

## Data Modeling Using the Entity-Relationship (ER) Model

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*<sup>1</sup>—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 Section 7.8, and briefly compare these to ER notation and concepts. Additional UML notation and concepts are presented in Section 8.6 and in Chapter 10.

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, 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 introduces some UML class diagram concepts, compares them to ER model concepts, and applies them to the same database example. Section 7.9 discusses more complex types of relationships. Section 7.10 summarizes the chapter.

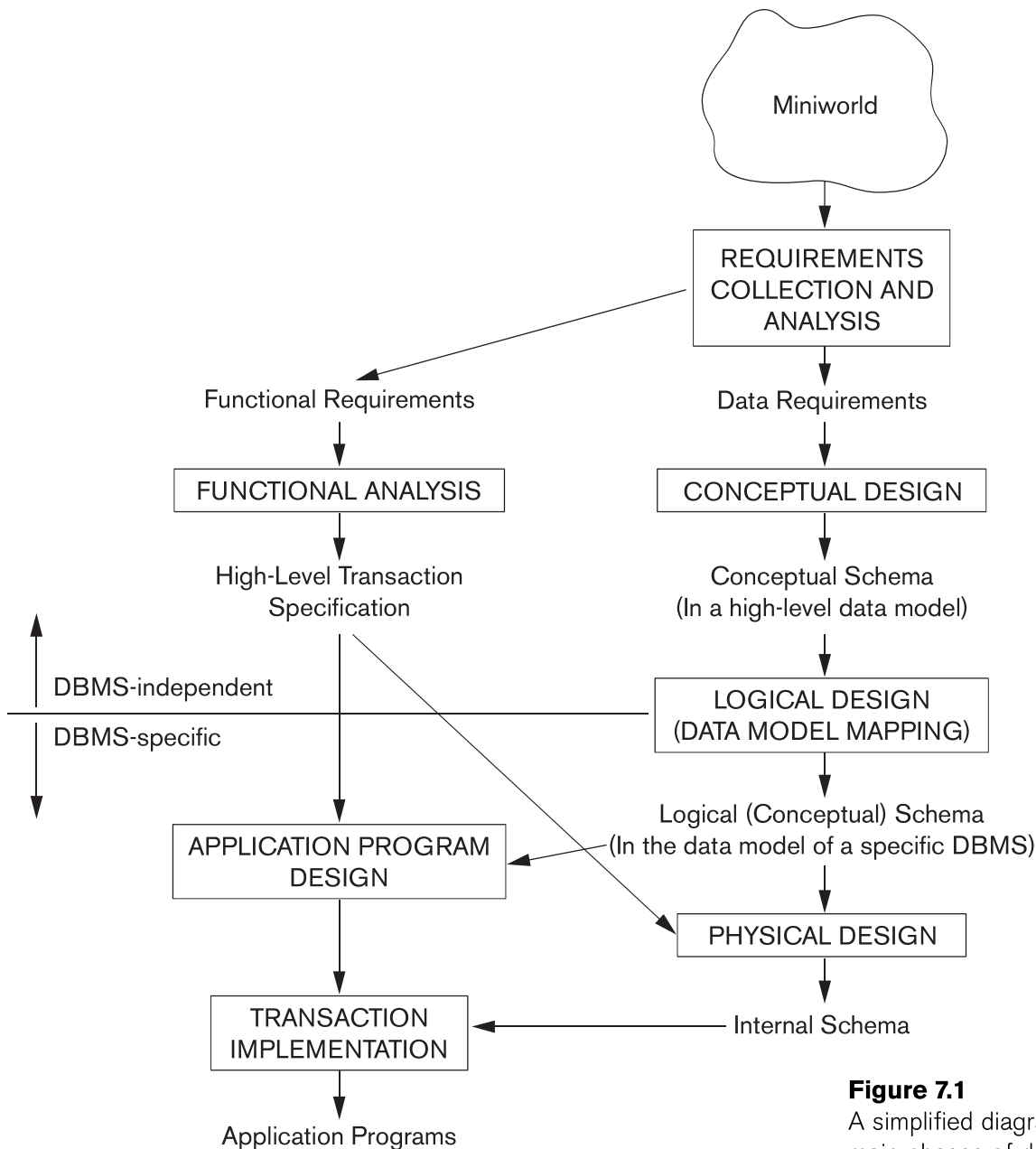
The material in Sections 7.8 and 7.9 may be excluded from an introductory course. If a more thorough coverage of data modeling concepts and conceptual database design is desired, the reader should continue to Chapter 8, where we describe extensions to the ER model that lead to the Enhanced-ER (EER) model, which includes concepts such as specialization, generalization, inheritance, and union types (categories). We also introduce some additional UML concepts and notation in Chapter 8.

## 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

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<sup>1</sup>A **class** is similar to an *entity type* in many ways.

**Figure 7.1**

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

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 10.

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 easier to create a good conceptual 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 10.

We present only the basic ER model concepts for conceptual schema design in this chapter. Additional modeling concepts are discussed in Chapter 8, 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,<sup>2</sup> 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.

