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part 2
Conceptual Data Modeling and Database Design

part 3
The Relational Data Model and SQL

chapter 4

The Enhanced Entity–Relationship (EER) Model

The ER modeling concepts discussed in Chapter 3 are sufficient for representing many database schemas for *traditional* database applications, which include many data-processing applications in business and industry. Since the late 1970s, however, designers of database applications have tried to design more accurate database schemas that reflect the data properties and constraints more precisely. This was particularly important for newer applications of database technology, such as databases for engineering design and manufacturing (CAD/CAM),[1] telecommunications, complex software systems, and geographic information systems (GISs), among many other applications. These types of databases have requirements that are more complex than the more traditional applications. This led to the development of additional *semantic data modeling* concepts that were incorporated into conceptual data models such as the ER model. Various semantic data models have been proposed in the literature. Many of these concepts were also developed independently in related areas of computer science, such as the **knowledge representation** area of artificial intelligence and the **object modeling** area in software engineering.

In this chapter, we describe features that have been proposed for semantic data models and show how the ER model can be enhanced to include these concepts, which leads to the **enhanced ER (EER)** model.[2] We start in Section 4.1 by incorporating the concepts of *class/subclass relationships* and *type inheritance* into the ER model. Then, in Section 4.2, we add the concepts of *specialization* and *generalization*. Section 4.3 discusses the various types of *constraints* on specialization/generalization, and Section 4.4 shows how the UNION construct can be modeled by including the

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

[2]EER has also been used to stand for *extended* ER model.

concept of *category* in the EER model. Section 4.5 gives a sample UNIVERSITY database schema in the EER model and summarizes the EER model concepts by giving formal definitions. We will use the terms *object* and *entity* interchangeably in this chapter, because many of these concepts are commonly used in object-oriented models.

We present the UML class diagram notation for representing specialization and generalization in Section 4.6, and we briefly compare these with EER notation and concepts. This serves as an example of alternative notation, and is a continuation of Section 3.8, which presented basic UML class diagram notation that corresponds to the basic ER model. In Section 4.7, we discuss the fundamental abstractions that are used as the basis of many semantic data models. Section 4.8 summarizes the chapter.

For a detailed introduction to conceptual modeling, Chapter 4 should be considered a continuation of Chapter 3. However, if only a basic introduction to ER modeling is desired, this chapter may be omitted. Alternatively, the reader may choose to skip some or all of the later sections of this chapter (Sections 4.4 through 4.8).

4.1 Subclasses, Superclasses, and Inheritance

The EER model includes *all the modeling concepts of the ER model* that were presented in Chapter 3. In addition, it includes the concepts of **subclass** and **superclass** and the related concepts of **specialization** and **generalization** (see Sections 4.2 and 4.3). Another concept included in the EER model is that of a **category** or **union type** (see Section 4.4), which is used to represent a collection of objects (entities) that is the *union* of objects of different entity types. Associated with these concepts is the important mechanism of **attribute and relationship inheritance**. Unfortunately, no standard terminology exists for these concepts, so we use the most common terminology. Alternative terminology is given in footnotes. We also describe a diagrammatic technique for displaying these concepts when they arise in an EER schema. We call the resulting schema diagrams **enhanced ER** or **EER diagrams**.

The first enhanced ER (EER) model concept we take up is that of a **subtype** or **subclass** of an entity type. As we discussed in Chapter 3, the name of an entity type is used to represent both a *type of entity* and the *entity set* or *collection of entities of that type* that exist in the database. For example, the entity type EMPLOYEE describes the type (that is, the attributes and relationships) of each employee entity, and also refers to the current set of EMPLOYEE entities in the COMPANY database. In many cases an entity type has numerous subgroupings or subtypes of its entities that are meaningful and need to be represented explicitly because of their significance to the database application. For example, the entities that are members of the EMPLOYEE entity type may be distinguished further into SECRETARY, ENGINEER, MANAGER, TECHNICIAN, SALARIED_EMPLOYEE, HOURLY_EMPLOYEE, and so on. The set or collection of entities in each of the latter groupings is a subset of the entities that belong to the EMPLOYEE entity set, meaning that every entity that is a member of one of these subgroupings is also an employee. We call each of these subgroupings a

subclass or **subtype** of the EMPLOYEE entity type, and the EMPLOYEE entity type is called the **superclass** or **supertype** for each of these subclasses. Figure 4.1 shows how to represent these concepts diagramatically in EER diagrams. (The circle notation in Figure 4.1 will be explained in Section 4.2.)

We call the relationship between a superclass and any one of its subclasses a **superclass/subclass** or **supertype/subtype** or simply **class/subclass relationship**.[3] In our previous example, EMPLOYEE/SECRETARY and EMPLOYEE/TECHNICIAN are two class/subclass relationships. Notice that a member entity of the subclass represents the *same real-world entity* as some member of the superclass; for example, a SECRETARY entity 'Joan Logano' is also the EMPLOYEE 'Joan Logano.' Hence, the subclass member is the same as the entity in the superclass, but in a distinct *specific role.* When we implement a superclass/subclass relationship in the database system, however, we may represent a member of the subclass as a distinct database object—say, a distinct record that is related via the key attribute to its superclass entity. In Section 9.2, we discuss various options for representing superclass/subclass relationships in relational databases.

An entity cannot exist in the database merely by being a member of a subclass; it must also be a member of the superclass. Such an entity can be included optionally

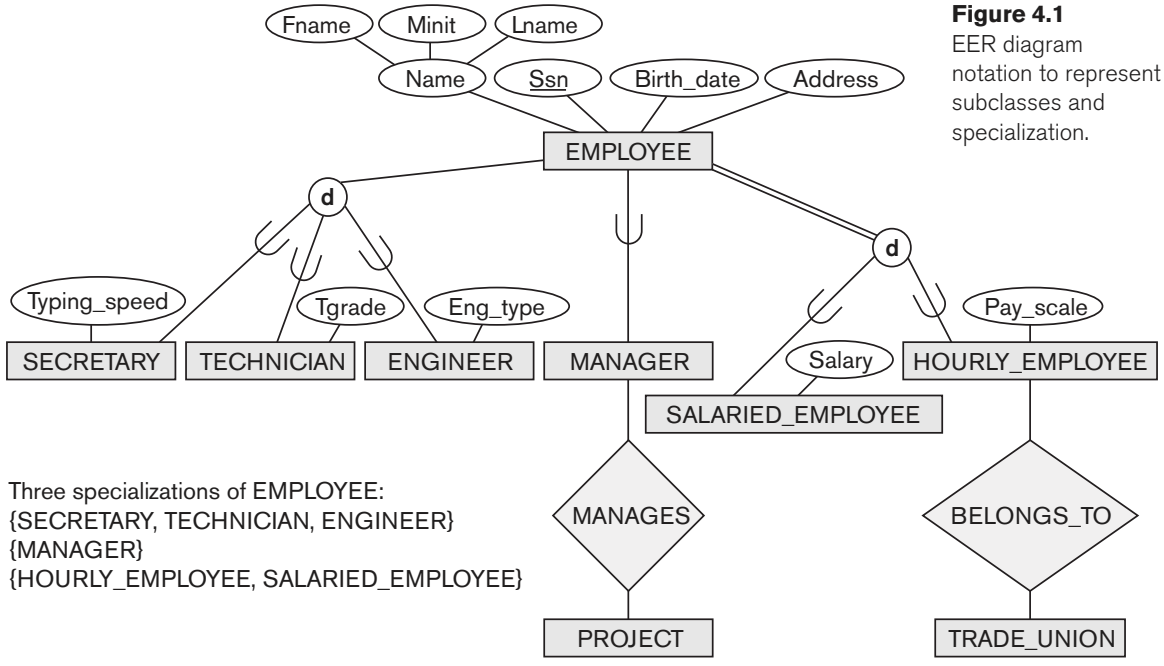


Figure 4.1
EER diagram notation to represent subclasses and specialization.

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

as a member of any number of subclasses. For example, a salaried employee who is also an engineer belongs to the two subclasses ENGINEER and SALARIED_EMPLOYEE of the EMPLOYEE entity type. However, it is not necessary that every entity in a superclass is a member of some subclass.

An important concept associated with subclasses (subtypes) is that of **type inheritance**. Recall that the *type* of an entity is defined by the attributes it possesses and the relationship types in which it participates. Because an entity in the subclass represents the same real-world entity from the superclass, it should possess values for its specific attributes *as well as* values of its attributes as a member of the superclass. We say that an entity that is a member of a subclass **inherits** all the attributes of the entity as a member of the superclass. The entity also inherits all the relationships in which the superclass participates. Notice that a subclass, with its own specific (or local) attributes and relationships together with all the attributes and relationships it inherits from the superclass, can be considered an *entity type* in its own right.[4]

4.2 Specialization and Generalization

4.2.1 Specialization

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

Figure 4.1 shows how we represent a specialization diagrammatically in an EER diagram. The subclasses that define a specialization are attached by lines to a circle that represents the specialization, which is connected in turn to the superclass. The *subset symbol* on each line connecting a subclass to the circle indicates the direction of the superclass/subclass relationship.[5] Attributes that apply only to entities of a particular subclass—such as TypingSpeed of SECRETARY—are attached to the rectangle representing that subclass. These are called **specific** (or **local**) **attributes** of the subclass. Similarly, a subclass can participate in **specific relationship types**, such as the HOURLY_EMPLOYEE subclass participating in the BELONGS_TO

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

[5]There are many alternative notations for specialization; we present the UML notation in Section 4.6 and other proposed notations in Appendix A.

relationship in Figure 4.1. We will explain the **d** symbol in the circles in Figure 4.1 and additional EER diagram notation shortly.

Figure 4.2 shows a few entity instances that belong to subclasses of the {SECRETARY, ENGINEER, TECHNICIAN} specialization. Again, notice that an entity that belongs to a subclass represents *the same real-world entity* as the entity connected to it in the EMPLOYEE superclass, even though the same entity is shown twice; for example, e_1 is shown in both EMPLOYEE and SECRETARY in Figure 4.2. As the figure suggests, a superclass/subclass relationship such as EMPLOYEE/SECRETARY somewhat resembles a 1:1 relationship *at the instance level* (see Figure 3.12). The main difference is that in a 1:1 relationship two *distinct entities* are related, whereas in a superclass/subclass relationship the entity in the subclass is the same real-world entity as the entity in the superclass but is playing a *specialized role*—for example, an EMPLOYEE specialized in the role of SECRETARY, or an EMPLOYEE specialized in the role of TECHNICIAN.

There are two main reasons for including class/subclass relationships and specializations. The first is that certain attributes may apply to some but not all entities of

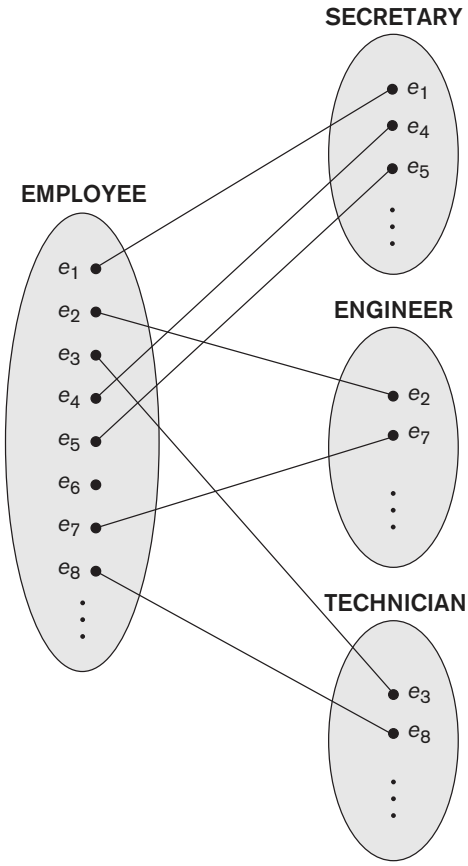


Figure 4.2
Instances of a specialization.

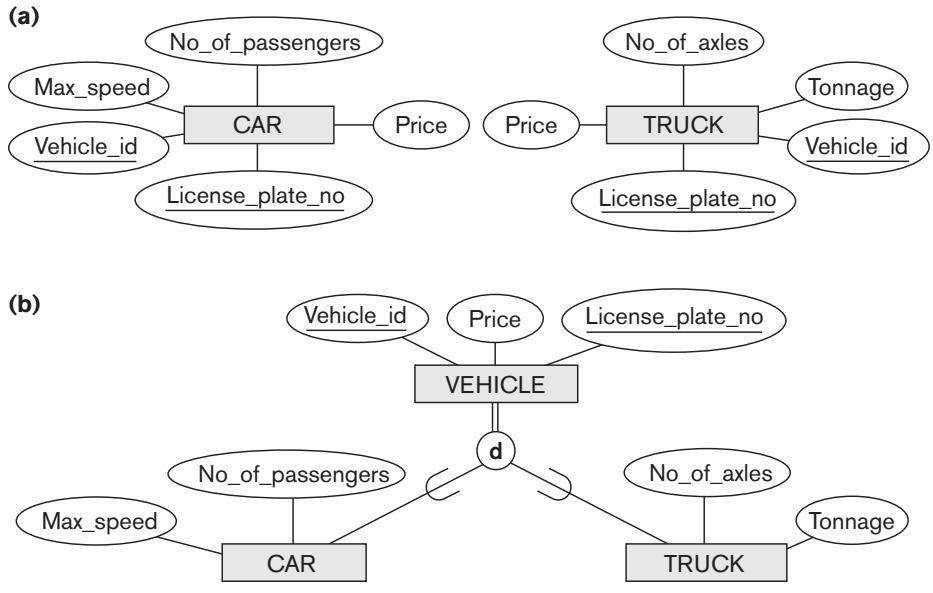
the superclass entity type. A subclass is defined in order to group the entities to which these attributes apply. The members of the subclass may still share the majority of their attributes with the other members of the superclass. For example, in Figure 4.1 the SECRETARY subclass has the specific attribute Typing_speed, whereas the ENGINEER subclass has the specific attribute Eng_type, but SECRETARY and ENGINEER share their other inherited attributes from the EMPLOYEE entity type.

The second reason for using subclasses is that some relationship types may be participated in only by entities that are members of the subclass. For example, if only HOURLY_EMPLOYEES can belong to a trade union, we can represent that fact by creating the subclass HOURLY_EMPLOYEE of EMPLOYEE and relating the subclass to an entity type TRADE_UNION via the BELONGS_TO relationship type, as illustrated in Figure 4.1.

4.2.2 Generalization

We can think of a *reverse process* of abstraction in which we suppress the differences among several entity types, identify their common features, and **generalize** them into a single **superclass** of which the original entity types are special **subclasses**. For example, consider the entity types CAR and TRUCK shown in Figure 4.3(a). Because they have several common attributes, they can be generalized into the entity type VEHICLE, as shown in Figure 4.3(b). Both CAR and TRUCK are now subclasses of the

Figure 4.3
Generalization. (a) Two entity types, CAR and TRUCK.
(b) Generalizing CAR and TRUCK into the superclass VEHICLE.



generalized superclass VEHICLE. We use the term **generalization** to refer to the process of defining a generalized entity type from the given entity types.

Notice that the generalization process can be viewed as being functionally the inverse of the specialization process; we can view {CAR, TRUCK} as a specialization of VEHICLE rather than viewing VEHICLE as a generalization of CAR and TRUCK. A diagrammatic notation to distinguish between generalization and specialization is used in some design methodologies. An arrow pointing to the generalized superclass represents a generalization process, whereas arrows pointing to the specialized subclasses represent a specialization process. We will *not* use this notation because the decision as to which process was followed in a particular situation is often subjective.

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

4.3 Constraints and Characteristics of Specialization and Generalization Hierarchies

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

4.3.1 Constraints on Specialization and Generalization

In general, we may have several specializations defined on the same entity type (or superclass), as shown in Figure 4.1. In such a case, entities may belong to subclasses in each of the specializations. A specialization may also consist of a *single* subclass only, such as the {MANAGER} specialization in Figure 4.1; in such a case, we do not use the circle notation.

In some specializations we can determine exactly the entities that will become members of each subclass by placing a condition on the value of some attribute of the superclass. Such subclasses are called **predicate-defined** (or **condition-defined**) **subclasses**. For example, if the EMPLOYEE entity type has an attribute Job_type, as shown in Figure 4.4, we can specify the condition of membership in the SECRETARY subclass by the condition (Job_type = 'Secretary'), which we call the **defining predicate** of the subclass. This condition is a *constraint* specifying that exactly those entities of the EMPLOYEE entity type whose attribute value for Job_type

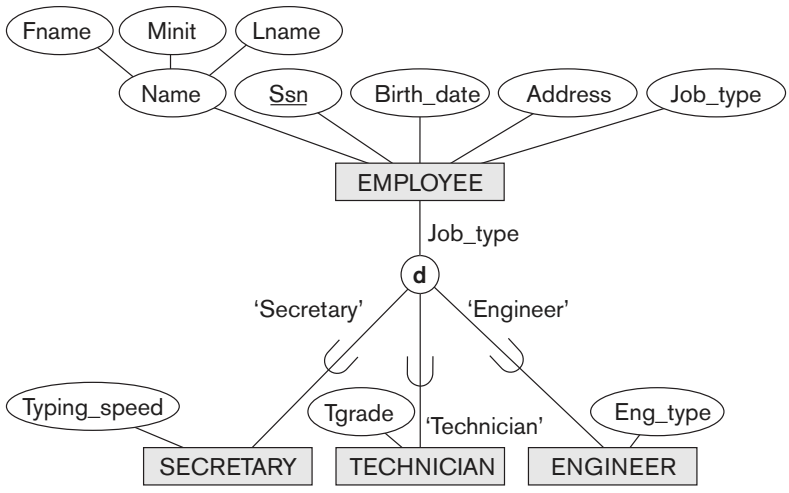


Figure 4.4
EER diagram notation for an attribute-defined specialization on Job_type.

is 'Secretary' belong to the subclass. We display a predicate-defined subclass by writing the predicate condition next to the line that connects the subclass to the specialization circle.

If *all* subclasses in a specialization have their membership condition on the *same* attribute of the superclass, the specialization itself is called an **attribute-defined specialization**, and the attribute is called the **defining attribute** of the specialization.[6] In this case, all the entities with the same value for the attribute belong to the same subclass. We display an attribute-defined specialization by placing the defining attribute name next to the arc from the circle to the superclass, as shown in Figure 4.4.

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

Two other constraints may apply to a specialization. The first is the **disjointness constraint**, which specifies that the subclasses of the specialization must be disjoint sets. This means that an entity can be a member of *at most* one of the subclasses of the specialization. A specialization that is attribute-defined implies the disjointness constraint (if the attribute used to define the membership predicate is single-valued). Figure 4.4 illustrates this case, where the **d** in the circle stands for *disjoint*. The **d** notation also applies to user-defined subclasses of a specialization that must be disjoint, as illustrated by the specialization {HOURLY_EMPLOYEE, SALARIED_EMPLOYEE} in Figure 4.1. If the subclasses are not constrained to be disjoint, their sets of entities

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

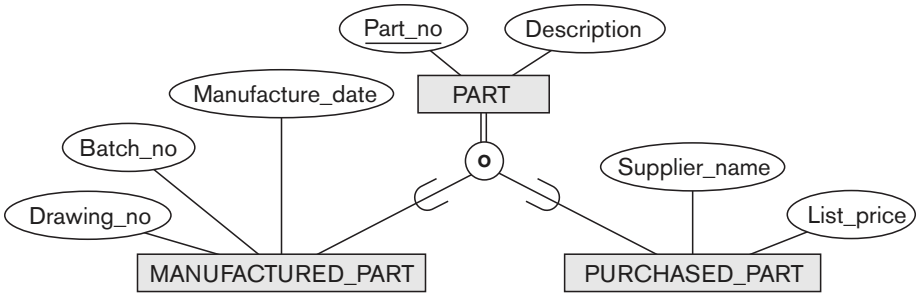


Figure 4.5
EER diagram notation for an overlapping (nondisjoint) specialization.

may be **overlapping**; that is, the same (real-world) entity may be a member of more than one subclass of the specialization. This case, which is the default, is displayed by placing an **o** in the circle, as shown in Figure 4.5.

The second constraint on specialization is called the **completeness** (or **totalness**) **constraint**, which may be total or partial. A **total specialization** constraint specifies that *every* entity in the superclass must be a member of at least one subclass in the specialization. For example, if every EMPLOYEE must be either an HOURLY_EMPLOYEE or a SALARIED_EMPLOYEE, then the specialization {HOURLY_EMPLOYEE, SALARIED_EMPLOYEE} in Figure 4.1 is a total specialization of EMPLOYEE. This is shown in EER diagrams by using a double line to connect the superclass to the circle. A single line is used to display a **partial specialization**, which allows an entity not to belong to any of the subclasses. For example, if some EMPLOYEE entities do not belong to any of the subclasses {SECRETARY, ENGINEER, TECHNICIAN} in Figures 4.1 and 4.4, then that specialization is partial.[7]

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

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

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

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

- Deleting an entity from a superclass implies that it is automatically deleted from all the subclasses to which it belongs.

[7]The notation of using single or double lines is similar to that for partial or total participation of an entity type in a relationship type, as described in Chapter 3.

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

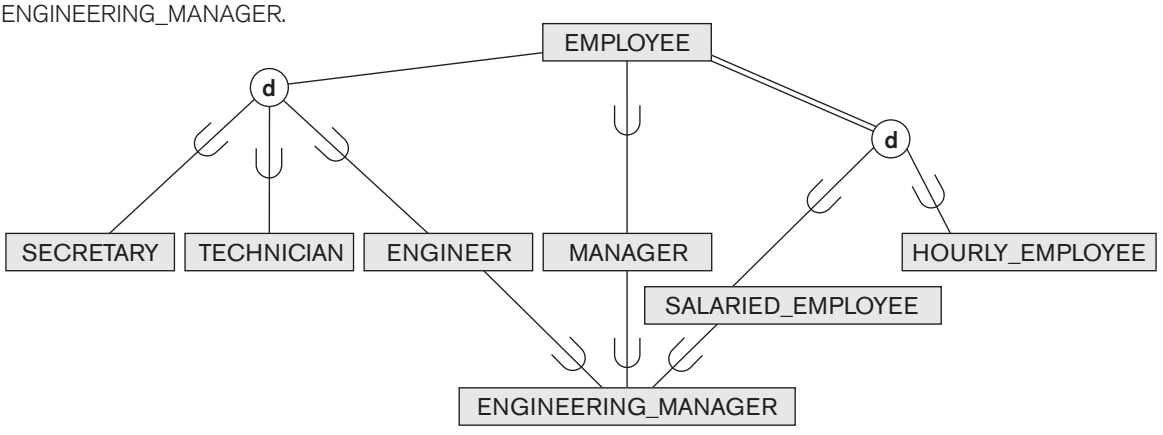
The reader is encouraged to make a complete list of rules for insertions and deletions for the various types of specializations.

4.3.2 Specialization and Generalization Hierarchies and Lattices

A subclass itself may have further subclasses specified on it, forming a hierarchy or a lattice of specializations. For example, in Figure 4.6 ENGINEER is a subclass of EMPLOYEE and is also a superclass of ENGINEERING_MANAGER; this represents the real-world constraint that every engineering manager is required to be an engineer. A **specialization hierarchy** has the constraint that every subclass participates *as a subclass* in *only one* class/subclass relationship; that is, each subclass has only one parent, which results in a **tree structure** or **strict hierarchy**. In contrast, for a **specialization lattice**, a subclass can be a subclass in *more than one* class/subclass relationship. Hence, Figure 4.6 is a lattice.

Figure 4.7 shows another specialization lattice of more than one level. This may be part of a conceptual schema for a UNIVERSITY database. Notice that this arrangement would have been a hierarchy except for the STUDENT_ASSISTANT subclass, which is a subclass in two distinct class/subclass relationships.

Figure 4.6
A specialization lattice with shared subclass ENGINEERING_MANAGER.



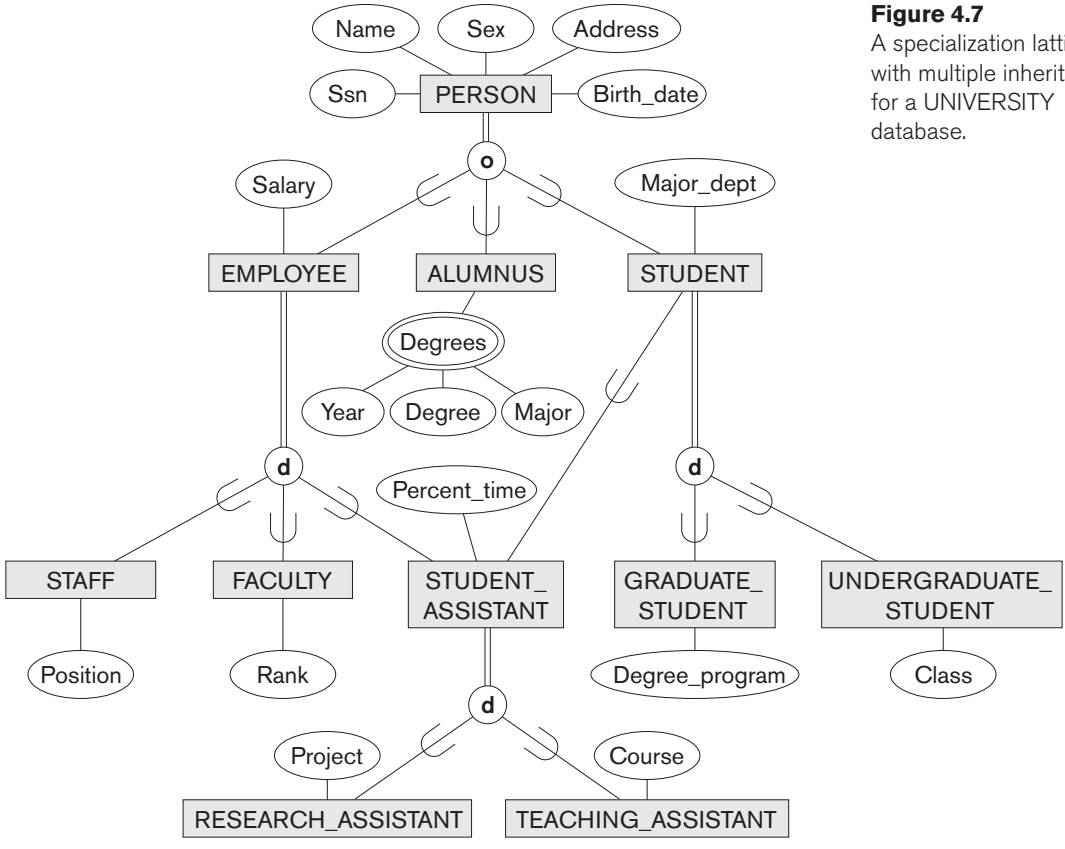


Figure 4.7
A specialization lattice with multiple inheritance for a UNIVERSITY database.

The requirements for the part of the UNIVERSITY database shown in Figure 4.7 are the following:

1. The database keeps track of three types of persons: employees, alumni, and students. A person can belong to one, two, or all three of these types. Each person has a name, SSN, sex, address, and birth date.
2. Every employee has a salary, and there are three types of employees: faculty, staff, and student assistants. Each employee belongs to exactly one of these types. For each alumnus, a record of the degree or degrees that he or she earned at the university is kept, including the name of the degree, the year granted, and the major department. Each student has a major department.
3. Each faculty has a rank, whereas each staff member has a staff position. Student assistants are classified further as either research assistants or teaching assistants, and the percent of time that they work is recorded in the database. Research assistants have their research project stored, whereas teaching assistants have the current course they work on.

4. Students are further classified as either graduate or undergraduate, with the specific attributes degree program (M.S., Ph.D., M.B.A., and so on) for graduate students and class (freshman, sophomore, and so on) for undergraduates.

In Figure 4.7, all person entities represented in the database are members of the PERSON entity type, which is specialized into the subclasses {EMPLOYEE, ALUMNUS, STUDENT}. This specialization is overlapping; for example, an alumnus may also be an employee and a student pursuing an advanced degree. The subclass STUDENT is the superclass for the specialization {GRADUATE_STUDENT, UNDERGRADUATE_STUDENT}, whereas EMPLOYEE is the superclass for the specialization {STUDENT_ASSISTANT, FACULTY, STAFF}. Notice that STUDENT_ASSISTANT is also a subclass of STUDENT. Finally, STUDENT_ASSISTANT is the superclass for the specialization into {RESEARCH_ASSISTANT, TEACHING_ASSISTANT}.

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

A subclass with *more than one* superclass is called a **shared subclass**, such as ENGINEERING_MANAGER in Figure 4.6. This leads to the concept known as **multiple inheritance**, where the shared subclass ENGINEERING_MANAGER directly inherits attributes and relationships from multiple superclasses. Notice that the existence of at least one shared subclass leads to a lattice (and hence to *multiple inheritance*); if no shared subclasses existed, we would have a hierarchy rather than a lattice and only **single inheritance** would exist. An important rule related to multiple inheritance can be illustrated by the example of the shared subclass STUDENT_ASSISTANT in Figure 4.7, which inherits attributes from both EMPLOYEE and STUDENT. Here, both EMPLOYEE and STUDENT inherit *the same attributes* from PERSON. The rule states that if an attribute (or relationship) originating in the *same superclass* (PERSON) is inherited more than once via different paths (EMPLOYEE and STUDENT) in the lattice, then it should be included only once in the shared subclass (STUDENT_ASSISTANT). Hence, the attributes of PERSON are inherited *only once* in the STUDENT_ASSISTANT subclass in Figure 4.7.

It is important to note here that some models and languages are limited to **single inheritance** and *do not allow* multiple inheritance (shared subclasses). It is also important to note that some models do not allow an entity to have multiple types, and hence an entity can be a member *of only one leaf class.*[8] In such a model, it is necessary to create additional subclasses as leaf nodes to cover all

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

possible combinations of classes that may have some entity that belongs to all these classes simultaneously. For example, in the overlapping specialization of PERSON into {EMPLOYEE, ALUMNUS, STUDENT} (or {E, A, S} for short), it would be necessary to create seven subclasses of PERSON in order to cover all possible types of entities: E, A, S, E_A, E_S, A_S, and E_A_S. Obviously, this can lead to extra complexity.

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

4.3.3 Utilizing Specialization and Generalization in Refining Conceptual Schemas

Now we elaborate on the differences between the specialization and generalization processes and how they are used to refine conceptual schemas during conceptual database design. In the specialization process, the database designers typically start with an entity type and then define subclasses of the entity type by successive specialization; that is, they repeatedly define more specific groupings of the entity type. For example, when designing the specialization lattice in Figure 4.7, we may first specify an entity type PERSON for a university database. Then we discover that three types of persons will be represented in the database: university employees, alumni, and students and we create the specialization {EMPLOYEE, ALUMNUS, STUDENT}. The overlapping constraint is chosen because a person may belong to more than one of the subclasses. We specialize EMPLOYEE further into {STAFF, FACULTY, STUDENT_ASSISTANT}, and specialize STUDENT into {GRADUATE_STUDENT, UNDERGRADUATE_STUDENT}. Finally, we specialize STUDENT_ASSISTANT into {RESEARCH_ASSISTANT, TEACHING_ASSISTANT}. This process is called **top-down conceptual refinement**. So far, we have a hierarchy; then we realize that STUDENT_ASSISTANT is a shared subclass, since it is also a subclass of STUDENT, leading to the lattice.

It is possible to arrive at the same hierarchy or lattice from the other direction. In such a case, the process involves generalization rather than specialization and corresponds to a **bottom-up conceptual synthesis**. For example, the database designers may first discover entity types such as STAFF, FACULTY, ALUMNUS, GRADUATE_STUDENT, UNDERGRADUATE_STUDENT, RESEARCH_ASSISTANT, TEACHING_ASSISTANT, and so on; then they generalize {GRADUATE_STUDENT, UNDERGRADUATE_STUDENT} into STUDENT; then {RESEARCH_ASSISTANT, TEACHING_ASSISTANT} into STUDENT_ASSISTANT; then {STAFF, FACULTY, STUDENT_ASSISTANT} into EMPLOYEE; and finally {EMPLOYEE, ALUMNUS, STUDENT} into PERSON.

The final design of hierarchies or lattices resulting from either process may be identical; the only difference relates to the manner or order in which the schema superclasses and subclasses were created during the design process. In practice, it is likely that a combination of the two processes is employed. Notice that the

notion of representing data and knowledge by using superclass/subclass hierarchies and lattices is quite common in knowledge-based systems and expert systems, which combine database technology with artificial intelligence techniques. For example, frame-based knowledge representation schemes closely resemble class hierarchies. Specialization is also common in software engineering design methodologies that are based on the object-oriented paradigm.

4.4 Modeling of UNION Types Using Categories

It is sometimes necessary to represent a collection of entities from different entity types. In this case, a subclass will represent a collection of entities that is a subset of the UNION of entities from distinct entity types; we call such a *subclass* a **union type** or a **category**.[9]

For example, suppose that we have three entity types: PERSON, BANK, and COMPANY. In a database for motor vehicle registration, an owner of a vehicle can be a person, a bank (holding a lien on a vehicle), or a company. We need to create a class (collection of entities) that includes entities of all three types to play the role of *vehicle owner*. A category (union type) OWNER that is a *subclass of the UNION* of the three entity sets of COMPANY, BANK, and PERSON can be created for this purpose. We display categories in an EER diagram as shown in Figure 4.8. The superclasses COMPANY, BANK, and PERSON are connected to the circle with the ∪ symbol, which stands for the *set union operation*. An arc with the subset symbol connects the circle to the (subclass) OWNER category. In Figure 4.8 we have two categories: OWNER, which is a subclass (subset) of the union of PERSON, BANK, and COMPANY; and REGISTERED_VEHICLE, which is a subclass (subset) of the union of CAR and TRUCK.

