld situation as an ER schema. In this section, we discuss design guidelines and choices for the EER concepts of specialization/generalization and categories (union types).

As we mentioned in Section 7.7.3, conceptual database design should be considered as an iterative refinement process until the most suitable design is reached. The following guidelines can help to guide the design process for EER concepts:

- In general, many specializations and subclasses can be defined to make the conceptual model accurate. However, the drawback is that the design becomes quite cluttered. It is important to represent only those subclasses that are deemed necessary to avoid extreme cluttering of the conceptual schema.
- If a subclass has few specific (local) attributes and no specific relationships, it can be merged into the superclass. The specific attributes would hold NULL values for entities that are not members of the subclass. A *type* attribute could specify whether an entity is a member of the subclass.
- Similarly, if all the subclasses of a specialization/generalization have few specific attributes and no specific relationships, they can be merged into the superclass and replaced with one or more *type* attributes that specify the subclass or subclasses that each entity belongs to (see Section 8.2 for how this criterion applies to relational databases).
- Union types and categories should generally be avoided unless the situation definitely warrants this type of construct, which does occur in some practical situations. If possible, we try to model using specialization/generalization as discussed at the end of Section 7.12.
- The choice of disjoint/overlapping and total/partial constraints on specialization/generalization is driven by the rules in the miniworld being modeled. If the requirements do not indicate any particular constraints, the default would generally be overlapping and partial, since this does not specify any restrictions on subclass membership.

As an example of applying these guidelines, consider Figure 7.24, where no specific (local) attributes are shown. We could merge all the subclasses into the EMPLOYEE entity type, and add the following attributes to EMPLOYEE:

- An attribute Job_type whose value set {'Secretary', 'Engineer', 'Technician'} would indicate which subclass in the first specialization each employee belongs to.

- An attribute Pay_method whose value set {'Salaried', 'Hourly'} would indicate which subclass in the second specialization each employee belongs to.
- An attribute Is_a_manager whose value set {'Yes', 'No'} would indicate whether an individual employee entity is a manager or not.

7.13.3 Formal Definitions for the EER Model Concepts

We now summarize the EER model concepts and give formal definitions. A **class**[28] is a set or collection of entities; this includes any of the EER schema constructs of group entities, such as entity types, subclasses, superclasses, and categories. A **subclass** S is a class whose entities must always be a subset of the entities in another class, called the **superclass** C of the **superclass/subclass** (or **IS-A**) **relationship**. We denote such a relationship by C/S. For such a superclass/subclass relationship, we must always have

$$S \subseteq C$$

A **specialization** $Z = \{S_1, S_2, ..., S_n\}$ is a set of subclasses that have the same superclass G; that is, G/S_i is a superclass/subclass relationship for $i = 1, 2, ..., n$. G is called a **generalized entity type** (or the **superclass** of the specialization, or a **generalization** of the subclasses $\{S_1, S_2, ..., S_n\}$). Z is said to be **total** if we always (at any point in time) have

$$\bigcup_{i=1}^{n} S_i = G$$

Otherwise, Z is said to be **partial**. Z is said to be **disjoint** if we always have

$$S_i \cap S_j = \varnothing \text{ (empty set) for } i \neq j$$

Otherwise, Z is said to be **overlapping**.

A subclass S of C is said to be **predicate-defined** if a predicate p on the attributes of C is used to specify which entities in C are members of S; that is, $S = C[p]$, where $C[p]$ is the set of entities in C that satisfy p. A subclass that is not defined by a predicate is called **user-defined**.

A specialization Z (or generalization G) is said to be **attribute-defined** if a predicate $(A = c_i)$, where A is an attribute of G and c_i is a constant value from the domain of A, is used to specify membership in each subclass S_i in Z. Notice that if $c_i \neq c_j$ for $i \neq j$, and A is a single-valued attribute, then the specialization will be disjoint.

A **category** T is a class that is a subset of the union of n defining superclasses $D_1, D_2, ..., D_n$, $n > 1$, and is formally specified as follows:

$$T \subseteq (D_1 \cup D_2 ... \cup D_n)$$

[28]The use of the word *class* here differs from its more common use in object-oriented programming languages such as C++. In C++, a class is a structured type definition along with its applicable functions (operations).

A predicate p_i on the attributes of D_i can be used to specify the members of each D_i that are members of T. If a predicate is specified on every D_i, we get

$$T = (D_1[p_1] \cup D_2[p_2] \ldots \cup D_n[p_n])$$

We should now extend the definition of **relationship type** given earlier in this chapter by allowing any class—not only any entity type—to participate in a relationship. Hence, we should replace the words *entity type* with *class* in that definition. The graphical notation of EER is consistent with ER because all classes are represented by rectangles.

7.14 Data Abstraction, Knowledge Representation, and Ontology Concepts

In this section we discuss in general terms some of the modeling concepts that we described quite specifically in our presentation of the ER and EER models in this chapter. This terminology is not only used in conceptual data modeling but also in artificial intelligence literature when discussing **knowledge representation** (**KR**). This section discusses the similarities and differences between conceptual modeling and knowledge representation, and introduces some of the alternative terminology and a few additional concepts.

The goal of KR techniques is to develop concepts for accurately modeling some **domain of knowledge** by creating an **ontology**[29] that describes the concepts of the domain and how these concepts are interrelated. Such an ontology is used to store and manipulate knowledge for drawing inferences, making decisions, or answering questions. The goals of KR are similar to those of semantic data models, but there are some important similarities and differences between the two disciplines:

- Both disciplines use an abstraction process to identify common properties and important aspects of objects in the miniworld (also known as *domain of discourse* in KR) while suppressing insignificant differences and unimportant details.
- Both disciplines provide concepts, relationships, constraints, operations, and languages for defining data and representing knowledge.
- KR is generally broader in scope than semantic data models. Different forms of knowledge, such as rules (used in inference, deduction, and search), incomplete and default knowledge, and temporal and spatial knowledge, are represented in KR schemes. Database models are being expanded to include some of these concepts (see Chapter 24).
- KR schemes include **reasoning mechanisms** that deduce additional facts from the facts stored in a database. Hence, whereas most current database systems are limited to answering direct queries, knowledge-based systems

[29]An *ontology* is somewhat similar to a conceptual schema, but with more knowledge, rules, and exceptions.

using KR schemes can answer queries that involve **inferences** over the stored data. Database technology is being extended with inference mechanisms (see Section 24.5).

- Whereas most data models concentrate on the representation of database schemas, or meta-knowledge, KR schemes often mix up the schemas with the instances themselves in order to provide flexibility in representing exceptions. This often results in inefficiencies when these KR schemes are implemented, especially when compared with databases and when a large amount of data (facts) needs to be stored.

We now discuss four **abstraction concepts** that are used in semantic data models, such as the EER model as well as in KR schemes: (1) classification and instantiation, (2) identification, (3) specialization and generalization, and (4) aggregation and association. The paired concepts of classification and instantiation are inverses of one another, as are generalization and specialization. The concepts of aggregation and association are also related. We discuss these abstract concepts and their relation to the concrete representations used in the EER model to clarify the data abstraction process and to improve our understanding of the related process of conceptual schema design. We close the section with a brief discussion of *ontology*, which is being used widely in recent knowledge representation research.

7.14.1 Classification and Instantiation

The process of **classification** involves systematically assigning similar objects/entities to object classes/entity types. We can now describe (in DB) or reason about (in KR) the classes rather than the individual objects. Collections of objects that share the same types of attributes, relationships, and constraints are classified into classes in order to simplify the process of discovering their properties. **Instantiation** is the inverse of classification and refers to the generation and specific examination of distinct objects of a class. An object instance is related to its object class by the **IS-AN-INSTANCE-OF** or **IS-A-MEMBER-OF** relationship. Although EER diagrams do not display instances, the UML diagrams (see Chapter 9) allow a form of instantiation by permitting the display of individual objects. We *did not* describe this feature in our introduction to UML class diagrams in Chapter 9.

In general, the objects of a class should have a similar type structure. However, some objects may display properties that differ in some respects from the other objects of the class; these **exception objects** also need to be modeled, and KR schemes allow more varied exceptions than do database models. In addition, certain properties apply to the class as a whole and not to the individual objects; KR schemes allow such **class properties**. UML diagrams (see Chapter 9) also allow specification of class properties.

In the EER model, entities are classified into entity types according to their basic attributes and relationships. Entities are further classified into subclasses and categories based on additional similarities and differences (exceptions) among them. Relationship instances are classified into relationship types. Hence, entity types, subclasses, categories, and relationship types are the different concepts that are used for classification in the EER model. The EER model does not provide explicitly for class properties, but it may be extended to do so. In UML, objects are classified into classes, and it is possible to display both class properties and individual objects (see Chapter 9).