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

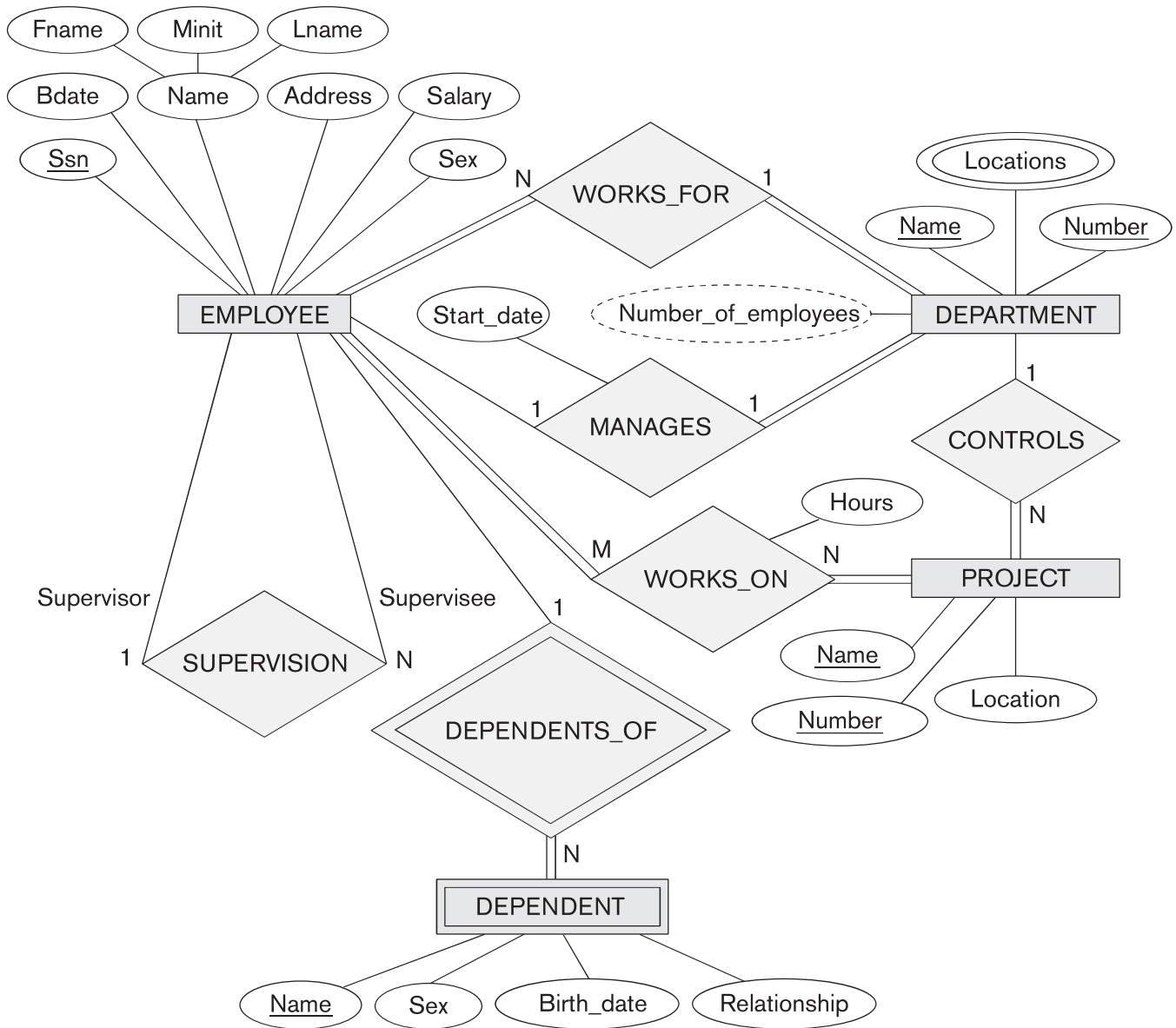
The ER model describes data as *entities*, *relationships*, and *attributes*. In Section 7.3.1 we introduce the concepts of entities and their attributes. We discuss entity types and key attributes in Section 7.3.2. Then, in Section 7.3.3, we specify the initial conceptual design of the entity types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

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<sup>2</sup>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.

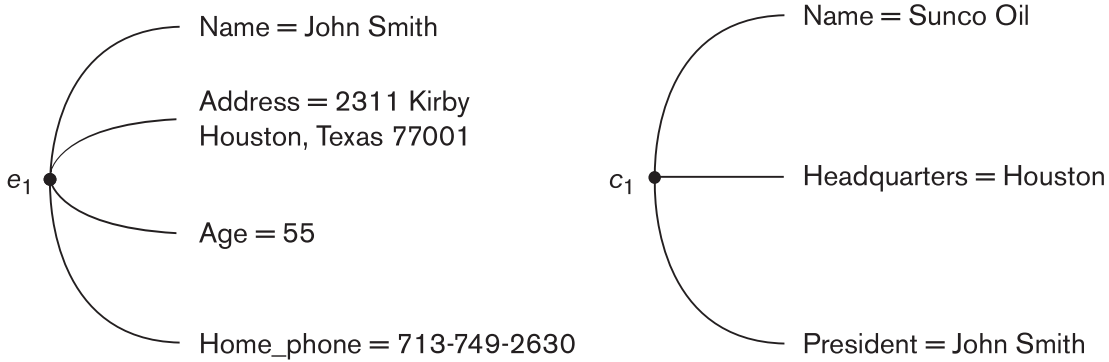


**Figure 7.2** An ER schema diagram for the COMPANY database. The diagrammatic notation is introduced gradually throughout this chapter and is summarized in Figure 7.14.

