

- 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.
- The database will store each employee's name, Social Security number,² 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. It is required to keep track of the current number of hours per week that an employee works on each project, as well as the direct supervisor of each employee (who is another employee).
- The database will keep track of the dependents of each employee for insurance purposes, including each dependent's first name, sex, birth date, and relationship to the employee.

Figure 3.2 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.

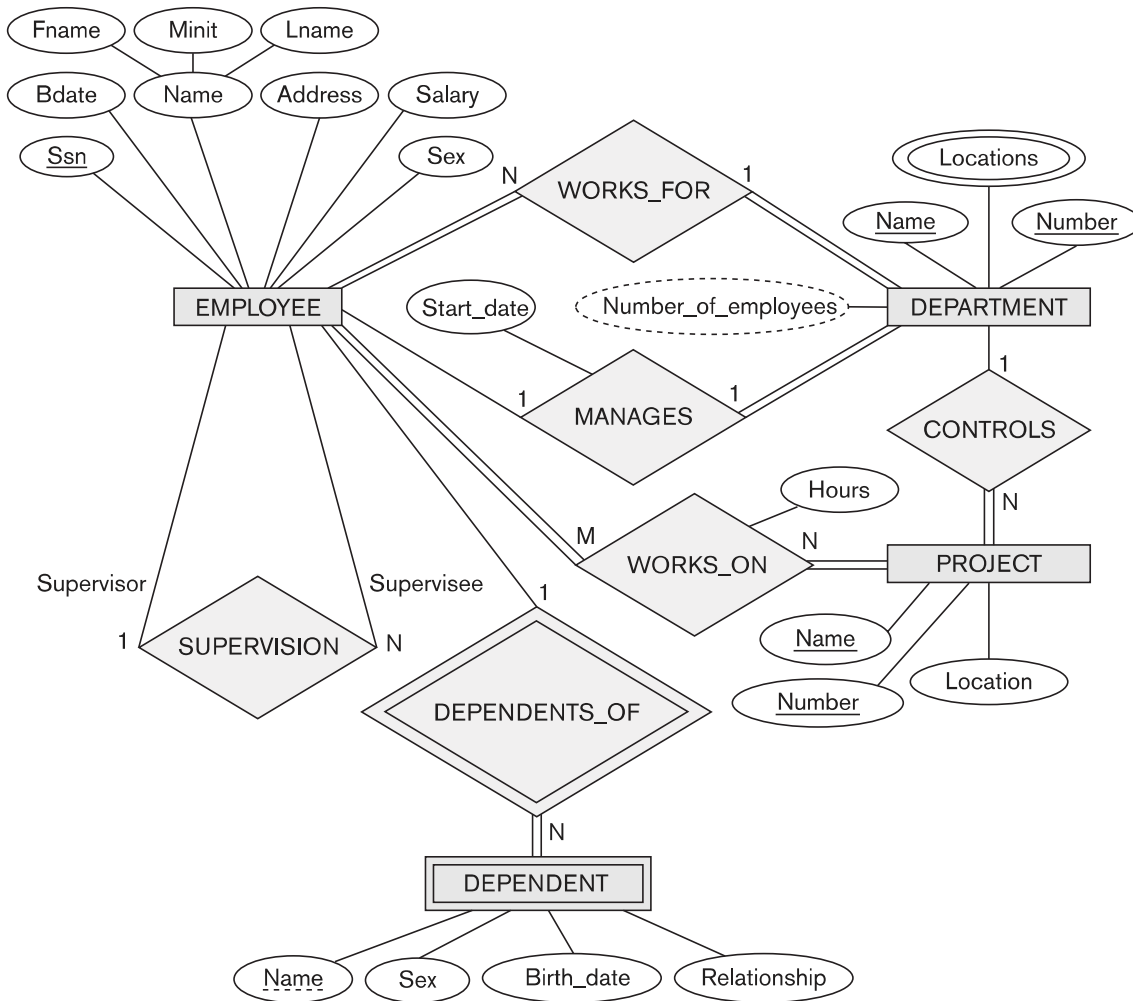
3.3 Entity Types, Entity Sets, Attributes, and Keys

The ER model describes data as *entities*, *relationships*, and *attributes*. In Section 3.3.1 we introduce the concepts of entities and their attributes. We discuss entity types and key attributes in Section 3.3.2. Then, in Section 3.3.3, we specify the initial conceptual design of the entity types for the COMPANY database. We describe relationships in Section 3.4.