A category has two or more superclasses that may represent collections of entities from *distinct entity types,* whereas other superclass/subclass relationships always have a single superclass. To better understand the difference, we can compare a category, such as OWNER in Figure 4.8, with the ENGINEERING_MANAGER shared subclass in Figure 4.6. The latter is a subclass of *each of* the three superclasses ENGINEER, MANAGER, and SALARIED_EMPLOYEE, so an entity that is a member of ENGINEERING_MANAGER must exist in *all three collections.* This represents the constraint that an engineering manager must be an ENGINEER, a MANAGER, *and* a SALARIED_EMPLOYEE; that is, the ENGINEERING_MANAGER entity set is a subset of the *intersection* of the three entity sets. On the other hand, a category is a subset of the *union* of its superclasses. Hence, an entity that is a member of OWNER must exist in *only one* of the superclasses. This represents the constraint that an OWNER may be a COMPANY, a BANK, *or* a PERSON in Figure 4.8.

[9]Our use of the term *category* is based on the ECR (entity–category–relationship) model (Elmasri et al., 1985).

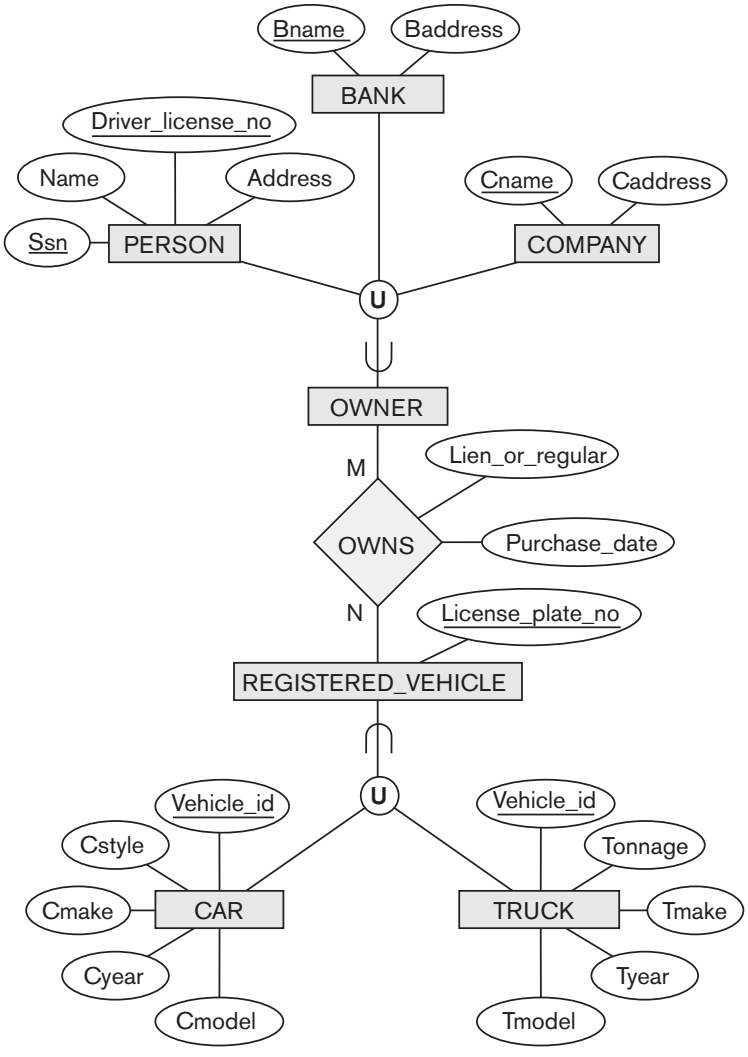


Figure 4.8
Two categories (union types): OWNER and REGISTERED_VEHICLE.

Attribute inheritance works more selectively in the case of categories. For example, in Figure 4.8 each OWNER entity inherits the attributes of a COMPANY, a PERSON, or a BANK, depending on the superclass to which the entity belongs. On the other hand, a shared subclass such as ENGINEERING_MANAGER (Figure 4.6) inherits *all* the attributes of its superclasses SALARIED_EMPLOYEE, ENGINEER, and MANAGER.

It is interesting to note the difference between the category REGISTERED_VEHICLE (Figure 4.8) and the generalized superclass VEHICLE (Figure 4.3(b)). In Figure 4.3(b), every car and every truck is a VEHICLE; but in Figure 4.8, the REGISTERED_VEHICLE category includes some cars and some trucks but not necessarily

all of them (for example, some cars or trucks may not be registered). In general, a specialization or generalization such as that in Figure 4.3(b), if it were *partial*, would not preclude VEHICLE from containing other types of entities, such as motorcycles. However, a category such as REGISTERED_VEHICLE in Figure 4.8 implies that only cars and trucks, but not other types of entities, can be members of REGISTERED_VEHICLE.

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

The superclasses of a category may have different key attributes, as demonstrated by the OWNER category in Figure 4.8, or they may have the same key attribute, as demonstrated by the REGISTERED_VEHICLE category. Notice that if a category is total (not partial), it may be represented alternatively as a total specialization (or a total generalization). In this case, the choice of which representation to use is subjective. If the two classes represent the same type of entities and share numerous attributes, including the same key attributes, specialization/generalization is preferred; otherwise, categorization (union type) is more appropriate.

It is important to note that some modeling methodologies do not have union types. In these models, a union type must be represented in a roundabout way (see Section 9.2).

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

In this section, we first give an example of a database schema in the EER model to illustrate the use of the various concepts discussed here and in Chapter 3. Then, we discuss design choices for conceptual schemas, and finally we summarize the EER model concepts and define them formally in the same manner in which we formally defined the concepts of the basic ER model in Chapter 3.

4.5.1 A Different UNIVERSITY Database Example

Consider a UNIVERSITY database that has *different requirements* from the UNIVERSITY database presented in Section 3.10. This database keeps track of students and their majors, transcripts, and registration as well as of the university's course offerings. The database also keeps track of the sponsored research projects of faculty and graduate students. This schema is shown in Figure 4.9. A discussion of the requirements that led to this schema follows.

For each person, the database maintains information on the person's Name [Name], Social Security number [Ssn], address [Address], sex [Sex], and birth date [Bdate]. Two subclasses of the PERSON entity type are identified: FACULTY and STUDENT. Specific attributes of FACULTY are rank [Rank] (assistant, associate, adjunct, research,

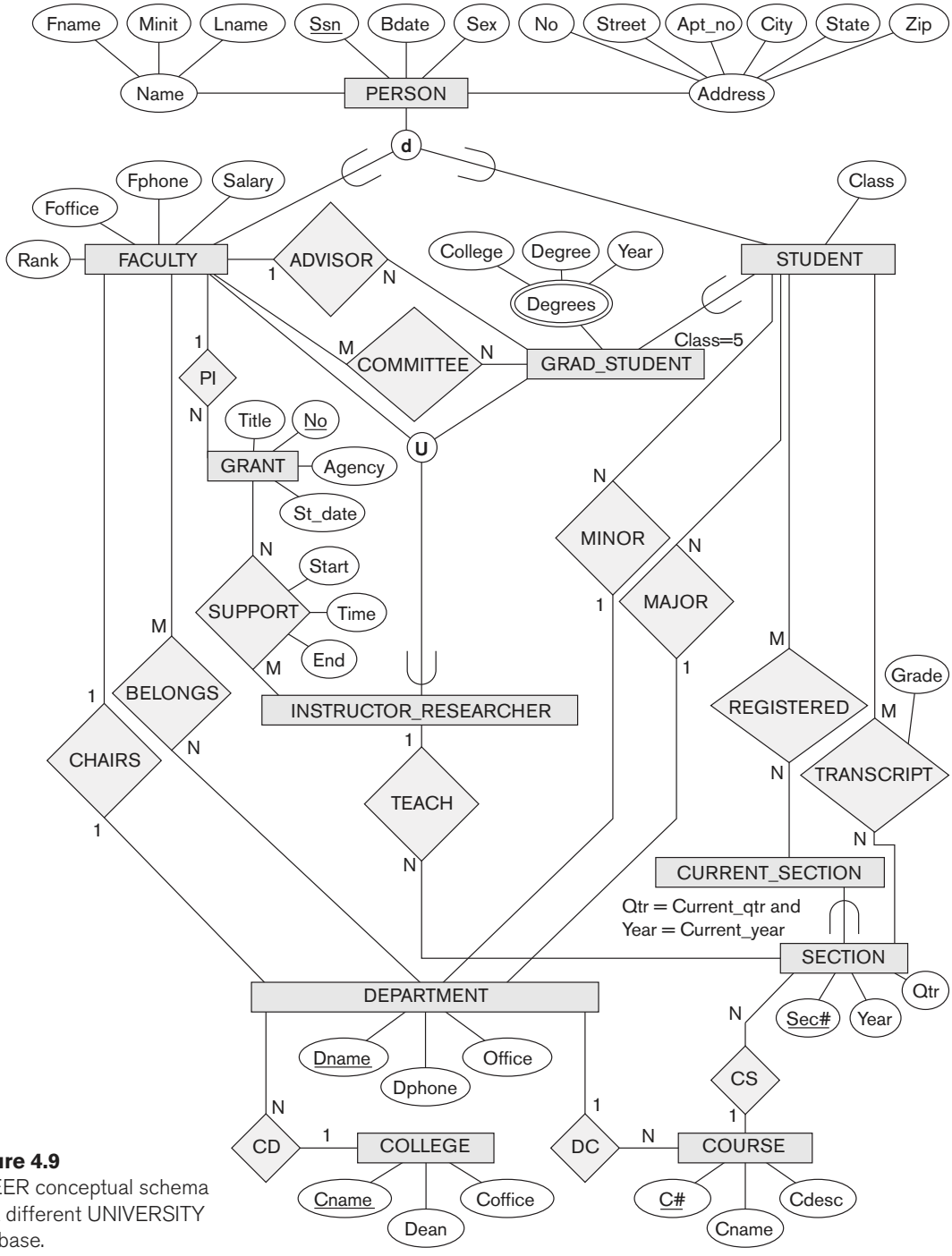


Figure 4.9
An EER conceptual schema for a different UNIVERSITY database.

visiting, and so on), office [Foffice], office phone [Fphone], and salary [Salary]. All faculty members are related to the academic department(s) with which they are affiliated [BELONGS] (a faculty member can be associated with several departments, so the relationship is M:N). A specific attribute of STUDENT is [Class] (freshman = 1, sophomore = 2, … , MS student = 5, PhD student = 6). Each STUDENT is also related to his or her major and minor departments (if known) [MAJOR] and [MINOR], to the course sections he or she is currently attending [REGISTERED], and to the courses completed [TRANSCRIPT]. Each TRANSCRIPT instance includes the grade the student received [Grade] in a section of a course.

GRAD_STUDENT is a subclass of STUDENT, with the defining predicate (Class = 5 OR Class = 6). For each graduate student, we keep a list of previous degrees in a composite, multivalued attribute [Degrees]. We also relate the graduate student to a faculty advisor [ADVISOR] and to a thesis committee [COMMITTEE], if one exists.

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

A course has attributes course number [C#], course name [Cname], and course description [Cdesc]. Several sections of each course are offered, with each section having the attributes section number [Sec#] and the year and quarter in which the section was offered ([Year] and [Qtr]).[10] Section numbers uniquely identify each section. The sections being offered during the current quarter are in a subclass CURRENT_SECTION of SECTION, with the defining predicate Qtr = Current_qtr and Year = Current_year. Each section is related to the instructor who taught or is teaching it ([TEACH]), if that instructor is in the database.

The category INSTRUCTOR_RESEARCHER is a subset of the union of FACULTY and GRAD_STUDENT and includes all faculty, as well as graduate students who are supported by teaching or research. Finally, the entity type GRANT keeps track of research grants and contracts awarded to the university. Each grant has attributes grant title [Title], grant number [No], the awarding agency [Agency], and the starting date [St_date]. A grant is related to one principal investigator [PI] and to all researchers it supports [SUPPORT]. Each instance of support has as attributes the starting date of support [Start], the ending date of the support (if known) [End], and the percentage of time being spent on the project [Time] by the researcher being supported.

4.5.2 Design Choices for Specialization/Generalization

It is not always easy to choose the most appropriate conceptual design for a database application. In Section 3.7.3, we presented some of the typical issues that confront a database designer when choosing among the concepts of entity

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

types, relationship types, and attributes to represent a particular miniworld situation as an ER schema. In this section, we discuss design guidelines and choices for the EER concepts of specialization/generalization and categories (union types).

As we mentioned in Section 3.7.3, conceptual database design should be considered as an iterative refinement process until the most suitable design is reached. The following guidelines can help to guide the design process for EER concepts:

- In general, many specializations and subclasses can be defined to make the conceptual model accurate. However, the drawback is that the design becomes quite cluttered. It is important to represent only those subclasses that are deemed necessary to avoid extreme cluttering of the conceptual schema.
- If a subclass has few specific (local) attributes and no specific relationships, it can be merged into the superclass. The specific attributes would hold NULL values for entities that are not members of the subclass. A *type* attribute could specify whether an entity is a member of the subclass.
- Similarly, if all the subclasses of a specialization/generalization have few specific attributes and no specific relationships, they can be merged into the superclass and replaced with one or more *type* attributes that specify the subclass or subclasses that each entity belongs to (see Section 9.2 for how this criterion applies to relational databases).
- Union types and categories should generally be avoided unless the situation definitely warrants this type of construct, which does occur in some practical situations. If possible, we try to model using specialization/generalization as discussed at the end of Section 4.4.
- The choice of disjoint/overlapping and total/partial constraints on specialization/generalization is driven by the rules in the miniworld being modeled. If the requirements do not indicate any particular constraints, the default would generally be overlapping and partial, since this does not specify any restrictions on subclass membership.

As an example of applying these guidelines, consider Figure 4.6, where no specific (local) attributes are shown. We could merge all the subclasses into the EMPLOYEE entity type and add the following attributes to EMPLOYEE:

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

- An attribute Is_a_manager whose value set {'Yes', 'No'} would indicate whether an individual employee entity is a manager or not.

4.5.3 Formal Definitions for the EER Model Concepts

We now summarize the EER model concepts and give formal definitions. A **class**[11] defines a type of entity and represents a set or collection of entities of that type; this includes any of the EER schema constructs that correspond to collections of entities, such as entity types, subclasses, superclasses, and categories. A **subclass** S is a class whose entities must always be a subset of the entities in another class, called the **superclass** C of the **superclass/subclass** (or **IS-A**) **relationship**. We denote such a relationship by C/S. For such a superclass/subclass relationship, we must always have

$$S \subseteq C$$

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

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

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

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

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

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

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

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

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

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

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

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

We should now extend the definition of **relationship type** given in Chapter 3 by allowing any class—not only any entity type—to participate in a relationship. Hence, we should replace the words *entity type* with *class* in that definition. The graphical notation of EER is consistent with ER because all classes are represented by rectangles.

4.6 Example of Other Notation: Representing Specialization and Generalization in UML Class Diagrams

We now discuss the UML notation for generalization/specialization and inheritance. We already presented basic UML class diagram notation and terminology in Section 3.8. Figure 4.10 illustrates a possible UML class diagram corresponding to the EER diagram in Figure 4.7. The basic notation for specialization/generalization (see Figure 4.10) is to connect the subclasses by vertical lines to a horizontal line, which has a triangle connecting the horizontal line through another vertical line to the superclass. A blank triangle indicates a specialization/generalization with the *disjoint* constraint, and a filled triangle indicates an *overlapping* constraint. The root superclass is called the **base class**, and the subclasses (leaf nodes) are called **leaf classes**.

The preceding discussion and the example in Figure 4.10, as well as the presentation in Section 3.8, gave a brief overview of UML class diagrams and terminology. We focused on the concepts that are relevant to ER and EER database modeling rather than on those concepts that are more relevant to software engineering. In UML, there are many details that we have not discussed because they are outside the scope of this text and are mainly relevant to software engineering. For example, classes can be of various types:

- Abstract classes define attributes and operations but do not have objects corresponding to those classes. These are mainly used to specify a set of attributes and operations that can be inherited.
- Concrete classes can have objects (entities) instantiated to belong to the class.
- Template classes specify a template that can be further used to define other classes.

In database design, we are mainly concerned with specifying concrete classes whose collections of objects are permanently (or persistently) stored in the database. The bibliographic notes at the end of this chapter give some references to books that describe complete details of UML.

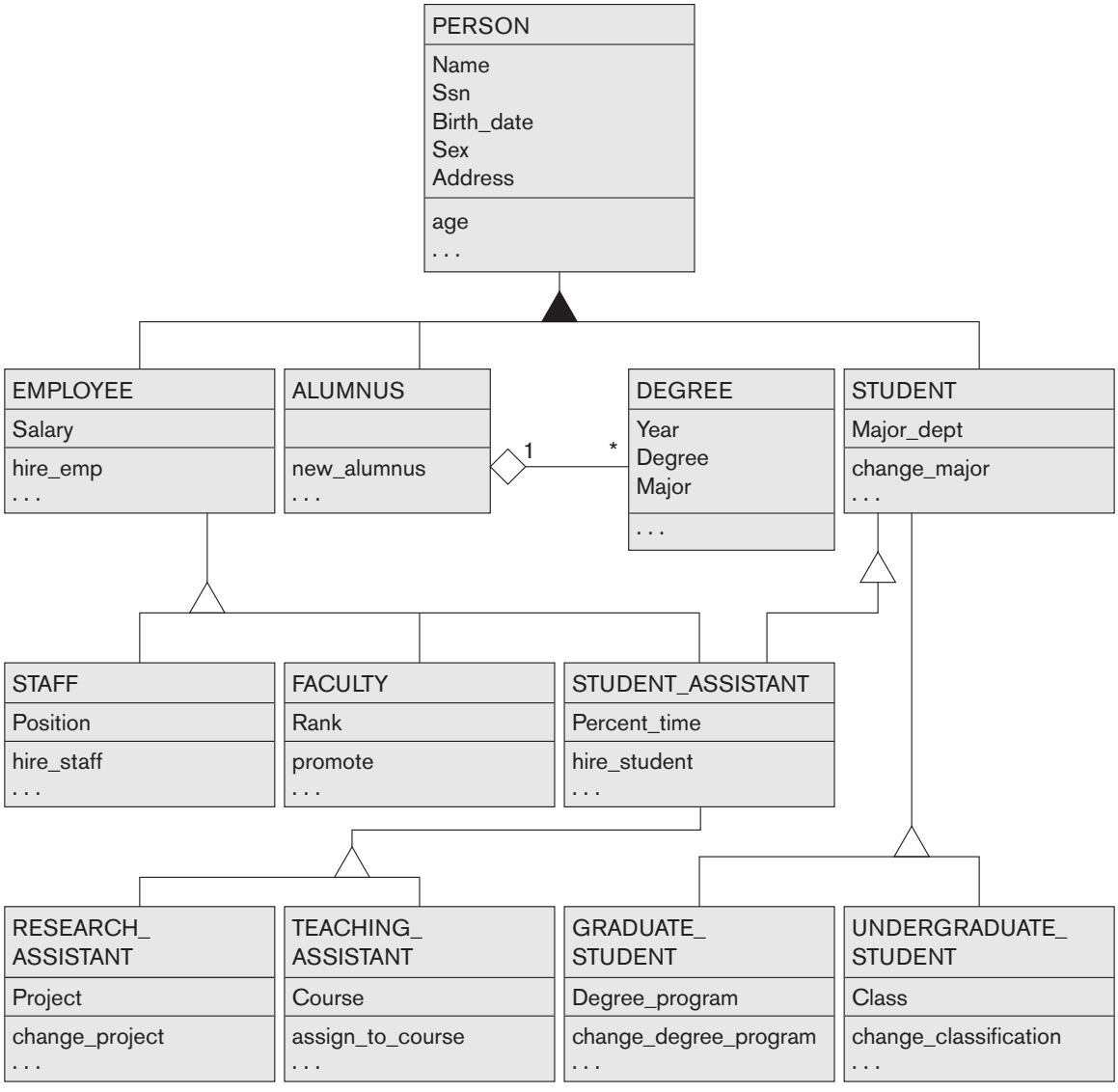


Figure 4.10
A UML class diagram corresponding to the EER diagram in Figure 4.7, illustrating UML notation for specialization/generalization.

4.7 Data Abstraction, Knowledge Representation, and Ontology Concepts

In this section, we discuss in general terms some of the modeling concepts that we described quite specifically in our presentation of the ER and EER models in Chapter 3 and earlier in this chapter. This terminology is not only used in conceptual

data modeling but also in artificial intelligence literature when discussing **knowledge representation** (**KR**). This section discusses the similarities and differences between conceptual modeling and knowledge representation, and introduces some of the alternative terminology and a few additional concepts.

The goal of KR techniques is to develop concepts for accurately modeling some **domain of knowledge** by creating an **ontology**[12] that describes the concepts of the domain and how these concepts are interrelated. The ontology is used to store and manipulate knowledge for drawing inferences, making decisions, or answering questions. The goals of KR are similar to those of semantic data models, but there are some important similarities and differences between the two disciplines:

- Both disciplines use an abstraction process to identify common properties and important aspects of objects in the miniworld (also known as *domain of discourse* in KR) while suppressing insignificant differences and unimportant details.
- Both disciplines provide concepts, relationships, constraints, operations, and languages for defining data and representing knowledge.
- KR is generally broader in scope than semantic data models. Different forms of knowledge, such as rules (used in inference, deduction, and search), incomplete and default knowledge, and temporal and spatial knowledge, are represented in KR schemes. Database models are being expanded to include some of these concepts (see Chapter 26).
- KR schemes include **reasoning mechanisms** that deduce additional facts from the facts stored in a database. Hence, whereas most current database systems are limited to answering direct queries, knowledge-based systems using KR schemes can answer queries that involve **inferences** over the stored data. Database technology is being extended with inference mechanisms (see Section 26.5).
- Whereas most data models concentrate on the representation of database schemas, or meta-knowledge, KR schemes often mix up the schemas with the instances themselves in order to provide flexibility in representing exceptions. This often results in inefficiencies when these KR schemes are implemented, especially when compared with databases and when a large amount of structured data (facts) needs to be stored.

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

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

4.7.1 Classification and Instantiation

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

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

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

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

4.7.2 Identification

Identification is the abstraction process whereby classes and objects are made uniquely identifiable by means of some **identifier**. For example, a class name uniquely identifies a whole class within a schema. An additional mechanism is necessary for telling distinct object instances apart by means of object identifiers. Moreover, it is necessary to identify multiple manifestations in the database of the same real-world

object. For example, we may have a tuple <'Matthew Clarke', '610618', '376-9821'> in a PERSON relation and another tuple <'301-54-0836', 'CS', 3.8> in a STUDENT relation that happen to represent the same real-world entity. There is no way to identify the fact that these two database objects (tuples) represent the same real-world entity unless we make a provision *at design time* for appropriate cross-referencing to supply this identification. Hence, identification is needed at two levels:

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

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

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

4.7.3 Specialization and Generalization

Specialization is the process of classifying a class of objects into more specialized subclasses. **Generalization** is the inverse process of generalizing several classes into a higher-level abstract class that includes the objects in all these classes. Specialization is conceptual refinement, whereas generalization is conceptual synthesis. Subclasses are used in the EER model to represent specialization and generalization. We call the relationship between a subclass and its superclass an **IS-A-SUBCLASS-OF** relationship, or simply an **IS-A** relationship. This is the same as the IS-A relationship discussed earlier in Section 4.5.3.

4.7.4 Aggregation and Association

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

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

In order to understand the different uses of aggregation better, consider the ER schema shown in Figure 4.11(a), which stores information about interviews by job applicants to various companies. The class COMPANY is an aggregation of the attributes (or component objects) Cname (company name) and Caddress (company address), whereas JOB_APPLICANT is an aggregate of Ssn, Name, Address, and Phone. The relationship attributes Contact_name and Contact_phone represent the name and phone number of the person in the company who is responsible for the interview. Suppose that some interviews result in job offers, whereas others do not. We would like to treat INTERVIEW as a class to associate it with JOB_OFFER. The schema shown in Figure 4.11(b) is *incorrect* because it requires each interview relationship instance to have a job offer. The schema shown in Figure 4.11(c) is *not allowed* because the ER model does not allow relationships among relationships.

One way to represent this situation is to create a higher-level aggregate class composed of COMPANY, JOB_APPLICANT, and INTERVIEW and to relate this class to JOB_OFFER, as shown in Figure 4.11(d). Although the EER model as described in this book does not have this facility, some semantic data models do allow it and call the resulting object a **composite** or **molecular object**. Other models treat entity types and relationship types uniformly and hence permit relationships among relationships, as illustrated in Figure 4.11(c).

To represent this situation correctly in the ER model as described here, we need to create a new weak entity type INTERVIEW, as shown in Figure 4.11(e), and relate it to JOB_OFFER. Hence, we can always represent these situations correctly in the ER model by creating additional entity types, although it may be conceptually more desirable to allow direct representation of aggregation, as in Figure 4.11(d), or to allow relationships among relationships, as in Figure 4.11(c).

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

4.7.5 Ontologies and the Semantic Web

In recent years, the amount of computerized data and information available on the Web has spiraled out of control. Many different models and formats are used. In addition to the database models that we present in this text, much information is stored in the form of **documents**, which have considerably less structure than

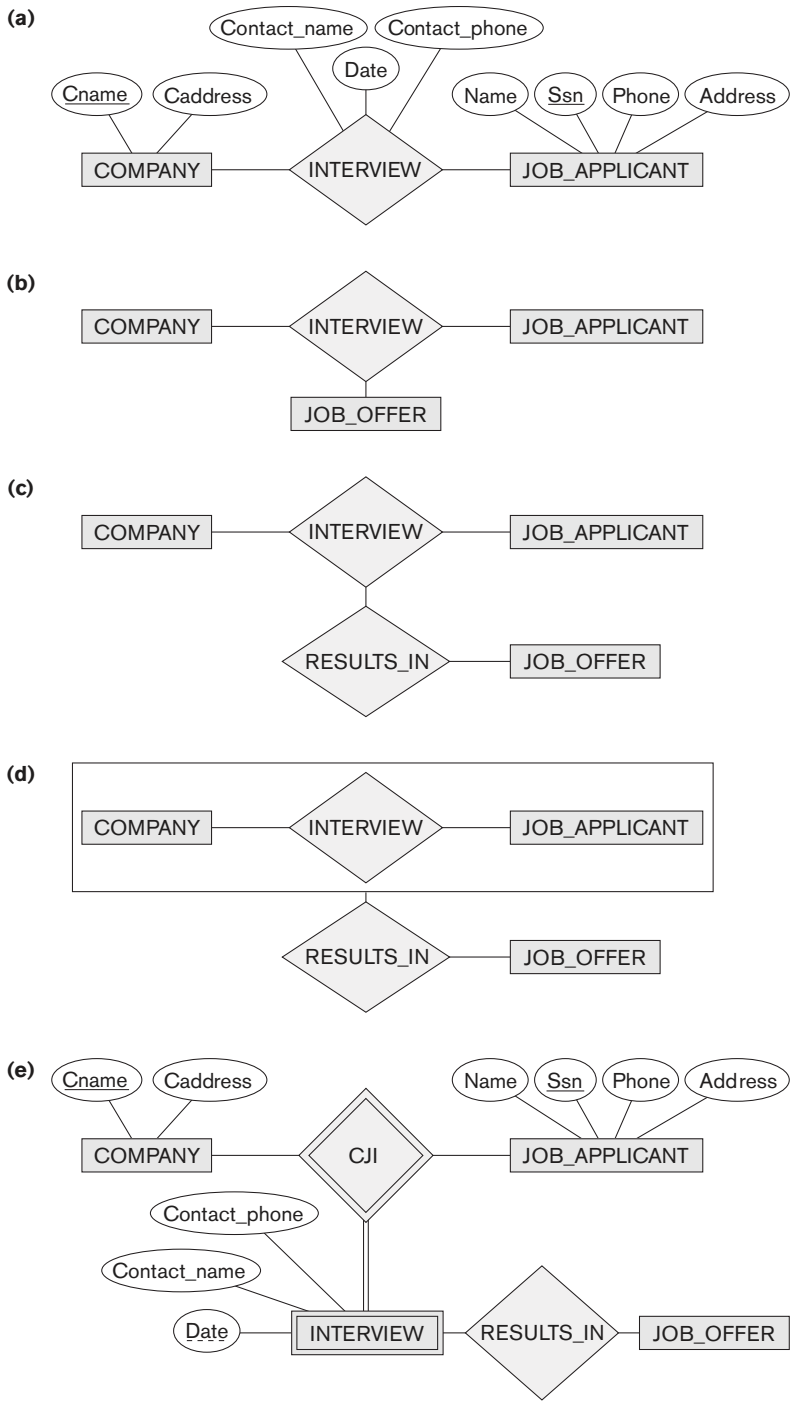


Figure 4.11
Aggregation. (a) The relationship type INTERVIEW. (b) Including JOB_OFFER in a ternary relationship type (incorrect). (c) Having the RESULTS_IN relationship participate in other relationships (not allowed in ER). (d) Using aggregation and a composite (molecular) object (generally not allowed in ER but allowed by some modeling tools). (e) Correct representation in ER.

database information does. One ongoing project that is attempting to allow information exchange among computers on the Web is called the **Semantic Web**, which attempts to create knowledge representation models that are quite general in order to allow meaningful information exchange and search among machines. The concept of *ontology* is considered to be the most promising basis for achieving the goals of the Semantic Web and is closely related to knowledge representation. In this section, we give a brief introduction to what ontology is and how it can be used as a basis to automate information understanding, search, and exchange.

The study of ontologies attempts to describe the concepts and relationships that are possible in reality through some common vocabulary; therefore, it can be considered as a way to describe the knowledge of a certain community about reality. Ontology originated in the fields of philosophy and metaphysics. One commonly used definition of **ontology** is *a specification* of a *conceptualization*.[13]

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

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

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

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

4.8 Summary

In this chapter we discussed extensions to the ER model that improve its representational capabilities. We called the resulting model the enhanced ER or EER model. We presented the concept of a subclass and its superclass and the related mechanism of attribute/relationship inheritance. We saw how it is sometimes necessary to create additional classes of entities, either because of additional specific attributes or because of specific relationship types. We discussed two main processes for defining superclass/subclass hierarchies and lattices: specialization and generalization.

Next, we showed how to display these new constructs in an EER diagram. We also discussed the various types of constraints that may apply to specialization or generalization. The two main constraints are total/partial and disjoint/overlapping. We discussed the concept of a category or union type, which is a subset of the union of two or more classes, and we gave formal definitions of all the concepts presented.

We introduced some of the notation and terminology of UML for representing specialization and generalization. In Section 4.7, we briefly discussed the discipline of knowledge representation and how it is related to semantic data modeling. We also gave an overview and summary of the types of abstract data representation concepts: classification and instantiation, identification, specialization and generalization, and aggregation and association. We saw how EER and UML concepts are related to each of these.

Review Questions

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

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

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

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

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

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

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

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

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

4.10. For each of the following UML terms (see Sections 3.8 and 4.6), discuss the corresponding term in the EER model, if any: *object*, *class*, *association*, *aggregation*, *generalization*, *multiplicity*, *attributes*, *discriminator*, *link*, *link attribute*, *reflexive association*, and *qualified association*.

4.11. Discuss the main differences between the notation for EER schema diagrams and UML class diagrams by comparing how common concepts are represented in each.

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

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

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

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

Exercises

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

4.17. Consider the BANK ER schema in Figure 3.21, and suppose that it is necessary to keep track of different types of ACCOUNTS (SAVINGS_ACCTS, CHECKING_ACCTS, …) and LOANS (CAR_LOANS, HOME_LOANS, …). Suppose that it is also desirable to keep track of each ACCOUNT's TRANSACTIONS (deposits, withdrawals, checks, …) and each LOAN's PAYMENTS; both of these include the amount, date, and time. Modify the BANK schema, using ER and EER concepts of specialization and generalization. State any assumptions you make about the additional requirements.

4.18. The following narrative describes a simplified version of the organization of Olympic facilities planned for the summer Olympics. Draw an EER diagram that shows the entity types, attributes, relationships, and specializations for this application. State any assumptions you make. The Olympic facilities are divided into sports complexes. Sports complexes are divided into *one-sport* and *multisport* types. Multisport complexes have areas of the complex designated for each sport with a location indicator (e.g., center, NE corner, and so

on). A complex has a location, chief organizing individual, total occupied area, and so on. Each complex holds a series of events (e.g., the track stadium may hold many different races). For each event there is a planned date, duration, number of participants, number of officials, and so on. A roster of all officials will be maintained together with the list of events each official will be involved in. Different equipment is needed for the events (e.g., goal posts, poles, parallel bars) as well as for maintenance. The two types of facilities (one-sport and multisport) will have different types of information. For each type, the number of facilities needed is kept, together with an approximate budget.