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

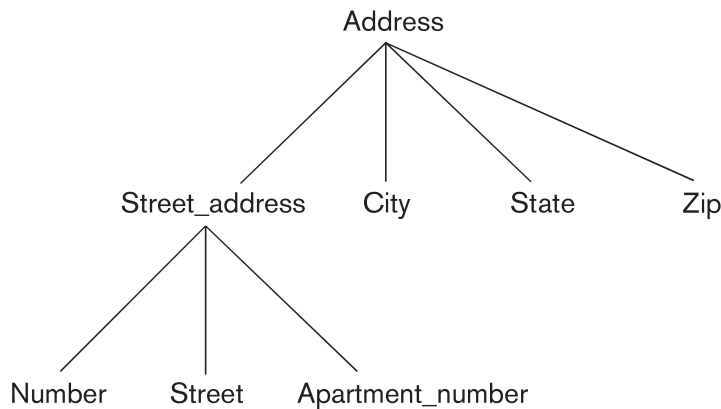


**Figure 7.3**  
Two entities, EMPLOYEE  $e_1$ , and COMPANY  $c_1$ , and their attributes.

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,<sup>3</sup> 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; 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



**Figure 7.4**  
A hierarchy of composite attributes.

<sup>3</sup>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 the five-digit Zip in our examples.

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 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 com-

ponents 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.<sup>4</sup> Both Phone and Address are themselves composite attributes.

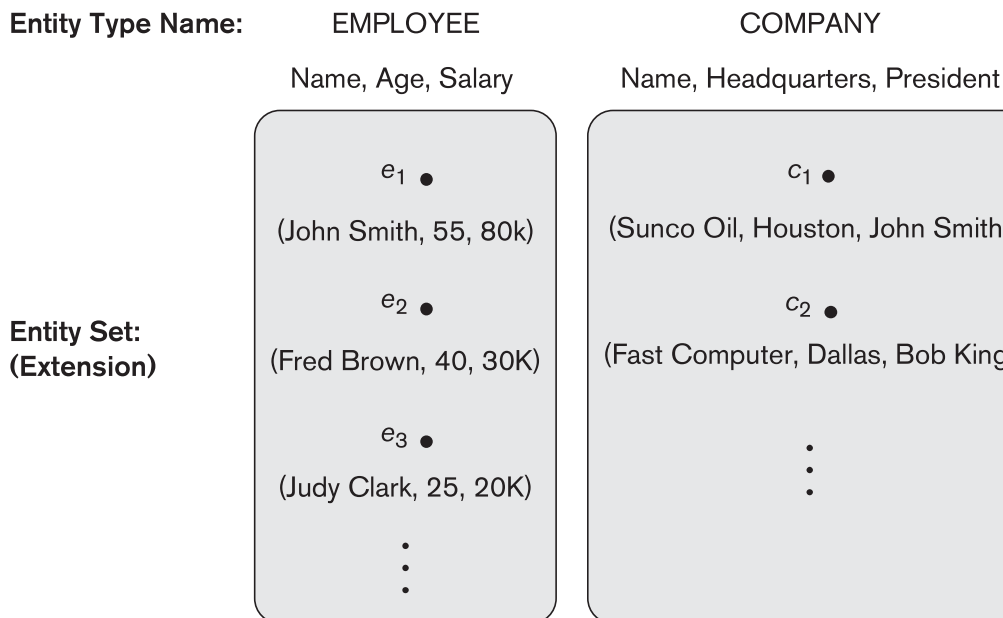
### 7.3.2 Entity Types, Entity Sets, Keys, and Value Sets

**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 two entity types: EMPLOYEE and COMPANY, and a list of some of the attributes for

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{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.



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

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<sup>4</sup>For those familiar with XML, we should note that complex attributes are similar to complex elements in XML (see Chapter 12).

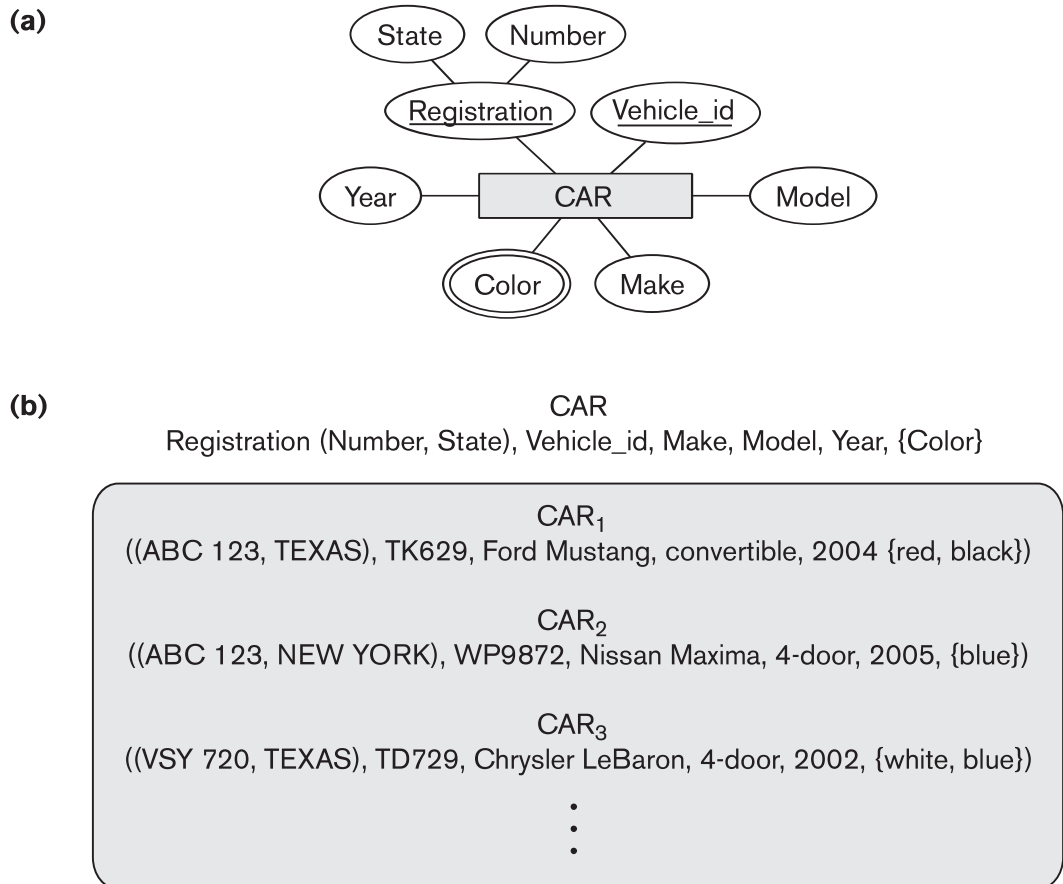
each. A few individual entities of each type are also illustrated, along with the values of their attributes. The collection of all entities of a particular entity type in the database at any point in time is called an **entity set**; the entity set is usually referred to using the same name as the entity 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<sup>5</sup> (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