3.3.1 Entities and Attributes

Entities and Their Attributes. The basic concept that the ER model represents is an **entity**, which is a *thing* or *object* 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

²The 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 3.2**

An ER schema diagram for the COMPANY database. The diagrammatic notation is introduced gradually throughout this chapter and is summarized in Figure 3.14.

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 3.3 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.

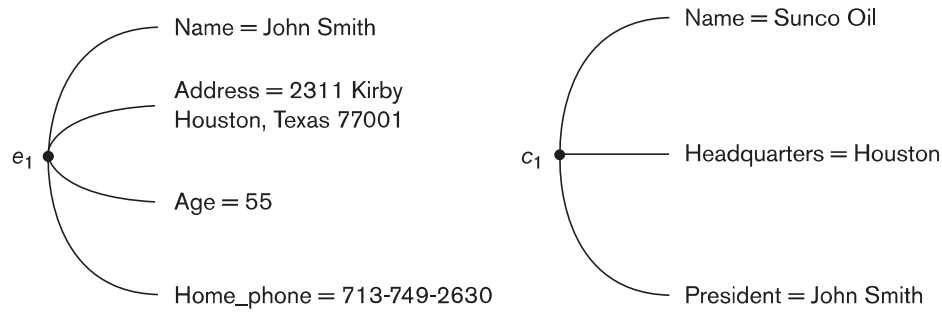


Figure 3.3
Two entities,
EMPLOYEE e_1 , and
COMPANY c_1 , and
their attributes.

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 3.3 can be subdivided into Street_address, City, State, and Zip,³ 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 3.4. 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

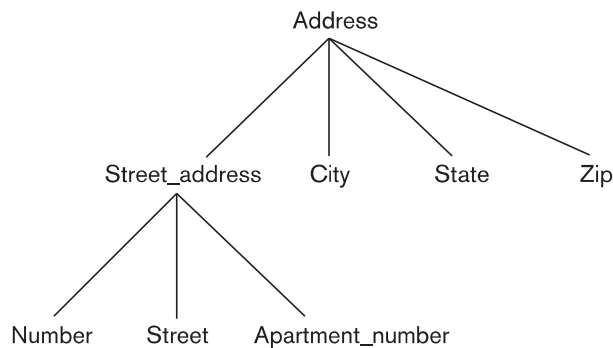


Figure 3.4
A hierarchy of
composite attributes.

³Zip 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.

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 any college degrees, 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 two values, if we assume that a car can have two 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 3.3. 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

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

Figure 3.5
A complex attribute:
Address_phone.

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 3.5.⁴ Both Phone and Address are themselves composite attributes.

3.3.2 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 3.6 shows 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