Knowledge representation models allow multiple classification schemes in which one class is an *instance* of another class (called a **meta-class**). Notice that this *cannot* be represented directly in the EER model, because we have only two levels—classes and instances. The only relationship among classes in the EER model is a superclass/subclass relationship, whereas in some KR schemes an additional class/instance relationship can be represented directly in a class hierarchy. An instance may itself be another class, allowing multiple-level classification schemes.

7.14.2 Identification

Identification is the abstraction process whereby classes and objects are made uniquely identifiable by means of some **identifier**. For example, a class name uniquely identifies a whole class within a schema. An additional mechanism is necessary for telling distinct object instances apart by means of object identifiers. Moreover, it is necessary to identify multiple manifestations in the database of the same real-world object. For example, we may have a tuple <'Matthew Clarke', '610618', '376-9821'> in a PERSON relation and another tuple <'301-54-0836', 'CS', 3.8> in a STUDENT relation that happen to represent the same real-world entity. There is no way to identify the fact that these two database objects (tuples) represent the same real-world entity unless we make a provision *at design time* for appropriate cross-referencing to supply this identification. Hence, identification is needed at two levels:

- To distinguish among database objects and classes
- To identify database objects and to relate them to their real-world counterparts

In the EER model, identification of schema constructs is based on a system of unique names for the constructs in a schema. For example, every class in an EER schema—whether it is an entity type, a subclass, a category, or a relationship type—must have a distinct name. The names of attributes of a particular class must also be distinct. Rules for unambiguously identifying attribute name references in a specialization or generalization lattice or hierarchy are needed as well.

At the object level, the values of key attributes are used to distinguish among entities of a particular entity type. For weak entity types, entities are identified by a combination of their own partial key values and the entities they are related to in the owner entity type(s). Relationship instances are identified by some combination of the entities that they relate to, depending on the cardinality ratio specified.

7.14.3 Specialization and Generalization

Specialization is the process of classifying a class of objects into more specialized subclasses. **Generalization** is the inverse process of generalizing several classes into a higher-level abstract class that includes the objects in all these classes. Specialization is conceptual refinement, whereas generalization is conceptual synthesis. Subclasses are used in the EER model to represent specialization and generalization. We call the relationship between a subclass and its superclass an **IS-A-SUBCLASS-OF** relationship, or simply an **IS-A** relationship. This is the same as the IS-A relationship discussed earlier in Section 7.13.3.

7.14.4 Aggregation and Association

Aggregation is an abstraction concept for building composite objects from their component objects. There are three cases where this concept can be related to the EER model. The first case is the situation in which we aggregate attribute values of an object to form the whole object. The second case is when we represent an aggregation relationship as an ordinary relationship. The third case, which the EER model does not provide for explicitly, involves the possibility of combining objects that are related by a particular relationship instance into a *higher-level aggregate object.* This is sometimes useful when the higher-level aggregate object is itself to be related to another object. We call the relationship between the primitive objects and their aggregate object **IS-A-PART-OF**; the inverse is called **IS-A-COMPONENT-OF.** UML provides for all three types of aggregation.

The abstraction of **association** is used to associate objects from several *independent classes.* Hence, it is somewhat similar to the second use of aggregation. It is represented in the EER model by relationship types, and in UML by associations (see Chapter 9). This abstract relationship is called **IS-ASSOCIATED-WITH.**

In order to understand the different uses of aggregation better, consider the ER schema shown in Figure 7.28(a), which stores information about interviews by job applicants to various companies. The class COMPANY is an aggregation of the attributes (or component objects) Cname (company name) and Caddress (company address), whereas JOB_APPLICANT is an aggregate of Ssn, Name, Address, and Phone. The relationship attributes Contact_name and Contact_phone represent the name and phone number of the person in the company who is responsible for the interview. Suppose that some interviews result in job offers, whereas others do not. We would like to treat INTERVIEW as a class to associate it with JOB_OFFER. The schema shown in Figure 7.28(b) is *incorrect* because it requires each interview relationship instance to have a job offer. The schema shown in Figure 7.28(c) is *not allowed* because the ER model does not allow relationships among relationships.

One way to represent this situation is to create a higher-level aggregate class composed of COMPANY, JOB_APPLICANT, and INTERVIEW and to relate this class to JOB_OFFER, as shown in Figure 7.28(d). Although the EER model as described in this book does not have this facility, some semantic data models do allow it and call the resulting object a **composite** or **molecular object**. Other models treat entity types and relationship types uniformly and hence permit relationships among relationships, as illustrated in Figure 7.28(c).

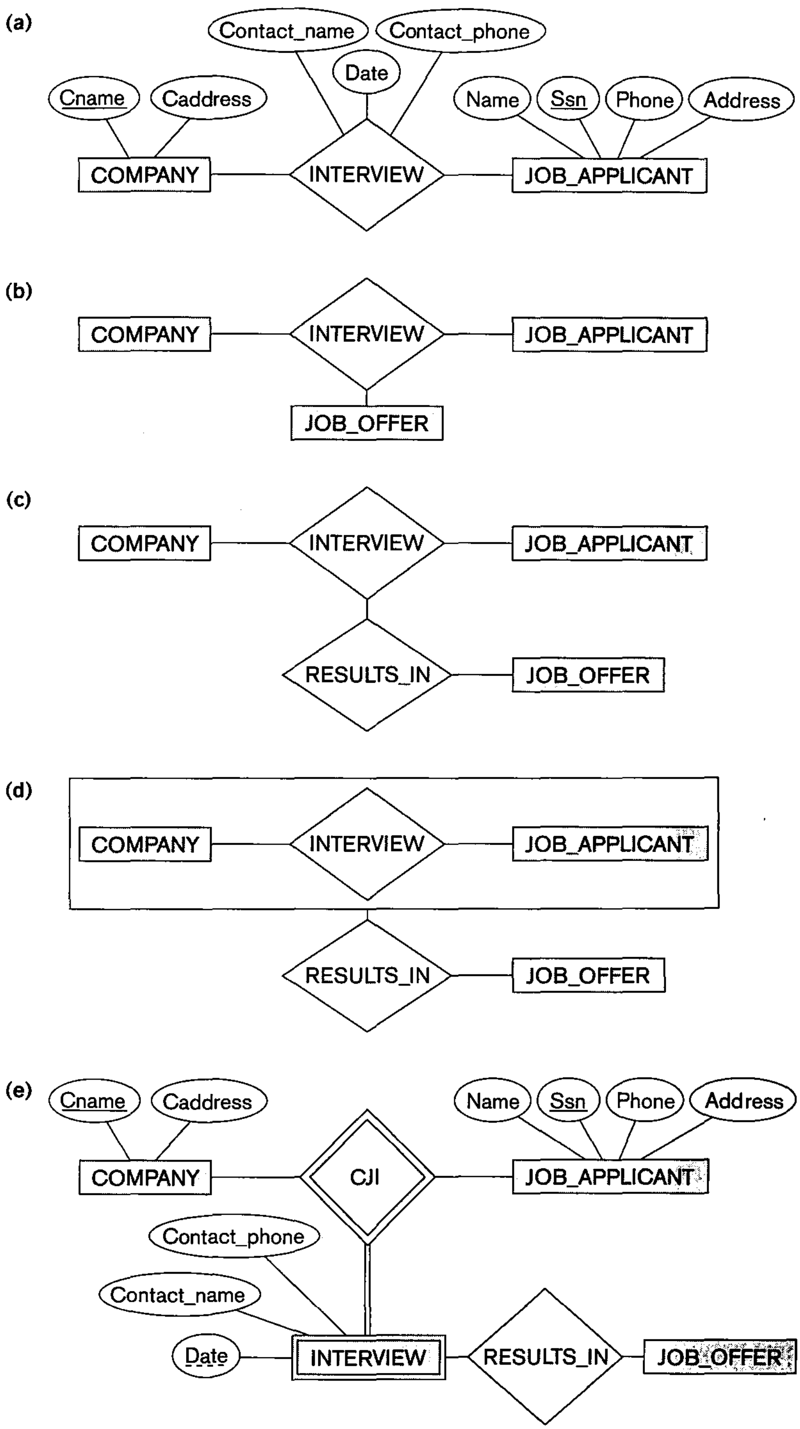


Figure 7.28
Aggregation. (a) The relationship type INTERVIEW. (b) Including JOB_OFFER in a ternary relationship type (incorrect). (c) Having the RESULTS_IN relationship participate in other relationships (not allowed in ER). (d) Using aggregation and a composite (molecular) object (generally not allowed in ER but allowed by some modeling tools). (e) Correct representation in ER.