**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.



<sup>5</sup>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 later in this chapter when we present UML class diagrams and in Appendix A.

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 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 9).

**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<sup>6</sup>  $P(V)$  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.<sup>7</sup> For a composite attribute  $A$ , the value set  $V$  is the power set of the Cartesian product of  $P(V_1), P(V_2), \dots, P(V_n)$ , where  $V_1, V_2, \dots, V_n$  are the value sets of the simple component attributes that form  $A$ :

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

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

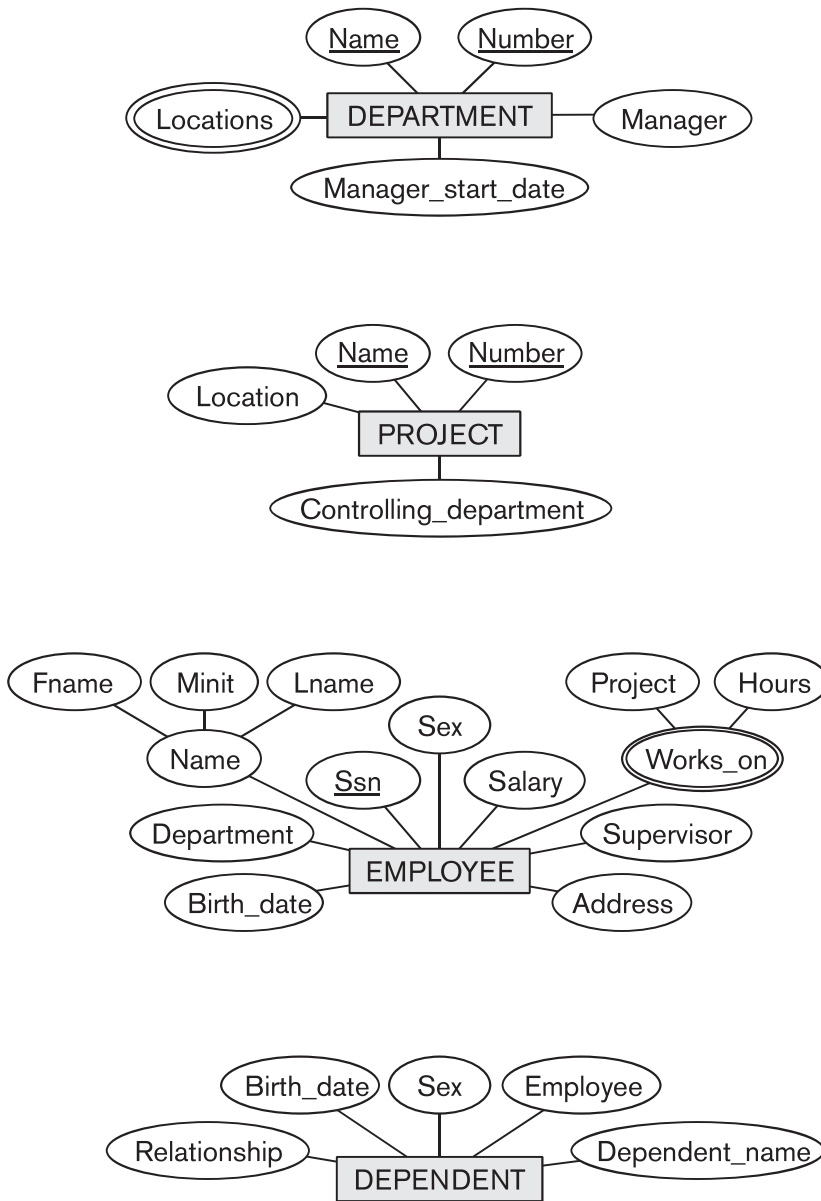
We can now define the entity types for the COMPANY database, based on the requirements described in Section 7.2. After defining several entity types and their attributes here, we refine our design in Section 7.4 after we introduce the concept of a relationship. According to the requirements listed in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

<sup>6</sup>The **power set**  $P(V)$  of a set  $V$  is the set of all subsets of  $V$ .