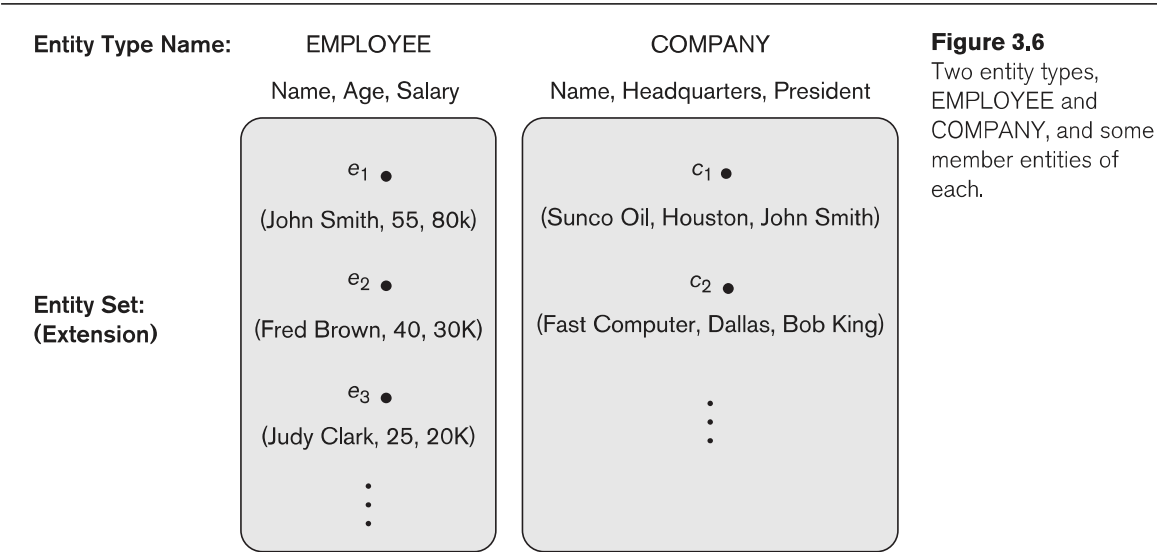


Figure 3.6
Two entity types,
EMPLOYEE and
COMPANY, and some
member entities of
each.

⁴For those familiar with XML, we should note that complex attributes are similar to complex elements in XML (see Chapter 13).

database at any point in time is called an **entity set** or **entity collection**; the entity set is usually referred to using the same name as the entity type, even though they are two separate concepts. For example, EMPLOYEE refers to both a *type of entity* as well as the current collection of *all employee entities* in the database. It is now more common to give separate names to the entity type and entity collection; for example in object and object-relational data models (see Chapter 12).

An entity type is represented in ER diagrams⁵ (see Figure 3.2) 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 3.7(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.

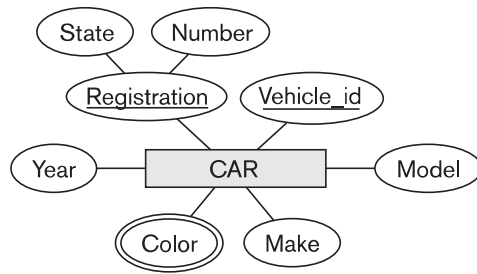
Key Attributes of an Entity Type. An important constraint on the entities of an entity type is the **key** or **uniqueness constraint** on attributes. An entity type usually has one or more attributes whose values are distinct for each individual entity in the entity set. Such an attribute is called 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 3.6 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 3.7(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 3.7) is a key in

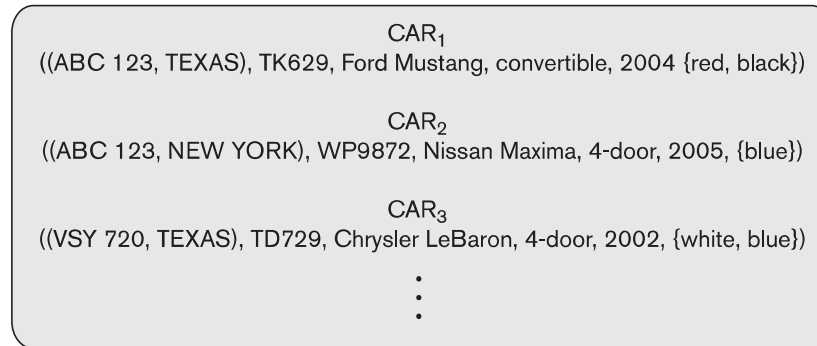
⁵We use a notation for ER diagrams that is close to the original proposed notation (Chen, 1976). Many other notations are in use; we illustrate some of them later in this chapter when we present UML class diagrams, and some additional diagrammatic notations are given in Appendix A.

(a)



(b)

CAR
Registration (Number, State), Vehicle_id, Make, Model, Year, {Color}

**Figure 3.7**

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

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 3.5).