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

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

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

To become a member of the library, applicants fill out a form including their SSN, campus and home mailing addresses, and phone numbers. The librari-

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

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

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

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

- The museum has a collection of ART_OBJECTS. Each ART_OBJECT has a unique Id_no, an Artist (if known), a Year (when it was created, if known), a Title, and a Description. The art objects are categorized in several ways, as discussed below.
- ART_OBJECTS are categorized based on their type. There are three main types—PAINTING, SCULPTURE, and STATUE—plus another type called OTHER to accommodate objects that do not fall into one of the three main types.
- A PAINTING has a Paint_type (oil, watercolor, etc.), material on which it is Drawn_on (paper, canvas, wood, etc.), and Style (modern, abstract, etc.).
- A SCULPTURE or a statue has a Material from which it was created (wood, stone, etc.), Height, Weight, and Style.
- An art object in the OTHER category has a Type (print, photo, etc.) and Style.
- ART_OBJECTs are categorized as either PERMANENT_COLLECTION (objects that are owned by the museum) and BORROWED. Information captured about objects in the PERMANENT_COLLECTION includes Date_acquired, Status (on display, on loan, or stored), and Cost. Information

captured about BORROWED objects includes the Collection from which it was borrowed, Date_borrowed, and Date_returned.

- Information describing the country or culture of Origin (Italian, Egyptian, American, Indian, and so forth) and Epoch (Renaissance, Modern, Ancient, and so forth) is captured for each ART_OBJECT.
- The museum keeps track of ARTIST information, if known: Name, DateBorn (if known), Date_died (if not living), Country_of_origin, Epoch, Main_style, and Description. The Name is assumed to be unique.
- Different EXHIBITIONS occur, each having a Name, Start_date, and End_date. EXHIBITIONS are related to all the art objects that were on display during the exhibition.
- Information is kept on other COLLECTIONS with which the museum interacts; this information includes Name (unique), Type (museum, personal, etc.), Description, Address, Phone, and current Contact_person.

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

4.21. Figure 4.12 shows an example of an EER diagram for a small-private-airport database; the database is used to keep track of airplanes, their owners, airport employees, and pilots. From the requirements for this database, the following information was collected: Each AIRPLANE has a registration number [Reg#], is of a particular plane type [OF_TYPE], and is stored in a particular hangar [STORED_IN]. Each PLANE_TYPE has a model number [Model], a capacity [Capacity], and a weight [Weight]. Each HANGAR has a number [Number], a capacity [Capacity], and a location [Location]. The database also keeps track of the OWNERs of each plane [OWNS] and the EMPLOYEEs who have maintained the plane [MAINTAIN]. Each relationship instance in OWNS relates an AIRPLANE to an OWNER and includes the purchase date [Pdate]. Each relationship instance in MAINTAIN relates an EMPLOYEE to a service record [SERVICE]. Each plane undergoes service many times; hence, it is related by [PLANE_SERVICE] to a number of SERVICE records. A SERVICE record includes as attributes the date of maintenance [Date], the number of hours spent on the work [Hours], and the type of work done [Work_code]. We use a weak entity type [SERVICE] to represent airplane service, because the airplane registration number is used to identify a service record. An OWNER is either a person or a corporation. Hence, we use a union type (category) [OWNER] that is a subset of the union of corporation [CORPORATION] and person [PERSON] entity types. Both pilots [PILOT] and employees [EMPLOYEE] are subclasses of PERSON. Each PILOT has specific attributes license number [Lic_num] and restrictions [Restr]; each EMPLOYEE has specific attributes salary [Salary] and shift worked [Shift]. All PERSON entities in the database have data kept on their Social Security number [Ssn], name [Name], address [Address], and telephone number [Phone]. For CORPORATION entities, the data kept includes name [Name], address [Address], and telephone number [Phone]. The database also keeps track of the types of

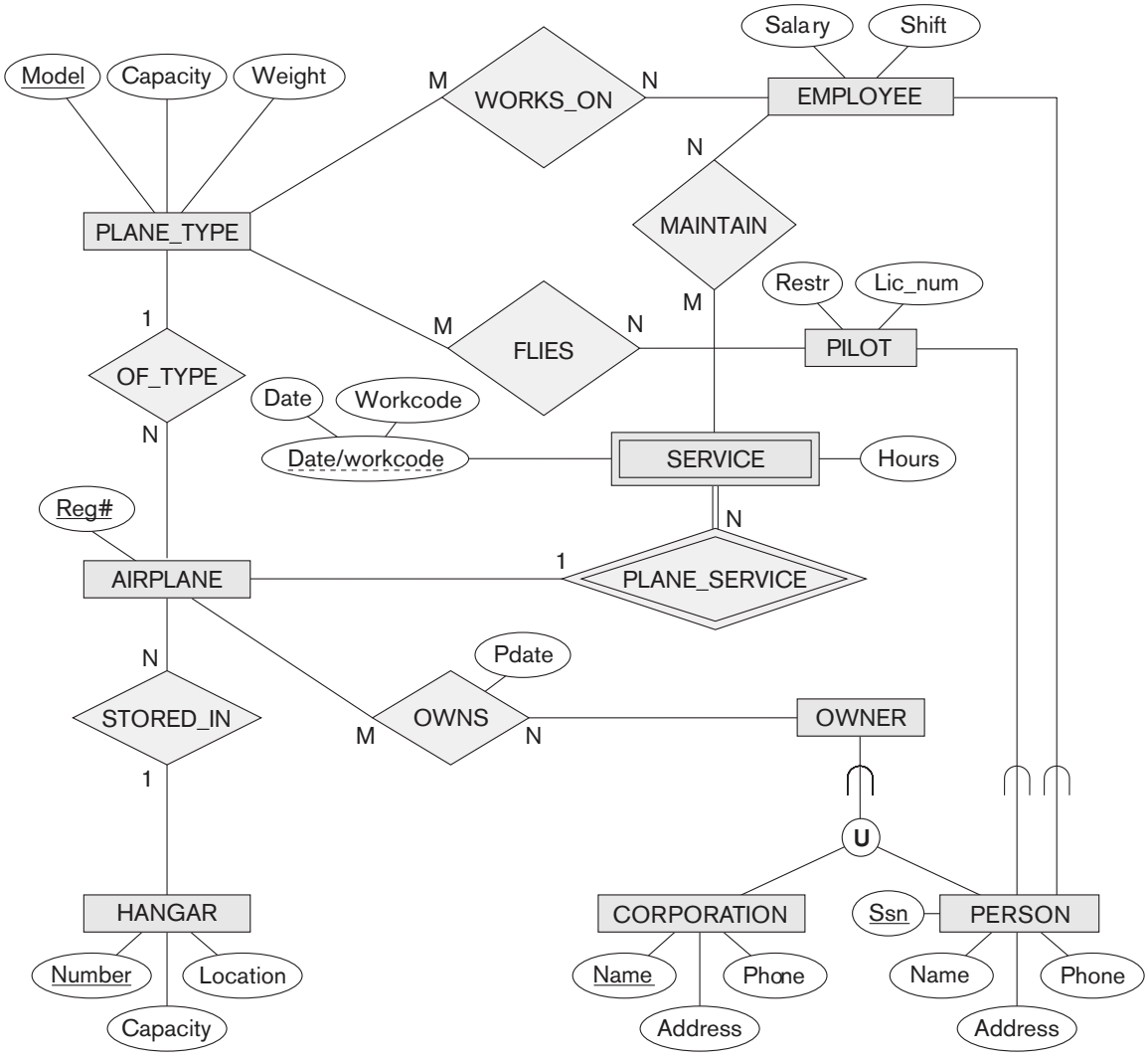


Figure 4.12
EER schema for a SMALL_AIRPORT database.

planes each pilot is authorized to fly [FLIES] and the types of planes each employee can do maintenance work on [WORKS_ON]. Show how the SMALL_AIRPORT EER schema in Figure 4.12 may be represented in UML notation. (*Note*: We have not discussed how to represent categories (union types) in UML, so you do not have to map the categories in this and the following question.)

4.22. Show how the UNIVERSITY EER schema in Figure 4.9 may be represented in UML notation.

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

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

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

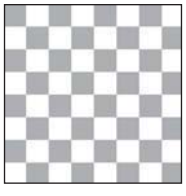
c. The left side is a specialization of the right side.

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

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

4.24. Draw a UML diagram for storing a played game of chess in a database. You may look at http://www.chessgames.com for an application similar to what you are designing. State clearly any assumptions you make in your UML diagram. A sample of assumptions you can make about the scope is as follows:

1. The game of chess is played between two players.
2. The game is played on an 8 × 8 board like the one shown below:



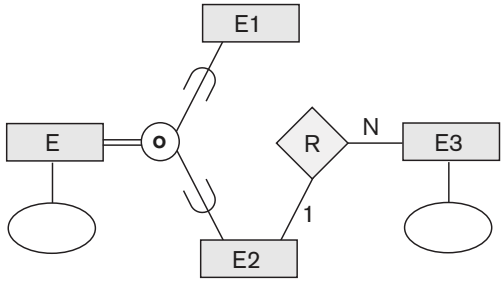
3. The players are assigned a color of black or white at the start of the game.
4. Each player starts with the following pieces (traditionally called chessmen):
   a. king
   b. queen
   c. 2 rooks
   d. 2 bishops
   e. 2 knights
   f. 8 pawns
5. Every piece has its own initial position.
6. Every piece has its own set of legal moves based on the state of the game. You do not need to worry about which moves are or are not legal except for the following issues:
   a. A piece may move to an empty square or capture an opposing piece.
   b. If a piece is captured, it is removed from the board.
   c. If a pawn moves to the last row, it is "promoted" by converting it to another piece (queen, rook, bishop, or knight).

   Note: Some of these functions may be spread over multiple classes.

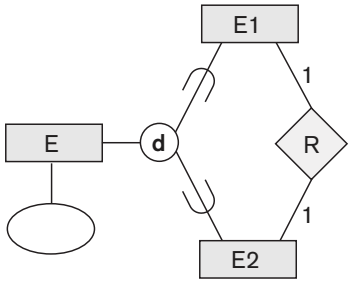
4.25. Draw an EER diagram for a game of chess as described in Exercise 4. 24. Focus on persistent storage aspects of the system. For example, the system would need to retrieve all the moves of every game played in sequential order.

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

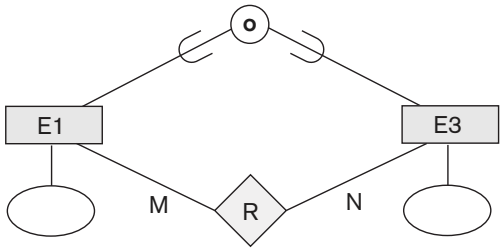
a.



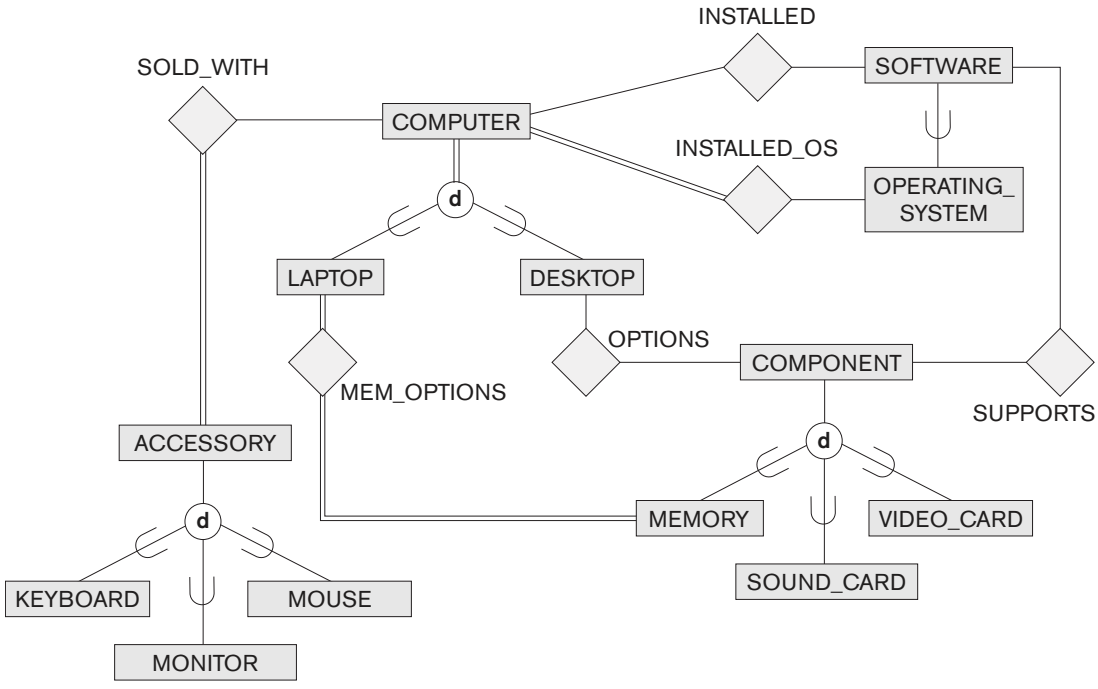
b.



c.



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



Laboratory Exercises

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

- Each student is identified by a unique identifier, first and last name, and an e-mail address.
- Each instructor teaches certain courses each term. Each course is identified by a course number, a section number, and the term in which it is taught. For

each course he or she teaches, the instructor specifies the minimum number of points required in order to earn letter grades A, B, C, D, and F. For example, 90 points for an A, 80 points for a B, 70 points for a C, and so forth.

- Students are enrolled in each course taught by the instructor.
- Each course has a number of grading components (such as midterm exam, final exam, project, and so forth). Each grading component has a maximum number of points (such as 100 or 50) and a weight (such as 20% or 10%). The weights of all the grading components of a course usually total 100.
- Finally, the instructor records the points earned by each student in each of the grading components in each of the courses. For example, student 1234 earns 84 points for the midterm exam grading component of the section 2 course CSc2310 in the fall term of 2009. The midterm exam grading component may have been defined to have a maximum of 100 points and a weight of 20% of the course grade.

Design an enhanced entity–relationship diagram for the grade book database and build the design using a data modeling tool such as ERwin or Rational Rose.

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

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

Design an enhanced entity–relationship diagram for the ONLINE_AUCTION database and build the design using a data modeling tool such as ERwin or Rational Rose.

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

- The personnel involved in the league include players, coaches, managers, and umpires. Each is identified by a unique personnel id. They are also described by their first and last names along with the date and place of birth.
- Players are further described by other attributes such as their batting orientation (left, right, or switch) and have a lifetime batting average (BA).
- Within the players group is a subset of players called pitchers. Pitchers have a lifetime ERA (earned run average) associated with them.
- Teams are uniquely identified by their names. Teams are also described by the city in which they are located and the division and league in which they play (such as Central division of the American League).
- Teams have one manager, a number of coaches, and a number of players.
- Games are played between two teams, with one designated as the home team and the other the visiting team on a particular date. The score (runs, hits, and errors) is recorded for each team. The team with the most runs is declared the winner of the game.
- With each finished game, a winning pitcher and a losing pitcher are recorded. In case there is a save awarded, the save pitcher is also recorded.
- With each finished game, the number of hits (singles, doubles, triples, and home runs) obtained by each player is also recorded.

Design an enhanced entity–relationship diagram for the BASEBALL database and enter the design using a data modeling tool such as ERwin or Rational Rose.

4.31. Consider the EER diagram for the UNIVERSITY database shown in Figure 4.9. Enter this design using a data modeling tool such as ERwin or Rational Rose. Make a list of the differences in notation between the diagram in the text and the corresponding equivalent diagrammatic notation you end up using with the tool.

4.32. Consider the EER diagram for the small AIRPORT database shown in Figure 4.12. Build this design using a data modeling tool such as ERwin or Rational Rose. Be careful how you model the category OWNER in this diagram. (*Hint*: Consider using CORPORATION_IS_OWNER and PERSON_IS_ OWNER as two distinct relationship types.)

4.33. Consider the UNIVERSITY database described in Exercise 3.16. You already developed an ER schema for this database using a data modeling tool such as

ERwin or Rational Rose in Lab Exercise 3.31. Modify this diagram by classifying COURSES as either UNDERGRAD_COURSES or GRAD_COURSES and INSTRUCTORS as either JUNIOR_PROFESSORS or SENIOR_PROFESSORS. Include appropriate attributes for these new entity types. Then establish relationships indicating that junior instructors teach undergraduate courses whereas senior instructors teach graduate courses.

Selected Bibliography

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

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

A survey of semantic data modeling appears in Hull and King (1987). Eick (1991) discusses design and transformations of conceptual schemas. Analysis of constraints for *n*-ary relationships is given in Soutou (1998). UML is described in detail in Booch, Rumbaugh, and Jacobson (1999). Fowler and Scott (2000) and Stevens and Pooley (2000) give concise introductions to UML concepts.

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

part 3

The Relational Data Model and SQL

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chapter 5

The Relational Data Model and Relational Database Constraints

This chapter opens Part 3 of the book, which covers relational databases. The relational data model was first introduced by Ted Codd of IBM Research in 1970 in a classic paper (Codd, 1970), and it attracted immediate attention due to its simplicity and mathematical foundation. The model uses the concept of a *mathematical relation*—which looks somewhat like a table of values—as its basic building block, and has its theoretical basis in set theory and first-order predicate logic. In this chapter we discuss the basic characteristics of the model and its constraints.

The first commercial implementations of the relational model became available in the early 1980s, such as the SQL/DS system on the MVS operating system by IBM and the Oracle DBMS. Since then, the model has been implemented in a large number of commercial systems, as well as a number of open source systems. Current popular commercial relational DBMSs (RDBMSs) include DB2 (from IBM), Oracle (from Oracle), Sybase DBMS (now from SAP), and SQLServer and Microsoft Access (from Microsoft). In addition, several open source systems, such as MySQL and PostgreSQL, are available.

Because of the importance of the relational model, all of Part 2 is devoted to this model and some of the languages associated with it. In Chapters 6 and 7, we describe some aspects of SQL, which is a comprehensive model and language that is the *standard* for commercial relational DBMSs. (Additional aspects of SQL will be covered in other chapters.) Chapter 8 covers the operations of the relational algebra and introduces the relational calculus—these are two formal languages associated with the relational model. The relational calculus is considered to be the basis for the SQL language, and the relational algebra is used in the internals of many database implementations for query processing and optimization (see Part 8 of the book).

Other features of the relational model are presented in subsequent parts of the book. Chapter 9 relates the relational model data structures to the constructs of the ER and EER models (presented in Chapters 3 and 4), and presents algorithms for designing a relational database schema by mapping a conceptual schema in the ER or EER model into a relational representation. These mappings are incorporated into many database design and CASE[1] tools. Chapters 10 and 11 in Part 4 discuss the programming techniques used to access database systems and the notion of connecting to relational databases via ODBC and JDBC standard protocols. We also introduce the topic of Web database programming in Chapter 11. Chapters 14 and 15 in Part 6 present another aspect of the relational model, namely the formal constraints of functional and multivalued dependencies; these dependencies are used to develop a relational database design theory based on the concept known as *normalization*.

In this chapter, we concentrate on describing the basic principles of the relational model of data. We begin by defining the modeling concepts and notation of the relational model in Section 5.1. Section 5.2 is devoted to a discussion of relational constraints that are considered an important part of the relational model and are automatically enforced in most relational DBMSs. Section 5.3 defines the update operations of the relational model, discusses how violations of integrity constraints are handled, and introduces the concept of a transaction. Section 5.4 summarizes the chapter.

This chapter and Chapter 8 focus on the formal foundations of the relational model, whereas Chapters 6 and 7 focus on the SQL practical relational model, which is the basis of most commercial and open source relational DBMSs. Many concepts are common between the formal and practical models, but a few differences exist that we shall point out.

5.1 Relational Model Concepts

The relational model represents the database as a collection of *relations*. Informally, each relation resembles a table of values or, to some extent, a *flat* file of records. It is called a **flat file** because each record has a simple linear or *flat* structure. For example, the database of files that was shown in Figure 1.2 is similar to the basic relational model representation. However, there are important differences between relations and files, as we shall soon see.

When a relation is thought of as a **table** of values, each row in the table represents a collection of related data values. A row represents a fact that typically corresponds to a real-world entity or relationship. The table name and column names are used to help to interpret the meaning of the values in each row. For example, the first table of Figure 1.2 is called STUDENT because each row represents facts about a particular student entity. The column names—Name, Student_number,

[1]CASE stands for computer-aided software engineering.

Class, and Major—specify how to interpret the data values in each row, based on the column each value is in. All values in a column are of the same data type.

In the formal relational model terminology, a row is called a *tuple,* a column header is called an *attribute,* and the table is called a *relation.* The data type describing the types of values that can appear in each column is represented by a *domain* of possible values. We now define these terms—*domain, tuple, attribute,* and *relation*—formally.

5.1.1 Domains, Attributes, Tuples, and Relations

A **domain** *D* is a set of atomic values. By **atomic** we mean that each value in the domain is indivisible as far as the formal relational model is concerned. A common method of specifying a domain is to specify a data type from which the data values forming the domain are drawn. It is also useful to specify a name for the domain, to help in interpreting its values. Some examples of domains follow:

- Usa_phone_numbers. The set of ten-digit phone numbers valid in the United States.
- Local_phone_numbers. The set of seven-digit phone numbers valid within a particular area code in the United States. The use of local phone numbers is quickly becoming obsolete, being replaced by standard ten-digit numbers.
- Social_security_numbers. The set of valid nine-digit Social Security numbers. (This is a unique identifier assigned to each person in the United States for employment, tax, and benefits purposes.)
- Names: The set of character strings that represent names of persons.
- Grade_point_averages. Possible values of computed grade point averages; each must be a real (floating-point) number between 0 and 4.
- Employee_ages. Possible ages of employees in a company; each must be an integer value between 15 and 80.
- Academic_department_names. The set of academic department names in a university, such as Computer Science, Economics, and Physics.
- Academic_department_codes. The set of academic department codes, such as 'CS', 'ECON', and 'PHYS'.

The preceding are called *logical* definitions of domains. A **data type** or **format** is also specified for each domain. For example, the data type for the domain Usa_phone_numbers can be declared as a character string of the form (*ddd*)*ddd-dddd*, where each *d* is a numeric (decimal) digit and the first three digits form a valid telephone area code. The data type for Employee_ages is an integer number between 15 and 80. For Academic_department_names, the data type is the set of all character strings that represent valid department names. A domain is thus given a name, data type, and format. Additional information for interpreting the values of a domain can also be given; for example, a numeric domain such as Person_weights should have the units of measurement, such as pounds or kilograms.

A **relation schema**[2] R, denoted by $R(A_1, A_2, \ldots, A_n)$, is made up of a relation name R and a list of attributes, $A_1, A_2, \ldots, A_n$. Each **attribute** A_i is the name of a role played by some domain D in the relation schema R. D is called the **domain** of A_i and is denoted by **dom**(A_i). A relation schema is used to *describe* a relation; R is called the **name** of this relation. The **degree** (or **arity**) of a relation is the number of attributes n of its relation schema.

A relation of degree seven, which stores information about university students, would contain seven attributes describing each student as follows:

STUDENT(Name, Ssn, Home_phone, Address, Office_phone, Age, Gpa)

Using the data type of each attribute, the definition is sometimes written as:

STUDENT(Name: string, Ssn: string, Home_phone: string, Address: string, Office_phone: string, Age: integer, Gpa: real)

For this relation schema, STUDENT is the name of the relation, which has seven attributes. In the preceding definition, we showed assignment of generic types such as string or integer to the attributes. More precisely, we can specify the following previously defined domains for some of the attributes of the STUDENT relation: dom(Name) = Names; dom(Ssn) = Social_security_numbers; dom(HomePhone) = USA_phone_numbers[3], dom(Office_phone) = USA_phone_numbers, and dom(Gpa) = Grade_point_averages. It is also possible to refer to attributes of a relation schema by their position within the relation; thus, the second attribute of the STUDENT relation is Ssn, whereas the fourth attribute is Address.

A **relation** (or **relation state**)[4] r of the relation schema $R(A_1, A_2, \ldots, A_n)$, also denoted by $r(R)$, is a set of n-tuples $r = \{t_1, t_2, \ldots, t_m\}$. Each n-**tuple** t is an ordered list of n values $t = \langle v_1, v_2, \ldots, v_n \rangle$, where each value v_i, $1 \leq i \leq n$, is an element of dom (A_i) or is a special NULL value. (NULL values are discussed further below and in Section 5.1.2.) The ith value in tuple t, which corresponds to the attribute A_i, is referred to as $t[A_i]$ or $t.A_i$ (or $t[i]$ if we use the positional notation). The terms **relation intension** for the schema R and **relation extension** for a relation state $r(R)$ are also commonly used.

Figure 5.1 shows an example of a STUDENT relation, which corresponds to the STUDENT schema just specified. Each tuple in the relation represents a particular student entity (or object). We display the relation as a table, where each tuple is shown as a *row* and each attribute corresponds to a *column header* indicating a role or interpretation of the values in that column. *NULL values* represent attributes whose values are unknown or do not exist for some individual STUDENT tuple.

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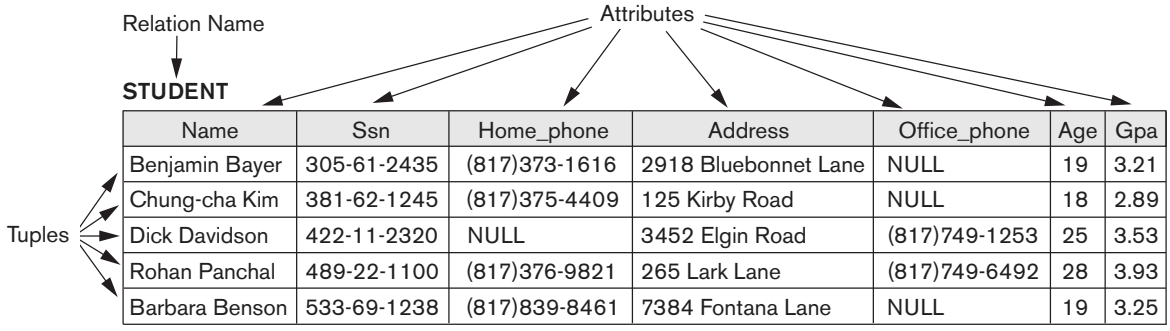
[2]A relation schema is sometimes called a **relation scheme**.

[3]With the large increase in phone numbers caused by the proliferation of mobile phones, most metropolitan areas in the United States now have multiple area codes, so seven-digit local dialing has been discontinued in most areas. We changed this domain to Usa_phone_numbers instead of Local_phone_numbers, which would be a more general choice. This illustrates how database requirements can change over time.

[4]This has also been called a **relation instance**. We will not use this term because *instance* is also used to refer to a single tuple or row.



Name	Ssn	Home_phone	Address	Office_phone	Age	Gpa
Benjamin Bayer	305-61-2435	(817)373-1616	2918 Bluebonnet Lane	NULL	19	3.21
Chung-cha Kim	381-62-1245	(817)375-4409	125 Kirby Road	NULL	18	2.89
Dick Davidson	422-11-2320	NULL	3452 Elgin Road	(817)749-1253	25	3.53
Rohan Panchal	489-22-1100	(817)376-9821	265 Lark Lane	(817)749-6492	28	3.93
Barbara Benson	533-69-1238	(817)839-8461	7384 Fontana Lane	NULL	19	3.25

Figure 5.1
The attributes and tuples of a relation STUDENT.

The earlier definition of a relation can be *restated* more formally using set theory concepts as follows. A relation (or relation state) $r(R)$ is a **mathematical relation** of degree n on the domains $\text{dom}(A_1)$, $\text{dom}(A_2)$, … , $\text{dom}(A_n)$, which is a **subset** of the **Cartesian product** (denoted by ×) of the domains that define R:

$$r(R) \subseteq (\text{dom}(A_1) \times \text{dom}(A_2) \times \ldots \times (\text{dom}(A_n))$$

The Cartesian product specifies all possible combinations of values from the underlying domains. Hence, if we denote the total number of values, or **cardinality,** in a domain D by $|D|$ (assuming that all domains are finite), the total number of tuples in the Cartesian product is

$$|\text{dom}(A_1)| \times |\text{dom}(A_2)| \times \ldots \times |\text{dom}(A_n)|$$

This product of cardinalities of all domains represents the total number of possible instances or tuples that can ever exist in any relation state $r(R)$. Of all these possible combinations, a relation state at a given time—the **current relation state**—reflects only the valid tuples that represent a particular state of the real world. In general, as the state of the real world changes, so does the relation state, by being transformed into another relation state. However, the schema R is relatively static and changes *very* infrequently—for example, as a result of adding an attribute to represent new information that was not originally stored in the relation.

It is possible for several attributes to *have the same domain.* The attribute names indicate different **roles**, or interpretations, for the domain. For example, in the STUDENT relation, the same domain USA_phone_numbers plays the role of Home_phone, referring to the *home phone of a student*, and the role of Office_phone, referring to the *office phone of the student*. A third possible attribute (not shown) with the same domain could be Mobile_phone.

5.1.2 Characteristics of Relations

The earlier definition of relations implies certain characteristics that make a relation different from a file or a table. We now discuss some of these characteristics.

Ordering of Tuples in a Relation. A relation is defined as a *set* of tuples. Mathematically, elements of a set have *no order* among them; hence, tuples in a relation do not have any particular order. In other words, a relation is not sensitive to the ordering of tuples. However, in a file, records are physically stored on disk (or in memory), so there always is an order among the records. This ordering indicates first, second, *i*th, and last records in the file. Similarly, when we display a relation as a table, the rows are displayed in a certain order.

Tuple ordering is not part of a relation definition because a relation attempts to represent facts at a logical or abstract level. Many tuple orders can be specified on the same relation. For example, tuples in the STUDENT relation in Figure 5.1 could be ordered by values of Name, Ssn, Age, or some other attribute. The definition of a relation does not specify any order: There is *no preference* for one ordering over another. Hence, the relation displayed in Figure 5.2 is considered *identical* to the one shown in Figure 5.1. When a relation is implemented as a file or displayed as a table, a particular ordering may be specified on the records of the file or the rows of the table.

Ordering of Values within a Tuple and an Alternative Definition of a Relation. According to the preceding definition of a relation, an n-tuple is an *ordered list* of n values, so the ordering of values in a tuple—and hence of attributes in a relation schema—is important. However, at a more abstract level, the order of attributes and their values is *not* that important as long as the correspondence between attributes and values is maintained.

An **alternative definition** of a relation can be given, making the ordering of values in a tuple *unnecessary*. In this definition, a relation schema $R = \{A_1, A_2, \ldots, A_n\}$ is a *set* of attributes (instead of an ordered list of attributes), and a relation state $r(R)$ is a finite set of mappings $r = \{t_1, t_2, \ldots, t_m\}$, where each tuple t_i is a **mapping** from R to D, and D is the **union** (denoted by $\cup$) of the attribute domains; that is, $D = \text{dom}(A_1) \cup \text{dom}(A_2) \cup \ldots \cup \text{dom}(A_n)$. In this definition, $t[A_i]$ must be in $\text{dom}(A_i)$ for $1 \leq i \leq n$ for each mapping t in r. Each mapping t_i is called a tuple.

According to this definition of tuple as a mapping, a **tuple** can be considered as a **set** of (<attribute>, <value>) pairs, where each pair gives the value of the mapping from an attribute A_i to a value v_i from $\text{dom}(A_i)$. The ordering of attributes is *not* important, because the *attribute name* appears with its *value*. By this definition, the

Figure 5.2
The relation STUDENT from Figure 5.1 with a different order of tuples.

STUDENT

Name	Ssn	Home_phone	Address	Office_phone	Age	Gpa
Dick Davidson	422-11-2320	NULL	3452 Elgin Road	(817)749-1253	25	3.53
Barbara Benson	533-69-1238	(817)839-8461	7384 Fontana Lane	NULL	19	3.25
Rohan Panchal	489-22-1100	(817)376-9821	265 Lark Lane	(817)749-6492	28	3.93
Chung-cha Kim	381-62-1245	(817)375-4409	125 Kirby Road	NULL	18	2.89
Benjamin Bayer	305-61-2435	(817)373-1616	2918 Bluebonnet Lane	NULL	19	3.21

$t = <$ (Name, Dick Davidson),(Ssn, 422-11-2320),(Home_phone, NULL),(Address, 3452 Elgin Road),
(Office_phone, (817)749-1253),(Age, 25),(Gpa, 3.53)>

$t = <$ (Address, 3452 Elgin Road),(Name, Dick Davidson),(Ssn, 422-11-2320),(Age, 25),
(Office_phone, (817)749-1253),(Gpa, 3.53),(Home_phone, NULL)>

Figure 5.3
Two identical tuples when the order of attributes and values is not part of relation definition.

two tuples shown in Figure 5.3 are identical. This makes sense at an abstract level, since there really is no reason to prefer having one attribute value appear before another in a tuple. When the attribute name and value are included together in a tuple, it is known as **self-describing data**, because the description of each value (attribute name) is included in the tuple.