To represent this situation correctly in the ER model as described here, we need to create a new weak entity type INTERVIEW, as shown in Figure 7.28(e), and relate it to JOB_OFFER. Hence, we can always represent these situations correctly in the ER model by creating additional entity types, although it may be conceptually more desirable to allow direct representation of aggregation, as in Figure 7.28(d), or to allow relationships among relationships, as in Figure 7.28(c).

The main structural distinction between aggregation and association is that when an association instance is deleted, the participating objects may continue to exist. However, if we support the notion of an aggregate object—for example, a CAR that is made up of objects ENGINE, CHASSIS, and TIRES—then deleting the aggregate CAR object amounts to deleting all its component objects.

7.14.5 Ontologies and the Semantic Web

In recent years, the amount of computerized data and information available on the Web has spiraled out of control. Many different models and formats are used. In addition to the database models that we present in this book, much information is stored in the form of **documents**, which have considerably less structure than database information does. One ongoing project that is attempting to allow information exchange among computers on the Web is called the **Semantic Web**, which attempts to create knowledge representation models that are quite general in order to allow meaningful information exchange and search among machines. The concept of *ontology* is considered to be the most promising basis for achieving the goals of the Semantic Web and is closely related to knowledge representation. In this section, we give a brief introduction to what ontology is and how it can be used as a basis to automate information understanding, search, and exchange.

The study of ontologies attempts to describe the structures and relationships that are possible in reality through some common vocabulary; therefore, it can be considered as a way to describe the knowledge of a certain community about reality. Ontology originated in the fields of philosophy and metaphysics. One commonly used definition of **ontology** is *a specification* of a *conceptualization.*[30]

In this definition, a **conceptualization** is the set of concepts that are used to represent the part of reality or knowledge that is of interest to a community of users. **Specification** refers to the language and vocabulary terms that are used to specify the conceptualization. The ontology includes both *specification* and *conceptualization.* For example, the same conceptualization may be specified in two different languages, giving two separate ontologies. Based on this quite general definition, there is no consensus on what an ontology is exactly. Some possible ways to describe ontologies are as follows:

- A **thesaurus** (or even a **dictionary** or a **glossary** of terms) describes the relationships between words (vocabulary) that represent various concepts.

[30]This definition is given in Gruber (1995).

- A **taxonomy** describes how concepts of a particular area of knowledge are related using structures similar to those used in a specialization or generalization.
- A detailed **database schema** is considered by some to be an ontology that describes the concepts (entities and attributes) and relationships of a miniworld from reality.
- A **logical theory** uses concepts from mathematical logic to try to define concepts and their interrelationships.

Usually the concepts used to describe ontologies are quite similar to the concepts we discussed in conceptual modeling, such as entities, attributes, relationships, specializations, and so on. The main difference between an ontology and, say, a database schema, is that the schema is usually limited to describing a small subset of a miniworld from reality in order to store and manage data. An ontology is usually considered to be more general in that it attempts to describe a part of reality or a domain of interest (for example, medical terms, electronic-commerce applications, sports, and so on) as completely as possible.

7.15 Summary

In this chapter we presented the modeling concepts of a high-level conceptual data model, the Entity-Relationship (ER) model. We started by discussing the role that a high-level data model plays in the database design process, and then we presented a sample set of database requirements for the COMPANY database, which is one of the examples that is used throughout this book. We defined the basic ER model concepts of entities and their attributes. Then we discussed NULL values and presented the various types of attributes, which can be nested arbitrarily to produce complex attributes:

- Simple or atomic
- Composite
- Multivalued

We also briefly discussed stored versus derived attributes. Then we discussed the ER model concepts at the schema or "intension" level:

- Entity types and their corresponding entity sets
- Key attributes of entity types
- Value sets (domains) of attributes
- Relationship types and their corresponding relationship sets
- Participation roles of entity types in relationship types

We presented two methods for specifying the structural constraints on relationship types. The first method distinguished two types of structural constraints:

- Cardinality ratios (1:1, 1:N, M:N for binary relationships)
- Participation constraints (total, partial)

We noted that, alternatively, another method of specifying structural constraints is to specify minimum and maximum numbers (min, max) on the participation of each entity type in a relationship type. We discussed weak entity types and the related concepts of owner entity types, identifying relationship types, and partial key attributes.

Entity-Relationship schemas can be represented diagrammatically as ER diagrams. We showed how to design an ER schema for the COMPANY database by first defining the entity types and their attributes and then refining the design to include relationship types. We also described ternary and higher-degree relationship types in more detail, and discussed the circumstances under which they are distinguished from binary relationships.

We then discussed extensions to the ER model that improve its representational capabilities. We called the resulting model the enhanced ER or EER model. We presented the concept of a subclass and its superclass and the related mechanism of attribute/relationship inheritance. We saw how it is sometimes necessary to create additional classes of entities, either because of additional specific attributes or because of specific relationship types. We discussed two main processes for defining superclass/subclass hierarchies and lattices: specialization and generalization. Next, we showed how to display these new constructs in an EER diagram. We also discussed the various types of constraints that may apply to specialization or generalization. The two main constraints are total/partial and disjoint/overlapping. In addition, a defining predicate for a subclass or a defining attribute for a specialization may be specified. We discussed the differences between user-defined and predicate-defined subclasses and between user-defined and attribute-defined specializations. Finally, we discussed the concept of a category or union type, which is a subset of the union of two or more classes, and we gave formal definitions of all the concepts presented. In Section 7.14 we briefly discussed the discipline of knowledge representation and how it is related to semantic data modeling.We also gave an overview and summary of the types of abstract data representation concepts: classification and instantiation, identification, specialization and generalization, and aggregation and association. We saw how EER concepts are related to each of these. We discuss additional advanced data modeling techniques in Chapter 24.

Review Questions

7.1. Discuss the role of a high-level data model in the database design process.

7.2. List the various cases where use of a NULL value would be appropriate.

7.3. Define the following terms: *entity, attribute, attribute value, relationship instance, composite attribute, multivalued attribute, derived attribute, complex attribute, key attribute,* and *value set (domain)*.

7.4. What is an entity type? What is an entity set? Explain the differences among an entity, an entity type, and an entity set.

7.5. Explain the difference between an attribute and a value set.

7.6. What is a relationship type? Explain the differences among a relationship instance, a relationship type, and a relationship set.

7.7. What is a participation role? When is it necessary to use role names in the description of relationship types?

7.8. Describe the two alternatives for specifying structural constraints on relationship types. What are the advantages and disadvantages of each?

7.9. Under what conditions can an attribute of a binary relationship type be migrated to become an attribute of one of the participating entity types?

7.10. When we think of relationships as attributes, what are the value sets of these attributes? What class of data models is based on this concept?

7.11. What is meant by a recursive relationship type? Give some examples of recursive relationship types.

7.12. When is the concept of a weak entity used in data modeling? Define the terms *owner entity type, weak entity type, identifying relationship type,* and *partial key.*

7.13. Can an identifying relationship of a weak entity type be of a degree greater than two? Give examples to illustrate your answer.

7.14. Discuss the conventions for displaying an ER schema as an ER diagram.

7.15. Discuss the naming conventions used for ER schema diagrams.

7.16. What is a subclass? When is a subclass needed in data modeling?

7.17. Define the following terms: *superclass of a subclass, superclass/subclass relationship, IS-A relationship, specialization, generalization, category, specific (local) attributes,* and *specific relationships.*

7.18. Discuss the mechanism of attribute/relationship inheritance. Why is it useful?

7.19. Discuss user-defined and predicate-defined subclasses, and identify the differences between the two.

7.20. Discuss user-defined and attribute-defined specializations, and identify the differences between the two.

7.21. Discuss the two main types of constraints on specializations and generalizations.

7.22. What is the difference between a specialization hierarchy and a specialization lattice?

7.23. What is the difference between specialization and generalization? Why do we not display this difference in schema diagrams?

7.24. How does a category differ from a regular shared subclass? What is a category used for? Illustrate your answer with examples.

7.25. List the various data abstraction concepts and the corresponding modeling concepts in the EER model.

7.26. What aggregation feature is missing from the EER model? How can the EER model be further enhanced to support it?

7.27. What are the main similarities and differences between conceptual database modeling techniques and knowledge representation techniques?