In our diagrammatic notation, if two attributes are underlined separately, then *each is a key on its own*. Unlike the relational model (see Section 5.2.2), 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 3.6, 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 typically displayed in basic ER diagrams and are similar to the basic **data types** available in most programming languages, such as integer, string, Boolean, float, enumerated type, subrange, and so on. However, data types of attributes can

be specified in UML class diagrams (see Section 3.8) and in other diagrammatic notations used in database design tools. 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 set⁶ $P(V)$ 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.⁷ 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 and correspond to the data as it actually exists in the miniworld.

3.3.3 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 3.2. After defining several entity types and their attributes here, we refine our design in Section 3.4 after we introduce the concept of a relationship. According to the requirements listed in Section 3.2, we can identify four entity types—one corresponding to each of the four items in the specification (see Figure 3.8):

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. In

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

⁷A **singleton** set is a set with only one element (value).

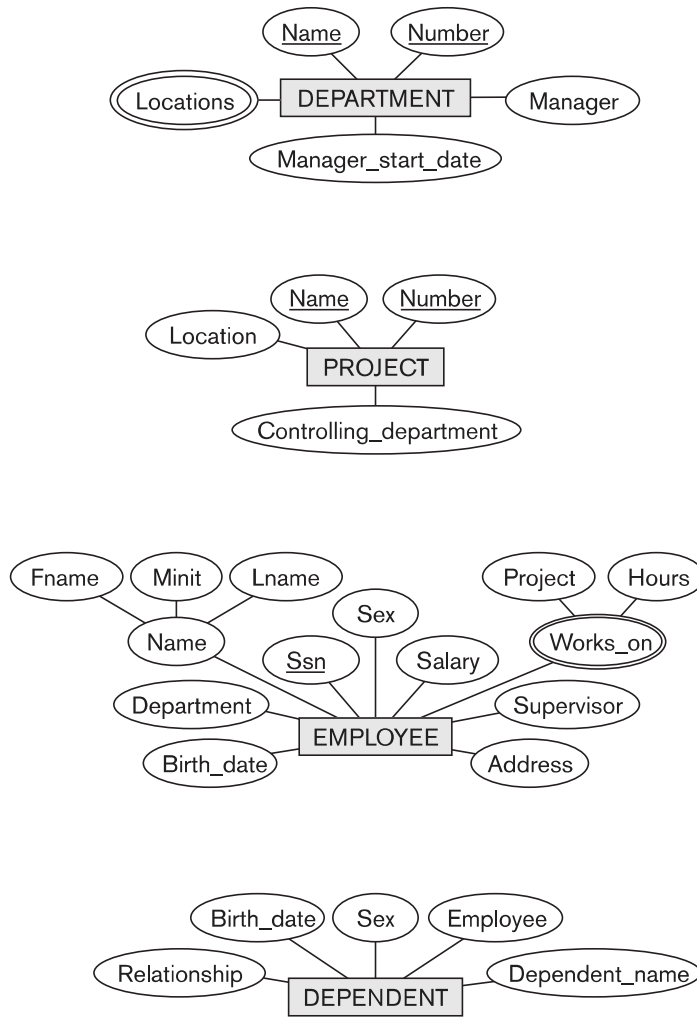


Figure 3.8
Preliminary design of
entity types for the
COMPANY database.
Some of the shown
attributes will be refined
into relationships.

our example, Name is modeled as a composite attribute, whereas Address is not, presumably after consultation with the users.

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

Another requirement is that an employee can work on several projects, and the database has to store the number of hours per week an employee works on each project. This requirement is listed as part of the third requirement in Section 3.2, 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 3.8; we shall see in the next section that this will be refined into a many-to-many relationship, once we introduce the concepts of relationships.