We will mostly use the **first definition** of relation, where the attributes are *ordered* in the relation schema and the values within tuples *are similarly ordered,* because it simplifies much of the notation. However, the alternative definition given here is more general.[5]

Values and NULLs in the Tuples. Each value in a tuple is an **atomic** value; that is, it is not divisible into components within the framework of the basic relational model. Hence, composite and multivalued attributes (see Chapter 3) are not allowed. This model is sometimes called the **flat relational model**. Much of the theory behind the relational model was developed with this assumption in mind, which is called the **first normal form** assumption.[6] Hence, multivalued attributes must be represented by separate relations, and composite attributes are represented only by their simple component attributes in the basic relational model.[7]

An important concept is that of NULL values, which are used to represent the values of attributes that may be unknown or may not apply to a tuple. A special value, called NULL, is used in these cases. For example, in Figure 5.1, some STUDENT tuples have NULL for their office phones because they do not have an office (that is, office phone *does not apply* to these students). Another student has a NULL for home phone, presumably because either he does not have a home phone or he has one but we do not know it (value is *unknown*). In general, we can have several meanings for NULL values, such as ***value unknown,*** **value** exists but is ***not available***, or ***attribute does not apply*** to this tuple (also known as ***value undefined***). An example of the last type of NULL will occur if we add an attribute Visa_status to the STUDENT relation that applies only to tuples representing foreign students. It is possible to devise different codes for different meanings of

[5]We will use the alternative definition of relation when we discuss query processing and optimization in Chapter 18.

[6]We discuss this assumption in more detail in Chapter 14.

[7]Extensions of the relational model remove these restrictions. For example, object-relational systems (Chapter 12) allow complex-structured attributes, as do the **non-first normal form** or **nested** relational models.

NULL values. Incorporating different types of NULL values into relational model operations has proven difficult and is outside the scope of our presentation.

The exact meaning of a NULL value governs how it fares during arithmetic aggregations or comparisons with other values. For example, a comparison of two NULL values leads to ambiguities—if both Customer A and B have NULL addresses, it *does not mean* they have the same address. During database design, it is best to avoid NULL values as much as possible. We will discuss this further in Chapters 7 and 8 in the context of operations and queries, and in Chapter 14 in the context of database design and normalization.

Interpretation (Meaning) of a Relation. The relation schema can be interpreted as a declaration or a type of **assertion**. For example, the schema of the STUDENT relation of Figure 5.1 asserts that, in general, a student entity has a Name, Ssn, Home_phone, Address, Office_phone, Age, and Gpa. Each tuple in the relation can then be interpreted as a **fact** or a particular instance of the assertion. For example, the first tuple in Figure 5.1 asserts the fact that there is a STUDENT whose Name is Benjamin Bayer, Ssn is 305-61-2435, Age is 19, and so on.

Notice that some relations may represent facts about *entities,* whereas other relations may represent facts about *relationships.* For example, a relation schema MAJORS (Student_ssn, Department_code) asserts that students major in academic disciplines. A tuple in this relation relates a student to his or her major discipline. Hence, the relational model represents facts about both entities and relationships *uniformly* as relations. This sometimes compromises understandability because one has to guess whether a relation represents an entity type or a relationship type. We introduced the entity–relationship (ER) model in detail in Chapter 3, where the entity and relationship concepts were described in detail. The mapping procedures in Chapter 9 show how different constructs of the ER/EER conceptual data models (see Part 2) get converted to relations.

An alternative interpretation of a relation schema is as a **predicate**; in this case, the values in each tuple are interpreted as values that *satisfy* the predicate. For example, the predicate STUDENT (Name, Ssn, …) is true for the five tuples in relation STUDENT of Figure 5.1. These tuples represent five different propositions or facts in the real world. This interpretation is quite useful in the context of logical programming languages, such as Prolog, because it allows the relational model to be used within these languages (see Section 26.5). An assumption called **the closed world assumption** states that the only true facts in the universe are those present within the extension (state) of the relation(s). Any other combination of values makes the predicate false. This interpretation is useful when we consider queries on relations based on relational calculus in Section 8.6.

5.1.3 Relational Model Notation

We will use the following notation in our presentation:

- A relation schema R of degree n is denoted by $R(A_1, A_2, \ldots, A_n)$.

- The uppercase letters Q, R, S denote relation names.
- The lowercase letters q, r, s denote relation states.
- The letters t, u, v denote tuples.
- In general, the name of a relation schema such as STUDENT also indicates the current set of tuples in that relation—the *current relation state*—whereas STUDENT(Name, Ssn, …) refers *only* to the relation schema.
- An attribute A can be qualified with the relation name R to which it belongs by using the dot notation $R.A$—for example, STUDENT.Name or STUDENT.Age. This is because the same name may be used for two attributes in different relations. However, all attribute names *in a particular relation* must be distinct.
- An n-tuple t in a relation $r(R)$ is denoted by $t = <v_1, v_2, \ldots, v_n>$, where v_i is the value corresponding to attribute A_i. The following notation refers to **component values** of tuples:
  - Both $t[A_i]$ and $t.A_i$ (and sometimes $t[i]$) refer to the value v_i in t for attribute A_i.
  - Both $t[A_u, A_w, \ldots, A_z]$ and $t.(A_u, A_w, \ldots, A_z)$, where $A_u, A_w, \ldots, A_z$ is a list of attributes from R, refer to the subtuple of values $<v_u, v_w, \ldots, v_z>$ from t corresponding to the attributes specified in the list.

As an example, consider the tuple t = <'Barbara Benson', '533-69-1238', '(817)839-8461', '7384 Fontana Lane', NULL, 19, 3.25> from the STUDENT relation in Figure 5.1; we have t[Name] = <'Barbara Benson'>, and t[Ssn, Gpa, Age] = <'533-69-1238', 3.25, 19>.

5.2 Relational Model Constraints and Relational Database Schemas

So far, we have discussed the characteristics of single relations. In a relational database, there will typically be many relations, and the tuples in those relations are usually related in various ways. The state of the whole database will correspond to the states of all its relations at a particular point in time. There are generally many restrictions or **constraints** on the actual values in a database state. These constraints are derived from the rules in the miniworld that the database represents, as we discussed in Section 1.6.8.

In this section, we discuss the various restrictions on data that can be specified on a relational database in the form of constraints. Constraints on databases can generally be divided into three main categories:

1. Constraints that are inherent in the data model. We call these **inherent model-based constraints** or **implicit constraints**.
2. Constraints that can be directly expressed in the schemas of the data model, typically by specifying them in the DDL (data definition language, see Section 2.3.1). We call these **schema-based constraints** or **explicit constraints**.

3. Constraints that *cannot* be directly expressed in the schemas of the data model, and hence must be expressed and enforced by the application programs or in some other way. We call these **application-based** or **semantic constraints** or **business rules**.

The characteristics of relations that we discussed in Section 5.1.2 are the inherent constraints of the relational model and belong to the first category. For example, the constraint that a relation cannot have duplicate tuples is an inherent constraint. The constraints we discuss in this section are of the second category, namely, constraints that can be expressed in the schema of the relational model via the DDL. Constraints in the third category are more general, relate to the meaning as well as behavior of attributes, and are difficult to express and enforce within the data model, so they are usually checked within the application programs that perform database updates. In some cases, these constraints can be specified as **assertions** in SQL (see Chapter 7).

Another important category of constraints is *data dependencies*, which include *functional dependencies* and *multivalued dependencies*. They are used mainly for testing the "goodness" of the design of a relational database and are utilized in a process called *normalization*, which is discussed in Chapters 14 and 15.

The schema-based constraints include domain constraints, key constraints, constraints on NULLs, entity integrity constraints, and referential integrity constraints.

5.2.1 Domain Constraints

Domain constraints specify that within each tuple, the value of each attribute A must be an atomic value from the domain dom(A). We have already discussed the ways in which domains can be specified in Section 5.1.1. The data types associated with domains typically include standard numeric data types for integers (such as short integer, integer, and long integer) and real numbers (float and double-precision float). Characters, Booleans, fixed-length strings, and variable-length strings are also available, as are date, time, timestamp, and other special data types. Domains can also be described by a subrange of values from a data type or as an enumerated data type in which all possible values are explicitly listed. Rather than describe these in detail here, we discuss the data types offered by the SQL relational standard in Section 6.1.

5.2.2 Key Constraints and Constraints on NULL Values

In the formal relational model, a *relation* is defined as a *set of tuples.* By definition, all elements of a set are distinct; hence, all tuples in a relation must also be distinct. This means that no two tuples can have the same combination of values for *all* their attributes. Usually, there are other **subsets of attributes** of a relation schema R with the property that no two tuples in any relation state r of R should have the same combination of values for these attributes. Suppose that we denote one such subset of attributes by SK; then for any two *distinct* tuples t_1 and t_2 in a relation state r of R, we have the constraint that:

$$t_1[\text{SK}] \neq t_2[\text{SK}]$$

Any such set of attributes SK is called a **superkey** of the relation schema *R*. A superkey SK specifies a *uniqueness constraint* that no two distinct tuples in any state *r* of *R* can have the same value for SK. Every relation has at least one default superkey—the set of all its attributes. A superkey can have redundant attributes, however, so a more useful concept is that of a *key,* which has no redundancy. A **key** *k* of a relation schema *R* is a superkey of *R* with the additional property that removing any attribute *A* from *K* leaves a set of attributes *K′* that is not a superkey of *R* any more. Hence, a key satisfies two properties:

1. Two distinct tuples in any state of the relation cannot have identical values for (all) the attributes in the key. This *uniqueness* property also applies to a superkey.
2. It is a *minimal superkey*—that is, a superkey from which we cannot remove any attributes and still have the uniqueness constraint hold. This *minimality* property is required for a key but is optional for a superkey.

Hence, a key is a superkey but not vice versa. A superkey may be a key (if it is minimal) or may not be a key (if it is not minimal). Consider the STUDENT relation of Figure 5.1. The attribute set {Ssn} is a key of STUDENT because no two student tuples can have the same value for Ssn.[8] Any set of attributes that includes Ssn—for example, {Ssn, Name, Age}—is a superkey. However, the superkey {Ssn, Name, Age} is not a key of STUDENT because removing Name or Age or both from the set still leaves us with a superkey. In general, any superkey formed from a single attribute is also a key. A key with multiple attributes must require *all* its attributes together to have the uniqueness property.

The value of a key attribute can be used to identify uniquely each tuple in the relation. For example, the Ssn value 305-61-2435 identifies uniquely the tuple corresponding to Benjamin Bayer in the STUDENT relation. Notice that a set of attributes constituting a key is a property of the relation schema; it is a constraint that should hold on *every* valid relation state of the schema. A key is determined from the meaning of the attributes, and the property is *time-invariant:* It must continue to hold when we insert new tuples in the relation. For example, we cannot and should not designate the Name attribute of the STUDENT relation in Figure 5.1 as a key because it is possible that two students with identical names will exist at some point in a valid state.[9]

In general, a relation schema may have more than one key. In this case, each of the keys is called a **candidate key**. For example, the CAR relation in Figure 5.4 has two candidate keys: License_number and Engine_serial_number. It is common to designate one of the candidate keys as the **primary key** of the relation. This is the candidate key whose values are used to *identify* tuples in the relation. We use the convention that the attributes that form the primary key of a relation schema are underlined, as shown in Figure 5.4. Notice that when a relation schema has several candidate keys,

[8]Note that Ssn is also a superkey.

[9]Names are sometimes used as keys, but then some artifact—such as appending an ordinal number—must be used to distinguish between persons with identical names.

CAR

License_number	Engine_serial_number	Make	Model	Year
Texas ABC-739	A69352	Ford	Mustang	02
Florida TVP-347	B43696	Oldsmobile	Cutlass	05
New York MPO-22	X83554	Oldsmobile	Delta	01
California 432-TFY	C43742	Mercedes	190-D	99
California RSK-629	Y82935	Toyota	Camry	04
Texas RSK-629	U028365	Jaguar	XJS	04

Figure 5.4
The CAR relation, with two candidate keys: License_number and Engine_serial_number.

the choice of one to become the primary key is somewhat arbitrary; however, it is usually better to choose a primary key with a single attribute or a small number of attributes. The other candidate keys are designated as **unique keys** and are not underlined.

Another constraint on attributes specifies whether NULL values are or are not permitted. For example, if every STUDENT tuple must have a valid, non-NULL value for the Name attribute, then Name of STUDENT is constrained to be NOT NULL.

5.2.3 Relational Databases and Relational Database Schemas

The definitions and constraints we have discussed so far apply to single relations and their attributes. A relational database usually contains many relations, with tuples in relations that are related in various ways. In this section, we define a relational database and a relational database schema.

A **relational database schema** S is a set of relation schemas $S = \{R_1, R_2, \ldots, R_m\}$ and a set of **integrity constraints** IC. A **relational database state**[10] DB of S is a set of relation states DB $= \{r_1, r_2, \ldots, r_m\}$ such that each r_i is a state of R_i and such that the r_i relation states satisfy the integrity constraints specified in IC. Figure 5.5 shows a relational database schema that we call COMPANY = {EMPLOYEE, DEPARTMENT, DEPT_LOCATIONS, PROJECT, WORKS_ON, DEPENDENT}. In each relation schema, the underlined attribute represents the primary key. Figure 5.6 shows a relational database state corresponding to the COMPANY schema. We will use this schema and database state in this chapter and in Chapters 4 through 6 for developing sample queries in different relational languages. (The data shown here is expanded and available for loading as a populated database from the Companion Website for the text, and can be used for the hands-on project exercises at the end of the chapters.)

When we refer to a relational database, we implicitly include both its schema and its current state. A database state that does not obey all the integrity constraints is

[10]A relational database *state* is sometimes called a relational database *snapshot* or *instance*. However, as we mentioned earlier, we will not use the term *instance* since it also applies to single tuples.

EMPLOYEE

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno

DEPARTMENT

Dname	Dnumber	Mgr_ssn	Mgr_start_date

DEPT_LOCATIONS

Dnumber	Dlocation

PROJECT

Pname	Pnumber	Plocation	Dnum

WORKS_ON

Essn	Pno	Hours

DEPENDENT

Essn	Dependent_name	Sex	Bdate	Relationship

Figure 5.5
Schema diagram for the COMPANY relational database schema.

called **not valid**, and a state that satisfies all the constraints in the defined set of integrity constraints IC is called a **valid state.**

In Figure 5.5, the Dnumber attribute in both DEPARTMENT and DEPT_LOCATIONS stands for the same real-world concept—the number given to a department. That same concept is called Dno in EMPLOYEE and Dnum in PROJECT. Attributes that represent the same real-world concept may or may not have identical names in different relations. Alternatively, attributes that represent different concepts may have the same name in different relations. For example, we could have used the attribute name Name for both Pname of PROJECT and Dname of DEPARTMENT; in this case, we would have two attributes that share the same name but represent different real-world concepts—project names and department names.

In some early versions of the relational model, an assumption was made that the same real-world concept, when represented by an attribute, would have *identical* attribute names in all relations. This creates problems when the same real-world concept is used in different roles (meanings) in the same relation. For example, the concept of Social Security number appears twice in the EMPLOYEE relation of Figure 5.5: once in the role of the employee's SSN, and once in the role of the supervisor's SSN. We are required to give them distinct attribute names—Ssn and Super_ssn, respectively—because they appear in the same relation and in order to distinguish their meaning.

Each relational DBMS must have a data definition language (DDL) for defining a relational database schema. Current relational DBMSs are mostly using SQL for this purpose. We present the SQL DDL in Sections 6.1 and 6.2.

Figure 5.6
One possible database state for the COMPANY relational database schema.

EMPLOYEE

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
John	B	Smith	123456789	1965-01-09	731 Fondren, Houston, TX	M	30000	333445555	5
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
Alicia	J	Zelaya	999887777	1968-01-19	3321 Castle, Spring, TX	F	25000	987654321	4
Jennifer	S	Wallace	987654321	1941-06-20	291 Berry, Bellaire, TX	F	43000	888665555	4
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5
Ahmad	V	Jabbar	987987987	1969-03-29	980 Dallas, Houston, TX	M	25000	987654321	4
James	E	Borg	888665555	1937-11-10	450 Stone, Houston, TX	M	55000	NULL	1

DEPARTMENT

Dname	Dnumber	Mgr_ssn	Mgr_start_date
Research	5	333445555	1988-05-22
Administration	4	987654321	1995-01-01
Headquarters	1	888665555	1981-06-19

DEPT_LOCATIONS

Dnumber	Dlocation
1	Houston
4	Stafford
5	Bellaire
5	Sugarland
5	Houston

WORKS_ON

Essn	Pno	Hours
123456789	1	32.5
123456789	2	7.5
666884444	3	40.0
453453453	1	20.0
453453453	2	20.0
333445555	2	10.0
333445555	3	10.0
333445555	10	10.0
333445555	20	10.0
999887777	30	30.0
999887777	10	10.0
987987987	10	35.0
987987987	30	5.0
987654321	30	20.0
987654321	20	15.0
888665555	20	NULL

PROJECT

Pname	Pnumber	Plocation	Dnum
ProductX	1	Bellaire	5
ProductY	2	Sugarland	5
ProductZ	3	Houston	5
Computerization	10	Stafford	4
Reorganization	20	Houston	1
Newbenefits	30	Stafford	4

DEPENDENT

Essn	Dependent_name	Sex	Bdate	Relationship
333445555	Alice	F	1986-04-05	Daughter
333445555	Theodore	M	1983-10-25	Son
333445555	Joy	F	1958-05-03	Spouse
987654321	Abner	M	1942-02-28	Spouse
123456789	Michael	M	1988-01-04	Son
123456789	Alice	F	1988-12-30	Daughter
123456789	Elizabeth	F	1967-05-05	Spouse

Integrity constraints are specified on a database schema and are expected to hold on *every valid database state* of that schema. In addition to domain, key, and NOT NULL constraints, two other types of constraints are considered part of the relational model: entity integrity and referential integrity.

5.2.4 Entity Integrity, Referential Integrity, and Foreign Keys

The **entity integrity constraint** states that no primary key value can be NULL. This is because the primary key value is used to identify individual tuples in a relation. Having NULL values for the primary key implies that we cannot identify some tuples. For example, if two or more tuples had NULL for their primary keys, we may not be able to distinguish them if we try to reference them from other relations.

Key constraints and entity integrity constraints are specified on individual relations. The **referential integrity constraint** is specified between two relations and is used to maintain the consistency among tuples in the two relations. Informally, the referential integrity constraint states that a tuple in one relation that refers to another relation must refer to an *existing tuple* in that relation. For example, in Figure 5.6, the attribute Dno of EMPLOYEE gives the department number for which each employee works; hence, its value in every EMPLOYEE tuple must match the Dnumber value of some tuple in the DEPARTMENT relation.

To define *referential integrity* more formally, first we define the concept of a *foreign key*. The conditions for a foreign key, given below, specify a referential integrity constraint between the two relation schemas R_1 and R_2. A set of attributes FK in relation schema R_1 is a **foreign key** of R_1 that **references** relation R_2 if it satisfies the following rules:

1. The attributes in FK have the same domain(s) as the primary key attributes PK of R_2; the attributes FK are said to **reference** or **refer to** the relation R_2.
2. A value of FK in a tuple t_1 of the current state $r_1(R_1)$ either occurs as a value of PK for some tuple t_2 in the current state $r_2(R_2)$ *or is NULL*. In the former case, we have $t_1[\text{FK}] = t_2[\text{PK}]$, and we say that the tuple t_1 **references** or **refers to** the tuple t_2.

In this definition, R_1 is called the **referencing relation** and R_2 is the **referenced relation**. If these two conditions hold, a **referential integrity constraint** from R_1 to R_2 is said to hold. In a database of many relations, there are usually many referential integrity constraints.

To specify these constraints, first we must have a clear understanding of the meaning or role that each attribute or set of attributes plays in the various relation schemas of the database. Referential integrity constraints typically arise from the *relationships among the entities* represented by the relation schemas. For example, consider the database shown in Figure 5.6. In the EMPLOYEE relation, the attribute Dno refers to the department for which an employee works; hence, we designate Dno to be a foreign key of EMPLOYEE referencing the DEPARTMENT relation. This means that a value of Dno in any tuple t_1 of the EMPLOYEE relation must match a value of

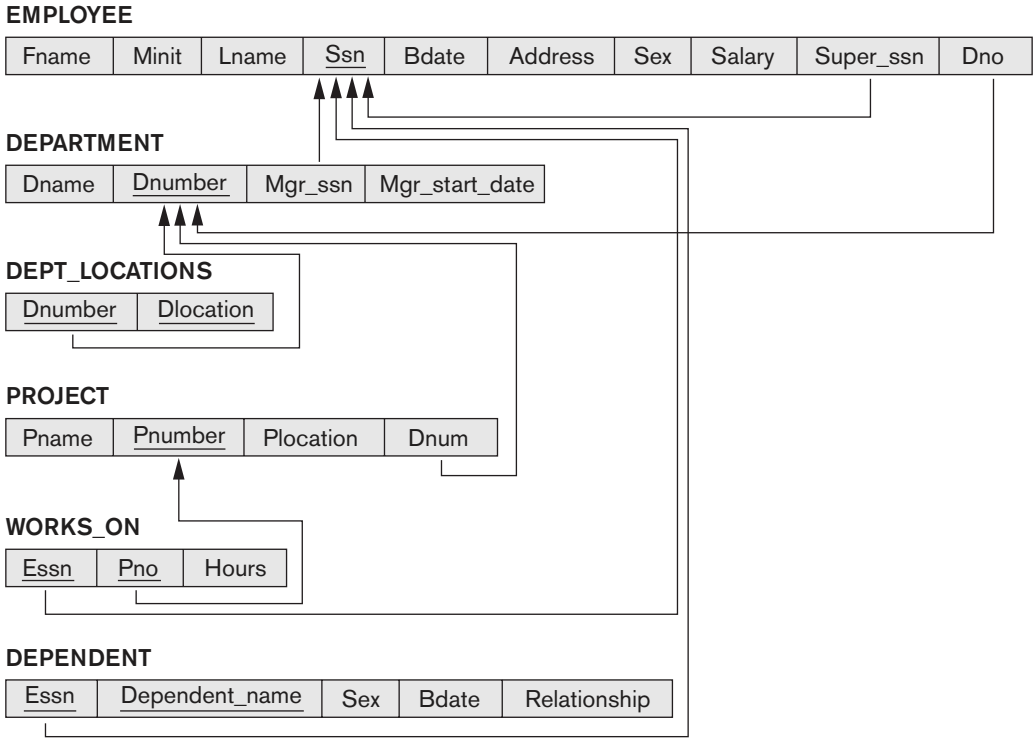
the primary key of DEPARTMENT—the Dnumber attribute—in some tuple t_2 of the DEPARTMENT relation, or the value of Dno *can be NULL* if the employee does not belong to a department or will be assigned to a department later. For example, in Figure 5.6 the tuple for employee 'John Smith' references the tuple for the 'Research' department, indicating that 'John Smith' works for this department.

Notice that a foreign key can *refer to its own relation.* For example, the attribute Super_ssn in EMPLOYEE refers to the supervisor of an employee; this is another employee, represented by a tuple in the EMPLOYEE relation. Hence, Super_ssn is a foreign key that references the EMPLOYEE relation itself. In Figure 5.6 the tuple for employee 'John Smith' references the tuple for employee 'Franklin Wong,' indicating that 'Franklin Wong' is the supervisor of 'John Smith'.

We can *diagrammatically display referential integrity constraints* by drawing a directed arc from each foreign key to the relation it references. For clarity, the arrowhead may point to the primary key of the referenced relation. Figure 5.7 shows the schema in Figure 5.5 with the referential integrity constraints displayed in this manner.

All integrity constraints should be specified on the relational database schema (that is, specified as part of its definition) if we want the DBMS to enforce these constraints on

Figure 5.7
Referential integrity constraints displayed on the COMPANY relational database schema.



the database states. Hence, the DDL includes provisions for specifying the various types of constraints so that the DBMS can automatically enforce them. In SQL, the CREATE TABLE statement of the SQL DDL allows the definition of primary key, unique key, NOT NULL, entity integrity, and referential integrity constraints, among other constraints (see Sections 6.1 and 6.2) .

5.2.5 Other Types of Constraints

The preceding integrity constraints are included in the data definition language because they occur in most database applications. Another class of general constraints, sometimes called *semantic integrity constraints,* are not part of the DDL and have to be specified and enforced in a different way. Examples of such constraints are *the salary of an employee should not exceed the salary of the employee's supervisor* and *the maximum number of hours an employee can work on all projects per week is 56*. Such constraints can be specified and enforced within the application programs that update the database, or by using a general-purpose **constraint specification language**. Mechanisms called **triggers** and **assertions** can be used in SQL, through the CREATE ASSERTION and CREATE TRIGGER statements, to specify some of these constraints (see Chapter 7). It is more common to check for these types of constraints within the application programs than to use constraint specification languages because the latter are sometimes difficult and complex to use, as we discuss in Section 26.1.

The types of constraints we discussed so far may be called **state constraints** because they define the constraints that a *valid state* of the database must satisfy. Another type of constraint, called **transition constraints**, can be defined to deal with state changes in the database.[11] An example of a transition constraint is: "the salary of an employee can only increase." Such constraints are typically enforced by the application programs or specified using active rules and triggers, as we discuss in Section 26.1.

5.3 Update Operations, Transactions, and Dealing with Constraint Violations

The operations of the relational model can be categorized into *retrievals* and *updates*. The relational algebra operations, which can be used to specify **retrievals**, are discussed in detail in Chapter 8. A relational algebra expression forms a new relation after applying a number of algebraic operators to an existing set of relations; its main use is for querying a database to retrieve information. The user formulates a query that specifies the data of interest, and a new relation is formed by applying relational operators to retrieve this data. The **result relation** becomes the answer to (or result of) the user's query. Chapter 8 also introduces the language

[11] State constraints are sometimes called *static constraints*, and transition constraints are sometimes called *dynamic constraints*.

called relational calculus, which is used to define a query declaratively without giving a specific order of operations.

In this section, we concentrate on the database **modification** or **update** operations. There are three basic operations that can change the states of relations in the database: Insert, Delete, and Update (or Modify). They insert new data, delete old data, or modify existing data records, respectively. **Insert** is used to insert one or more new tuples in a relation, **Delete** is used to delete tuples, and **Update** (or **Modify**) is used to change the values of some attributes in existing tuples. Whenever these operations are applied, the integrity constraints specified on the relational database schema should not be violated. In this section we discuss the types of constraints that may be violated by each of these operations and the types of actions that may be taken if an operation causes a violation. We use the database shown in Figure 5.6 for examples and discuss only domain constraints, key constraints, entity integrity constraints, and the referential integrity constraints shown in Figure 5.7. For each type of operation, we give some examples and discuss any constraints that each operation may violate.

5.3.1 The Insert Operation

The **Insert** operation provides a list of attribute values for a new tuple *t* that is to be inserted into a relation *R*. Insert can violate any of the four types of constraints. Domain constraints can be violated if an attribute value is given that does not appear in the corresponding domain or is not of the appropriate data type. Key constraints can be violated if a key value in the new tuple *t* already exists in another tuple in the relation $r(R)$. Entity integrity can be violated if any part of the primary key of the new tuple *t* is NULL. Referential integrity can be violated if the value of any foreign key in *t* refers to a tuple that does not exist in the referenced relation. Here are some examples to illustrate this discussion.

- *Operation*:
  Insert <'Cecilia', 'F', 'Kolonsky', NULL, '1960-04-05', '6357 Windy Lane, Katy, TX', F, 28000, NULL, 4> into EMPLOYEE.
  Result: This insertion violates the entity integrity constraint (NULL for the primary key Ssn), so it is rejected.
- *Operation*:
  Insert <'Alicia', 'J', 'Zelaya', '999887777', '1960-04-05', '6357 Windy Lane, Katy, TX', F, 28000, '987654321', 4> into EMPLOYEE.
  Result: This insertion violates the key constraint because another tuple with the same Ssn value already exists in the EMPLOYEE relation, and so it is rejected.
- *Operation*:
  Insert <'Cecilia', 'F', 'Kolonsky', '677678989', '1960-04-05', '6357 Windswept, Katy, TX', F, 28000, '987654321', 7> into EMPLOYEE.
  Result: This insertion violates the referential integrity constraint specified on Dno in EMPLOYEE because no corresponding referenced tuple exists in DEPARTMENT with Dnumber = 7.

- *Operation*:
  Insert <'Cecilia', 'F', 'Kolonsky', '677678989', '1960-04-05', '6357 Windy Lane, Katy, TX', F, 28000, NULL, 4> into EMPLOYEE.
  Result: This insertion satisfies all constraints, so it is acceptable.

If an insertion violates one or more constraints, the default option is to *reject the insertion.* In this case, it would be useful if the DBMS could provide a reason to the user as to why the insertion was rejected. Another option is to attempt to *correct the reason for rejecting the insertion,* but this is *typically not used for violations caused by Insert*; rather, it is used more often in correcting violations for Delete and Update. In the first operation, the DBMS could ask the user to provide a value for Ssn, and could then accept the insertion if a valid Ssn value is provided. In operation 3, the DBMS could either ask the user to change the value of Dno to some valid value (or set it to NULL), or it could ask the user to insert a DEPARTMENT tuple with Dnumber = 7 and could accept the original insertion only after such an operation was accepted. Notice that in the latter case the insertion violation can **cascade** back to the EMPLOYEE relation if the user attempts to insert a tuple for department 7 with a value for Mgr_ssn that does not exist in the EMPLOYEE relation.

5.3.2 The Delete Operation

The **Delete** operation can violate only referential integrity. This occurs if the tuple being deleted is referenced by foreign keys from other tuples in the database. To specify deletion, a condition on the attributes of the relation selects the tuple (or tuples) to be deleted. Here are some examples.

- *Operation*:
  Delete the WORKS_ON tuple with Essn = '999887777' and Pno = 10.
  Result: This deletion is acceptable and deletes exactly one tuple.
- *Operation*:
  Delete the EMPLOYEE tuple with Ssn = '999887777'.
  Result: This deletion is not acceptable, because there are tuples in WORKS_ON that refer to this tuple. Hence, if the tuple in EMPLOYEE is deleted, referential integrity violations will result.
- *Operation*:
  Delete the EMPLOYEE tuple with Ssn = '333445555'.
  Result: This deletion will result in even worse referential integrity violations, because the tuple involved is referenced by tuples from the EMPLOYEE, DEPARTMENT, WORKS_ON, and DEPENDENT relations.

Several options are available if a deletion operation causes a violation. The first option, called **restrict,** is to *reject the deletion.* The second option, called **cascade,** is to *attempt to cascade (or propagate) the deletion* by deleting tuples that reference the tuple that is being deleted. For example, in operation 2, the DBMS could automatically delete the offending tuples from WORKS_ON with Essn = '999887777'. A third option, called **set null** or **set default,** is to *modify the referencing attribute values* that cause the violation; each such value is either set to NULL or changed to

reference another default valid tuple. Notice that if a referencing attribute that causes a violation is *part of the primary key,* it *cannot* be set to NULL; otherwise, it would violate entity integrity.

Combinations of these three options are also possible. For example, to avoid having operation 3 cause a violation, the DBMS may automatically delete all tuples from WORKS_ON and DEPENDENT with Essn = '333445555'. Tuples in EMPLOYEE with Super_ssn = '333445555' and the tuple in DEPARTMENT with Mgr_ssn = '333445555' can have their Super_ssn and Mgr_ssn values changed to other valid values or to NULL. Although it may make sense to delete automatically the WORKS_ON and DEPENDENT tuples that refer to an EMPLOYEE tuple, it may not make sense to delete other EMPLOYEE tuples or a DEPARTMENT tuple.

In general, when a referential integrity constraint is specified in the DDL, the DBMS will allow the database designer to *specify which of the options* applies in case of a violation of the constraint. We discuss how to specify these options in the SQL DDL in Chapter 6.

5.3.3 The Update Operation

The **Update** (or **Modify**) operation is used to change the values of one or more attributes in a tuple (or tuples) of some relation *R*. It is necessary to specify a condition on the attributes of the relation to select the tuple (or tuples) to be modified. Here are some examples.

- *Operation*:
  Update the salary of the EMPLOYEE tuple with Ssn = '999887777' to 28000.
  Result: Acceptable.
- *Operation*:
  Update the Dno of the EMPLOYEE tuple with Ssn = '999887777' to 1.
  Result: Acceptable.
- *Operation*:
  Update the Dno of the EMPLOYEE tuple with Ssn = '999887777' to 7.
  Result: Unacceptable, because it violates referential integrity.
- *Operation*:
  Update the Ssn of the EMPLOYEE tuple with Ssn = '999887777' to '987654321'.
  Result: Unacceptable, because it violates primary key constraint by repeating a value that already exists as a primary key in another tuple; it violates referential integrity constraints because there are other relations that refer to the existing value of Ssn.

Updating an attribute that is *neither part of a primary key nor part of a foreign key* usually causes no problems; the DBMS need only check to confirm that the new value is of the correct data type and domain. Modifying a primary key value is similar to deleting one tuple and inserting another in its place because we use the primary key to identify tuples. Hence, the issues discussed earlier in both Sections 5.3.1 (Insert) and 5.3.2 (Delete) come into play. If a foreign key attribute is modified, the

DBMS must make sure that the new value refers to an existing tuple in the referenced relation (or is set to NULL). Similar options exist to deal with referential integrity violations caused by Update as those options discussed for the Delete operation. In fact, when a referential integrity constraint is specified in the DDL, the DBMS will allow the user to choose separate options to deal with a violation caused by Delete and a violation caused by Update (see Section 6.2).