<sup>7</sup>A **singleton** set is a set with only one element (value).



**Figure 7.8**

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

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

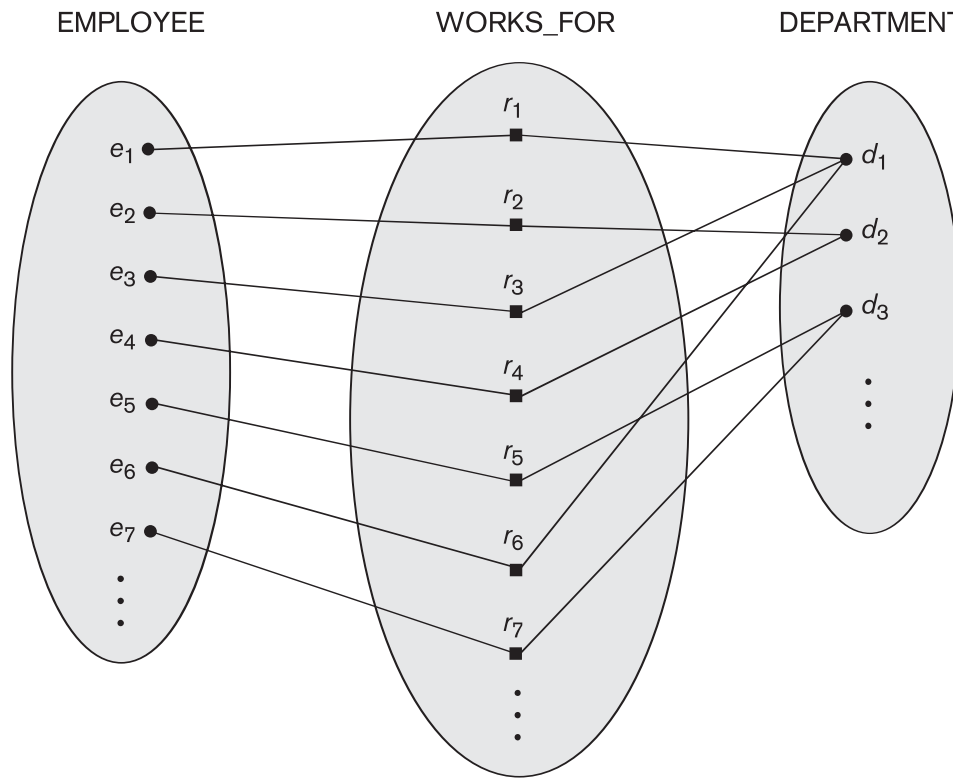
In Figure 7.8 there are several *implicit relationships* among the various entity types. In fact, whenever an attribute of one entity type refers to another entity type, some relationship exists. For example, the attribute `Manager` of `DEPARTMENT` refers to an employee who manages the department; the 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  $E_1, E_2, \dots, E_n$  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**  $r_j$ , where each  $r_j$  associates  $n$  individual entities  $(e_1, e_2, \dots, e_n)$ , and each entity  $e_j$  in  $r_j$  is a member of entity set  $E_j$ ,  $1 \leq j \leq n$ . Hence, a relationship set is a mathematical relation on  $E_1, E_2, \dots, E_n$ ; alternatively, it can be defined as a subset of the Cartesian product of the entity sets  $E_1 \times E_2 \times \dots \times E_n$ . Each of the entity types  $E_1, E_2, \dots, E_n$  is said to participate in the relationship type  $R$ ; similarly, each of the individual entities  $e_1, e_2, \dots, e_n$  is said to **participate** in the relationship instance  $r_j = (e_1, e_2, \dots, e_n)$ .

Informally, each relationship instance  $r_j$  in  $R$  is an association of entities, where the association includes exactly one entity from each participating entity type. Each such relationship instance  $r_j$  represents the fact that the entities participating in  $r_j$  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

**Figure 7.9**

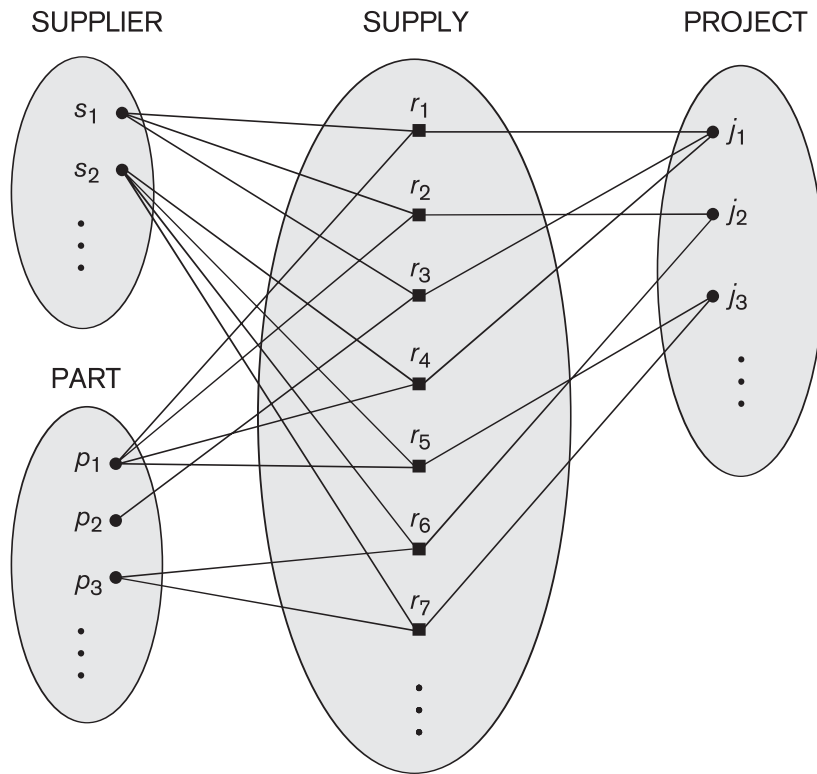
Some instances in the WORKS\_FOR relationship set, which represents a relationship type WORKS\_FOR between EMPLOYEE and DEPARTMENT.