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

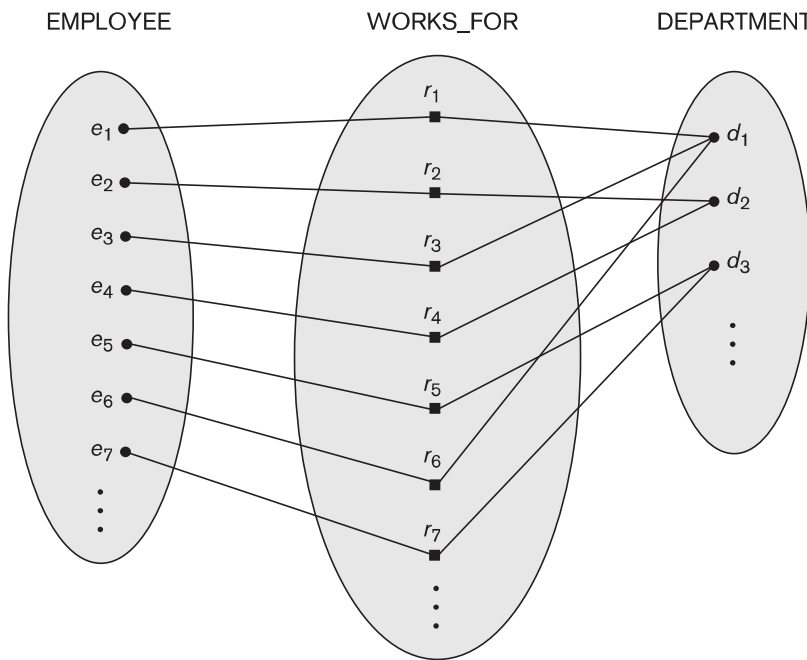
In Figure 3.8 there are several *implicit relationships* among the various entity types. In fact, whenever an attribute of one entity type refers to another entity type, some relationship exists. For example, the attribute *Manager* of *DEPARTMENT* refers to an employee who manages the department; the 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**. The initial *COMPANY* database schema from Figure 3.8 will be refined in Section 3.6 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 3.4.1 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 3.4.2, and then we discuss structural constraints on relationships—such as cardinality ratios and existence dependencies—in Section 3.4.3. Section 3.4.4 shows how relationship types can also have attributes.

3.4.1 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. Similar to 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, \dots, e_n) , and each entity e_j in r_i 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 $r_i = (e_1, e_2, \dots, e_n)$.

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

**Figure 3.9**

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

EMPLOYEE and DEPARTMENT, which associates each employee with the department for which the employee works. Each relationship instance in the relationship set WORKS_FOR associates one EMPLOYEE entity and one DEPARTMENT entity. Figure 3.9 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 3.9, the employees e_1 , e_3 , and e_6 work for department d_1 ; the employees e_2 and e_4 work for department d_2 ; and the 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 3.2).

3.4.2 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 3.10, 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

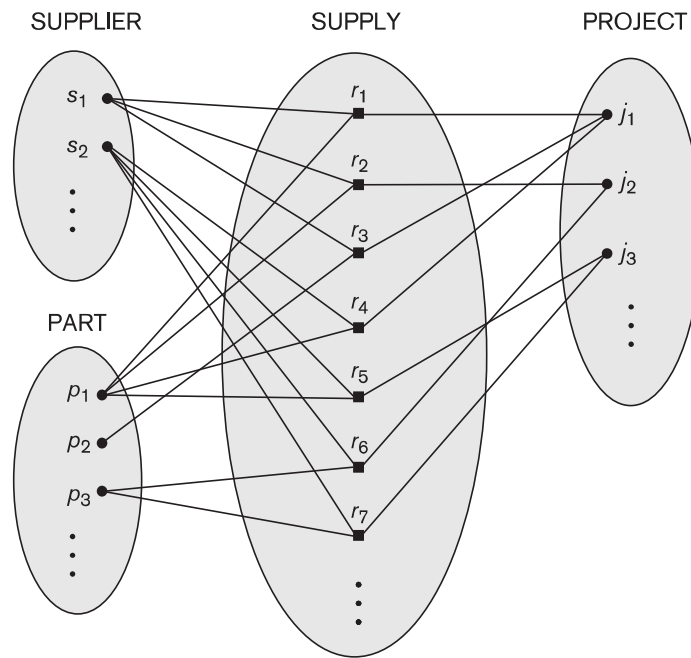


Figure 3.10
Some relationship
instances in the
SUPPLY ternary
relationship set.