5.3.4 The Transaction Concept

A database application program running against a relational database typically executes one or more *transactions*. A **transaction** is an executing program that includes some database operations, such as reading from the database, or applying insertions, deletions, or updates to the database. At the end of the transaction, it must leave the database in a valid or consistent state that satisfies all the constraints specified on the database schema. A single transaction may involve any number of retrieval operations (to be discussed as part of relational algebra and calculus in Chapter 8, and as a part of the language SQL in Chapters 6 and 7) and any number of update operations. These retrievals and updates will together form an atomic unit of work against the database. For example, a transaction to apply a bank withdrawal will typically read the user account record, check if there is a sufficient balance, and then update the record by the withdrawal amount.

A large number of commercial applications running against relational databases in **online transaction processing (OLTP)** systems are executing transactions at rates that reach several hundred per second. Transaction processing concepts, concurrent execution of transactions, and recovery from failures will be discussed in Chapters 20 to 22.

5.4 Summary

In this chapter we presented the modeling concepts, data structures, and constraints provided by the relational model of data. We started by introducing the concepts of domains, attributes, and tuples. Then, we defined a relation schema as a list of attributes that describe the structure of a relation. A relation, or relation state, is a set of tuples that conforms to the schema.

Several characteristics differentiate relations from ordinary tables or files. The first is that a relation is not sensitive to the ordering of tuples. The second involves the ordering of attributes in a relation schema and the corresponding ordering of values within a tuple. We gave an alternative definition of relation that does not require ordering of attributes, but we continued to use the first definition, which requires attributes and tuple values to be ordered, for convenience. Then, we discussed values in tuples and introduced NULL values to represent missing or unknown information. We emphasized that NULL values should be avoided as much as possible.

We classified database constraints into inherent model-based constraints, explicit schema-based constraints, and semantic constraints or business rules. Then, we

discussed the schema constraints pertaining to the relational model, starting with domain constraints, then key constraints (including the concepts of superkey, key, and primary key), and the NOT NULL constraint on attributes. We defined relational databases and relational database schemas. Additional relational constraints include the entity integrity constraint, which prohibits primary key attributes from being NULL. We described the interrelation referential integrity constraint, which is used to maintain consistency of references among tuples from various relations.

The modification operations on the relational model are Insert, Delete, and Update. Each operation may violate certain types of constraints (refer to Section 5.3). Whenever an operation is applied, the resulting database state must be a valid state. Finally, we introduced the concept of a transaction, which is important in relational DBMSs because it allows the grouping of several database operations into a single atomic action on the database.

Review Questions

5.1. Define the following terms as they apply to the relational model of data: *domain*, *attribute*, *n-tuple*, *relation schema*, *relation state*, *degree of a relation*, *relational database schema*, and *relational database state*.

5.2. Why are tuples in a relation not ordered?

5.3. Why are duplicate tuples not allowed in a relation?

5.4. What is the difference between a key and a superkey?

5.5. Why do we designate one of the candidate keys of a relation to be the primary key?

5.6. Discuss the characteristics of relations that make them different from ordinary tables and files.

5.7. Discuss the various reasons that lead to the occurrence of NULL values in relations.

5.8. Discuss the entity integrity and referential integrity constraints. Why is each considered important?

5.9. Define *foreign key*. What is this concept used for?

5.10. What is a transaction? How does it differ from an Update operation?

Exercises

5.11. Suppose that each of the following Update operations is applied directly to the database state shown in Figure 5.6. Discuss *all* integrity constraints

violated by each operation, if any, and the different ways of enforcing these constraints.

a. Insert <'Robert', 'F', 'Scott', '943775543', '1972-06-21', '2365 Newcastle Rd, Bellaire, TX', M, 58000, '888665555', 1> into EMPLOYEE.
b. Insert <'ProductA', 4, 'Bellaire', 2> into PROJECT.
c. Insert <'Production', 4, '943775543', '2007-10-01'> into DEPARTMENT.
d. Insert <'677678989', NULL, '40.0'> into WORKS_ON.
e. Insert <'453453453', 'John', 'M', '1990-12-12', 'spouse'> into DEPENDENT.
f. Delete the WORKS_ON tuples with Essn = '333445555'.
g. Delete the EMPLOYEE tuple with Ssn = '987654321'.
h. Delete the PROJECT tuple with Pname = 'ProductX'.
i. Modify the Mgr_ssn and Mgr_start_date of the DEPARTMENT tuple with Dnumber = 5 to '123456789' and '2007-10-01', respectively.
j. Modify the Super_ssn attribute of the EMPLOYEE tuple with Ssn = '999887777' to '943775543'.
k. Modify the Hours attribute of the WORKS_ON tuple with Essn = '999887777' and Pno = 10 to '5.0'.

5.12. Consider the AIRLINE relational database schema shown in Figure 5.8, which describes a database for airline flight information. Each FLIGHT is identified by a Flight_number, and consists of one or more FLIGHT_LEGs with Leg_numbers 1, 2, 3, and so on. Each FLIGHT_LEG has scheduled arrival and departure times, airports, and one or more LEG_INSTANCEs—one for each Date on which the flight travels. FAREs are kept for each FLIGHT. For each FLIGHT_LEG instance, SEAT_RESERVATIONs are kept, as are the AIRPLANE used on the leg and the actual arrival and departure times and airports. An AIRPLANE is identified by an Airplane_id and is of a particular AIRPLANE_TYPE. CAN_LAND relates AIRPLANE_TYPEs to the AIRPORTs at which they can land. An AIRPORT is identified by an Airport_code. Consider an update for the AIRLINE database to enter a reservation on a particular flight or flight leg on a given date.

a. Give the operations for this update.
b. What types of constraints would you expect to check?
c. Which of these constraints are key, entity integrity, and referential integrity constraints, and which are not?
d. Specify all the referential integrity constraints that hold on the schema shown in Figure 5.8.

5.13. Consider the relation CLASS(Course#, Univ_Section#, Instructor_name, Semester, Building_code, Room#, Time_period, Weekdays, Credit_hours). This represents classes taught in a university, with unique Univ_section#s. Identify what you think should be various candidate keys, and write in your own words the conditions or assumptions under which each candidate key would be valid.

AIRPORT

Airport_code	Name	City	State

FLIGHT

Flight_number	Airline	Weekdays

FLIGHT_LEG

Flight_number	Leg_number	Departure_airport_code	Scheduled_departure_time
		Arrival_airport_code	Scheduled_arrival_time

LEG_INSTANCE

Flight_number	Leg_number	Date	Number_of_available_seats	Airplane_id
		Departure_airport_code	Departure_time	Arrival_airport_code	Arrival_time

FARE

Flight_number	Fare_code	Amount	Restrictions

AIRPLANE_TYPE

Airplane_type_name	Max_seats	Company

CAN_LAND

Airplane_type_name	Airport_code

AIRPLANE

Airplane_id	Total_number_of_seats	Airplane_type

SEAT_RESERVATION

Flight_number	Leg_number	Date	Seat_number	Customer_name	Customer_phone

Figure 5.8
The AIRLINE relational database schema.

5.14. Consider the following six relations for an order-processing database application in a company:

CUSTOMER(Cust#, Cname, City)

ORDER(Order#, Odate, Cust#, Ord_amt)

ORDER_ITEM(Order#, Item#, Qty)

ITEM(Item#, Unit_price)

SHIPMENT(Order#, Warehouse#, Ship_date)

WAREHOUSE(Warehouse#, City)

Here, Ord_amt refers to total dollar amount of an order; Odate is the date the order was placed; and Ship_date is the date an order (or part of an order) is shipped from the warehouse. Assume that an order can be shipped from several warehouses. Specify the foreign keys for this schema, stating any assumptions you make. What other constraints can you think of for this database?

5.15. Consider the following relations for a database that keeps track of business trips of salespersons in a sales office:

SALESPERSON(Ssn, Name, Start_year, Dept_no)

TRIP(Ssn, From_city, To_city, Departure_date, Return_date, Trip_id)

EXPENSE(Trip_id, Account#, Amount)

A trip can be charged to one or more accounts. Specify the foreign keys for this schema, stating any assumptions you make.

5.16. Consider the following relations for a database that keeps track of student enrollment in courses and the books adopted for each course:

STUDENT(Ssn, Name, Major, Bdate)

COURSE(Course#, Cname, Dept)

ENROLL(Ssn, Course#, Quarter, Grade)

BOOK_ADOPTION(Course#, Quarter, Book_isbn)

TEXT(Book_isbn, Book_title, Publisher, Author)

Specify the foreign keys for this schema, stating any assumptions you make.

5.17. Consider the following relations for a database that keeps track of automobile sales in a car dealership (OPTION refers to some optional equipment installed on an automobile):

CAR(Serial_no, Model, Manufacturer, Price)

OPTION(Serial_no, Option_name, Price)

SALE(Salesperson_id, Serial_no, Date, Sale_price)

SALESPERSON(Salesperson_id, Name, Phone)

First, specify the foreign keys for this schema, stating any assumptions you make. Next, populate the relations with a few sample tuples, and then give an example of an insertion in the SALE and SALESPERSON relations that *violates* the referential integrity constraints and of another insertion that does not.

5.18. Database design often involves decisions about the storage of attributes. For example, a Social Security number can be stored as one attribute or split into three attributes (one for each of the three hyphen-delineated groups of

numbers in a Social Security number—XXX-XX-XXXX). However, Social Security numbers are usually represented as just one attribute. The decision is based on how the database will be used. This exercise asks you to think about specific situations where dividing the SSN is useful.

5.19. Consider a STUDENT relation in a UNIVERSITY database with the following attributes (Name, Ssn, Local_phone, Address, Cell_phone, Age, Gpa). Note that the cell phone may be from a different city and state (or province) from the local phone. A possible tuple of the relation is shown below:

Name	Ssn	Local_phone	Address	Cell_phone	Age	Gpa
George Shaw William Edwards	123-45-6789	555-1234	123 Main St., Anytown, CA 94539	555-4321	19	3.75

a. Identify the critical missing information from the Local_phone and Cell_phone attributes. (*Hint*: How do you call someone who lives in a different state or province?)

b. Would you store this additional information in the Local_phone and Cell_phone attributes or add new attributes to the schema for STUDENT?

c. Consider the Name attribute. What are the advantages and disadvantages of splitting this field from one attribute into three attributes (first name, middle name, and last name)?

d. What general guideline would you recommend for deciding when to store information in a single attribute and when to split the information?

e. Suppose the student can have between 0 and 5 phones. Suggest two different designs that allow this type of information.

5.20. Recent changes in privacy laws have disallowed organizations from using Social Security numbers to identify individuals unless certain restrictions are satisfied. As a result, most U.S. universities cannot use SSNs as primary keys (except for financial data). In practice, Student_id, a unique identifier assigned to every student, is likely to be used as the primary key rather than SSN since Student_id can be used throughout the system.

a. Some database designers are reluctant to use generated keys (also known as *surrogate keys*) for primary keys (such as Student_id) because they are artificial. Can you propose any natural choices of keys that can be used to identify the student record in a UNIVERSITY database?

b. Suppose that you are able to guarantee uniqueness of a natural key that includes last name. Are you guaranteed that the last name will not change during the lifetime of the database? If last name can change, what solutions can you propose for creating a primary key that still includes last name but remains unique?

c. What are the advantages and disadvantages of using generated (surrogate) keys?

Selected Bibliography

The relational model was introduced by Codd (1970) in a classic paper. Codd also introduced relational algebra and laid the theoretical foundations for the relational model in a series of papers (Codd, 1971, 1972, 1972a, 1974); he was later given the Turing Award, the highest honor of the ACM (Association for Computing Machinery) for his work on the relational model. In a later paper, Codd (1979) discussed extending the relational model to incorporate more meta-data and semantics about the relations; he also proposed a three-valued logic to deal with uncertainty in relations and incorporating NULLs in the relational algebra. The resulting model is known as RM/T. Childs (1968) had earlier used set theory to model databases. Later, Codd (1990) published a book examining over 300 features of the relational data model and database systems. Date (2001) provides a retrospective review and analysis of the relational data model.

Since Codd's pioneering work, much research has been conducted on various aspects of the relational model. Todd (1976) describes an experimental DBMS called PRTV that directly implements the relational algebra operations. Schmidt and Swenson (1975) introduce additional semantics into the relational model by classifying different types of relations. Chen's (1976) entity–relationship model, which is discussed in Chapter 3, is a means to communicate the real-world semantics of a relational database at the conceptual level. Wiederhold and Elmasri (1979) introduce various types of connections between relations to enhance its constraints. Extensions of the relational model are discussed in Chapters 11 and 26. Additional bibliographic notes for other aspects of the relational model and its languages, systems, extensions, and theory are given in Chapters 6 to 9, 14, 15, 23, and 30. Maier (1983) and Atzeni and De Antonellis (1993) provide an extensive theoretical treatment of the relational data model.

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chapter 6

Basic SQL

The SQL language may be considered one of the major reasons for the commercial success of relational databases. Because it became a standard for relational databases, users were less concerned about migrating their database applications from other types of database systems—for example, older network or hierarchical systems—to relational systems. This is because even if the users became dissatisfied with the particular relational DBMS product they were using, converting to another relational DBMS product was not expected to be too expensive and time-consuming because both systems followed the same language standards. In practice, of course, there are differences among various commercial relational DBMS packages. However, if the user is diligent in using only those features that are part of the standard, and if two relational DBMSs faithfully support the standard, then conversion between two systems should be simplified. Another advantage of having such a standard is that users may write statements in a database application program that can access data stored in two or more relational DBMSs without having to change the database sublanguage (SQL), as long as both/all of the relational DBMSs support standard SQL.

This chapter presents the *practical* relational model, which is based on the SQL standard for *commercial* relational DBMSs, whereas Chapter 5 presented the most important concepts underlying the *formal* relational data model. In Chapter 8 (Sections 8.1 through 8.5), we shall discuss the *relational algebra* operations, which are very important for understanding the types of requests that may be specified on a relational database. They are also important for query processing and optimization in a relational DBMS, as we shall see in Chapters 18 and 19. However, the relational algebra operations are too low-level for most commercial DBMS users because a query in relational algebra is written as a sequence of operations that, when executed, produces the required result. Hence, the user must specify how—that is, *in what order*—to execute the query operations. On the other hand, the SQL language

provides a higher-level *declarative* language interface, so the user only specifies *what* the result is to be, leaving the actual optimization and decisions on how to execute the query to the DBMS. Although SQL includes some features from relational algebra, it is based to a greater extent on the *tuple relational calculus*, which we describe in Section 8.6. However, the SQL syntax is more user-friendly than either of the two formal languages.

The name **SQL** is presently expanded as Structured Query Language. Originally, SQL was called SEQUEL (Structured English QUEry Language) and was designed and implemented at IBM Research as the interface for an experimental relational database system called SYSTEM R. SQL is now the standard language for commercial relational DBMSs. The standardization of SQL is a joint effort by the American National Standards Institute (ANSI) and the International Standards Organization (ISO), and the first SQL standard is called SQL-86 or SQL1. A revised and much expanded standard called SQL-92 (also referred to as SQL2) was subsequently developed. The next standard that is well-recognized is SQL:1999, which started out as SQL3. Additional updates to the standard are SQL:2003 and SQL:2006, which added XML features (see Chapter 13) among other updates to the language. Another update in 2008 incorporated more object database features into SQL (see Chapter 12), and a further update is SQL:2011. We will try to cover the latest version of SQL as much as possible, but some of the newer features are discussed in later chapters. It is also not possible to cover the language in its entirety in this text. It is important to note that when new features are added to SQL, it usually takes a few years for some of these features to make it into the commercial SQL DBMSs.

SQL is a comprehensive database language: It has statements for data definitions, queries, and updates. Hence, it is both a DDL *and* a DML. In addition, it has facilities for defining views on the database, for specifying security and authorization, for defining integrity constraints, and for specifying transaction controls. It also has rules for embedding SQL statements into a general-purpose programming language such as Java or C/C++.[1]

The later SQL standards (starting with **SQL:1999**) are divided into a **core** specification plus specialized **extensions**. The core is supposed to be implemented by all RDBMS vendors that are SQL compliant. The extensions can be implemented as optional modules to be purchased independently for specific database applications such as data mining, spatial data, temporal data, data warehousing, online analytical processing (OLAP), multimedia data, and so on.

Because the subject of SQL is both important and extensive, we devote two chapters to its basic features. In this chapter, Section 6.1 describes the SQL DDL commands for creating schemas and tables, and gives an overview of the basic data types in SQL. Section 6.2 presents how basic constraints such as key and referential integrity are specified. Section 6.3 describes the basic SQL constructs for

[1]Originally, SQL had statements for creating and dropping indexes on the files that represent relations, but these have been dropped from the SQL standard for some time.

specifying retrieval queries, and Section 6.4 describes the SQL commands for insertion, deletion, and update.

In Chapter 7, we will describe more complex SQL retrieval queries, as well as the ALTER commands for changing the schema. We will also describe the CREATE ASSERTION statement, which allows the specification of more general constraints on the database, and the concept of triggers, which is presented in more detail in Chapter 26. We discuss the SQL facility for defining views on the database in Chapter 7. Views are also called *virtual* or *derived tables* because they present the user with what appear to be tables; however, the information in those tables is derived from previously defined tables.

Section 6.5 lists some SQL features that are presented in other chapters of the book; these include object-oriented features in Chapter 12, XML in Chapter 13, transaction control in Chapter 20, active databases (triggers) in Chapter 26, online analytical processing (OLAP) features in Chapter 29, and security/authorization in Chapter 30. Section 6.6 summarizes the chapter. Chapters 10 and 11 discuss the various database programming techniques for programming with SQL.

6.1 SQL Data Definition and Data Types

SQL uses the terms **table**, **row**, and **column** for the formal relational model terms *relation*, *tuple*, and *attribute*, respectively. We will use the corresponding terms interchangeably. The main SQL command for data definition is the CREATE statement, which can be used to create schemas, tables (relations), types, and domains, as well as other constructs such as views, assertions, and triggers. Before we describe the relevant CREATE statements, we discuss schema and catalog concepts in Section 6.1.1 to place our discussion in perspective. Section 6.1.2 describes how tables are created, and Section 6.1.3 describes the most important data types available for attribute specification. Because the SQL specification is very large, we give a description of the most important features. Further details can be found in the various SQL standards documents (see end-of-chapter bibliographic notes).

6.1.1 Schema and Catalog Concepts in SQL

Early versions of SQL did not include the concept of a relational database schema; all tables (relations) were considered part of the same schema. The concept of an SQL schema was incorporated starting with SQL2 in order to group together tables and other constructs that belong to the same database application (in some systems, a *schema* is called a *database*). An **SQL schema** is identified by a **schema name** and includes an **authorization identifier** to indicate the user or account who owns the schema, as well as **descriptors** for *each element* in the schema. Schema **elements** include tables, types, constraints, views, domains, and other constructs (such as authorization grants) that describe the schema. A schema is created via the CREATE SCHEMA statement, which can include all the schema elements' definitions. Alternatively, the schema can be assigned a name and authorization identifier, and the

elements can be defined later. For example, the following statement creates a schema called COMPANY owned by the user with authorization identifier 'Jsmith'. Note that each statement in SQL ends with a semicolon.

CREATE SCHEMA COMPANY **AUTHORIZATION** 'Jsmith';

In general, not all users are authorized to create schemas and schema elements. The privilege to create schemas, tables, and other constructs must be explicitly granted to the relevant user accounts by the system administrator or DBA.

In addition to the concept of a schema, SQL uses the concept of a **catalog**—a named collection of schemas.[2] Database installations typically have a default environment and schema, so when a user connects and logs in to that database installation, the user can refer directly to tables and other constructs within that schema without having to specify a particular schema name. A catalog always contains a special schema called INFORMATION_SCHEMA, which provides information on all the schemas in the catalog and all the element descriptors in these schemas. Integrity constraints such as referential integrity can be defined between relations only if they exist in schemas within the same catalog. Schemas within the same catalog can also share certain elements, such as type and domain definitions.

6.1.2 The CREATE TABLE Command in SQL

The **CREATE TABLE** command is used to specify a new relation by giving it a name and specifying its attributes and initial constraints. The attributes are specified first, and each attribute is given a name, a data type to specify its domain of values, and possibly attribute constraints, such as NOT NULL. The key, entity integrity, and referential integrity constraints can be specified within the CREATE TABLE statement after the attributes are declared, or they can be added later using the ALTER TABLE command (see Chapter 7). Figure 6.1 shows sample data definition statements in SQL for the COMPANY relational database schema shown in Figure 3.7.

Typically, the SQL schema in which the relations are declared is implicitly specified in the environment in which the CREATE TABLE statements are executed. Alternatively, we can explicitly attach the schema name to the relation name, separated by a period. For example, by writing

CREATE TABLE COMPANY.EMPLOYEE

rather than

CREATE TABLE EMPLOYEE

as in Figure 6.1, we can explicitly (rather than implicitly) make the EMPLOYEE table part of the COMPANY schema.

The relations declared through CREATE TABLE statements are called **base tables** (or base relations); this means that the table and its rows are actually created

[2]SQL also includes the concept of a *cluster* of catalogs.

```
CREATE TABLE EMPLOYEE
        ( Fname                 VARCHAR(15)             NOT NULL,
          Minit                 CHAR,
          Lname                 VARCHAR(15)             NOT NULL,
          Ssn                   CHAR(9)                 NOT NULL,
          Bdate                 DATE,
          Address               VARCHAR(30),
          Sex                   CHAR,
          Salary                DECIMAL(10,2),
          Super_ssn             CHAR(9),
          Dno                   INT                     NOT NULL,
        PRIMARY KEY (Ssn),
CREATE TABLE DEPARTMENT
        ( Dname                 VARCHAR(15)             NOT NULL,
          Dnumber               INT                     NOT NULL,
          Mgr_ssn               CHAR(9)                 NOT NULL,
          Mgr_start_date        DATE,
        PRIMARY KEY (Dnumber),
        UNIQUE (Dname),
        FOREIGN KEY (Mgr_ssn) REFERENCES EMPLOYEE(Ssn) );
CREATE TABLE DEPT_LOCATIONS
        ( Dnumber               INT                     NOT NULL,
          Dlocation             VARCHAR(15)             NOT NULL,
        PRIMARY KEY (Dnumber, Dlocation),
        FOREIGN KEY (Dnumber) REFERENCES DEPARTMENT(Dnumber) );
CREATE TABLE PROJECT
        ( Pname                 VARCHAR(15)             NOT NULL,
          Pnumber               INT                     NOT NULL,
          Plocation             VARCHAR(15),
          Dnum                  INT                     NOT NULL,
        PRIMARY KEY (Pnumber),
        UNIQUE (Pname),
        FOREIGN KEY (Dnum) REFERENCES DEPARTMENT(Dnumber) );
CREATE TABLE WORKS_ON
        ( Essn                  CHAR(9)                 NOT NULL,
          Pno                   INT                     NOT NULL,
          Hours                 DECIMAL(3,1)            NOT NULL,
        PRIMARY KEY (Essn, Pno),
        FOREIGN KEY (Essn) REFERENCES EMPLOYEE(Ssn),
        FOREIGN KEY (Pno) REFERENCES PROJECT(Pnumber) );
CREATE TABLE DEPENDENT
        ( Essn                  CHAR(9)                 NOT NULL,
          Dependent_name        VARCHAR(15)             NOT NULL,
          Sex                   CHAR,
          Bdate                 DATE,
          Relationship          VARCHAR(8),
        PRIMARY KEY (Essn, Dependent_name),
        FOREIGN KEY (Essn) REFERENCES EMPLOYEE(Ssn) );
```

Figure 6.1
SQL CREATE TABLE data definition statements for defining the COMPANY schema from Figure 5.7.

and stored as a file by the DBMS. Base relations are distinguished from **virtual relations**, created through the CREATE VIEW statement (see Chapter 7), which may or may not correspond to an actual physical file. In SQL, the attributes in a base table are considered to be *ordered in the sequence in which they are specified* in the CREATE TABLE statement. However, rows (tuples) are not considered to be ordered within a table (relation).

It is important to note that in Figure 6.1, there are some *foreign keys that may cause errors* because they are specified either via circular references or because they refer to a table that has not yet been created. For example, the foreign key Super_ssn in the EMPLOYEE table is a circular reference because it refers to the EMPLOYEE table itself. The foreign key Dno in the EMPLOYEE table refers to the DEPARTMENT table, which has not been created yet. To deal with this type of problem, these constraints can be left out of the initial CREATE TABLE statement, and then added later using the ALTER TABLE statement (see Chapter 7). We displayed all the foreign keys in Figure 6.1 to show the complete COMPANY schema in one place.

6.1.3 Attribute Data Types and Domains in SQL

The basic **data types** available for attributes include numeric, character string, bit string, Boolean, date, and time.

- **Numeric** data types include integer numbers of various sizes (INTEGER or INT, and SMALLINT) and floating-point (real) numbers of various precision (FLOAT or REAL, and DOUBLE PRECISION). Formatted numbers can be declared by using DECIMAL(i, j)—or DEC(i, j) or NUMERIC(i, j)—where i, the *precision*, is the total number of decimal digits and j, the *scale*, is the number of digits after the decimal point. The default for scale is zero, and the default for precision is implementation-defined.
- **Character-string** data types are either fixed length—CHAR(n) or CHARACTER(n), where n is the number of characters—or varying length—VARCHAR(n) or CHAR VARYING(n) or CHARACTER VARYING(n), where n is the maximum number of characters. When specifying a literal string value, it is placed between single quotation marks (apostrophes), and it is *case sensitive* (a distinction is made between uppercase and lowercase).[3] For fixed-length strings, a shorter string is padded with blank characters to the right. For example, if the value 'Smith' is for an attribute of type CHAR(10), it is padded with five blank characters to become 'Smith' if needed. Padded blanks are generally ignored when strings are compared. For comparison purposes, strings are considered ordered in alphabetic (or lexicographic) order; if a string *str1* appears before another string *str2* in alphabetic order, then *str1* is considered to be less than *str2*.[4] There is also a concatenation operator denoted by || (double vertical bar) that can concatenate two strings

[3]This is not the case with SQL keywords, such as CREATE or CHAR. With keywords, SQL is *case insensitive*, meaning that SQL treats uppercase and lowercase letters as equivalent in keywords.

[4]For nonalphabetic characters, there is a defined order.

in SQL. For example, 'abc' || 'XYZ' results in a single string 'abcXYZ'. Another variable-length string data type called CHARACTER LARGE OBJECT or CLOB is also available to specify columns that have large text values, such as documents. The CLOB maximum length can be specified in kilobytes (K), megabytes (M), or gigabytes (G). For example, CLOB(20M) specifies a maximum length of 20 megabytes.

- **Bit-string** data types are either of fixed length *n*—BIT(*n*)—or varying length—BIT VARYING(*n*), where *n* is the maximum number of bits. The default for *n*, the length of a character string or bit string, is 1. Literal bit strings are placed between single quotes but preceded by a B to distinguish them from character strings; for example, B'10101'.[5] Another variable-length bitstring data type called BINARY LARGE OBJECT or BLOB is also available to specify columns that have large binary values, such as images. As for CLOB, the maximum length of a BLOB can be specified in kilobits (K), megabits (M), or gigabits (G). For example, BLOB(30G) specifies a maximum length of 30 gigabits.
- A **Boolean** data type has the traditional values of TRUE or FALSE. In SQL, because of the presence of NULL values, a three-valued logic is used, so a third possible value for a Boolean data type is UNKNOWN. We discuss the need for UNKNOWN and the three-valued logic in Chapter 7.
- The **DATE** data type has ten positions, and its components are YEAR, MONTH, and DAY in the form YYYY-MM-DD. The TIME data type has at least eight positions, with the components HOUR, MINUTE, and SECOND in the form HH:MM:SS. Only valid dates and times should be allowed by the SQL implementation. This implies that months should be between 1 and 12 and days must be between 01 and 31; furthermore, a day should be a valid day for the corresponding month. The < (less than) comparison can be used with dates or times—an *earlier* date is considered to be smaller than a later date, and similarly with time. Literal values are represented by single-quoted strings preceded by the keyword DATE or TIME; for example, DATE '2014-09-27' or TIME '09:12:47'. In addition, a data type TIME(*i*), where *i* is called *time fractional seconds precision*, specifies *i* + 1 additional positions for TIME—one position for an additional period (.) separator character, and *i* positions for specifying decimal fractions of a second. A TIME WITH TIME ZONE data type includes an additional six positions for specifying the *displacement* from the standard universal time zone, which is in the range +13:00 to –12:59 in units of HOURS:MINUTES. If WITH TIME ZONE is not included, the default is the local time zone for the SQL session.

Some additional data types are discussed below. The list of types discussed here is not exhaustive; different implementations have added more data types to SQL.

- A **timestamp** data type (TIMESTAMP) includes the DATE and TIME fields, plus a minimum of six positions for decimal fractions of seconds and an optional WITH TIME ZONE qualifier. Literal values are represented by single-quoted

[5]Bit strings whose length is a multiple of 4 can be specified in *hexadecimal* notation, where the literal string is preceded by X and each hexadecimal character represents 4 bits.

strings preceded by the keyword TIMESTAMP, with a blank space between data and time; for example, TIMESTAMP '2014-09-27 09:12:47.648302'.

- Another data type related to DATE, TIME, and TIMESTAMP is the INTERVAL data type. This specifies an **interval**—a *relative value* that can be used to increment or decrement an absolute value of a date, time, or timestamp. Intervals are qualified to be either YEAR/MONTH intervals or DAY/TIME intervals.

The format of DATE, TIME, and TIMESTAMP can be considered as a special type of string. Hence, they can generally be used in string comparisons by being **cast** (or **coerced** or converted) into the equivalent strings.

It is possible to specify the data type of each attribute directly, as in Figure 6.1; alternatively, a domain can be declared, and the domain name can be used with the attribute specification. This makes it easier to change the data type for a domain that is used by numerous attributes in a schema, and improves schema readability. For example, we can create a domain SSN_TYPE by the following statement:

```
CREATE DOMAIN SSN_TYPE AS CHAR(9);
```

We can use SSN_TYPE in place of CHAR(9) in Figure 6.1 for the attributes Ssn and Super_ssn of EMPLOYEE, Mgr_ssn of DEPARTMENT, Essn of WORKS_ON, and Essn of DEPENDENT. A domain can also have an optional default specification via a DEFAULT clause, as we discuss later for attributes. Notice that domains may not be available in some implementations of SQL.

In SQL, there is also a **CREATE TYPE** command, which can be used to create user defined types or UDTs. These can then be used either as data types for attributes, or as the basis for creating tables. We shall discuss CREATE TYPE in detail in Chapter 12, because it is often used in conjunction with specifying object database features that have been incorporated into more recent versions of SQL.

6.2 Specifying Constraints in SQL

This section describes the basic constraints that can be specified in SQL as part of table creation. These include key and referential integrity constraints, restrictions on attribute domains and NULLs, and constraints on individual tuples within a relation using the CHECK clause. We discuss the specification of more general constraints, called assertions, in Chapter 7.

6.2.1 Specifying Attribute Constraints and Attribute Defaults

Because SQL allows NULLs as attribute values, a *constraint* NOT NULL may be specified if NULL is not permitted for a particular attribute. This is always implicitly specified for the attributes that are part of the *primary key* of each relation, but it can be specified for any other attributes whose values are required not to be NULL, as shown in Figure 6.1.

It is also possible to define a *default value* for an attribute by appending the clause **DEFAULT** <value> to an attribute definition. The default value is included in any

```
CREATE TABLE EMPLOYEE
    ( … ,
      Dno          INT            NOT NULL       DEFAULT 1,
    CONSTRAINT EMPPK
      PRIMARY KEY (Ssn),
    CONSTRAINT EMPSUPERFK
      FOREIGN KEY (Super_ssn) REFERENCES EMPLOYEE(Ssn)
                    ON DELETE SET NULL          ON UPDATE CASCADE,
    CONSTRAINT EMPDEPTFK
      FOREIGN KEY(Dno) REFERENCES DEPARTMENT(Dnumber)
                    ON DELETE SET DEFAULT       ON UPDATE CASCADE);
CREATE TABLE DEPARTMENT
    ( … ,
      Mgr_ssn CHAR(9)          NOT NULL       DEFAULT '888665555',
      … ,
    CONSTRAINT DEPTPK
      PRIMARY KEY(Dnumber),
    CONSTRAINT DEPTSK
      UNIQUE (Dname),
    CONSTRAINT DEPTMGRFK
      FOREIGN KEY (Mgr_ssn) REFERENCES EMPLOYEE(Ssn)
                    ON DELETE SET DEFAULT       ON UPDATE CASCADE);
CREATE TABLE DEPT_LOCATIONS
    ( … ,
    PRIMARY KEY (Dnumber, Dlocation),
    FOREIGN KEY (Dnumber) REFERENCES DEPARTMENT(Dnumber)
                    ON DELETE CASCADE           ON UPDATE CASCADE);
```

Figure 6.2
Example illustrating how default attribute values and referential integrity triggered actions are specified in SQL.

new tuple if an explicit value is not provided for that attribute. Figure 6.2 illustrates an example of specifying a default manager for a new department and a default department for a new employee. If no default clause is specified, the default *default value* is NULL for attributes *that do not have* the NOT NULL constraint.

Another type of constraint can restrict attribute or domain values using the **CHECK** clause following an attribute or domain definition.[6] For example, suppose that department numbers are restricted to integer numbers between 1 and 20; then, we can change the attribute declaration of Dnumber in the DEPARTMENT table (see Figure 6.1) to the following:

```
Dnumber INT NOT NULL CHECK (Dnumber > 0 AND Dnumber < 21);
```

The CHECK clause can also be used in conjunction with the CREATE DOMAIN statement. For example, we can write the following statement:

```
CREATE DOMAIN D_NUM AS INTEGER
CHECK (D_NUM > 0 AND D_NUM < 21);
```

[6]The CHECK clause can also be used for other purposes, as we shall see.