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 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 7.9.



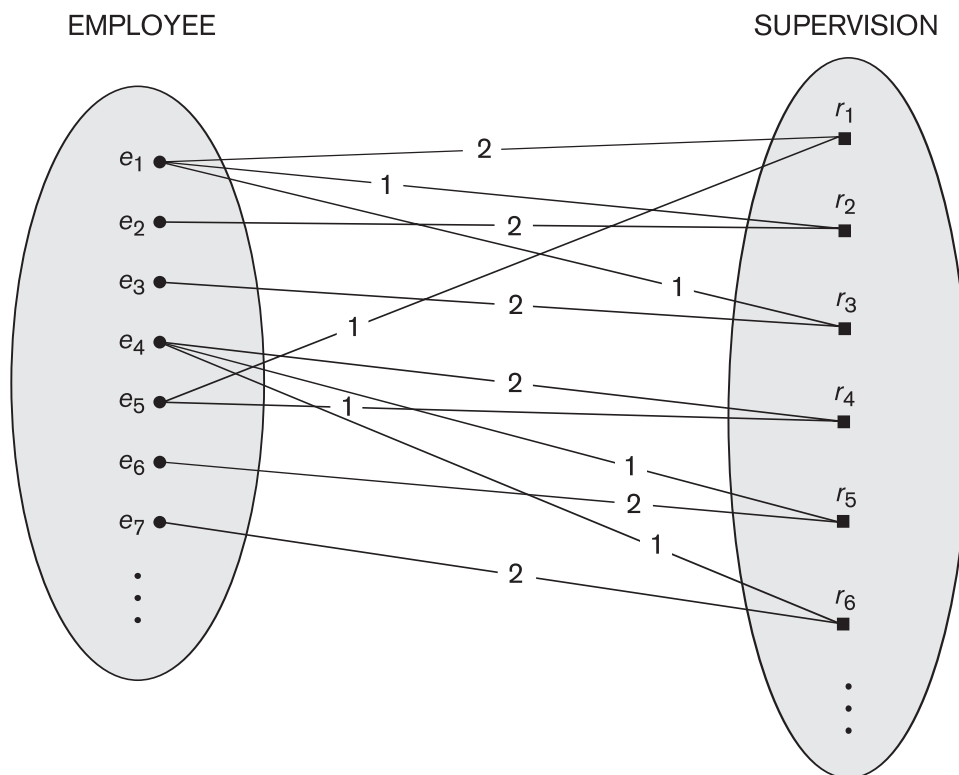
**Figure 7.10**  
Some relationship instances in the SUPPLY ternary relationship set.

**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 7.8 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.<sup>8</sup>

<sup>8</sup>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 11), 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.

**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).



**Figure 7.11**

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

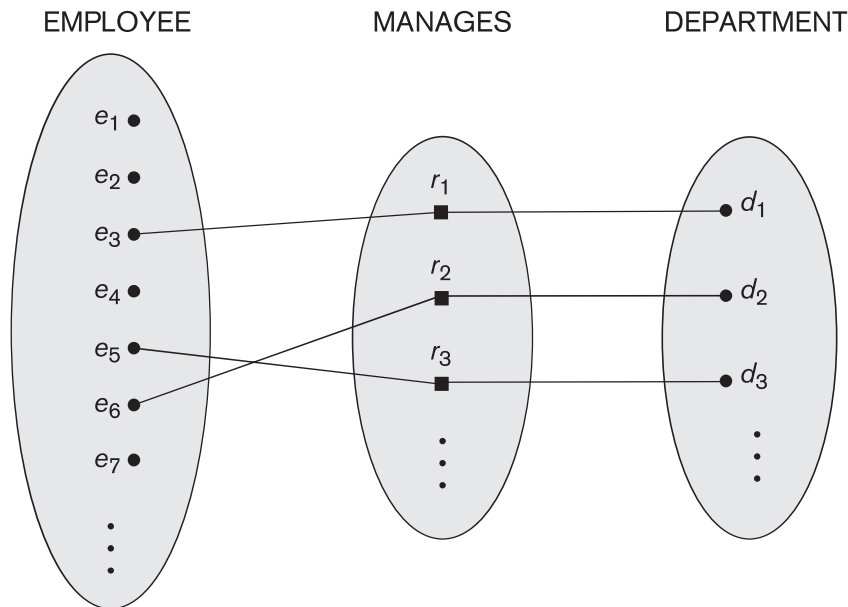
### 7.4.3 Constraints on Binary Relationship Types