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 3.9.

Relationships as Attributes. It is sometimes convenient to think of a binary relationship type in terms of attributes, as we discussed in Section 3.3.3. Consider the WORKS_FOR relationship type in Figure 3.9. 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 3.8 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 or two points of view. In this example, the alternative point of view is to think of a multivalued attribute Employees of the entity type DEPARTMENT whose value for each DEPARTMENT entity is the set of EMPLOYEE entities who work for that department. The value set of this Employees attribute is the power set of the EMPLOYEE entity set. Either of these two attributes—Department of EMPLOYEE or Employees of DEPARTMENT—can represent the WORKS_FOR relationship type. If both are represented, they are constrained to be inverses of each other.⁸

⁸This concept of representing relationship types as attributes is used in a class of data models called **functional data models**. In object databases (see Chapter 12), relationships can be represented by reference attributes, either in one direction or in both directions as inverses. In relational databases (see Chapter 5), 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 it 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** or **self-referencing relationships**. Figure 3.11 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 different employee entities e_j and e_k , one of which plays the role of supervisor and the other the role of supervisee. In Figure 3.11, 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).

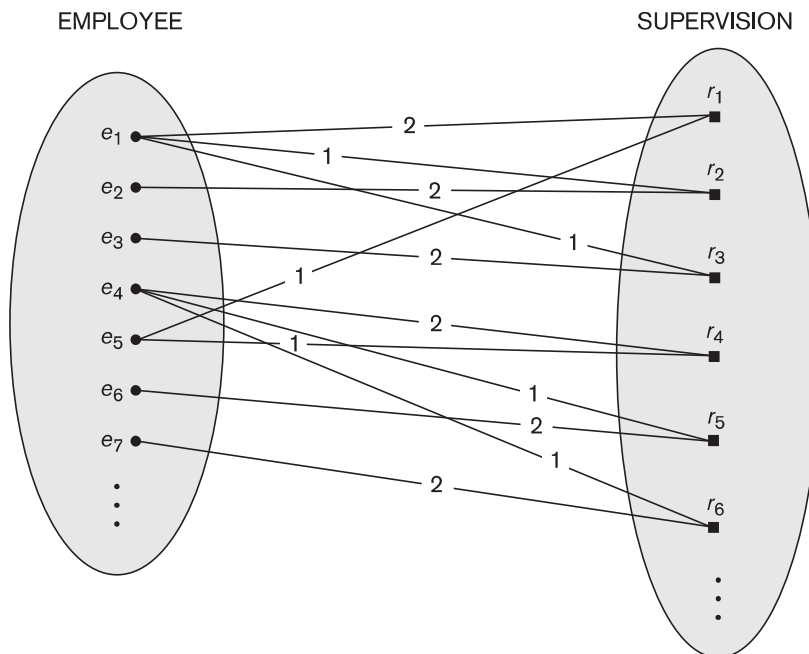


Figure 3.11

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

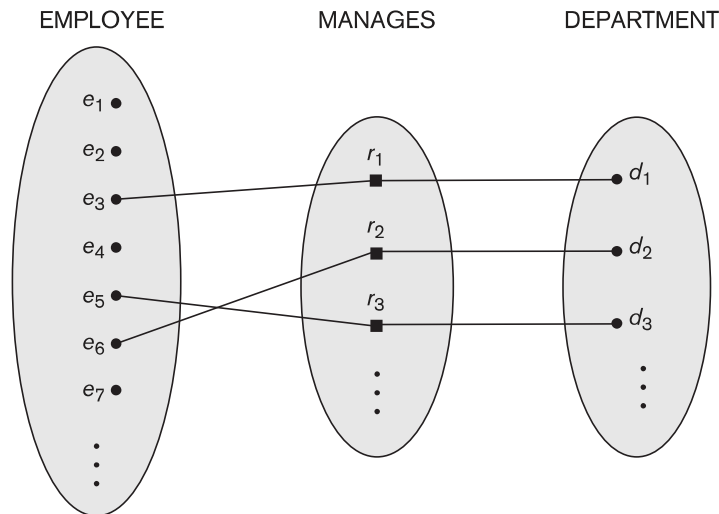
3.4.3 Constraints on Binary Relationship Types

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 3.9, 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 (N),⁹ but an employee can be related to (work for) at most one department (1). This means that for this particular relationship type 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 3.12), 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 at

Figure 3.12
A 1:1 relationship,
MANAGES.