We can then use the created domain D_NUM as the attribute type for all attributes that refer to department numbers in Figure 6.1, such as Dnumber of DEPARTMENT, Dnum of PROJECT, Dno of EMPLOYEE, and so on.

6.2.2 Specifying Key and Referential Integrity Constraints

Because keys and referential integrity constraints are very important, there are special clauses within the CREATE TABLE statement to specify them. Some examples to illustrate the specification of keys and referential integrity are shown in Figure 6.1.[7] The **PRIMARY KEY** clause specifies one or more attributes that make up the primary key of a relation. If a primary key has a *single* attribute, the clause can follow the attribute directly. For example, the primary key of DEPARTMENT can be specified as follows (instead of the way it is specified in Figure 6.1):

```
Dnumber INT PRIMARY KEY,
```

The **UNIQUE** clause specifies alternate (unique) keys, also known as candidate keys as illustrated in the DEPARTMENT and PROJECT table declarations in Figure 6.1. The **UNIQUE** clause can also be specified directly for a unique key if it is a single attribute, as in the following example:

```
Dname VARCHAR(15) UNIQUE,
```

Referential integrity is specified via the **FOREIGN KEY** clause, as shown in Figure 6.1. As we discussed in Section 5.2.4, a referential integrity constraint can be violated when tuples are inserted or deleted, or when a foreign key or primary key attribute value is updated. The default action that SQL takes for an integrity violation is to **reject** the update operation that will cause a violation, which is known as the RESTRICT option. However, the schema designer can specify an alternative action to be taken by attaching a **referential triggered action** clause to any foreign key constraint. The options include SET NULL, CASCADE, and SET DEFAULT. An option must be qualified with either ON DELETE or ON UPDATE. We illustrate this with the examples shown in Figure 6.2. Here, the database designer chooses ON DELETE SET NULL and ON UPDATE CASCADE for the foreign key Super_ssn of EMPLOYEE. This means that if the tuple for a *supervising employee* is *deleted*, the value of Super_ssn is automatically set to NULL for all employee tuples that were referencing the deleted employee tuple. On the other hand, if the Ssn value for a supervising employee is *updated* (say, because it was entered incorrectly), the new value is *cascaded* to Super_ssn for all employee tuples referencing the updated employee tuple.[8]

In general, the action taken by the DBMS for SET NULL or SET DEFAULT is the same for both ON DELETE and ON UPDATE: The value of the affected referencing attributes is changed to NULL for SET NULL and to the specified default value of the

[7]Key and referential integrity constraints were not included in early versions of SQL.

[8]Notice that the foreign key Super_ssn in the EMPLOYEE table is a circular reference and hence may have to be added later as a named constraint using the ALTER TABLE statement as we discussed at the end of Section 6.1.2.

referencing attribute for SET DEFAULT. The action for CASCADE ON DELETE is to delete all the referencing tuples, whereas the action for CASCADE ON UPDATE is to change the value of the referencing foreign key attribute(s) to the updated (new) primary key value for all the referencing tuples. It is the responsibility of the database designer to choose the appropriate action and to specify it in the database schema. As a general rule, the CASCADE option is suitable for "relationship" relations (see Section 9.1) , such as WORKS_ON; for relations that represent multivalued attributes, such as DEPT_LOCATIONS; and for relations that represent weak entity types, such as DEPENDENT.

6.2.3 Giving Names to Constraints

Figure 6.2 also illustrates how a constraint may be given a **constraint name**, following the keyword **CONSTRAINT**. The names of all constraints within a particular schema must be unique. A constraint name is used to identify a particular constraint in case the constraint must be dropped later and replaced with another constraint, as we discuss in Chapter 7. Giving names to constraints is optional. It is also possible to temporarily *defer* a constraint until the end of a transaction, as we shall discuss in Chapter 20 when we present transaction concepts.

6.2.4 Specifying Constraints on Tuples Using CHECK

In addition to key and referential integrity constraints, which are specified by special keywords, other *table constraints* can be specified through additional CHECK clauses at the end of a CREATE TABLE statement. These can be called **row-based** constraints because they apply to each row *individually* and are checked whenever a row is inserted or modified. For example, suppose that the DEPARTMENT table in Figure 6.1 had an additional attribute Dept_create_date, which stores the date when the department was created. Then we could add the following CHECK clause at the end of the CREATE TABLE statement for the DEPARTMENT table to make sure that a manager's start date is later than the department creation date.

```
CHECK (Dept_create_date <= Mgr_start_date);
```

The CHECK clause can also be used to specify more general constraints using the CREATE ASSERTION statement of SQL. We discuss this in Chapter 7 because it requires the full power of queries, which are discussed in Sections 6.3 and 7.1.

6.3 Basic Retrieval Queries in SQL

SQL has one basic statement for retrieving information from a database: the **SELECT** statement. The SELECT statement *is not the same as* the SELECT operation of relational algebra, which we shall discuss in Chapter 8. There are many options and flavors to the SELECT statement in SQL, so we will introduce its features gradually. We will use example queries specified on the schema of Figure 5.5 and will

refer to the sample database state shown in Figure 5.6 to show the results of some of these queries. In this section, we present the features of SQL for *simple retrieval queries*. Features of SQL for specifying more complex retrieval queries are presented in Section 7.1.

Before proceeding, we must point out an *important distinction* between the practical SQL model and the formal relational model discussed in Chapter 5: SQL allows a table (relation) to have two or more tuples that are identical in all their attribute values. Hence, in general, an **SQL** table is not a *set of tuples*, because a set does not allow two identical members; rather, it is a **multiset** (sometimes called a *bag*) of tuples. Some SQL relations are *constrained to be sets* because a key constraint has been declared or because the DISTINCT option has been used with the SELECT statement (described later in this section). We should be aware of this distinction as we discuss the examples.

6.3.1 The SELECT-FROM-WHERE Structure of Basic SQL Queries

Queries in SQL can be very complex. We will start with simple queries, and then progress to more complex ones in a step-by-step manner. The basic form of the SELECT statement, sometimes called a **mapping** or a **select-from-where block**, is formed of the three clauses SELECT, FROM, and WHERE and has the following form:[9]

SELECT <attribute list>
FROM <table list>
WHERE <condition>;

where

- <attribute list> is a list of attribute names whose values are to be retrieved by the query.
- <table list> is a list of the relation names required to process the query.
- <condition> is a conditional (Boolean) expression that identifies the tuples to be retrieved by the query.

In SQL, the basic logical comparison operators for comparing attribute values with one another and with literal constants are =, <, <=, >, >=, and <>. These correspond to the relational algebra operators =, <, ≤, >, ≥, and ≠, respectively, and to the C/C++ programming language operators =, <, <=, >, >=, and !=. The main syntactic difference is the *not equal* operator. SQL has additional comparison operators that we will present gradually.

We illustrate the basic SELECT statement in SQL with some sample queries. The queries are labeled here with the same query numbers used in Chapter 8 for easy cross-reference.

[9]The SELECT and FROM clauses are required in all SQL queries. The WHERE is optional (see Section 6.3.3).

Query 0. Retrieve the birth date and address of the employee(s) whose name is 'John B. Smith'.

```
Q0:   SELECT   Bdate, Address
      FROM     EMPLOYEE
      WHERE    Fname = 'John' AND Minit = 'B' AND Lname = 'Smith';
```

This query involves only the EMPLOYEE relation listed in the FROM clause. The query *selects* the individual EMPLOYEE tuples that satisfy the condition of the WHERE clause, then *projects* the result on the Bdate and Address attributes listed in the SELECT clause.

The SELECT clause of SQL specifies the attributes whose values are to be retrieved, which are called the **projection attributes** in relational algebra (see Chapter 8) and the WHERE clause specifies the Boolean condition that must be true for any retrieved tuple, which is known as the **selection condition** in relational algebra. Figure 6.3(a) shows the result of query Q0 on the database of Figure 5.6.

We can think of an implicit **tuple variable** or *iterator* in the SQL query ranging or *looping* over each individual tuple in the EMPLOYEE table and evaluating the condition in the WHERE clause. Only those tuples that satisfy the condition—that is, those tuples for which the condition evaluates to TRUE after substituting their corresponding attribute values—are selected.

Query 1. Retrieve the name and address of all employees who work for the 'Research' department.

```
Q1:   SELECT   Fname, Lname, Address
      FROM     EMPLOYEE, DEPARTMENT
      WHERE    Dname = 'Research' AND Dnumber = Dno;
```

In the WHERE clause of Q1, the condition Dname = 'Research' is a **selection condition** that chooses the particular tuple of interest in the DEPARTMENT table, because Dname is an attribute of DEPARTMENT. The condition Dnumber = Dno is called a **join condition**, because it combines two tuples: one from DEPARTMENT and one from EMPLOYEE, whenever the value of Dnumber in DEPARTMENT is equal to the value of Dno in EMPLOYEE. The result of query Q1 is shown in Figure 6.3(b). In general, any number of selection and join conditions may be specified in a single SQL query.

A query that involves only selection and join conditions plus projection attributes is known as a **select-project-join** query. The next example is a select-project-join query with *two* join conditions.

Query 2. For every project located in 'Stafford', list the project number, the controlling department number, and the department manager's last name, address, and birth date.

```
Q2:   SELECT   Pnumber, Dnum, Lname, Address, Bdate
      FROM     PROJECT, DEPARTMENT, EMPLOYEE
      WHERE    Dnum = Dnumber AND Mgr_ssn = Ssn AND
               Plocation = 'Stafford'
```

Figure 6.3
Results of SQL queries when applied to the COMPANY database state shown in Figure 5.6. (a) Q0. (b) Q1. (c) Q2. (d) Q8. (e) Q9. (f) Q10. (g) Q1C.

(a)

Bdate	Address
1965-01-09	731Fondren, Houston, TX

(b)

Fname	Lname	Address
John	Smith	731 Fondren, Houston, TX
Franklin	Wong	638 Voss, Houston, TX
Ramesh	Narayan	975 Fire Oak, Humble, TX
Joyce	English	5631 Rice, Houston, TX

(c)

Pnumber	Dnum	Lname	Address	Bdate
10	4	Wallace	291Berry, Bellaire, TX	1941-06-20
30	4	Wallace	291Berry, Bellaire, TX	1941-06-20

(d)

E.Fname	E.Lname	S.Fname	S.Lname
John	Smith	Franklin	Wong
Franklin	Wong	James	Borg
Alicia	Zelaya	Jennifer	Wallace
Jennifer	Wallace	James	Borg
Ramesh	Narayan	Franklin	Wong
Joyce	English	Franklin	Wong
Ahmad	Jabbar	Jennifer	Wallace

(e)

E.Fname
123456789
333445555
999887777
987654321
666884444
453453453
987987987
888665555

(f)

Ssn	Dname
123456789	Research
333445555	Research
999887777	Research
987654321	Research
666884444	Research
453453453	Research
987987987	Research
888665555	Research
123456789	Administration
333445555	Administration
999887777	Administration
987654321	Administration
666884444	Administration
453453453	Administration
987987987	Administration
888665555	Administration
123456789	Headquarters
333445555	Headquarters
999887777	Headquarters
987654321	Headquarters
666884444	Headquarters
453453453	Headquarters
987987987	Headquarters
888665555	Headquarters

(g)

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
John	B	Smith	123456789	1965-09-01	731 Fondren, Houston, TX	M	30000	333445555	5
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5

The join condition Dnum = Dnumber relates a project tuple to its controlling department tuple, whereas the join condition Mgr_ssn = Ssn relates the controlling department tuple to the employee tuple who manages that department. Each tuple in the result will be a *combination* of one project, one department (that controls the project), and one employee (that manages the department). The projection attributes are used to choose the attributes to be displayed from each combined tuple. The result of query Q2 is shown in Figure 6.3(c).

6.3.2 Ambiguous Attribute Names, Aliasing, Renaming, and Tuple Variables

In SQL, the same name can be used for two (or more) attributes as long as the attributes are in *different tables.* If this is the case, and a multitable query refers to two or more attributes with the same name, we *must* **qualify** the attribute name with the relation name to prevent ambiguity. This is done by *prefixing* the relation name to the attribute name and separating the two by a period. To illustrate this, suppose that in Figures 5.5 and 5.6 the Dno and Lname attributes of the EMPLOYEE relation were called Dnumber and Name, and the Dname attribute of DEPARTMENT was also called Name; then, to prevent ambiguity, query Q1 would be rephrased as shown in Q1A. We must prefix the attributes Name and Dnumber in Q1A to specify which ones we are referring to, because the same attribute names are used in both relations:

```
Q1A:  SELECT   Fname, EMPLOYEE.Name, Address
      FROM     EMPLOYEE, DEPARTMENT
      WHERE    DEPARTMENT.Name = 'Research' AND
               DEPARTMENT.Dnumber = EMPLOYEE.Dnumber;
```

Fully qualified attribute names can be used for clarity even if there is no ambiguity in attribute names. Q1 can be rewritten as Q1′ below with fully qualified attribute names. We can also rename the table names to shorter names by creating an *alias* for each table name to avoid repeated typing of long table names (see Q8 below).

```
Q1′:  SELECT   EMPLOYEE.Fname, EMPLOYEE.LName,
               EMPLOYEE.Address
      FROM     EMPLOYEE, DEPARTMENT
      WHERE    DEPARTMENT.DName = 'Research' AND
               DEPARTMENT.Dnumber = EMPLOYEE.Dno;
```

The ambiguity of attribute names also arises in the case of queries that refer to the same relation twice, as in the following example.

Query 8. For each employee, retrieve the employee's first and last name and the first and last name of his or her immediate supervisor.

```
Q8:   SELECT   E.Fname, E.Lname, S.Fname, S.Lname
      FROM     EMPLOYEE AS E, EMPLOYEE AS S
      WHERE    E.Super_ssn = S.Ssn;
```

In this case, we are required to declare alternative relation names E and S, called **aliases** or **tuple variables**, for the EMPLOYEE relation. An alias can follow the keyword **AS**, as shown in Q8, or it can directly follow the relation name—for example, by writing EMPLOYEE E, EMPLOYEE S in the FROM clause of Q8. It is also possible to **rename** the relation attributes within the query in SQL by giving them aliases. For example, if we write

EMPLOYEE **AS** E(Fn, Mi, Ln, Ssn, Bd, Addr, Sex, Sal, Sssn, Dno)

in the FROM clause, Fn becomes an alias for Fname, Mi for Minit, Ln for Lname, and so on.

In Q8, we can think of E and S as two *different copies* of the EMPLOYEE relation; the first, E, represents employees in the role of supervisees or subordinates; the second, S, represents employees in the role of supervisors. We can now join the two copies. Of course, in reality there is *only one* EMPLOYEE relation, and the join condition is meant to join the relation with itself by matching the tuples that satisfy the join condition E.Super_ssn = S.Ssn. Notice that this is an example of a one-level recursive query, as we will discuss in Section 8.4.2. In earlier versions of SQL, it was not possible to specify a general recursive query, with an unknown number of levels, in a single SQL statement. A construct for specifying recursive queries has been incorporated into SQL:1999 (see Chapter 7).

The result of query Q8 is shown in Figure 6.3(d). Whenever one or more aliases are given to a relation, we can use these names to represent different references to that same relation. This permits multiple references to the same relation within a query.

We can use this alias-naming or **renaming** mechanism in any SQL query to specify tuple variables for every table in the WHERE clause, whether or not the same relation needs to be referenced more than once. In fact, this practice is recommended since it results in queries that are easier to comprehend. For example, we could specify query Q1 as in Q1B:

```
Q1B:  SELECT   E.Fname, E.LName, E.Address
      FROM     EMPLOYEE AS E, DEPARTMENT AS D
      WHERE    D.DName = 'Research' AND D.Dnumber = E.Dno;
```

6.3.3 Unspecified WHERE Clause and Use of the Asterisk

We discuss two more features of SQL here. A *missing* WHERE clause indicates no condition on tuple selection; hence, *all tuples* of the relation specified in the FROM clause qualify and are selected for the query result. If more than one relation is specified in the FROM clause and there is no WHERE clause, then the CROSS PRODUCT—*all possible tuple combinations*—of these relations is selected. For example, Query 9 selects all EMPLOYEE Ssns (Figure 6.3(e)), and Query 10 selects all combinations of an EMPLOYEE Ssn and a DEPARTMENT Dname, regardless of whether the employee works for the department or not (Figure 6.3(f)).

Queries 9 and 10. Select all EMPLOYEE Ssns (Q9) and all combinations of EMPLOYEE Ssn and DEPARTMENT Dname (Q10) in the database.

```
Q9:    SELECT   Ssn
       FROM     EMPLOYEE;

Q10:   SELECT   Ssn, Dname
       FROM     EMPLOYEE, DEPARTMENT;
```

It is extremely important to specify every selection and join condition in the WHERE clause; if any such condition is overlooked, incorrect and very large relations may result. Notice that Q10 is similar to a CROSS PRODUCT operation followed by a PROJECT operation in relational algebra (see Chapter 8). If we specify all the attributes of EMPLOYEE and DEPARTMENT in Q10, we get the actual CROSS PRODUCT (except for duplicate elimination, if any).

To retrieve all the attribute values of the selected tuples, we do not have to list the attribute names explicitly in SQL; we just specify an *asterisk* (*), which stands for *all the attributes*. The * can also be prefixed by the relation name or alias; for example, EMPLOYEE.* refers to all attributes of the EMPLOYEE table.

Query Q1C retrieves all the attribute values of any EMPLOYEE who works in DEPARTMENT number 5 (Figure 6.3(g)), query Q1D retrieves all the attributes of an EMPLOYEE and the attributes of the DEPARTMENT in which he or she works for every employee of the 'Research' department, and Q10A specifies the CROSS PRODUCT of the EMPLOYEE and DEPARTMENT relations.

```
Q1C:   SELECT   *
       FROM     EMPLOYEE
       WHERE    Dno = 5;

Q1D:   SELECT   *
       FROM     EMPLOYEE, DEPARTMENT
       WHERE    Dname = 'Research' AND Dno = Dnumber;

Q10A:  SELECT   *
       FROM     EMPLOYEE, DEPARTMENT;
```

6.3.4 Tables as Sets in SQL

As we mentioned earlier, SQL usually treats a table not as a set but rather as a **multiset**; *duplicate tuples can appear more than once* in a table, and in the result of a query. SQL does not automatically eliminate duplicate tuples in the results of queries, for the following reasons:

- Duplicate elimination is an expensive operation. One way to implement it is to sort the tuples first and then eliminate duplicates.
- The user may want to see duplicate tuples in the result of a query.
- When an aggregate function (see Section 7.1.7) is applied to tuples, in most cases we do not want to eliminate duplicates.

(a)

Salary
30000
40000
25000
43000
38000
25000
25000
55000

(b)

Salary
30000
40000
25000
43000
38000
55000

(c)

Fname	Lname

(d)

Fname	Lname
James	Borg

Figure 6.4
Results of additional SQL queries when applied to the COMPANY database state shown in Figure 5.6. (a) Q11. (b) Q11A. (c) Q16. (d) Q18.

An SQL table with a key is restricted to being a set, since the key value must be distinct in each tuple.[10] If we *do want* to eliminate duplicate tuples from the result of an SQL query, we use the keyword **DISTINCT** in the SELECT clause, meaning that only distinct tuples should remain in the result. In general, a query with SELECT DISTINCT eliminates duplicates, whereas a query with SELECT ALL does not. Specifying SELECT with neither ALL nor DISTINCT—as in our previous examples—is equivalent to SELECT ALL. For example, Q11 retrieves the salary of every employee; if several employees have the same salary, that salary value will appear as many times in the result of the query, as shown in Figure 6.4(a). If we are interested only in distinct salary values, we want each value to appear only once, regardless of how many employees earn that salary. By using the keyword **DISTINCT** as in Q11A, we accomplish this, as shown in Figure 6.4(b).

Query 11. Retrieve the salary of every employee (Q11) and all distinct salary values (Q11A).

```
Q11:   SELECT   ALL Salary
       FROM     EMPLOYEE;

Q11A:  SELECT   DISTINCT Salary
       FROM     EMPLOYEE;
```

SQL has directly incorporated some of the set operations from mathematical *set theory*, which are also part of relational algebra (see Chapter 8). There are set union (**UNION**), set difference (**EXCEPT**),[11] and set intersection (**INTERSECT**) operations. The relations resulting from these set operations are sets of tuples; that is, *duplicate tuples are eliminated from the result.* These set operations apply only to *type-compatible relations*, so we must make sure that the two relations on which we apply the operation have the same attributes and that the attributes appear in the same order in both relations. The next example illustrates the use of UNION.

[10] In general, an SQL table is not required to have a key, although in most cases there will be one.

[11] In some systems, the keyword MINUS is used for the set difference operation instead of EXCEPT.

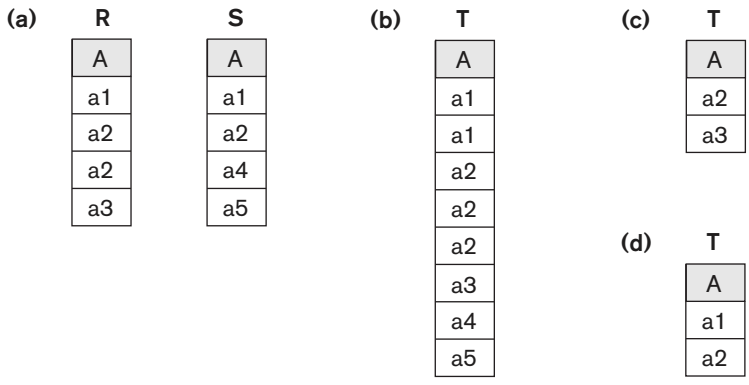

Figure 6.5
The results of SQL multiset operations. (a) Two tables, R(A) and S(A). (b) R(A)UNION ALL S(A). (c) R(A) EXCEPT ALL S(A). (d) R(A) INTERSECT ALL S(A).

Query 4. Make a list of all project numbers for projects that involve an employee whose last name is 'Smith', either as a worker or as a manager of the department that controls the project.

```
Q4A:  ( SELECT    DISTINCT Pnumber
        FROM      PROJECT, DEPARTMENT, EMPLOYEE
        WHERE     Dnum = Dnumber AND Mgr_ssn = Ssn
                  AND      Lname = 'Smith' )
        UNION
      ( SELECT    DISTINCT Pnumber
        FROM      PROJECT, WORKS_ON, EMPLOYEE
        WHERE     Pnumber = Pno AND Essn = Ssn
                  AND      Lname = 'Smith' );
```

The first SELECT query retrieves the projects that involve a 'Smith' as manager of the department that controls the project, and the second retrieves the projects that involve a 'Smith' as a worker on the project. Notice that if several employees have the last name 'Smith', the project names involving any of them will be retrieved. Applying the UNION operation to the two SELECT queries gives the desired result.

SQL also has corresponding multiset operations, which are followed by the keyword **ALL** (UNION ALL, EXCEPT ALL, INTERSECT ALL). Their results are multisets (duplicates are not eliminated). The behavior of these operations is illustrated by the examples in Figure 6.5. Basically, each tuple—whether it is a duplicate or not—is considered as a different tuple when applying these operations.

6.3.5 Substring Pattern Matching and Arithmetic Operators

In this section we discuss several more features of SQL. The first feature allows comparison conditions on only parts of a character string, using the **LIKE** comparison operator. This can be used for string **pattern matching**. Partial strings are specified using two reserved characters: % replaces an arbitrary number of zero or more characters, and the underscore (_) replaces a single character. For example, consider the following query.

Query 12. Retrieve all employees whose address is in Houston, Texas.

```
Q12:  SELECT   Fname, Lname
      FROM     EMPLOYEE
      WHERE    Address LIKE '%Houston,TX%';
```

To retrieve all employees who were born during the 1970s, we can use Query Q12A. Here, '7' must be the third character of the string (according to our format for date), so we use the value '_ _ 5 _ _ _ _ _ _ _', with each underscore serving as a placeholder for an arbitrary character.

Query 12A. Find all employees who were born during the 1950s.

```
Q12:  SELECT   Fname, Lname
      FROM     EMPLOYEE
      WHERE    Bdate LIKE '_ _ 7 _ _ _ _ _ _ _';
```

If an underscore or % is needed as a literal character in the string, the character should be preceded by an *escape character*, which is specified after the string using the keyword ESCAPE. For example, 'AB_CD\%EF' ESCAPE '\' represents the literal string 'AB_CD%EF' because \ is specified as the escape character. Any character not used in the string can be chosen as the escape character. Also, we need a rule to specify apostrophes or single quotation marks (' ') if they are to be included in a string because they are used to begin and end strings. If an apostrophe (') is needed, it is represented as two consecutive apostrophes (") so that it will not be interpreted as ending the string. Notice that substring comparison implies that attribute values are not atomic (indivisible) values, as we had assumed in the formal relational model (see Section 5.1) .

Another feature allows the use of arithmetic in queries. The standard arithmetic operators for addition (+), subtraction (–), multiplication (*), and division (/) can be applied to numeric values or attributes with numeric domains. For example, suppose that we want to see the effect of giving all employees who work on the 'ProductX' project a 10% raise; we can issue Query 13 to see what their salaries would become. This example also shows how we can rename an attribute in the query result using AS in the SELECT clause.

Query 13. Show the resulting salaries if every employee working on the 'ProductX' project is given a 10% raise.

```
Q13:  SELECT   E.Fname, E.Lname, 1.1 * E.Salary AS Increased_sal
      FROM     EMPLOYEE AS E, WORKS_ON AS W, PROJECT AS P
      WHERE    E.Ssn = W.Essn AND W.Pno = P.Pnumber AND
               P.Pname = 'ProductX';
```

For string data types, the concatenate operator || can be used in a query to append two string values. For date, time, timestamp, and interval data types, operators include incrementing (+) or decrementing (–) a date, time, or timestamp by an interval. In addition, an interval value is the result of the difference between two date, time, or timestamp values. Another comparison operator, which can be used for convenience, is **BETWEEN**, which is illustrated in Query 14.

Query 14. Retrieve all employees in department 5 whose salary is between $30,000 and $40,000.

```
Q14:  SELECT   *
      FROM     EMPLOYEE
      WHERE    (Salary BETWEEN 30000 AND 40000) AND Dno = 5;
```

The condition (Salary **BETWEEN** 30000 **AND** 40000) in Q14 is equivalent to the condition ((Salary >= 30000) **AND** (Salary <= 40000)).

6.3.6 Ordering of Query Results

SQL allows the user to order the tuples in the result of a query by the values of one or more of the attributes that appear in the query result, by using the **ORDER BY** clause. This is illustrated by Query 15.

Query 15. Retrieve a list of employees and the projects they are working on, ordered by department and, within each department, ordered alphabetically by last name, then first name.

```
Q15:  SELECT   D.Dname, E.Lname, E.Fname, P.Pname
      FROM     DEPARTMENT AS D, EMPLOYEE AS E, WORKS_ON AS W,
               PROJECT AS P
      WHERE    D.Dnumber = E.Dno AND E.Ssn = W.Essn AND W.Pno =
               P.Pnumber
      ORDER BY D.Dname, E.Lname, E.Fname;
```

The default order is in ascending order of values. We can specify the keyword **DESC** if we want to see the result in a descending order of values. The keyword **ASC** can be used to specify ascending order explicitly. For example, if we want descending alphabetical order on Dname and ascending order on Lname, Fname, the ORDER BY clause of Q15 can be written as

```
ORDER BY D.Dname DESC, E.Lname ASC, E.Fname ASC
```

6.3.7 Discussion and Summary of Basic SQL Retrieval Queries

A *simple* retrieval query in SQL can consist of up to four clauses, but only the first two—SELECT and FROM—are mandatory. The clauses are specified in the following order, with the clauses between square brackets […] being optional:

```
SELECT      <attribute list>
FROM        <table list>
[ WHERE     <condition> ]
[ ORDER BY  <attribute list> ];
```

The SELECT clause lists the attributes to be retrieved, and the FROM clause specifies all relations (tables) needed in the simple query. The WHERE clause identifies the conditions for selecting the tuples from these relations, including

join conditions if needed. ORDER BY specifies an order for displaying the results of a query. Two additional clauses GROUP BY and HAVING will be described in Section 7.1.8.

In Chapter 7, we will present more complex features of SQL retrieval queries. These include the following: nested queries that allow one query to be included as part of another query; aggregate functions that are used to provide summaries of the information in the tables; two additional clauses (GROUP BY and HAVING) that can be used to provide additional power to aggregate functions; and various types of joins that can combine records from various tables in different ways.

6.4 INSERT, DELETE, and UPDATE Statements in SQL

In SQL, three commands can be used to modify the database: INSERT, DELETE, and UPDATE. We discuss each of these in turn.

6.4.1 The INSERT Command

In its simplest form, INSERT is used to add a single tuple (row) to a relation (table). We must specify the relation name and a list of values for the tuple. The values should be listed *in the same order* in which the corresponding attributes were specified in the CREATE TABLE command. For example, to add a new tuple to the EMPLOYEE relation shown in Figure 5.5 and specified in the CREATE TABLE EMPLOYEE … command in Figure 6.1, we can use U1:

```
U1:   INSERT INTO   EMPLOYEE
      VALUES        ( 'Richard', 'K', 'Marini', '653298653', '1962-12-30', '98
                    Oak Forest, Katy, TX', 'M', 37000, '653298653', 4 );
```

A second form of the INSERT statement allows the user to specify explicit attribute names that correspond to the values provided in the INSERT command. This is useful if a relation has many attributes but only a few of those attributes are assigned values in the new tuple. However, the values must include all attributes with NOT NULL specification *and* no default value. Attributes with NULL allowed or DEFAULT values are the ones that can be *left out*. For example, to enter a tuple for a new EMPLOYEE for whom we know only the Fname, Lname, Dno, and Ssn attributes, we can use U1A:

```
U1A:  INSERT INTO   EMPLOYEE (Fname, Lname, Dno, Ssn)
      VALUES        ('Richard', 'Marini', 4, '653298653');
```

Attributes not specified in U1A are set to their DEFAULT or to NULL, and the values are listed in the same order as the *attributes are listed in the INSERT* command itself. It is also possible to insert into a relation *multiple tuples* separated by commas in a single INSERT command. The attribute values forming *each tuple* are enclosed in parentheses.

A DBMS that fully implements SQL should support and enforce all the integrity constraints that can be specified in the DDL. For example, if we issue the command in U2 on the database shown in Figure 5.6, the DBMS should *reject* the operation because no DEPARTMENT tuple exists in the database with Dnumber = 2. Similarly, U2A would be *rejected* because no Ssn value is provided and it is the primary key, which cannot be NULL.

```
U2:   INSERT INTO   EMPLOYEE (Fname, Lname, Ssn, Dno)
      VALUES        ('Robert', 'Hatcher', '980760540', 2);
      (U2 is rejected if referential integrity checking is provided by DBMS.)

U2A:  INSERT INTO   EMPLOYEE (Fname, Lname, Dno)
      VALUES        ('Robert', 'Hatcher', 5);
      (U2A is rejected if NOT NULL checking is provided by DBMS.)
```

A variation of the INSERT command inserts multiple tuples into a relation in conjunction with creating the relation and loading it with the *result of a query*. For example, to create a temporary table that has the employee last name, project name, and hours per week for each employee working on a project, we can write the statements in U3A and U3B:

```
U3A:  CREATE TABLE      WORKS_ON_INFO
      ( Emp_name        VARCHAR(15),
        Proj_name       VARCHAR(15),
        Hours_per_week  DECIMAL(3,1) );

U3B:  INSERT INTO       WORKS_ON_INFO ( Emp_name, Proj_name,
                        Hours_per_week )
      SELECT            E.Lname, P.Pname, W.Hours
      FROM              PROJECT P, WORKS_ON W, EMPLOYEE E
      WHERE             P.Pnumber = W.Pno AND W.Essn = E.Ssn;
```

A table WORKS_ON_INFO is created by U3A and is loaded with the joined information retrieved from the database by the query in U3B. We can now query WORKS_ON_INFO as we would any other relation; when we do not need it anymore, we can remove it by using the DROP TABLE command (see Chapter 7). Notice that the WORKS_ON_INFO table may not be up to date; that is, if we update any of the PROJECT,WORKS_ON, or EMPLOYEE relations after issuing U3B, the information in WORKS_ON_INFO *may become outdated*. We have to create a view (see Chapter 7) to keep such a table up to date.

Most DBMSs have *bulk loading* tools that allow a user to load formatted data from a file into a table without having to write a large number of INSERT commands. The user can also write a program to read each record in the file, format it as a row in the table, and insert it using the looping constructs of a programming language (see Chapters 10 and 11, where we discuss database programming techniques).

Another variation for loading data is to create a new table TNEW that has the same attributes as an existing table T, and load some of the data currently in T into TNEW. The syntax for doing this uses the LIKE clause. For example, if we

want to create a table D5EMPS with a similar structure to the EMPLOYEE table and load it with the rows of employees who work in department 5, we can write the following SQL:

```
CREATE TABLE    D5EMPS LIKE EMPLOYEE
(SELECT         E.*
FROM            EMPLOYEE AS E
WHERE           E.Dno = 5) WITH DATA;
```

The clause WITH DATA specifies that the table will be created and loaded with the data specified in the query, although in some implementations it may be left out.