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

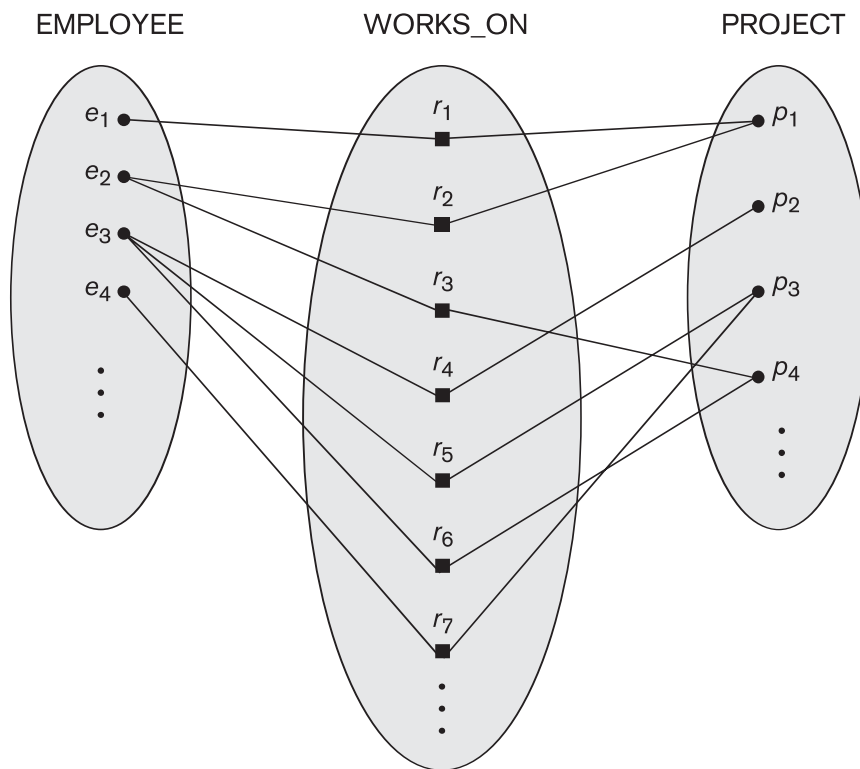
**Cardinality Ratios for Binary Relationships.** The **cardinality ratio** for a binary relationship specifies the *maximum* number of relationship instances that an entity can participate in. For example, in the WORKS\_FOR binary relationship type, DEPARTMENT:EMPLOYEE is of cardinality ratio 1:N, meaning that each department can be related to (that is, employs) any number of employees,<sup>9</sup> 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 mini-

**Figure 7.12**  
A 1:1 relationship,  
MANAGES.



<sup>9</sup>N stands for *any number* of related entities (zero or more).



**Figure 7.13**  
An M:N relationship,  
WORKS\_ON.

world rule is that an employee can work on several projects and a project can have several employees.

Cardinality ratios for binary relationships are represented on 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.

**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 7.9.

#### 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**,<sup>10</sup> and we call the relationship type that relates a weak entity type to its owner the **identifying relationship** of the weak entity type.<sup>11</sup> 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 that are 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*.<sup>12</sup> In our 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

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<sup>10</sup>The identifying entity type is also sometimes called the **parent entity type** or the **dominant entity type**.

<sup>11</sup>The weak entity type is also sometimes called the **child entity type** or the **subordinate entity type**.

<sup>12</sup>The partial key is sometimes called the **discriminator**.

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 7.9.

## 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.<sup>13</sup> 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.
- 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

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<sup>13</sup>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.

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

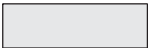

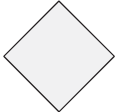
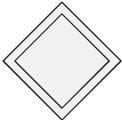


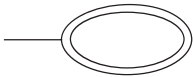
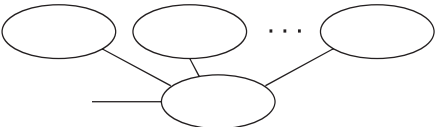

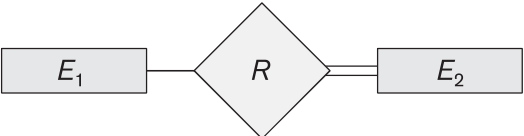
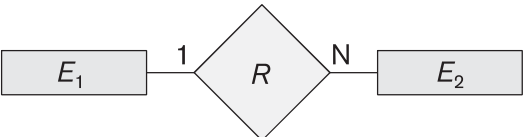
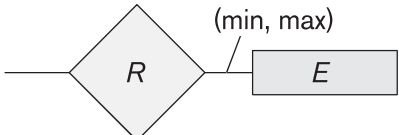
When designing a database schema, the choice of names for entity types, attributes, relationship types, and (particularly) roles is not always straightforward. One should choose names that convey, as much as possible, the meanings attached to the different constructs in the schema. We choose to use *singular 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 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

Symbol	Meaning
	Entity
	Weak Entity
	Relationship
	Identifying Relationship
	Attribute
	Key Attribute
	Multivalued Attribute
	Composite Attribute
	Derived Attribute
	Total Participation of $E_2$ in $R$
	Cardinality Ratio 1: N for $E_1:E_2$ in $R$
	Structural Constraint (min, max) on Participation of $E$ in $R$

**Figure 7.14**

Summary of the notation for ER diagrams.