⁹N stands for *any number* of related entities (zero or more). In some notations, the asterisk symbol (*) is used instead of N.

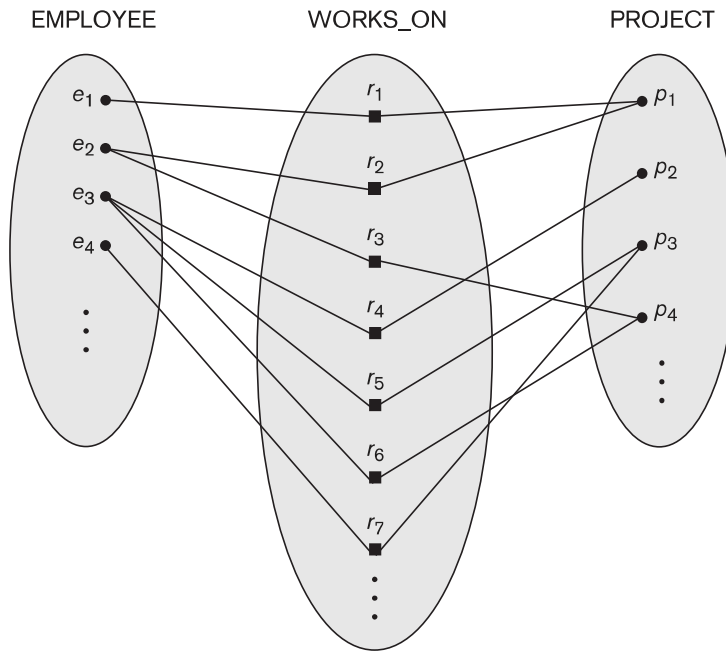


Figure 3.13
An M:N relationship,
WORKS_ON.

most one department and a department can have at most one manager. The relationship type WORKS_ON (Figure 3.13) 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.

Cardinality ratios for binary relationships are represented on ER diagrams by displaying 1, M, and N on the diamonds as shown in Figure 3.2. 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 3.7.4) 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 3.9). 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 3.12 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 3.2). Notice that in this notation, we can either specify no minimum (partial participation) or a minimum of one (total participation). An alternative notation (see Section 3.7.4) 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 3.9.

3.4.4 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 a particular employee works on a particular project, we can include an attribute Hours for the WORKS_ON relationship type in Figure 3.13. 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 3.12.

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 (manager) 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 3.9, 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 at most one department, and hence participates in at most one relationship instance in WORKS_FOR, but a department can have many employees, each with a different start date. 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 (many-to-many) 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 3.13); 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.

3.5 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**,¹⁰ and we call the relationship type that relates a weak entity type to its owner the **identifying relationship** of the weak entity type.¹¹ 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 3.2). 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*.¹² 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 3.2). 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 multivalued composite attribute with the 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 the weak entity type participates independently in relationship types other than its identifying relationship type.

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 3.9.

¹⁰The identifying entity type is also sometimes called the **parent entity type** or the **dominant entity type**.

¹¹The weak entity type is also sometimes called the **child entity type** or the **subordinate entity type**.

¹²The partial key is sometimes called the **discriminator**.

3.6 Refining the ER Design for the COMPANY Database

We can now refine the database design in Figure 3.8 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 3.2. 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**, which is a 1:1(one-to-one) 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.¹³ The attribute **Start_date** is assigned to this relationship type.
- **WORKS_FOR**, a 1:N (one-to-many) 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 (many-to-many) 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 previous six relationship types, we remove from the entity types in Figure 3.8 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.

¹³The 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.