7.28. Discuss the similarities and differences between an ontology and a database schema.

Exercises

7.29. Consider the following set of requirements for a UNIVERSITY database that is used to keep track of students' transcripts. This is similar but not identical to the database shown in Figure 1.2:

a. The university keeps track of each student's name, student number, Social Security number, current address and phone number, permanent address and phone number, birth date, sex, class (freshman, sophomore, ..., graduate), major department, minor department (if any), and degree program (B.A., B.S., ..., Ph.D.). Some user applications need to refer to the city, state, and ZIP Code of the student's permanent address and to the student's last name. Both Social Security number and student number have unique values for each student.

b. Each department is described by a name, department code, office number, office phone number, and college. Both name and code have unique values for each department.

c. Each course has a course name, description, course number, number of semester hours, level, and offering department. The value of the course number is unique for each course.

d. Each section has an instructor, semester, year, course, and section number. The section number distinguishes sections of the same course that are taught during the same semester/year; its values are 1, 2, 3, ..., up to the number of sections taught during each semester.

e. A grade report has a student, section, letter grade, and numeric grade (0, 1, 2, 3, or 4).

Design an ER schema for this application, and draw an ER diagram for the schema. Specify key attributes of each entity type, and structural constraints on each relationship type. Note any unspecified requirements, and make appropriate assumptions to make the specification complete.

7.30. Composite and multivalued attributes can be nested to any number of levels. Suppose we want to design an attribute for a STUDENT entity type to keep track of previous college education. Such an attribute will have one entry for each college previously attended, and each such entry will be composed of college name, start and end dates, degree entries (degrees awarded at that college, if any), and transcript entries (courses completed at that college, if any). Each degree entry contains the degree name and the month and year the degree was awarded, and each transcript entry contains a course name, semester, year, and grade. Design an attribute to hold this information. Use the conventions in Figure 7.5.

7.31. Show an alternative design for the attribute described in Exercise 7.30 that uses only entity types (including weak entity types, if needed) and relationship types.

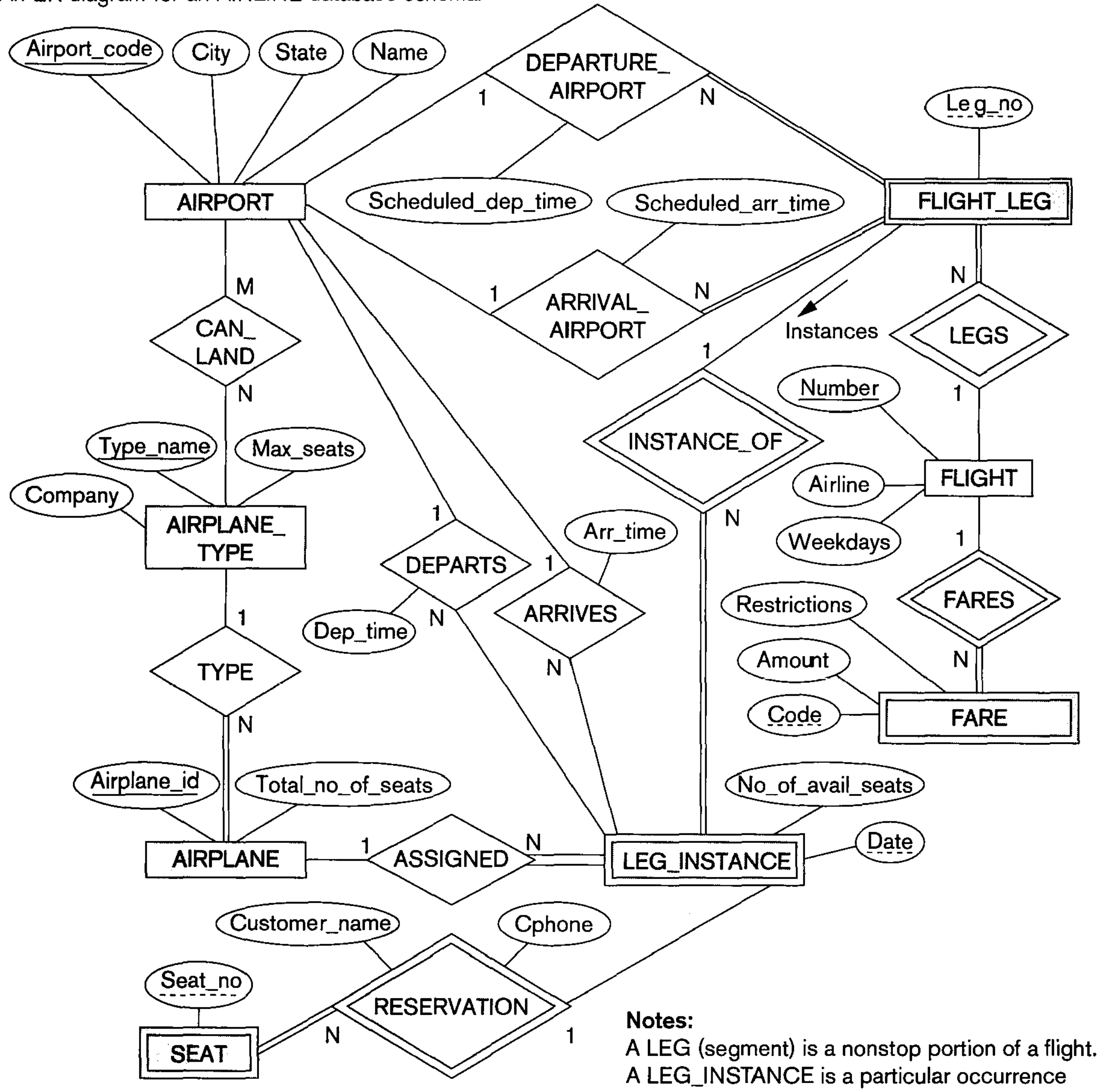
7.32. Consider the ER diagram in Figure 7.29, which shows a simplified schema for an airline reservations system. Extract from the ER diagram the requirements and constraints that produced this schema. Try to be as precise as possible in your requirements and constraints specification.

7.33. In Chapters 1 and 2, we discussed the database environment and database users. We can consider many entity types to describe such an environment, such as DBMS, stored database, DBA, and catalog/data dictionary. Try to specify all the entity types that can fully describe a database system and its environment; then specify the relationship types among them, and draw an ER diagram to describe such a general database environment.

7.34. Design an ER schema for keeping track of information about votes taken in the U.S. House of Representatives during the current two-year congressional session. The database needs to keep track of each U.S. STATE's Name (e.g., 'Texas', 'New York', 'California') and include the Region of the state (whose domain is {'Northeast', 'Midwest', 'Southeast', 'Southwest', 'West'}). Each CONGRESS_PERSON in the House of Representatives is described by his or her Name, plus the District represented, the Start_date when the congressperson was first elected, and the political Party to which he or she belongs (whose domain is {'Republican', 'Democrat', 'Independent', 'Other'}). The database keeps track of each BILL (i.e., proposed law), including the Bill_name, the Date_of_vote on the bill, whether the bill Passed_or_failed (whose domain is {'Yes', 'No'}), and the Sponsor (the congressperson(s) who sponsored—that is, proposed—the bill). The database also keeps track of how each congressperson voted on each bill (domain of Vote attribute is {'Yes', 'No', 'Abstain', 'Absent'}). Draw an ER schema diagram for this application. State clearly any assumptions you make.

7.35. A database is being constructed to keep track of the teams and games of a sports league. A team has a number of players, not all of whom participate in each game. It is desired to keep track of the players participating in each game for each team, the positions they played in that game, and the result of the game. Design an ER schema diagram for this application, stating any assumptions you make. Choose your favorite sport (e.g., soccer, baseball, football).

Figure 7.29
An ER diagram for an AIRLINE database schema.



Notes:
A LEG (segment) is a nonstop portion of a flight.
A LEG_INSTANCE is a particular occurrence of a LEG on a particular date.

7.36. Consider the ER diagram shown in Figure 7.30 for part of a BANK database. Each bank can have multiple branches, and each branch can have multiple accounts and loans.

a. List the strong (nonweak) entity types in the ER diagram.

b. Is there a weak entity type? If so, give its name, partial key, and identifying relationship.