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 7.9 discusses choices concerning the degree of a relationship. In Chapter 8, we discuss other refinements concerning specialization/generalization. Chapter 10 discusses additional top-down and bottom-up refinements that are common in large-scale conceptual schema design.

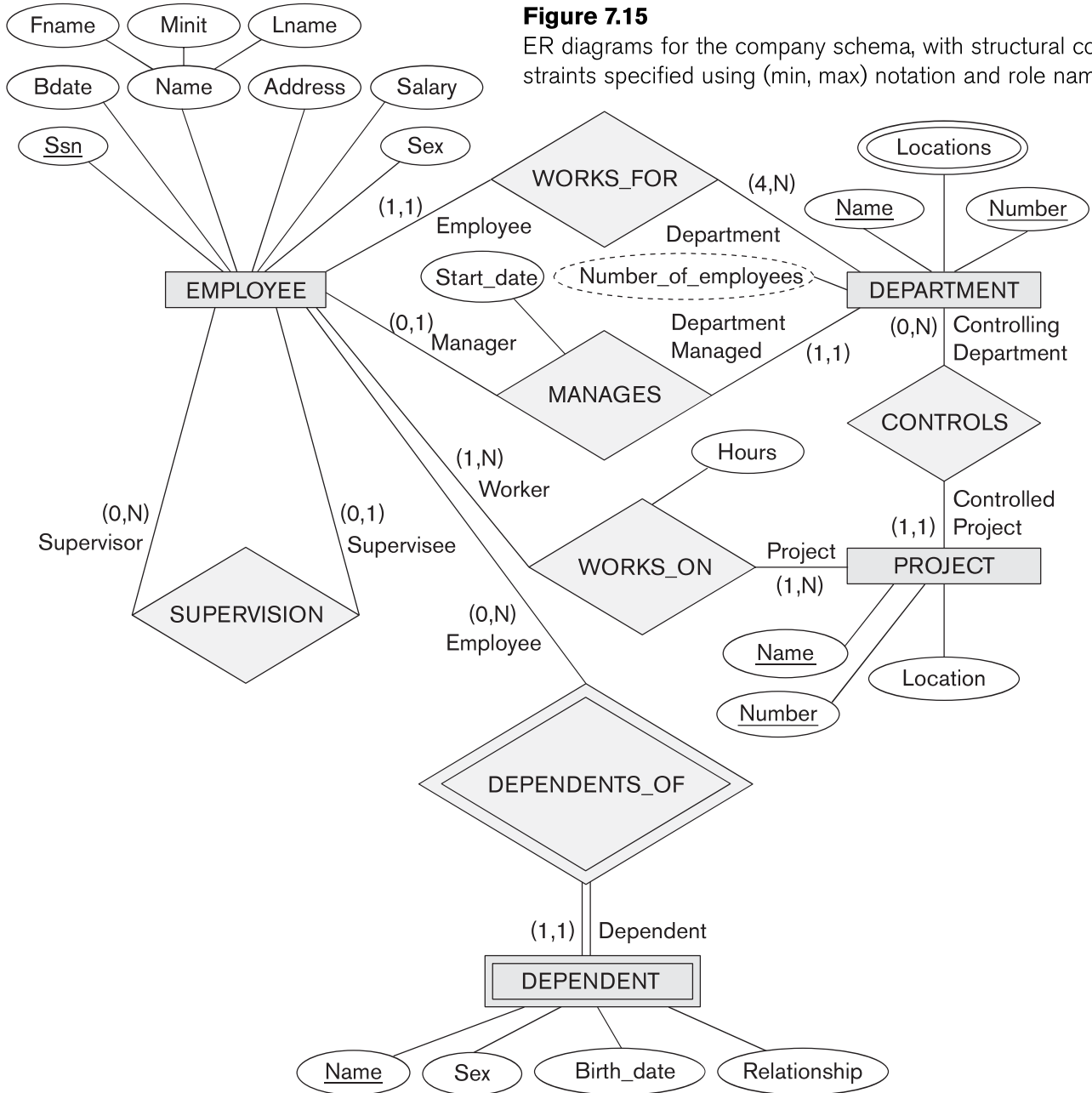
### 7.7.4 Alternative Notations for ER Diagrams

There are many alternative diagrammatic notations for displaying ER diagrams. Appendix A gives some of the more popular notations. In Section 7.8, 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  $0 \leq \text{min} \leq \text{max}$  and  $\text{max} \geq 1$ . 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.<sup>14</sup> Usually, one uses either the cardinality ratio/single-line/double-line notation *or* the (min, max) notation. The (min, max)



<sup>14</sup>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).

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 7.9.

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

## 7.8 Example of Other Notation: UML Class Diagrams

The UML methodology is being used extensively in software design and has many types of diagrams for various software design purposes. We only briefly present the basics of **UML class diagrams** here, and compare them with ER diagrams. In some ways, class diagrams can be considered as an alternative notation to ER diagrams. Additional UML notation and concepts are presented in Section 8.6, and in Chapter 10. Figure 7.16 shows how the COMPANY ER database schema in Figure 7.15 can be displayed using UML class diagram notation. The *entity types* in Figure 7.15 are modeled as *classes* in Figure 7.16. An *entity* in ER corresponds to an *object* in UML.

**Figure 7.16**  
The COMPANY conceptual schema in UML class diagram notation.