6.4.2 The DELETE Command

The DELETE command removes tuples from a relation. It includes a WHERE clause, similar to that used in an SQL query, to select the tuples to be deleted. Tuples are explicitly deleted from only one table at a time. However, the deletion may propagate to tuples in other relations if *referential triggered actions* are specified in the referential integrity constraints of the DDL (see Section 6.2.2).[12] Depending on the number of tuples selected by the condition in the WHERE clause, zero, one, or several tuples can be deleted by a single DELETE command. A missing WHERE clause specifies that all tuples in the relation are to be deleted; however, the table remains in the database as an empty table. We must use the DROP TABLE command to remove the table definition (see Chapter 7). The DELETE commands in U4A to U4D, if applied independently to the database state shown in Figure 5.6, will delete zero, one, four, and all tuples, respectively, from the EMPLOYEE relation:

```
U4A:  DELETE FROM   EMPLOYEE
      WHERE         Lname = 'Brown';
U4B:  DELETE FROM   EMPLOYEE
      WHERE         Ssn = '123456789';
U4C:  DELETE FROM   EMPLOYEE
      WHERE         Dno = 5;
U4D:  DELETE FROM   EMPLOYEE;
```

6.4.3 The UPDATE Command

The **UPDATE** command is used to modify attribute values of one or more selected tuples. As in the DELETE command, a WHERE clause in the UPDATE command selects the tuples to be modified from a single relation. However, updating a primary key value may propagate to the foreign key values of tuples in other relations if such a *referential triggered action* is specified in the referential integrity

[12]Other actions can be automatically applied through triggers (see Section 26.1) and other mechanisms.

constraints of the DDL (see Section 6.2.2). An additional **SET** clause in the UPDATE command specifies the attributes to be modified and their new values. For example, to change the location and controlling department number of project number 10 to 'Bellaire' and 5, respectively, we use U5:

```
U5:   UPDATE   PROJECT
      SET      Plocation = 'Bellaire', Dnum = 5
      WHERE    Pnumber = 10;
```

Several tuples can be modified with a single UPDATE command. An example is to give all employees in the 'Research' department a 10% raise in salary, as shown in U6. In this request, the modified Salary value depends on the original Salary value in each tuple, so two references to the Salary attribute are needed. In the SET clause, the reference to the Salary attribute on the right refers to the old Salary value *before modification*, and the one on the left refers to the new Salary value *after modification*:

```
U6:   UPDATE   EMPLOYEE
      SET      Salary = Salary * 1.1
      WHERE    Dno = 5;
```

It is also possible to specify NULL or DEFAULT as the new attribute value. Notice that each UPDATE command explicitly refers to a single relation only. To modify multiple relations, we must issue several UPDATE commands.

6.5 Additional Features of SQL

SQL has a number of additional features that we have not described in this chapter but that we discuss elsewhere in the book. These are as follows:

- In Chapter 7, which is a continuation of this chapter, we will present the following SQL features: various techniques for specifying complex retrieval queries, including nested queries, aggregate functions, grouping, joined tables, outer joins, case statements, and recursive queries; SQL views, triggers, and assertions; and commands for schema modification.
- SQL has various techniques for writing programs in various programming languages that include SQL statements to access one or more databases. These include embedded (and dynamic) SQL, SQL/CLI (Call Level Interface) and its predecessor ODBC (Open Data Base Connectivity), and SQL/PSM (Persistent Stored Modules). We discuss these techniques in Chapter 10. We also describe how to access SQL databases through the Java programming language using JDBC and SQLJ.
- Each commercial RDBMS will have, in addition to the SQL commands, a set of commands for specifying physical database design parameters, file structures for relations, and access paths such as indexes. We called these commands a *storage definition language* (*SDL*) in Chapter 2. Earlier versions of SQL had commands for **creating indexes**, but these were removed from the

language because they were not at the conceptual schema level. Many systems still have the CREATE INDEX commands; but they require a special privilege. We describe this in Chapter 17.

- SQL has transaction control commands. These are used to specify units of database processing for concurrency control and recovery purposes. We discuss these commands in Chapter 20 after we discuss the concept of transactions in more detail.
- SQL has language constructs for specifying the *granting and revoking of privileges* to users. Privileges typically correspond to the right to use certain SQL commands to access certain relations. Each relation is assigned an owner, and either the owner or the DBA staff can grant to selected users the privilege to use an SQL statement—such as SELECT, INSERT, DELETE, or UPDATE—to access the relation. In addition, the DBA staff can grant the privileges to create schemas, tables, or views to certain users. These SQL commands—called **GRANT** and **REVOKE**—are discussed in Chapter 20, where we discuss database security and authorization.
- SQL has language constructs for creating triggers. These are generally referred to as **active database** techniques, since they specify actions that are automatically triggered by events such as database updates. We discuss these features in Section 26.1, where we discuss active database concepts.
- SQL has incorporated many features from object-oriented models to have more powerful capabilities, leading to enhanced relational systems known as **object-relational**. Capabilities such as creating complex-structured attributes, specifying abstract data types (called **UDT**s or user-defined types) for attributes and tables, creating **object identifiers** for referencing tuples, and specifying **operations** on types are discussed in Chapter 12.
- SQL and relational databases can interact with new technologies such as XML (see Chapter 13) and OLAP/data warehouses (Chapter 29).

6.6 Summary

In this chapter, we introduced the SQL database language. This language and its variations have been implemented as interfaces to many commercial relational DBMSs, including Oracle's Oracle; ibm's DB2; Microsoft's SQL Server; and many other systems including Sybase and INGRES. Some open source systems also provide SQL, such as MySQL and PostgreSQL. The original version of SQL was implemented in the experimental DBMS called SYSTEM R, which was developed at IBM Research. SQL is designed to be a comprehensive language that includes statements for data definition, queries, updates, constraint specification, and view definition. We discussed the following features of SQL in this chapter: the data definition commands for creating tables, SQL basic data types, commands for constraint specification, simple retrieval queries, and database update commands. In the next chapter, we will present the following features of SQL: complex retrieval queries; views; triggers and assertions; and schema modification commands.

Review Questions

6.1. How do the relations (tables) in SQL differ from the relations defined formally in Chapter 3? Discuss the other differences in terminology. Why does SQL allow duplicate tuples in a table or in a query result?

6.2. List the data types that are allowed for SQL attributes.

6.3. How does SQL allow implementation of the entity integrity and referential integrity constraints described in Chapter 3? What about referential triggered actions?

6.4. Describe the four clauses in the syntax of a simple SQL retrieval query. Show what type of constructs can be specified in each of the clauses. Which are required and which are optional?

Exercises

6.5. Consider the database shown in Figure 1.2, whose schema is shown in Figure 2.1. What are the referential integrity constraints that should hold on the schema? Write appropriate SQL DDL statements to define the database.

6.6. Repeat Exercise 6.5, but use the AIRLINE database schema of Figure 5.8.

6.7. Consider the LIBRARY relational database schema shown in Figure 6.6. Choose the appropriate action (reject, cascade, set to NULL, set to default) for each referential integrity constraint, both for the *deletion* of a referenced tuple and for the *update* of a primary key attribute value in a referenced tuple. Justify your choices.

6.8. Write appropriate SQL DDL statements for declaring the LIBRARY relational database schema of Figure 6.6. Specify the keys and referential triggered actions.

6.9. How can the key and foreign key constraints be enforced by the DBMS? Is the enforcement technique you suggest difficult to implement? Can the constraint checks be executed efficiently when updates are applied to the database?

6.10. Specify the following queries in SQL on the COMPANY relational database schema shown in Figure 5.5. Show the result of each query if it is applied to the COMPANY database in Figure 5.6.

a. Retrieve the names of all employees in department 5 who work more than 10 hours per week on the ProductX project.

b. List the names of all employees who have a dependent with the same first name as themselves.

c. Find the names of all employees who are directly supervised by 'Franklin Wong'.

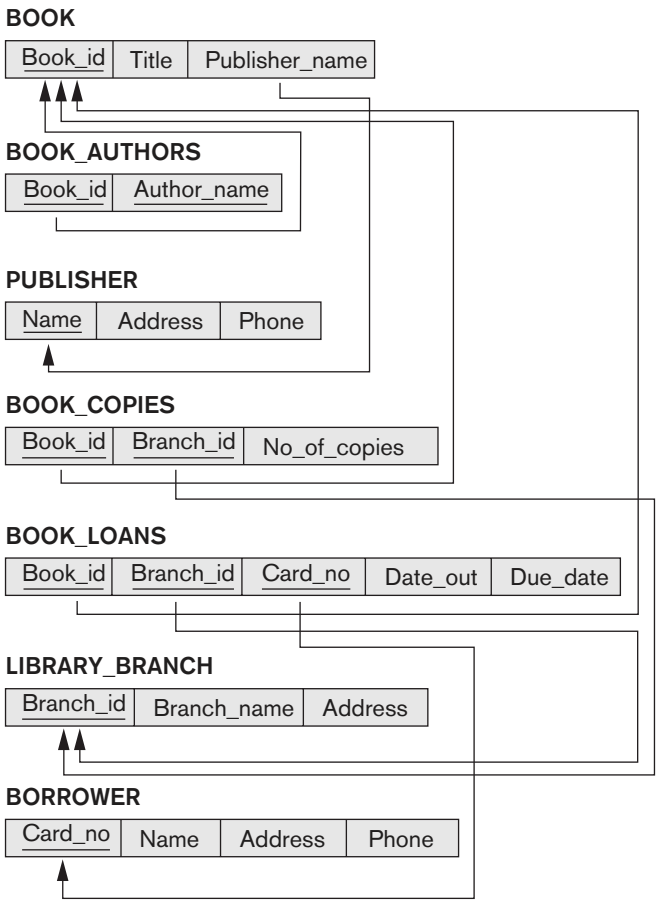

Figure 6.6
A relational database schema for a LIBRARY database.

6.11. Specify the updates of Exercise 3.11 using the SQL update commands.

6.12. Specify the following queries in SQL on the database schema of Figure 1.2.

a. Retrieve the names of all senior students majoring in 'cs' (computer science).

b. Retrieve the names of all courses taught by Professor King in 2007 and 2008.

c. For each section taught by Professor King, retrieve the course number, semester, year, and number of students who took the section.

d. Retrieve the name and transcript of each senior student (Class = 4) majoring in CS. A transcript includes course name, course number, credit hours, semester, year, and grade for each course completed by the student.

6.13. Write SQL update statements to do the following on the database schema shown in Figure 1.2.

a. Insert a new student, <'Johnson', 25, 1, 'Math'>, in the database.

b. Change the class of student 'Smith' to 2.

c. Insert a new course, <'Knowledge Engineering', 'cs4390', 3, 'cs'>.

d. Delete the record for the student whose name is 'Smith' and whose student number is 17.

6.14. Design a relational database schema for a database application of your choice.

a. Declare your relations using the SQL DDL.

b. Specify a number of queries in SQL that are needed by your database application.

c. Based on your expected use of the database, choose some attributes that should have indexes specified on them.

d. Implement your database, if you have a DBMS that supports SQL.

6.15. Consider that the EMPLOYEE table's constraint EMPSUPERFK as specified in Figure 6.2 is changed to read as follows:

```
CONSTRAINT EMPSUPERFK
  FOREIGN KEY (Super_ssn) REFERENCES EMPLOYEE(Ssn)
                ON DELETE CASCADE ON UPDATE CASCADE,
```

Answer the following questions:

a. What happens when the following command is run on the database state shown in Figure 5.6?

```
DELETE EMPLOYEE WHERE Lname = 'Borg'
```

b. Is it better to CASCADE or SET NULL in case of EMPSUPERFK constraint ON DELETE?

6.16. Write SQL statements to create a table EMPLOYEE_BACKUP to back up the EMPLOYEE table shown in Figure 5.6.

Selected Bibliography

The SQL language, originally named SEQUEL, was based on the language SQUARE (Specifying Queries as Relational Expressions) described by Boyce et al. (1975). The syntax of SQUARE was modified into SEQUEL (Chamberlin & Boyce, 1974) and then into SEQUEL 2 (Chamberlin et al., 1976), on which SQL is based. The original implementation of SEQUEL was done at IBM Research, San Jose, California. We will give additional references to various aspects of SQL at the end of Chapter 7.

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chapter 7

More SQL: Complex Queries, Triggers, Views, and Schema Modification

This chapter describes more advanced features of the SQL language for relational databases. We start in Section 7.1 by presenting more complex features of SQL retrieval queries, such as nested queries, joined tables, outer joins, aggregate functions, and grouping, and case statements. In Section 7.2, we describe the CREATE ASSERTION statement, which allows the specification of more general constraints on the database. We also introduce the concept of triggers and the CREATE TRIGGER statement, which will be presented in more detail in Section 26.1 when we present the principles of active databases. Then, in Section 7.3, we describe the SQL facility for defining views on the database. Views are also called *virtual* or *derived tables* because they present the user with what appear to be tables; however, the information in those tables is derived from previously defined tables. Section 7.4 introduces the SQL ALTER TABLE statement, which is used for modifying the database tables and constraints. Section 7.5 is the chapter summary.

This chapter is a continuation of Chapter 6. The instructor may skip parts of this chapter if a less detailed introduction to SQL is intended.

7.1 More Complex SQL Retrieval Queries

In Section 6.3, we described some basic types of retrieval queries in SQL. Because of the generality and expressive power of the language, there are many additional features that allow users to specify more complex retrievals from the database. We discuss several of these features in this section.

7.1.1 Comparisons Involving NULL and Three-Valued Logic

SQL has various rules for dealing with NULL values. Recall from Section 5.1.2 that NULL is used to represent a missing value, but that it usually has one of three different interpretations—value *unknown* (value exists but is not known, or it is not known whether or not the value exists), value *not available* (value exists but is purposely withheld), or value *not applicable* (the attribute does not apply to this tuple or is undefined for this tuple). Consider the following examples to illustrate each of the meanings of NULL.

1. **Unknown value.** A person's date of birth is not known, so it is represented by NULL in the database. An example of the other case of unknown would be NULL for a person's home phone because it is not known whether or not the person has a home phone.
2. **Unavailable or withheld value.** A person has a home phone but does not want it to be listed, so it is withheld and represented as NULL in the database.
3. **Not applicable attribute.** An attribute LastCollegeDegree would be NULL for a person who has no college degrees because it does not apply to that person.

It is often not possible to determine which of the meanings is intended; for example, a NULL for the home phone of a person can have any of the three meanings. Hence, SQL does not distinguish among the different meanings of NULL.

In general, each individual NULL value is considered to be different from every other NULL value in the various database records. When a record with NULL in one of its attributes is involved in a comparison operation, the result is considered to be UNKNOWN (it may be TRUE or it may be FALSE). Hence, SQL uses a three-valued logic with values TRUE, FALSE, and UNKNOWN instead of the standard two-valued (Boolean) logic with values TRUE or FALSE. It is therefore necessary to define the results (or truth values) of three-valued logical expressions when the logical connectives AND, OR, and NOT are used. Table 7.1 shows the resulting values.

Table 7.1 Logical Connectives in Three-Valued Logic

(a)

AND	TRUE	FALSE	UNKNOWN
TRUE	TRUE	FALSE	UNKNOWN
FALSE	FALSE	FALSE	FALSE
UNKNOWN	UNKNOWN	FALSE	UNKNOWN

(b)

OR	TRUE	FALSE	UNKNOWN
TRUE	TRUE	TRUE	TRUE
FALSE	TRUE	FALSE	UNKNOWN
UNKNOWN	TRUE	UNKNOWN	UNKNOWN

(c)

NOT	
TRUE	FALSE
FALSE	TRUE
UNKNOWN	UNKNOWN

In Tables 7.1(a) and 7.1(b), the rows and columns represent the values of the results of comparison conditions, which would typically appear in the WHERE clause of an SQL query. Each expression result would have a value of TRUE, FALSE, or UNKNOWN. The result of combining the two values using the AND logical connective is shown by the entries in Table 7.1(a). Table 7.1(b) shows the result of using the OR logical connective. For example, the result of (FALSE AND UNKNOWN) is FALSE, whereas the result of (FALSE OR UNKNOWN) is UNKNOWN. Table 7.1(c) shows the result of the NOT logical operation. Notice that in standard Boolean logic, only TRUE or FALSE values are permitted; there is no UNKNOWN value.

In select-project-join queries, the general rule is that only those combinations of tuples that evaluate the logical expression in the WHERE clause of the query to TRUE are selected. Tuple combinations that evaluate to FALSE or UNKNOWN are not selected. However, there are exceptions to that rule for certain operations, such as outer joins, as we shall see in Section 7.1.6.

SQL allows queries that check whether an attribute value is **NULL**. Rather than using = or <> to compare an attribute value to NULL, SQL uses the comparison operators **IS** or IS **NOT**. This is because SQL considers each NULL value as being distinct from every other NULL value, so equality comparison is not appropriate. It follows that when a join condition is specified, tuples with NULL values for the join attributes are not included in the result (unless it is an OUTER JOIN; see Section 7.1.6). Query 18 illustrates NULL comparison by retrieving any employees who do not have a supervisor.

Query 18. Retrieve the names of all employees who do not have supervisors.

```
Q18:    SELECT    Fname, Lname
        FROM      EMPLOYEE
        WHERE     Super_ssn IS NULL;
```

7.1.2 Nested Queries, Tuples, and Set/Multiset Comparisons

Some queries require that existing values in the database be fetched and then used in a comparison condition. Such queries can be conveniently formulated by using **nested queries**, which are complete select-from-where blocks within another SQL query. That other query is called the **outer query**. These nested queries can also appear in the WHERE clause or the FROM clause or the SELECT clause or other SQL clauses as needed. Query 4 is formulated in Q4 without a nested query, but it can be rephrased to use nested queries as shown in Q4A. Q4A introduces the comparison operator **IN**, which compares a value v with a set (or multiset) of values V and evaluates to **TRUE** if v is one of the elements in V.

In Q4A, the first nested query selects the project numbers of projects that have an employee with last name 'Smith' involved as manager, whereas the second nested query selects the project numbers of projects that have an employee with last name 'Smith' involved as worker. In the outer query, we use the **OR** logical connective to retrieve a PROJECT tuple if the PNUMBER value of that tuple is in the result of either nested query.

```
Q4A:  SELECT   DISTINCT Pnumber
      FROM     PROJECT
      WHERE    Pnumber IN
               ( SELECT     Pnumber
                 FROM       PROJECT, DEPARTMENT, EMPLOYEE
                 WHERE      Dnum = Dnumber AND
                            Mgr_ssn = Ssn AND Lname = 'Smith' )
               OR
               Pnumber IN
               ( SELECT     Pno
                 FROM       WORKS_ON, EMPLOYEE
                 WHERE      Essn = Ssn AND Lname = 'Smith' );
```

If a nested query returns a single attribute *and* a single tuple, the query result will be a single (**scalar**) value. In such cases, it is permissible to use = instead of IN for the comparison operator. In general, the nested query will return a **table** (relation), which is a set or multiset of tuples.

SQL allows the use of **tuples** of values in comparisons by placing them within parentheses. To illustrate this, consider the following query:

```
SELECT   DISTINCT Essn
FROM     WORKS_ON
WHERE    (Pno, Hours) IN   ( SELECT     Pno, Hours
                             FROM       WORKS_ON
                             WHERE      Essn = '123456789' );
```

This query will select the Essns of all employees who work the same (project, hours) combination on some project that employee 'John Smith' (whose Ssn = '123456789') works on. In this example, the IN operator compares the subtuple of values in parentheses (Pno, Hours) within each tuple in WORKS_ON with the set of type-compatible tuples produced by the nested query.

In addition to the IN operator, a number of other comparison operators can be used to compare a single value *v* (typically an attribute name) to a set or multiset *v* (typically a nested query). The = ANY (or = SOME) operator returns TRUE if the value *v* is equal to *some value* in the set *V* and is hence equivalent to IN. The two keywords ANY and SOME have the same effect. Other operators that can be combined with ANY (or SOME) include >, >=, <, <=, and <>. The keyword ALL can also be combined with each of these operators. For example, the comparison condition (*v* > ALL *V*) returns TRUE if the value *v* is greater than *all* the values in the set (or multiset) *V*. An example is the following query, which returns the names of employees whose salary is greater than the salary of all the employees in department 5:

```
SELECT   Lname, Fname
FROM     EMPLOYEE
WHERE    Salary > ALL   ( SELECT     Salary
                          FROM       EMPLOYEE
                          WHERE      Dno = 5 );
```

Notice that this query can also be specified using the MAX aggregate function (see Section 7.1.7).

In general, we can have several levels of nested queries. We can once again be faced with possible ambiguity among attribute names if attributes of the same name exist—one in a relation in the FROM clause of the *outer query*, and another in a relation in the FROM clause of the *nested query*. The rule is that a reference to an *unqualified attribute* refers to the relation declared in the **innermost nested query**. For example, in the SELECT clause and WHERE clause of the first nested query of Q4A, a reference to any unqualified attribute of the PROJECT relation refers to the PROJECT relation specified in the FROM clause of the nested query. To refer to an attribute of the PROJECT relation specified in the outer query, we specify and refer to an *alias* (tuple variable) for that relation. These rules are similar to scope rules for program variables in most programming languages that allow nested procedures and functions. To illustrate the potential ambiguity of attribute names in nested queries, consider Query 16.

Query 16. Retrieve the name of each employee who has a dependent with the same first name and is the same sex as the employee.

```
Q16:  SELECT   E.Fname, E.Lname
      FROM     EMPLOYEE AS E
      WHERE    E.Ssn IN    ( SELECT   D.Essn
                             FROM     DEPENDENT AS D
                             WHERE    E.Fname = D.Dependent_name
                                      AND E.Sex = D.Sex );
```

In the nested query of Q16, we must qualify E.Sex because it refers to the Sex attribute of EMPLOYEE from the outer query, and DEPENDENT also has an attribute called Sex. If there were any unqualified references to Sex in the nested query, they would refer to the Sex attribute of DEPENDENT. However, we would not *have to* qualify the attributes Fname and Ssn of EMPLOYEE if they appeared in the nested query because the DEPENDENT relation does not have attributes called Fname and Ssn, so there is no ambiguity.

It is generally advisable to create tuple variables (aliases) for *all the tables referenced in an SQL query* to avoid potential errors and ambiguities, as illustrated in Q16.

7.1.3 Correlated Nested Queries

Whenever a condition in the WHERE clause of a nested query references some attribute of a relation declared in the outer query, the two queries are said to be **correlated**. We can understand a correlated query better by considering that the *nested query is evaluated once for each tuple (or combination of tuples) in the outer query.* For example, we can think of Q16 as follows: For *each* EMPLOYEE tuple, evaluate the nested query, which retrieves the Essn values for all DEPENDENT tuples with the same sex and name as that EMPLOYEE tuple; if the Ssn value of the EMPLOYEE tuple is *in* the result of the nested query, then select that EMPLOYEE tuple.

In general, a query written with nested select-from-where blocks and using the = or IN comparison operators can *always* be expressed as a single block query. For example, Q16 may be written as in Q16A:

```
Q16A:   SELECT   E.Fname, E.Lname
        FROM     EMPLOYEE AS E, DEPENDENT AS D
        WHERE    E.Ssn = D.Essn AND E.Sex = D.Sex
                 AND E.Fname = D.Dependent_name;
```

7.1.4 The EXISTS and UNIQUE Functions in SQL

EXISTS and UNIQUE are Boolean functions that return TRUE or FALSE; hence, they can be used in a WHERE clause condition. The EXISTS function in SQL is used to check whether the result of a nested query is *empty* (contains no tuples) or not. The result of EXISTS is a Boolean value **TRUE** if the nested query result contains at least one tuple, or **FALSE** if the nested query result contains no tuples. We illustrate the use of EXISTS—and NOT EXISTS—with some examples. First, we formulate Query 16 in an alternative form that uses EXISTS as in Q16B:

```
Q16B:   SELECT   E.Fname, E.Lname
        FROM     EMPLOYEE AS E
        WHERE    EXISTS ( SELECT   *
                          FROM     DEPENDENT AS D
                          WHERE    E.Ssn = D.Essn AND E.Sex = D.Sex
                                   AND E.Fname = D.Dependent_name);
```

EXISTS and NOT EXISTS are typically used in conjunction with a *correlated* nested query. In Q16B, the nested query references the Ssn, Fname, and Sex attributes of the EMPLOYEE relation from the outer query. We can think of Q16B as follows: For each EMPLOYEE tuple, evaluate the nested query, which retrieves all DEPENDENT tuples with the same Essn, Sex, and Dependent_name as the EMPLOYEE tuple; if at least one tuple EXISTS in the result of the nested query, then select that EMPLOYEE tuple. EXISTS(Q) returns **TRUE** if there is *at least one tuple* in the result of the nested query Q, and returns **FALSE** otherwise. On the other hand, NOT EXISTS(Q) returns **TRUE** if there are *no tuples* in the result of nested query Q, and returns **FALSE** otherwise. Next, we illustrate the use of NOT EXISTS.

Query 6. Retrieve the names of employees who have no dependents.

```
Q6:     SELECT   Fname, Lname
        FROM     EMPLOYEE
        WHERE    NOT EXISTS ( SELECT   *
                              FROM     DEPENDENT
                              WHERE    Ssn = Essn );
```

In Q6, the correlated nested query retrieves all DEPENDENT tuples related to a particular EMPLOYEE tuple. If *none exist,* the EMPLOYEE tuple is selected because the **WHERE**-clause condition will evaluate to **TRUE** in this case. We can explain Q6 as follows: For *each* EMPLOYEE tuple, the correlated nested query selects all

DEPENDENT tuples whose Essn value matches the EMPLOYEE Ssn; if the result is empty, no dependents are related to the employee, so we select that EMPLOYEE tuple and retrieve its Fname and Lname.

Query 7. List the names of managers who have at least one dependent.

```
Q7:   SELECT   Fname, Lname
      FROM     EMPLOYEE
      WHERE    EXISTS ( SELECT   *
                        FROM     DEPENDENT
                        WHERE    Ssn = Essn )
               AND
               EXISTS ( SELECT   *
                        FROM     DEPARTMENT
                        WHERE    Ssn = Mgr_ssn );
```

One way to write this query is shown in Q7, where we specify two nested correlated queries; the first selects all DEPENDENT tuples related to an EMPLOYEE, and the second selects all DEPARTMENT tuples managed by the EMPLOYEE. If at least one of the first and at least one of the second exists, we select the EMPLOYEE tuple. Can you rewrite this query using only a single nested query or no nested queries?

The query Q3: *Retrieve the name of each employee who works on* all *the projects controlled by department number 5* can be written using EXISTS and NOT EXISTS in SQL systems. We show two ways of specifying this query Q3 in SQL as Q3A and Q3B. This is an example of certain types of queries that require *universal quantification*, as we will discuss in Section 8.6.7. One way to write this query is to use the construct (*S2* EXCEPT *S1*) as explained next, and checking whether the result is empty.[1] This option is shown as Q3A.

```
Q3A:  SELECT   Fname, Lname
      FROM     EMPLOYEE
      WHERE    NOT EXISTS ( ( SELECT   Pnumber
                              FROM     PROJECT
                              WHERE    Dnum = 5)
                              EXCEPT   ( SELECT   Pno
                                         FROM     WORKS_ON
                                         WHERE    Ssn = Essn) );
```

In Q3A, the first subquery (which is not correlated with the outer query) selects all projects controlled by department 5, and the second subquery (which is correlated) selects all projects that the particular employee being considered works on. If the set difference of the first subquery result MINUS (EXCEPT) the second subquery result is empty, it means that the employee works on all the projects and is therefore selected.

[1]Recall that EXCEPT is the set difference operator. The keyword MINUS is also sometimes used, for example, in Oracle.

The second option is shown as Q3B. Notice that we need two-level nesting in Q3B and that this formulation is quite a bit more complex than Q3A.

```
Q3B:  SELECT   Lname, Fname
      FROM     EMPLOYEE
      WHERE    NOT EXISTS  ( SELECT   *
                             FROM     WORKS_ON B
                             WHERE    ( B.Pno IN  ( SELECT   Pnumber
                                                    FROM     PROJECT
                                                    WHERE    Dnum = 5 )
                             AND
                             NOT EXISTS  ( SELECT   *
                                           FROM     WORKS_ON C
                                           WHERE    C.Essn = Ssn
                                           AND      C.Pno = B.Pno )));
```

In Q3B, the outer nested query selects any WORKS_ON (B) tuples whose Pno is of a project controlled by department 5, *if* there is not a WORKS_ON (C) tuple with the same Pno and the same Ssn as that of the EMPLOYEE tuple under consideration in the outer query. If no such tuple exists, we select the EMPLOYEE tuple. The form of Q3B matches the following rephrasing of Query 3: Select each employee such that there does not exist a project controlled by department 5 that the employee does not work on. It corresponds to the way we will write this query in tuple relation calculus (see Section 8.6.7).

There is another SQL function, UNIQUE(Q), which returns TRUE if there are no duplicate tuples in the result of query Q; otherwise, it returns FALSE. This can be used to test whether the result of a nested query is a set (no duplicates) or a multiset (duplicates exist).

7.1.5 Explicit Sets and Renaming in SQL

We have seen several queries with a nested query in the WHERE clause. It is also possible to use an **explicit set of values** in the WHERE clause, rather than a nested query. Such a set is enclosed in parentheses in SQL.

Query 17. Retrieve the Social Security numbers of all employees who work on project numbers 1, 2, or 3.

```
Q17:  SELECT   DISTINCT Essn
      FROM     WORKS_ON
      WHERE    Pno IN (1, 2, 3);
```

In SQL, it is possible to **rename** any attribute that appears in the result of a query by adding the qualifier AS followed by the desired new name. Hence, the AS construct can be used to alias both attribute and relation names in general, and it can be used in appropriate parts of a query. For example, Q8A shows how query Q8 from Section 4.3.2 can be slightly changed to retrieve the last name of each employee and his or her supervisor while renaming the resulting attribute names

as Employee_name and Supervisor_name. The new names will appear as column headers for the query result.

```
Q8A:  SELECT  E.Lname AS Employee_name, S.Lname AS Supervisor_name
      FROM    EMPLOYEE AS E, EMPLOYEE AS S
      WHERE   E.Super_ssn = S.Ssn;
```

7.1.6 Joined Tables in SQL and Outer Joins

The concept of a **joined table** (or **joined relation**) was incorporated into SQL to permit users to specify a table resulting from a join operation *in the* FROM *clause* of a query. This construct may be easier to comprehend than mixing together all the select and join conditions in the WHERE clause. For example, consider query Q1, which retrieves the name and address of every employee who works for the 'Research' department. It may be easier to specify the join of the EMPLOYEE and DEPARTMENT relations in the WHERE clause, and then to select the desired tuples and attributes. This can be written in SQL as in Q1A:

```
Q1A:  SELECT  Fname, Lname, Address
      FROM    (EMPLOYEE JOIN DEPARTMENT ON Dno = Dnumber)
      WHERE   Dname = 'Research';
```

The FROM clause in Q1A contains a single *joined table*. The attributes of such a table are all the attributes of the first table, EMPLOYEE, followed by all the attributes of the second table, DEPARTMENT. The concept of a joined table also allows the user to specify different types of join, such as NATURAL JOIN and various types of OUTER JOIN. In a **NATURAL JOIN** on two relations *R* and *S,* no join condition is specified; an implicit *EQUIJOIN condition* for *each pair of attributes with the same name* from *R* and *S* is created. Each such pair of attributes is included *only once* in the resulting relation (see Sections 8.3.2 and 8.4.4 for more details on the various types of join operations in relational algebra).

If the names of the join attributes are not the same in the base relations, it is possible to rename the attributes so that they match, and then to apply NATURAL JOIN. In this case, the AS construct can be used to rename a relation and all its attributes in the FROM clause. This is illustrated in Q1B, where the DEPARTMENT relation is renamed as DEPT and its attributes are renamed as Dname, Dno (to match the name of the desired join attribute Dno in the EMPLOYEE table), Mssn, and Msdate. The implied join condition for this NATURAL JOIN is EMPLOYEE.Dno = DEPT.Dno, because this is the only pair of attributes with the same name after renaming:

```
Q1B:  SELECT  Fname, Lname, Address
      FROM    (EMPLOYEE NATURAL JOIN
              (DEPARTMENT AS DEPT (Dname, Dno, Mssn, Msdate)))
      WHERE   Dname = 'Research';
```

The default type of join in a joined table is called an **inner join**, where a tuple is included in the result only if a matching tuple exists in the other relation. For example, in query Q8A, only employees who *have a supervisor* are included in the result;

an EMPLOYEE tuple whose value for Super_ssn is NULL is excluded. If the user requires that all employees be included, a different type of join called **OUTER JOIN** must be used explicitly (see Section 8.4.4 for the definition of OUTER JOIN in relational algebra). There are several variations of OUTER JOIN, as we shall see. In the SQL standard, this is handled by explicitly specifying the keyword OUTER JOIN in a joined table, as illustrated in Q8B:

```
Q8B:  SELECT  E.Lname AS Employee_name,
              S.Lname AS Supervisor_name
      FROM    (EMPLOYEE AS E LEFT OUTER JOIN EMPLOYEE AS S
              ON E.Super_ssn = S.Ssn);
```

In SQL, the options available for specifying joined tables include INNER JOIN (only pairs of tuples that match the join condition are retrieved, same as JOIN), LEFT OUTER JOIN (every tuple in the left table must appear in the result; if it does not have a matching tuple, it is padded with NULL values for the attributes of the right table), RIGHT OUTER JOIN (every tuple in the right table must appear in the result; if it does not have a matching tuple, it is padded with NULL values for the attributes of the left table), and FULL OUTER JOIN. In the latter three options, the keyword OUTER may be omitted. If the join attributes have the same name, one can also specify the natural join variation of outer joins by using the keyword NATURAL before the operation (for example, NATURAL LEFT OUTER JOIN). The keyword CROSS JOIN is used to specify the CARTESIAN PRODUCT operation (see Section 8.2.2), although this should be used only with the utmost care because it generates all possible tuple combinations.