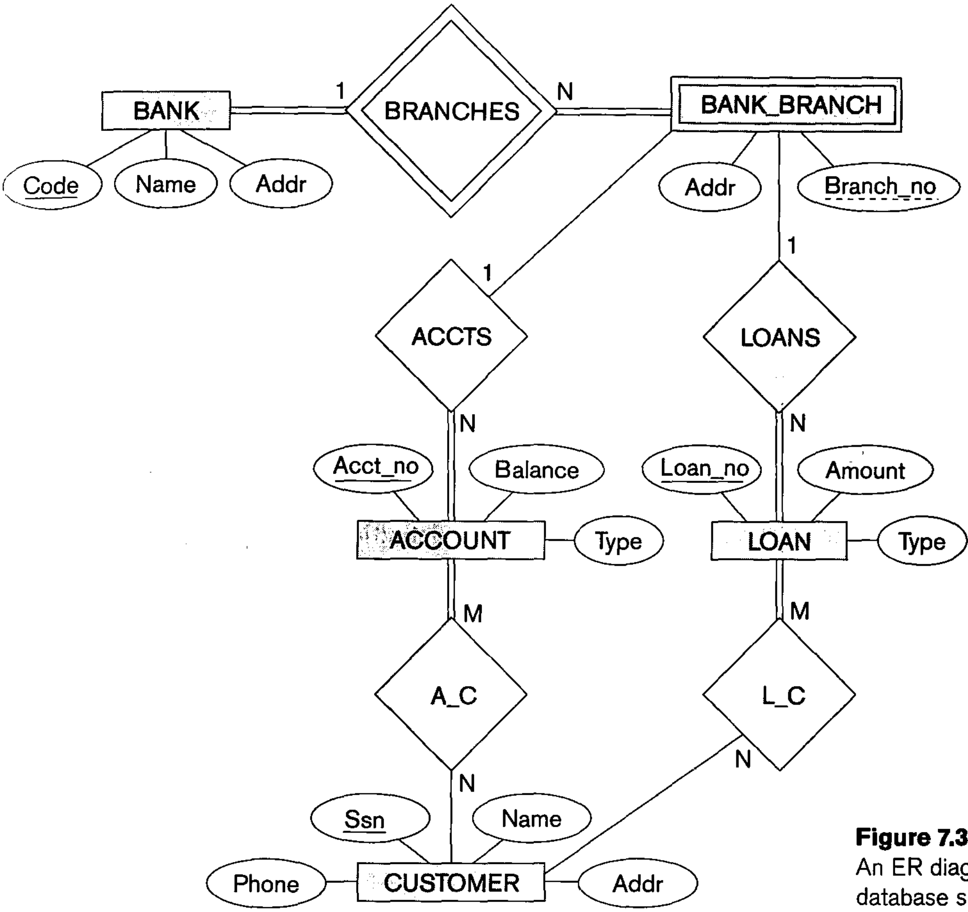


Figure 7.30
An ER diagram for a BANK database schema.

c. What constraints do the partial key and the identifying relationship of the weak entity type specify in this diagram?

d. List the names of all relationship types, and specify the (min, max) constraint on each participation of an entity type in a relationship type. Justify your choices.

e. List concisely the user requirements that led to this ER schema design.

f. Suppose that every customer must have at least one account but is restricted to at most two loans at a time, and that a bank branch cannot have more than 1,000 loans. How does this show up on the (min, max) constraints?

7.37. Consider the ER diagram in Figure 7.31. Assume that an employee may work in up to two departments or may not be assigned to any department. Assume that each department must have one and may have up to three phone numbers. Supply (min, max) constraints on this diagram. *State clearly any addi-*

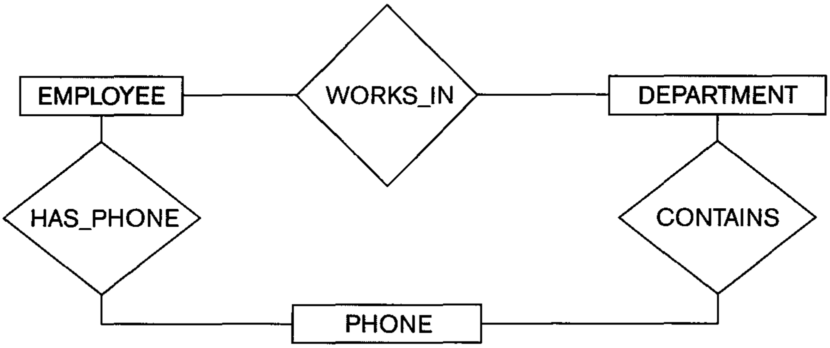


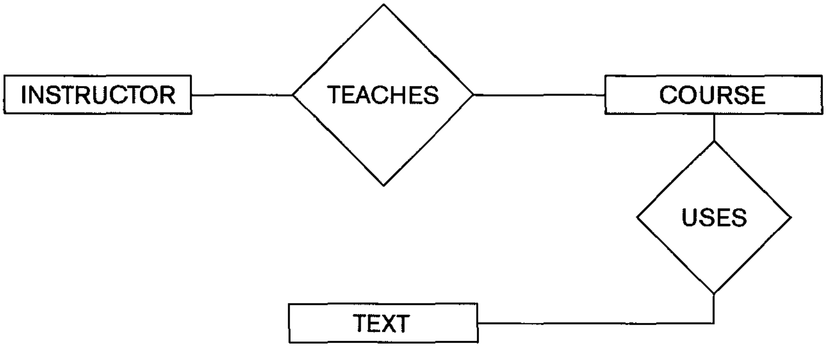
Figure 7.31
Part of an ER diagram for a COMPANY database.

tional assumptions you make. Under what conditions would the relationship HAS_PHONE be redundant in this example?

7.38. Consider the ER diagram in Figure 7.32. Assume that a course may or may not use a textbook, but that a text by definition is a book that is used in some course. A course may not use more than five books. Instructors teach from two to four courses. Supply (min, max) constraints on this diagram. *State clearly any additional assumptions you make.* If we add the relationship ADOPTS, to indicate the textbook(s) that an instructor uses for a course, should it be a binary relationship between INSTRUCTOR and TEXT, or a ternary relationship between all three entity types? What (min, max) constraints would you put on it? Why?

7.39. Consider an entity type SECTION in a UNIVERSITY database, which describes the section offerings of courses. The attributes of SECTION are Section_number, Semester, Year, Course_number, Instructor, Room_no (where section is taught), Building (where section is taught), Weekdays (domain is the possible combinations of weekdays in which a section can be offered {'MWF', 'MW', 'TT', and so on}), and Hours (domain is all possible time periods during which sections are offered {'9–9:50 A.M.', '10–10:50 A.M.', ..., '3:30–4:50 P.M.', '5:30–6:20 P.M.', and so on}). Assume that Section_number is unique for each course within a particular semester/year combination (that

Figure 7.32
Part of an ER diagram for a COURSES database.



is, if a course is offered multiple times during a particular semester, its section offerings are numbered 1, 2, 3, and so on). There are several composite keys for section, and some attributes are components of more than one key. Identify three composite keys, and show how they can be represented in an ER schema diagram.

7.40. Cardinality ratios often dictate the detailed design of a database. The cardinality ratio depends on the real-world meaning of the entity types involved and is defined by the specific application. For the following binary relationships, suggest cardinality ratios based on the common-sense meaning of the entity types. Clearly state any assumptions you make.

	Entity 1	Cardinality Ratio	Entity 2
1.	STUDENT	____________	SOCIAL_SECURITY_CARD
2.	STUDENT	____________	TEACHER
3.	CLASSROOM	____________	WALL
4.	COUNTRY	____________	CURRENT_PRESIDENT
5.	COURSE	____________	TEXTBOOK
6.	ITEM (that can be found in an order)	____________	ORDER
7.	STUDENT	____________	CLASS
8.	CLASS	____________	INSTRUCTOR
9.	INSTRUCTOR	____________	OFFICE
10.	EBAY_AUCTION_ITEM	____________	EBAY_BID

7.41. Consider the ER schema for the MOVIES database in Figure 7.33.

Assume that MOVIES is a populated database. ACTOR is used as a generic term and includes actresses. Given the constraints shown in the ER schema, respond to the following statements with *True*, *False*, or *Maybe*. Assign a response of *Maybe* to statements that, while not explicitly shown to be *True*, cannot be proven *False* based on the schema as shown. Justify each answer.

a. There are no actors in this database that have been in no movies.
b. There are some actors who have acted in more than ten movies.
c. Some actors have done a lead role in multiple movies.
d. A movie can have only a maximum of two lead actors.
e. Every director has been an actor in some movie.
f. No producer has ever been an actor.
g. A producer cannot be an actor in some other movie.
h. There are movies with more than a dozen actors.
i. Some producers have been a director as well.

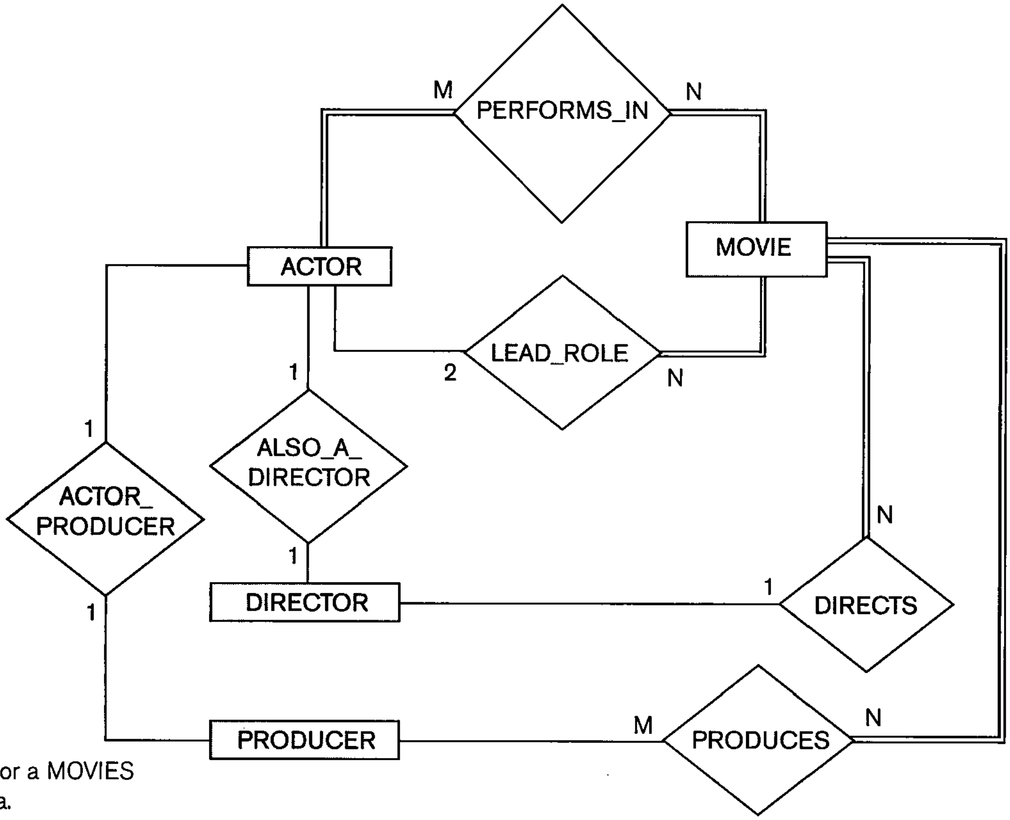


Figure 7.33
An ER diagram for a MOVIES database schema.

j. Most movies have one director and one producer.

k. Some movies have one director but several producers.

l. There are some actors who have done a lead role, directed a movie, and produced some movie.

m. No movie has a director who also acted in that movie.

7.42. Given the ER schema for the MOVIES database in Figure 7.33, draw an instance diagram using three movies that have been released recently. Draw instances of each entity type: MOVIES, ACTORS, PRODUCERS, DIRECTORS involved; make up instances of the relationships as they exist in reality for those movies.

7.43. Design an EER schema for a database application that you are interested in. Specify all constraints that should hold on the database. Make sure that the schema has at least five entity types, four relationship types, a weak entity type, a superclass/subclass relationship, a category, and an n-ary ($n > 2$) relationship type.

7.44. Consider the BANK ER schema in Figure 7.30, and suppose that it is necessary to keep track of different types of ACCOUNTS (SAVINGS_ACCTS, CHECKING_ACCTS, ...) and LOANS (CAR_LOANS, HOME_LOANS, ...). Suppose that it is also desirable to keep track of each ACCOUNT's TRANSACTIONS (deposits, withdrawals, checks, ...) and each LOAN's PAYMENTS; both of these include the amount, date, and time. Modify the BANK schema, using ER and EER concepts of specialization and generalization. State any assumptions you make about the additional requirements.

7.45. The following narrative describes a simplified version of the organization of Olympic facilities planned for the summer Olympics. Draw an EER diagram that shows the entity types, attributes, relationships, and specializations for this application. State any assumptions you make. The Olympic facilities are divided into sports complexes. Sports complexes are divided into *one-sport* and *multisport* types. Multisport complexes have areas of the complex designated for each sport with a location indicator (e.g., center, NE corner, and so on). A complex has a location, chief organizing individual, total occupied area, and so on. Each complex holds a series of events (e.g., the track stadium may hold many different races). For each event there is a planned date, duration, number of participants, number of officials, and so on. A roster of all officials will be maintained together with the list of events each official will be involved in. Different equipment is needed for the events (e.g., goal posts, poles, parallel bars) as well as for maintenance. The two types of facilities (one-sport and multisport) will have different types of information. For each type, the number of facilities needed is kept, together with an approximate budget.

7.46. Identify all the important concepts represented in the library database case study described below. In particular, identify the abstractions of classification (entity types and relationship types), aggregation, identification, and specialization/generalization. Specify (min, max) cardinality constraints whenever possible. List details that will affect the eventual design but that have no bearing on the conceptual design. List the semantic constraints separately. Draw an EER diagram of the library database.

Case Study: The Georgia Tech Library (GTL) has approximately 16,000 members, 100,000 titles, and 250,000 volumes (an average of 2.5 copies per book). About 10 percent of the volumes are out on loan at any one time. The librarians ensure that the books that members want to borrow are available when the members want to borrow them. Also, the librarians must know how many copies of each book are in the library or out on loan at any given time. A catalog of books is available online that lists books by author, title, and subject area. For each title in the library, a book description is kept in the catalog that ranges from one sentence to several pages. The reference librarians want to be able to access this description when members request information about a book. Library staff includes chief librarian, departmental associate librarians, reference librarians, check-out staff, and library assistants.

Books can be checked out for 21 days. Members are allowed to have only five books out at a time. Members usually return books within three to four weeks. Most members know that they have one week of grace before a notice is sent to them, so they try to return books before the grace period ends. About 5 percent of the members have to be sent reminders to return books. Most overdue books are returned within a month of the due date. Approximately 5 percent of the overdue books are either kept or never returned. The most active members of the library are defined as those who borrow books at least ten times during the year. The top 1 percent of membership does 15 percent of the borrowing, and the top 10 percent of the membership does 40 percent of the borrowing. About 20 percent of the members are totally inactive in that they are members who never borrow.

To become a member of the library, applicants fill out a form including their SSN, campus and home mailing addresses, and phone numbers. The librarians issue a numbered, machine-readable card with the member's photo on it. This card is good for four years. A month before a card expires, a notice is sent to a member for renewal. Professors at the institute are considered automatic members. When a new faculty member joins the institute, his or her information is pulled from the employee records and a library card is mailed to his or her campus address. Professors are allowed to check out books for three-month intervals and have a two-week grace period. Renewal notices to professors are sent to their campus address.

The library does not lend some books, such as reference books, rare books, and maps. The librarians must differentiate between books that can be lent and those that cannot be lent. In addition, the librarians have a list of some books they are interested in acquiring but cannot obtain, such as rare or out-of-print books and books that were lost or destroyed but have not been replaced. Some books may have the same title; therefore, the title cannot be used as a means of identification. Every book is identified by its International Standard Book Number (ISBN), a unique international code assigned to all books. Two books with the same title can have different ISBNs if they are in different languages or have different bindings (hardcover or softcover). Editions of the same book have different ISBNs.

The proposed database system must be designed to keep track of the members, the books, the catalog, and the borrowing activity.

7.47. Design a database to keep track of information for an art museum. Assume that the following requirements were collected:

- The museum has a collection of ART_OBJECTS. Each ART_OBJECT has a unique Id_no, an Artist (if known), a Year (when it was created, if known), a Title, and a Description. The art objects are categorized in several ways, as discussed in the following requirements.

- ART_OBJECTS are categorized based on their type. There are three main types: PAINTING, SCULPTURE, and STATUE, plus another type called OTHER to accommodate objects that do not fall into one of the three main types.
- A PAINTING has a Paint_type (oil, watercolor, etc.), material on which it is Drawn_on (paper, canvas, wood, etc.), and Style (modern, abstract, etc.).
- A SCULPTURE or a statue has a Material from which it was created (wood, stone, etc.), Height, Weight, and Style.
- An art object in the OTHER category has a Type (print, photo, etc.) and Style.
- ART_OBJECTs are categorized as either PERMANENT_COLLECTION (objects that are owned by the museum) and BORROWED. Information captured about objects in the PERMANENT_COLLECTION includes Date_acquired, Status (on display, on loan, or stored), and Cost. Information captured about BORROWED objects includes the Collection from which it was borrowed, Date_borrowed, and Date_returned.
- Information describing the country or culture of Origin (Italian, Egyptian, American, Indian, and so forth) and Epoch (Renaissance, Modern, Ancient, and so forth) is captured for each ART_OBJECT.
- The museum keeps track of ARTIST information, if known: Name, DateBorn (if known), Date_died (if not living), Country_of_origin, Epoch, Main_style, and Description. The Name is assumed to be unique.
- Different EXHIBITIONS occur, each having a Name, Start_date, and End_date. EXHIBITIONS are related to all the art objects that were on display during the exhibition.
- Information is kept on other COLLECTIONS with which the museum interacts, including Name (unique), Type (museum, personal, etc.), Description, Address, Phone, and current Contact_person.

Draw an EER schema diagram for this application. Discuss any assumptions you make, and that justify your EER design choices.

7.48. Consider the entity sets and attributes shown in the table on the next page. Place a checkmark in one column in each row to indicate the relationship between the far left and right columns.

a. The left side has a relationship with the right side.

b. The right side is an attribute of the left side.

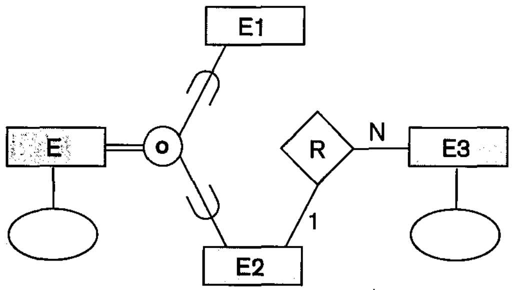
c. The left side is a specialization of the right side.

d. The left side is a generalization of the right side.

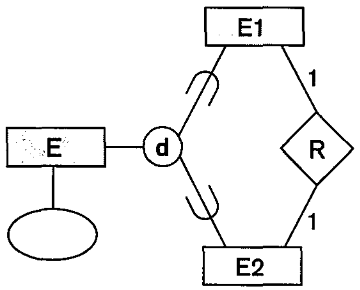
	Entity Set	(a) Has a Relationship with	(b) Has an Attribute that Is	(c) Is a Specialization of	(d) Is a Generalization of	Entity Set or Attribute
1.	MOTHER					PERSON
2.	DAUGHTER					MOTHER
3.	STUDENT					PERSON
4.	STUDENT					Student_id
5.	SCHOOL					STUDENT
6.	SCHOOL					CLASS_ROOM
7.	ANIMAL					HORSE
8.	HORSE					Breed
9.	HORSE					Age
10.	EMPLOYEE					SSN
11.	FURNITURE					CHAIR
12.	CHAIR					Weight
13.	HUMAN					WOMAN
14.	SOLDIER					PERSON
15.	ENEMY_COMBATANT					PERSON

7.49. Which of the following EER diagrams is/are incorrect and why? State clearly any assumptions you make.

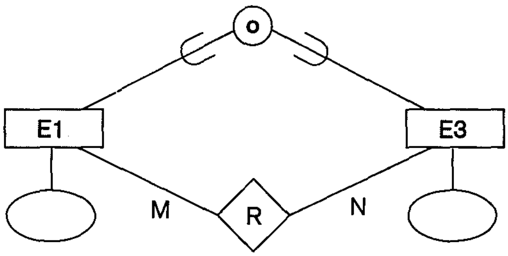
a.



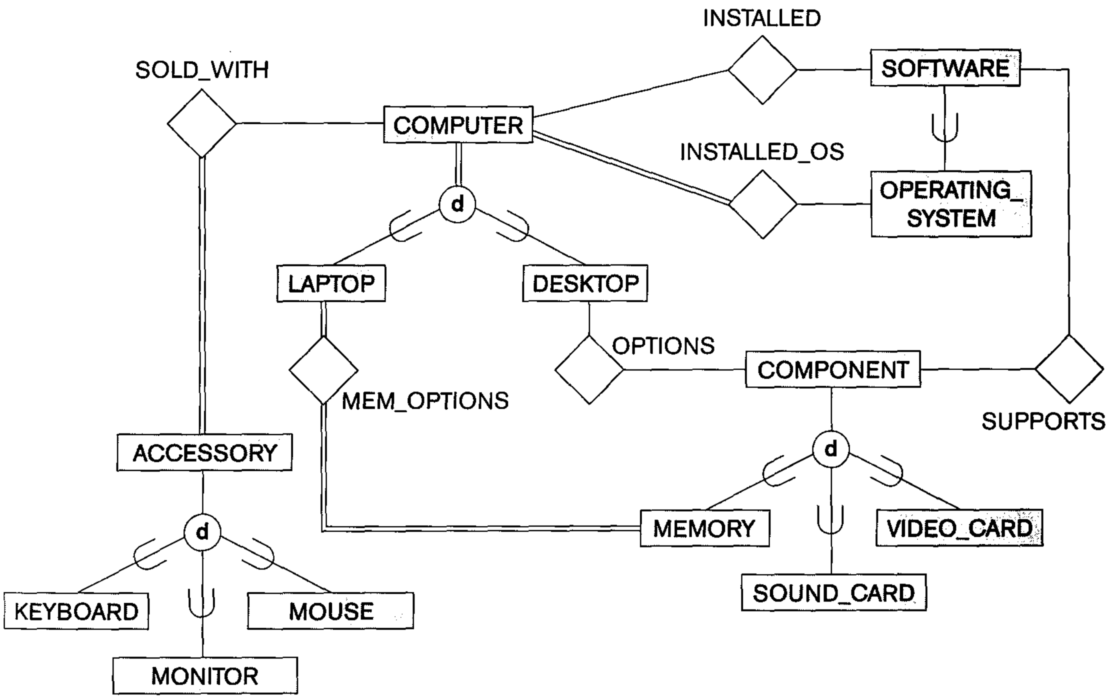
b.



c.



7.50. Consider the following EER diagram that describes the computer systems at a company. Provide your own attributes and key for each entity type. Supply max cardinality constraints justifying your choice. Write a complete narrative description of what this EER diagram represents.



Laboratory Exercises

7.51. Consider the UNIVERSITY database described in Exercise 7.29. Build the ER schema for this database using a data modeling tool such as ERwin or Rational Rose.

7.52. Consider a MAIL_ORDER database in which employees take orders for parts from customers. The data requirements are summarized as follows:

- The mail order company has employees, each identified by a unique employee number, first and last name, and ZIP Code.
- Each customer of the company is identified by a unique customer number, first and last name, and ZIP Code.
- Each part sold by the company is identified by a unique part number, a part name, price, and quantity in stock.
- Each order placed by a customer is taken by an employee and is given a unique order number. Each order contains specified quantities of one or more parts. Each order has a date of receipt as well as an expected ship date. The actual ship date is also recorded.

Design an Entity-Relationship diagram for the mail order database and build the design using a data modeling tool such as ERwin or Rational Rose.

7.53. Consider a MOVIE database in which data is recorded about the movie industry. The data requirements are summarized as follows:

- Each movie is identified by title and year of release. Each movie has a length in minutes. Each has a production company, and each is classified under one or more genres (such as horror, action, drama, and so forth). Each movie has one or more directors and one or more actors appear in it. Each movie also has a plot outline. Finally, each movie has zero or more quotable quotes, each of which is spoken by a particular actor appearing in the movie.
- Actors are identified by name and date of birth and appear in one or more movies. Each actor has a role in the movie.
- Directors are also identified by name and date of birth and direct one or more movies. It is possible for a director to act in a movie (including one that he or she may also direct).
- Production companies are identified by name and each has an address. A production company produces one or more movies.

Design an Entity-Relationship diagram for the movie database and enter the design using a data modeling tool such as ERwin or Rational Rose.

7.54. Consider a CONFERENCE_REVIEW database in which researchers submit their research papers for consideration. Reviews by reviewers are recorded for use in the paper selection process. The database system caters primarily to reviewers who record answers to evaluation questions for each paper they review and make recommendations regarding whether to accept or reject the paper. The data requirements are summarized as follows:

- Authors of papers are uniquely identified by e-mail id. First and last names are also recorded.
- Each paper is assigned a unique identifier by the system and is described by a title, abstract, and the name of the electronic file containing the paper.

- A paper may have multiple authors, but one of the authors is designated as the contact author.
- Reviewers of papers are uniquely identified by e-mail address. Each reviewer's first name, last name, phone number, affiliation, and topics of interest are also recorded.
- Each paper is assigned between two and four reviewers. A reviewer rates each paper assigned to him or her on a scale of 1 to 10 in four categories: technical merit, readability, originality, and relevance to the conference. Finally, each reviewer provides an overall recommendation regarding each paper.
- Each review contains two types of written comments: one to be seen by the review committee only and the other as feedback to the author(s).

Design an Entity-Relationship diagram for the CONFERENCE_REVIEW database and build the design using a data modeling tool such as ERwin or Rational Rose.

7.55. Consider the ER diagram for the AIRLINE database shown in Figure 7.29. Build this design using a data modeling tool such as ERwin or Rational Rose.

7.56. Consider a GRADE_BOOK database in which instructors within an academic department record points earned by individual students in their classes. The data requirements are summarized as follows:

- Each student is identified by a unique identifier, first and last name, and an e-mail address.
- Each instructor teaches certain courses each term. Each course is identified by a course number, a section number, and the term in which it is taught. For each course he or she teaches, the instructor specifies the minimum number of points required in order to earn letter grades A, B, C, D, and F. For example, 90 points for an A, 80 points for a B, 70 points for a C, and so forth.
- Students are enrolled in each course taught by the instructor.
- Each course has a number of grading components (such as midterm exam, final exam, project, and so forth). Each grading component has a maximum number of points (such as 100 or 50) and a weight (such as 20% or 10%). The weights of all the grading components of a course usually total 100.
- Finally, the instructor records the points earned by each student in each of the grading components in each of the courses. For example, student 1234 earns 84 points for the midterm exam grading component of the section 2 course CSc2310 in the fall term of 2009. The midterm exam grading component may have been defined to have a maximum of 100 points and a weight of 20% of the course grade.

Design an Enhanced Entity-Relationship diagram for the grade book database and build the design using a data modeling tool such as ERwin or Rational Rose.

7.57. Consider an ONLINE_AUCTION database system in which members (buyers and sellers) participate in the sale of items. The data requirements for this system are summarized as follows:

- The online site has members, each of whom is identified by a unique member number and is described by an e-mail address, name, password, home address, and phone number.
- A member may be a buyer or a seller. A buyer has a shipping address recorded in the database. A seller has a bank account number and routing number recorded in the database.
- Items are placed by a seller for sale and are identified by a unique item number assigned by the system. Items are also described by an item title, a description, starting bid price, bidding increment, the start date of the auction, and the end date of the auction.
- Items are also categorized based on a fixed classification hierarchy (for example, a modem may be classified as COMPUTER→HARDWARE →MODEM).
- Buyers make bids for items they are interested in. Bid price and time of bid is recorded. The bidder at the end of the auction with the highest bid price is declared the winner and a transaction between buyer and seller may then proceed.
- The buyer and seller may record feedback regarding their completed transactions. Feedback contains a rating of the other party participating in the transaction (1–10) and a comment.

Design an Enhanced Entity-Relationship diagram for the ONLINE_AUCTION database and build the design using a data modeling tool such as ERwin or Rational Rose.

7.58. Consider a database system for a baseball organization such as the major leagues. The data requirements are summarized as follows:

- The personnel involved in the league include players, coaches, managers, and umpires. Each is identified by a unique personnel id. They are also described by their first and last names along with the date and place of birth.
- Players are further described by other attributes such as their batting orientation (left, right, or switch) and have a lifetime batting average (BA).
- Within the players group is a subset of players called pitchers. Pitchers have a lifetime ERA (earned run average) associated with them.
- Teams are uniquely identified by their names. Teams are also described by the city in which they are located and the division and league in which they play (such as Central division of the American League).
- Teams have one manager, a number of coaches, and a number of players.
- Games are played between two teams with one designated as the home team and the other the visiting team on a particular date. The score (runs,

hits, and errors) are recorded for each team. The team with the most runs is declared the winner of the game.

- With each finished game, a winning pitcher and a losing pitcher are recorded. In case there is a save awarded, the save pitcher is also recorded.
- With each finished game, the number of hits (singles, doubles, triples, and home runs) obtained by each player is also recorded.

Design an Enhanced Entity-Relationship diagram for the BASEBALL database and enter the design using a data modeling tool such as ERwin or Rational Rose.

7.59. Consider the EER diagram for the UNIVERSITY database shown in Figure 7.27. Enter this design using a data modeling tool such as ERwin or Rational Rose. Make a list of the differences in notation between the diagram in the text and the corresponding equivalent diagrammatic notation you end up using with the tool.

7.60. Consider the UNIVERSITY database described in Exercise 7.29. You already developed an ER schema for this database using a data modeling tool such as ERwin or Rational Rose in Lab Exercise 7.51. Modify this diagram by classifying COURSES as either UNDERGRAD_COURSES or GRAD_COURSES and INSTRUCTORS as either JUNIOR_PROFESSORS or SENIOR_PROFESSORS. Include appropriate attributes for these new entity types. Then establish relationships indicating that junior instructors teach undergraduate courses while senior instructors teach graduate courses.

Selected Bibliography

The Entity-Relationship model was introduced by Chen (1976), and related work appears in Schmidt and Swenson (1975), Wiederhold and Elmasri (1979), and Senko (1975). Since then, numerous modifications to the ER model have been suggested. We have incorporated some of these in our presentation. Structural constraints on relationships are discussed in Abrial (1974), Elmasri and Wiederhold (1980), and Lenzerini and Santucci (1983). Multivalued and composite attributes are incorporated in the ER model in Elmasri et al. (1985). Although we did not discuss languages for the ER model and its extensions, there have been several proposals for such languages. Elmasri and Wiederhold (1981) proposed the GORDAS query language for the ER model. Another ER query language was proposed by Markowitz and Raz (1983). Senko (1980) presented a query language for Senko's DIAM model. A formal set of operations called the ER algebra was presented by Parent and Spaccapietra (1985). Gogolla and Hohenstein (1991) presented another formal language for the ER model. Campbell et al. (1985) presented a set of ER operations and showed that they are relationally complete.

A conference for the dissemination of research results related to the ER model has been held regularly since 1979. The conference, now known as the International Conference on Conceptual Modeling, has been held in Los Angeles (ER 1979, ER

1983, ER 1997), Washington, D.C. (ER 1981), Chicago (ER 1985), Dijon, France (ER 1986), New York City (ER 1987), Rome (ER 1988), Toronto (ER 1989), Lausanne, Switzerland (ER 1990), San Mateo, California (ER 1991), Karlsruhe, Germany (ER 1992), Arlington, Texas (ER 1993), Manchester, England (ER 1994), Brisbane, Australia (ER 1995), Cottbus, Germany (ER 1996), Singapore (ER 1998), Paris, France (ER 1999), Salt Lake City, Utah (ER 2000), Yokohama, Japan (ER 2001), Tampere, Finland (ER 2002), Chicago, Illinois (ER 2003), Shanghai, China (ER 2004), Klagenfurt, Austria (ER 2005), Tucson, Arizona (ER 2006), Auckland, New Zealand (ER 2007), Barcelona, Catalonia, Spain (ER 2008), and Gramado, RS, Brazil (ER 2009). The 2010 conference is to be held in Vancouver, BC, Canada.

Many papers have proposed conceptual or semantic data models. We give a representative list here. One group of papers, including Abrial (1974), Senko's DIAM model (1975), the NIAM method (Verheijen and VanBekkum 1982), and Bracchi et al. (1976), presents semantic models that are based on the concept of binary relationships. Another group of early papers discusses methods for extending the relational model to enhance its modeling capabilities. This includes the papers by Schmid and Swenson (1975), Navathe and Schkolnick (1978), Codd's RM/T model (1979), Furtado (1978), and the structural model of Wiederhold and Elmasri (1979).

The ER model was proposed originally by Chen (1976) and is formalized in Ng (1981). Since then, numerous extensions of its modeling capabilities have been proposed, as in Scheuermann et al. (1979), Dos Santos et al. (1979), Teorey et al. (1986), Gogolla and Hohenstein (1991), and the Entity-Category-Relationship (ECR) model of Elmasri et al. (1985). Smith and Smith (1977) present the concepts of generalization and aggregation. The semantic data model of Hammer and McLeod (1981) introduced the concepts of class/subclass lattices, as well as other advanced modeling concepts.

A survey of semantic data modeling appears in Hull and King (1987). Eick (1991) discusses design and transformations of conceptual schemas. Analysis of constraints for *n*-ary relationships is given in Soutou (1998).

Fensel (2000, 2003) discuss the Semantic Web and application of ontologies. Uschold and Gruninger (1996) and Gruber (1995) discuss ontologies. The June 2002 issue of *Communications of the ACM* is devoted to ontology concepts and applications. Fensel (2003) is a book that discusses ontologies and e-commerce.