It is also possible to *nest* join specifications; that is, one of the tables in a join may itself be a joined table. This allows the specification of the join of three or more tables as a single joined table, which is called a **multiway join**. For example, Q2A is a different way of specifying query Q2 from Section 6.3.1 using the concept of a joined table:

```
Q2A:  SELECT  Pnumber, Dnum, Lname, Address, Bdate
      FROM    ((PROJECT JOIN DEPARTMENT ON Dnum = Dnumber)
              JOIN EMPLOYEE ON Mgr_ssn = Ssn)
      WHERE   Plocation = 'Stafford';
```

Not all SQL implementations have implemented the new syntax of joined tables. In some systems, a different syntax was used to specify outer joins by using the comparison operators + =, = +, and + = + for left, right, and full outer join, respectively, when specifying the join condition. For example, this syntax is available in Oracle. To specify the left outer join in Q8B using this syntax, we could write the query Q8C as follows:

```
Q8C:  SELECT  E.Lname, S.Lname
      FROM    EMPLOYEE E, EMPLOYEE S
      WHERE   E.Super_ssn + = S.Ssn;
```

7.1.7 Aggregate Functions in SQL

Aggregate functions are used to summarize information from multiple tuples into a single-tuple summary. **Grouping** is used to create subgroups of tuples before summarization. Grouping and aggregation are required in many database

applications, and we will introduce their use in SQL through examples. A number of built-in aggregate functions exist: **COUNT**, **SUM**, **MAX**, **MIN**, and **AVG**.[2] The COUNT function returns the *number of tuples or values* as specified in a query. The functions SUM, MAX, MIN, and AVG can be applied to a set or multiset of numeric values and return, respectively, the sum, maximum value, minimum value, and average (mean) of those values. These functions can be used in the SELECT clause or in a HAVING clause (which we introduce later). The functions MAX and MIN can also be used with attributes that have nonnumeric domains if the domain values have a *total ordering* among one another.[3] We illustrate the use of these functions with several queries.

Query 19. Find the sum of the salaries of all employees, the maximum salary, the minimum salary, and the average salary.

```
Q19:    SELECT    SUM (Salary), MAX (Salary), MIN (Salary), AVG (Salary)
        FROM      EMPLOYEE;
```

This query returns a *single-row* summary of all the rows in the EMPLOYEE table. We could use AS to rename the column names in the resulting single-row table; for example, as in Q19A.

```
Q19A:   SELECT    SUM (Salary) AS Total_Sal, MAX (Salary) AS Highest_Sal,
                  MIN (Salary) AS Lowest_Sal, AVG (Salary) AS Average_Sal
        FROM      EMPLOYEE;
```

If we want to get the preceding aggregate function values for employees of a specific department—say, the 'Research' department—we can write Query 20, where the EMPLOYEE tuples are restricted by the WHERE clause to those employees who work for the 'Research' department.

Query 20. Find the sum of the salaries of all employees of the 'Research' department, as well as the maximum salary, the minimum salary, and the average salary in this department.

```
Q20:    SELECT    SUM (Salary), MAX (Salary), MIN (Salary), AVG (Salary)
        FROM      (EMPLOYEE JOIN DEPARTMENT ON Dno = Dnumber)
        WHERE     Dname = 'Research';
```

Queries 21 and 22. Retrieve the total number of employees in the company (Q21) and the number of employees in the 'Research' department (Q22).

```
Q21:    SELECT    COUNT (*)
        FROM      EMPLOYEE;

Q22:    SELECT    COUNT (*)
        FROM      EMPLOYEE, DEPARTMENT
        WHERE     DNO = DNUMBER AND DNAME = 'Research';
```

[2]Additional aggregate functions for more advanced statistical calculation were added in SQL-99.

[3]Total order means that for any two values in the domain, it can be determined that one appears before the other in the defined order; for example, DATE, TIME, and TIMESTAMP domains have total orderings on their values, as do alphabetic strings.

Here the asterisk (*) refers to the *rows* (tuples), so COUNT (*) returns the number of rows in the result of the query. We may also use the COUNT function to count values in a column rather than tuples, as in the next example.

Query 23. Count the number of distinct salary values in the database.

```
Q23:    SELECT    COUNT (DISTINCT Salary)
        FROM      EMPLOYEE;
```

If we write COUNT(SALARY) instead of COUNT(DISTINCT SALARY) in Q23, then duplicate values will not be eliminated. However, any tuples with NULL for SALARY will not be counted. In general, NULL values are **discarded** when aggregate functions are applied to a particular column (attribute); the only exception is for COUNT(*) because tuples instead of values are counted. In the previous examples, any Salary values that are NULL are not included in the aggregate function calculation. The general rule is as follows: when an aggregate function is applied to a collection of values, NULLs are removed from the collection before the calculation; if the collection becomes empty because all values are NULL, the aggregate function will return NULL (except in the case of COUNT, where it will return 0 for an empty collection of values).

The preceding examples summarize *a whole relation* (Q19, Q21, Q23) or a selected subset of tuples (Q20, Q22), and hence all produce a table with a single row or a single value. They illustrate how functions are applied to retrieve a summary value or summary tuple from a table. These functions can also be used in selection conditions involving nested queries. We can specify a correlated nested query with an aggregate function, and then use the nested query in the WHERE clause of an outer query. For example, to retrieve the names of all employees who have two or more dependents (Query 5), we can write the following:

```
Q5:     SELECT    Lname, Fname
        FROM      EMPLOYEE
        WHERE     ( SELECT    COUNT (*)
                    FROM      DEPENDENT
                    WHERE     Ssn = Essn ) >= 2;
```

The correlated nested query counts the number of dependents that each employee has; if this is greater than or equal to two, the employee tuple is selected.

SQL also has aggregate functions SOME and ALL that can be applied to a collection of Boolean values; SOME returns TRUE if at least one element in the collection is TRUE, whereas ALL returns TRUE if all elements in the collection are TRUE.

7.1.8 Grouping: The GROUP BY and HAVING Clauses

In many cases we want to apply the aggregate functions *to subgroups of tuples in a relation,* where the subgroups are based on some attribute values. For example, we may want to find the average salary of employees *in each department* or the number

of employees who work *on each project*. In these cases we need to **partition** the relation into nonoverlapping subsets (or **groups**) of tuples. Each group (partition) will consist of the tuples that have the same value of some attribute(s), called the **grouping attribute(s)**. We can then apply the function to each such group independently to produce summary information about each group. SQL has a **GROUP BY** clause for this purpose. The GROUP BY clause specifies the grouping attributes, which should *also appear in the SELECT clause,* so that the value resulting from applying each aggregate function to a group of tuples appears along with the value of the grouping attribute(s).

Query 24. For each department, retrieve the department number, the number of employees in the department, and their average salary.

```
Q24:    SELECT    Dno, COUNT (*), AVG (Salary)
        FROM      EMPLOYEE
        GROUP BY  Dno;
```

In Q24, the EMPLOYEE tuples are partitioned into groups—each group having the same value for the GROUP BY attribute Dno. Hence, each group contains the employees who work in the same department. The COUNT and AVG functions are applied to each such group of tuples. Notice that the SELECT clause includes only the grouping attribute and the aggregate functions to be applied on each group of tuples. Figure 7.1(a) illustrates how grouping works and shows the result of Q24.

If NULLs exist in the grouping attribute, then a **separate group** is created for all tuples with a *NULL value in the grouping attribute.* For example, if the EMPLOYEE table had some tuples that had NULL for the grouping attribute Dno, there would be a separate group for those tuples in the result of Q24.

Query 25. For each project, retrieve the project number, the project name, and the number of employees who work on that project.

```
Q25:    SELECT    Pnumber, Pname, COUNT (*)
        FROM      PROJECT, WORKS_ON
        WHERE     Pnumber = Pno
        GROUP BY  Pnumber, Pname;
```

Q25 shows how we can use a join condition in conjunction with GROUP BY. In this case, the grouping and functions are applied *after* the joining of the two relations in the WHERE clause.

Sometimes we want to retrieve the values of these functions only for *groups that satisfy certain conditions.* For example, suppose that we want to modify Query 25 so that only projects with more than two employees appear in the result. SQL provides a **HAVING** clause, which can appear in conjunction with a GROUP BY clause, for this purpose. HAVING provides a condition on the summary information regarding the group of tuples associated with each value of the grouping attributes. Only the groups that satisfy the condition are retrieved in the result of the query. This is illustrated by Query 26.

Figure 7.1
Results of GROUP BY and HAVING. (a) Q24. (b) Q26.

(a)

Fname	Minit	Lname	Ssn	...	Salary	Super_ssn	Dno
John	B	Smith	123456789		30000	333445555	5
Franklin	T	Wong	333445555		40000	888665555	5
Ramesh	K	Narayan	666884444		38000	333445555	5
Joyce	A	English	453453453	...	25000	333445555	5
Alicia	J	Zelaya	999887777		25000	987654321	4
Jennifer	S	Wallace	987654321		43000	888665555	4
Ahmad	V	Jabbar	987987987		25000	987654321	4
James	E	Bong	888665555		55000	NULL	1

Grouping EMPLOYEE tuples by the value of Dno

Dno	Count (*)	Avg (Salary)
5	4	33250
4	3	31000
1	1	55000

Result of Q24

(b)

Pname	Pnumber	...	Essn	Pno	Hours
ProductX	1		123456789	1	32.5
ProductX	1		453453453	1	20.0
ProductY	2		123456789	2	7.5
ProductY	2		453453453	2	20.0
ProductY	2		333445555	2	10.0
ProductZ	3		666884444	3	40.0
ProductZ	3		333445555	3	10.0
Computerization	10	...	333445555	10	10.0
Computerization	10		999887777	10	10.0
Computerization	10		987987987	10	35.0
Reorganization	20		333445555	20	10.0
Reorganization	20		987654321	20	15.0
Reorganization	20		888665555	20	NULL
Newbenefits	30		987987987	30	5.0
Newbenefits	30		987654321	30	20.0
Newbenefits	30		999887777	30	30.0

These groups are not selected by the HAVING condition of Q26.

After applying the WHERE clause but before applying HAVING

Pname	Pnumber	...	Essn	Pno	Hours
ProductY	2		123456789	2	7.5
ProductY	2		453453453	2	20.0
ProductY	2		333445555	2	10.0
Computerization	10		333445555	10	10.0
Computerization	10	...	999887777	10	10.0
Computerization	10		987987987	10	35.0
Reorganization	20		333445555	20	10.0
Reorganization	20		987654321	20	15.0
Reorganization	20		888665555	20	NULL
Newbenefits	30		987987987	30	5.0
Newbenefits	30		987654321	30	20.0
Newbenefits	30		999887777	30	30.0

After applying the HAVING clause condition

Pname	Count (*)
ProductY	3
Computerization	3
Reorganization	3
Newbenefits	3

Result of Q26
(Pnumber not shown)

Query 26. For each project *on which more than two employees work,* retrieve the project number, the project name, and the number of employees who work on the project.

```
Q26:    SELECT     Pnumber, Pname, COUNT (*)
        FROM       PROJECT, WORKS_ON
        WHERE      Pnumber = Pno
        GROUP BY   Pnumber, Pname
        HAVING     COUNT (*) > 2;
```

Notice that although selection conditions in the WHERE clause limit the *tuples* to which functions are applied, the HAVING clause serves to choose *whole groups*. Figure 7.1(b) illustrates the use of HAVING and displays the result of Q26.

Query 27. For each project, retrieve the project number, the project name, and the number of employees from department 5 who work on the project.

```
Q27:    SELECT     Pnumber, Pname, COUNT (*)
        FROM       PROJECT, WORKS_ON, EMPLOYEE
        WHERE      Pnumber = Pno AND Ssn = Essn AND Dno = 5
        GROUP BY   Pnumber, Pname;
```

In Q27, we restrict the tuples in the relation (and hence the tuples in each group) to those that satisfy the condition specified in the WHERE clause—namely, that they work in department number 5. Notice that we must be extra careful when two different conditions apply (one to the aggregate function in the SELECT clause and another to the function in the HAVING clause). For example, suppose that we want to count the *total* number of employees whose salaries exceed $40,000 in each department, but only for departments where more than five employees work. Here, the condition (SALARY > 40000) applies only to the COUNT function in the SELECT clause. Suppose that we write the following *incorrect* query:

```
SELECT     Dno, COUNT (*)
FROM       EMPLOYEE
WHERE      Salary>40000
GROUP BY   Dno
HAVING     COUNT (*) > 5;
```

This is incorrect because it will select only departments that have more than five employees *who each earn more than $40,000.* The rule is that the WHERE clause is executed first, to select individual tuples or joined tuples; the HAVING clause is applied later, to select individual groups of tuples. In the incorrect query, the tuples are already restricted to employees who earn more than $40,000 *before* the function in the HAVING clause is applied. One way to write this query correctly is to use a nested query, as shown in Query 28.

Query 28. For each department that has more than five employees, retrieve the department number and the number of its employees who are making more than $40,000.

```
Q28:    SELECT      Dno, COUNT (*)
        FROM        EMPLOYEE
        WHERE       Salary>40000 AND Dno IN
                    ( SELECT      Dno
                      FROM        EMPLOYEE
        GROUP BY    Dno
                      HAVING      COUNT (*) > 5)
        GROUP BY    Dno;
```

7.1.9 Other SQL Constructs: WITH and CASE

In this section, we illustrate two additional SQL constructs. The WITH clause allows a user to define a table that will only be used in a particular query; it is somewhat similar to creating a view (see Section 7.3) that will be used only in one query and then dropped. This construct was introduced as a convenience in SQL:99 and may not be available in all SQL based DBMSs. Queries using WITH can generally be written using other SQL constructs. For example, we can rewrite Q28 as Q28′:

```
Q28′:   WITH        BIGDEPTS (Dno) AS
                    ( SELECT      Dno
                      FROM        EMPLOYEE
                      GROUP BY    Dno
                      HAVING      COUNT (*) > 5)
        SELECT      Dno, COUNT (*)
        FROM        EMPLOYEE
        WHERE       Salary>40000 AND Dno IN BIGDEPTS
        GROUP BY    Dno;
```

In Q28′, we defined in the WITH clause a temporary table BIG_DEPTS whose result holds the Dno's of departments with more than five employees, then used this table in the subsequent query. Once this query is executed, the temporary table BIGDEPTS is discarded.

SQL also has a CASE construct, which can be used when a value can be different based on certain conditions. This can be used in any part of an SQL query where a value is expected, including when querying, inserting or updating tuples. We illustrate this with an example. Suppose we want to give employees different raise amounts depending on which department they work for; for example, employees in department 5 get a $2,000 raise, those in department 4 get $1,500 and those in department 1 get $3,000 (see Figure 5.6 for the employee tuples). Then we could re-write the update operation U6 from Section 6.4.3 as U6′:

```
U6′:    UPDATE      EMPLOYEE
        SET         Salary =
        CASE        WHEN      Dno = 5     THEN Salary + 2000
                    WHEN      Dno = 4     THEN Salary + 1500
                    WHEN      Dno = 1     THEN Salary + 3000
                    ELSE      Salary + 0 ;
```

In U6′, the salary raise value is determined through the CASE construct based on the department number for which each employee works. The CASE construct can also be used when inserting tuples that can have different attributes being NULL depending on the type of record being inserted into a table, as when a specialization (see Chapter 4) is mapped into a single table (see Chapter 9) or when a union type is mapped into relations.

7.1.10 Recursive Queries in SQL

In this section, we illustrate how to write a recursive query in SQL. This syntax was added in SQL:99 to allow users the capability to specify a recursive query in a declarative manner. An example of a **recursive relationship** between tuples of the same type is the relationship between an employee and a supervisor. This relationship is described by the foreign key Super_ssn of the EMPLOYEE relation in Figures 5.5 and 5.6, and it relates each employee tuple (in the role of supervisee) to another employee tuple (in the role of supervisor). An example of a recursive operation is to retrieve all supervisees of a supervisory employee *e* at all levels—that is, all employees *e*′ directly supervised by *e*, all employees *e*′ directly supervised by each employee *e*′, all employees *e*‴ directly supervised by each employee *e*″, and so on. In SQL:99, this query can be written as follows:

```
Q29:    WITH RECURSIVE    SUP_EMP (SupSsn, EmpSsn) AS
              ( SELECT    SupervisorSsn, Ssn
                FROM      EMPLOYEE
                UNION
                SELECT    E.Ssn, S.SupSsn
                FROM      EMPLOYEE AS E, SUP_EMP AS S
                WHERE     E.SupervisorSsn = S.EmpSsn)
        SELECT*
        FROM              SUP_EMP;
```

In Q29, we are defining a view SUP_EMP that will hold the result of the recursive query. The view is initially empty. It is first loaded with the first level (supervisor, supervisee) Ssn combinations via the first part (**SELECT** SupervisorSss, Ssn **FROM** EMPLOYEE), which is called the **base query**. This will be combined via UNION with each successive level of supervisees through the second part, where the view contents are joined again with the base values to get the second level combinations, which are UNIONed with the first level. This is repeated with successive levels until a **fixed point** is reached, where no more tuples are added to the view. At this point, the result of the recursive query is in the view SUP_EMP.

7.1.11 Discussion and Summary of SQL Queries

A retrieval query in SQL can consist of up to six clauses, but only the first two—SELECT and FROM—are mandatory. The query can span several lines, and is ended by a semicolon. Query terms are separated by spaces, and parentheses can be used to group relevant parts of a query in the standard way. The clauses are

specified in the following order, with the clauses between square brackets […] being optional:

SELECT <attribute and function list>
FROM <table list>
[**WHERE** <condition>]
[**GROUP BY** <grouping attribute(s)>]
[**HAVING** <group condition>]
[**ORDER BY** <attribute list>];

The SELECT clause lists the attributes or functions to be retrieved. The FROM clause specifies all relations (tables) needed in the query, including joined relations, but not those in nested queries. The WHERE clause specifies the conditions for selecting the tuples from these relations, including join conditions if needed. GROUP BY specifies grouping attributes, whereas HAVING specifies a condition on the groups being selected rather than on the individual tuples. The built-in aggregate functions COUNT, SUM, MIN, MAX, and AVG are used in conjunction with grouping, but they can also be applied to all the selected tuples in a query without a GROUP BY clause. Finally, ORDER BY specifies an order for displaying the result of a query.

In order to formulate queries correctly, it is useful to consider the steps that define the *meaning* or *semantics* of each query. A query is evaluated *conceptually*[4] by first applying the FROM clause (to identify all tables involved in the query or to materialize any joined tables), followed by the WHERE clause to select and join tuples, and then by GROUP BY and HAVING. Conceptually, ORDER BY is applied at the end to sort the query result. If none of the last three clauses (GROUP BY, HAVING, and ORDER BY) are specified, we can *think conceptually* of a query as being executed as follows: For *each combination of tuples*—one from each of the relations specified in the FROM clause—evaluate the WHERE clause; if it evaluates to TRUE, place the values of the attributes specified in the SELECT clause from this tuple combination in the result of the query. Of course, this is not an efficient way to implement the query in a real system, and each DBMS has special query optimization routines to decide on an execution plan that is efficient to execute. We discuss query processing and optimization in Chapters 18 and 19.

In general, there are numerous ways to specify the same query in SQL. This flexibility in specifying queries has advantages and disadvantages. The main advantage is that users can choose the technique with which they are most comfortable when specifying a query. For example, many queries may be specified with join conditions in the WHERE clause, or by using joined relations in the FROM clause, or with some form of nested queries and the IN comparison operator. Some users may be more comfortable with one approach, whereas others may be more comfortable with another. From the programmer's and the system's point of view regarding query optimization, it is generally preferable to write a query with as little nesting and implied ordering as possible.

The disadvantage of having numerous ways of specifying the same query is that this may confuse the user, who may not know which technique to use to specify

[4]The actual order of query evaluation is implementation dependent; this is just a way to conceptually view a query in order to correctly formulate it.

particular types of queries. Another problem is that it may be more efficient to execute a query specified in one way than the same query specified in an alternative way. Ideally, this should not be the case: The DBMS should process the same query in the same way regardless of how the query is specified. But this is quite difficult in practice, since each DBMS has different methods for processing queries specified in different ways. Thus, an additional burden on the user is to determine which of the alternative specifications is the most efficient to execute. Ideally, the user should worry only about specifying the query correctly, whereas the DBMS would determine how to execute the query efficiently. In practice, however, it helps if the user is aware of which types of constructs in a query are more expensive to process than others.

7.2 Specifying Constraints as Assertions and Actions as Triggers

In this section, we introduce two additional features of SQL: the **CREATE ASSERTION** statement and the **CREATE TRIGGER** statement. Section 7.2.1 discusses CREATE ASSERTION, which can be used to specify additional types of constraints that are outside the scope of the *built-in relational model constraints* (primary and unique keys, entity integrity, and referential integrity) that we presented in Section 5.2. These built-in constraints can be specified within the **CREATE TABLE** statement of SQL (see Sections 6.1 and 6.2).

In Section 7.2.2 we introduce **CREATE TRIGGER**, which can be used to specify automatic actions that the database system will perform when certain events and conditions occur. This type of functionality is generally referred to as **active databases**. We only introduce the basics of **triggers** in this chapter, and present a more complete discussion of active databases in Section 26.1.

7.2.1 Specifying General Constraints as Assertions in SQL

In SQL, users can specify general constraints—those that do not fall into any of the categories described in Sections 6.1 and 6.2— via **declarative assertions**, using the **CREATE ASSERTION** statement. Each assertion is given a constraint name and is specified via a condition similar to the WHERE clause of an SQL query. For example, to specify the constraint that *the salary of an employee must not be greater than the salary of the manager of the department that the employee works for* in SQL, we can write the following assertion:

```
CREATE ASSERTION SALARY_CONSTRAINT
CHECK ( NOT EXISTS ( SELECT     *
                     FROM       EMPLOYEE E, EMPLOYEE M,
                                DEPARTMENT D
                     WHERE      E.Salary>M.Salary
                                AND     E.Dno = D.Dnumber
                                AND     D.Mgr_ssn = M.Ssn ) );
```

The constraint name SALARY_CONSTRAINT is followed by the keyword CHECK, which is followed by a **condition** in parentheses that must hold true on every database state for the assertion to be satisfied. The constraint name can be used later to disable the constraint or to modify or drop it. The DBMS is responsible for ensuring that the condition is not violated. Any WHERE clause condition can be used, but many constraints can be specified using the EXISTS and NOT EXISTS style of SQL conditions. Whenever some tuples in the database cause the condition of an ASSERTION statement to evaluate to FALSE, the constraint is **violated**. The constraint is **satisfied** by a database state if *no combination of tuples* in that database state violates the constraint.

The basic technique for writing such assertions is to specify a query that selects any tuples *that violate the desired condition*. By including this query inside a NOT EXISTS clause, the assertion will specify that the result of this query must be empty so that the condition will always be TRUE. Thus, the assertion is violated if the result of the query is not empty. In the preceding example, the query selects all employees whose salaries are greater than the salary of the manager of their department. If the result of the query is not empty, the assertion is violated.

Note that the CHECK clause and constraint condition can also be used to specify constraints on *individual* attributes and domains (see Section 6.2.1) and on *individual* tuples (see Section 6.2.4). A major difference between CREATE ASSERTION and the individual domain constraints and tuple constraints is that the CHECK clauses on individual attributes, domains, and tuples are checked in SQL *only when tuples are inserted or updated* in a specific table. Hence, constraint checking can be implemented more efficiently by the DBMS in these cases. The schema designer should use CHECK on attributes, domains, and tuples only when he or she is sure that the constraint can *only be violated by insertion or updating of tuples*. On the other hand, the schema designer should use CREATE ASSERTION only in cases where it is not possible to use CHECK on attributes, domains, or tuples, so that simple checks are implemented more efficiently by the DBMS.

7.2.2 Introduction to Triggers in SQL

Another important statement in SQL is CREATE TRIGGER. In many cases it is convenient to specify the type of action to be taken when certain events occur and when certain conditions are satisfied. For example, it may be useful to specify a condition that, if violated, causes some user to be informed of the violation. A manager may want to be informed if an employee's travel expenses exceed a certain limit by receiving a message whenever this occurs. The action that the DBMS must take in this case is to send an appropriate message to that user. The condition is thus used to **monitor** the database. Other actions may be specified, such as executing a specific *stored procedure* or triggering other updates. The CREATE TRIGGER statement is used to implement such actions in SQL. We discuss triggers in detail in Section 26.1 when we describe *active databases*. Here we just give a simple example of how triggers may be used.

Suppose we want to check whenever an employee's salary is greater than the salary of his or her direct supervisor in the COMPANY database (see Figures 5.5 and 5.6). Several events can trigger this rule: inserting a new employee record, changing an employee's salary, or changing an employee's supervisor. Suppose that the action to take would be to call an external stored procedure SALARY_VIOLATION,[5] which will notify the supervisor. The trigger could then be written as in R5 below. Here we are using the syntax of the Oracle database system.

```
R5: CREATE TRIGGER SALARY_VIOLATION
    BEFORE INSERT OR UPDATE OF SALARY, SUPERVISOR_SSN
      ON EMPLOYEE
    FOR EACH ROW
      WHEN ( NEW.SALARY > ( SELECT SALARY FROM EMPLOYEE
                            WHERE SSN = NEW.SUPERVISOR_SSN ) )
                            INFORM_SUPERVISOR(NEW.Supervisor_ssn,
                            NEW.Ssn );
```

The trigger is given the name SALARY_VIOLATION, which can be used to remove or deactivate the trigger later. A typical trigger which is regarded as an ECA (Event, Condition, Action) rule has three components:

1. The **event(s)**: These are usually database update operations that are explicitly applied to the database. In this example the events are: inserting a new employee record, changing an employee's salary, or changing an employee's supervisor. The person who writes the trigger must make sure that all possible events are accounted for. In some cases, it may be necessary to write more than one trigger to cover all possible cases. These events are specified after the keyword **BEFORE** in our example, which means that the trigger should be executed before the triggering operation is executed. An alternative is to use the keyword **AFTER**, which specifies that the trigger should be executed after the operation specified in the event is completed.
2. The **condition** that determines whether the rule action should be executed: Once the triggering event has occurred, an *optional* condition may be evaluated. If *no condition* is specified, the action will be executed once the event occurs. If a condition is specified, it is first evaluated, and only *if it evaluates to true* will the rule action be executed. The condition is specified in the WHEN clause of the trigger.
3. The **action** to be taken: The action is usually a sequence of SQL statements, but it could also be a database transaction or an external program that will be automatically executed. In this example, the action is to execute the stored procedure INFORM_SUPERVISOR.

Triggers can be used in various applications, such as maintaining database consistency, monitoring database updates, and updating derived data automatically. A complete discussion is given in Section 26.1.

[5]Assuming that an appropriate external procedure has been declared. We discuss stored procedures in Chapter 10.

7.3 Views (Virtual Tables) in SQL

In this section we introduce the concept of a view in SQL. We show how views are specified, and then we discuss the problem of updating views and how views can be implemented by the DBMS.

7.3.1 Concept of a View in SQL

A **view** in SQL terminology is a single table that is derived from other tables.[6] These other tables can be *base tables* or previously defined views. A view does not necessarily exist in physical form; it is considered to be a **virtual table**, in contrast to **base tables**, whose tuples are always physically stored in the database. This limits the possible update operations that can be applied to views, but it does not provide any limitations on querying a view.

We can think of a view as a way of specifying a table that we need to reference frequently, even though it may not exist physically. For example, referring to the COMPANY database in Figure 5.5, we may frequently issue queries that retrieve the employee name and the project names that the employee works on. Rather than having to specify the join of the three tables EMPLOYEE, WORKS_ON, and PROJECT every time we issue this query, we can define a view that is specified as the result of these joins. Then we can issue queries on the view, which are specified as single-table retrievals rather than as retrievals involving two joins on three tables. We call the EMPLOYEE, WORKS_ON, and PROJECT tables the **defining tables** of the view.

7.3.2 Specification of Views in SQL

In SQL, the command to specify a view is **CREATE VIEW**. The view is given a (virtual) table name (or view name), a list of attribute names, and a query to specify the contents of the view. If none of the view attributes results from applying functions or arithmetic operations, we do not have to specify new attribute names for the view, since they would be the same as the names of the attributes of the defining tables in the default case. The views in V1 and V2 create virtual tables whose schemas are illustrated in Figure 7.2 when applied to the database schema of Figure 5.5.

```
V1:   CREATE VIEW     WORKS_ON1
      AS SELECT       Fname, Lname, Pname, Hours
         FROM         EMPLOYEE, PROJECT, WORKS_ON
         WHERE        Ssn = Essn AND Pno = Pnumber;

V2:   CREATE VIEW     DEPT_INFO(Dept_name, No_of_emps, Total_sal)
      AS SELECT       Dname, COUNT (*), SUM (Salary)
         FROM         DEPARTMENT, EMPLOYEE
         WHERE        Dnumber = Dno
         GROUP BY     Dname;
```

[6]As used in SQL, the term *view* is more limited than the term *user view* discussed in Chapters 1 and 2, since a user view would possibly include many relations.

WORKS_ON1

Fname	Lname	Pname	Hours

DEPT_INFO

Dept_name	No_of_emps	Total_sal

Figure 7.2
Two views specified on the database schema of Figure 5.5.

In V1, we did not specify any new attribute names for the view WORKS_ON1 (although we could have); in this case, WORKS_ON1 *inherits* the names of the view attributes from the defining tables EMPLOYEE, PROJECT, and WORKS_ON. View V2 explicitly specifies new attribute names for the view DEPT_INFO, using a one-to-one correspondence between the attributes specified in the CREATE VIEW clause and those specified in the SELECT clause of the query that defines the view.

We can now specify SQL queries on a view—or virtual table—in the same way we specify queries involving base tables. For example, to retrieve the last name and first name of all employees who work on the 'ProductX' project, we can utilize the WORKS_ON1 view and specify the query as in QV1:

```
QV1:    SELECT    Fname, Lname
        FROM      WORKS_ON1
        WHERE     Pname = 'ProductX';
```

The same query would require the specification of two joins if specified on the base relations directly; one of the main advantages of a view is to simplify the specification of certain queries. Views are also used as a security and authorization mechanism (see Section 7.3.4 and Chapter 30).

A view is supposed to be *always up-to-date*; if we modify the tuples in the base tables on which the view is defined, the view must automatically reflect these changes. Hence, the view does not have to be realized or materialized at the time of *view definition* but rather at the time when we *specify a query* on the view. It is the responsibility of the DBMS and not the user to make sure that the view is kept up-to-date. We will discuss various ways the DBMS can utilize to keep a view up-to-date in the next subsection.

If we do not need a view anymore, we can use the **DROP VIEW** command to dispose of it. For example, to get rid of the view V1, we can use the SQL statement in V1A:

```
V1A:    DROP VIEW    WORKS_ON1;
```

7.3.3 View Implementation, View Update, and Inline Views

The problem of how a DBMS can efficiently implement a view for efficient querying is complex. Two main approaches have been suggested. One strategy, called **query modification**, involves modifying or transforming the view query (submitted by the

user) into a query on the underlying base tables. For example, the query QV1 would be automatically modified to the following query by the DBMS:

```
SELECT   Fname, Lname
FROM     EMPLOYEE, PROJECT, WORKS_ON
WHERE    Ssn = Essn AND Pno = Pnumber
         AND Pname = 'ProductX';
```

The disadvantage of this approach is that it is inefficient for views defined via complex queries that are time-consuming to execute, especially if multiple view queries are going to be applied to the same view within a short period of time. The second strategy, called **view materialization**, involves physically creating a temporary or permanent view table when the view is first queried or created and keeping that table on the assumption that other queries on the view will follow. In this case, an efficient strategy for automatically updating the view table when the base tables are updated must be developed in order to keep the view up-to-date. Techniques using the concept of **incremental update** have been developed for this purpose, where the DBMS can determine what new tuples must be inserted, deleted, or modified in a *materialized view table* when a database update is applied *to one of the defining base tables*. The view is generally kept as a materialized (physically stored) table as long as it is being queried. If the view is not queried for a certain period of time, the system may then automatically remove the physical table and recompute it from scratch when future queries reference the view.

Different strategies as to when a materialized view is updated are possible. The **immediate update** strategy updates a view as soon as the base tables are changed; the **lazy update** strategy updates the view when needed by a view query; and the **periodic update** strategy updates the view periodically (in the latter strategy, a view query may get a result that is not up-to-date).

A user can always issue a retrieval query against any view. However, issuing an INSERT, DELETE, or UPDATE command on a view table is in many cases not possible. In general, an update on a view defined on a *single table* without any *aggregate functions* can be mapped to an update on the underlying base table under certain conditions. For a view involving joins, an update operation may be mapped to update operations on the underlying base relations in *multiple ways*. Hence, it is often not possible for the DBMS to determine which of the updates is intended. To illustrate potential problems with updating a view defined on multiple tables, consider the WORKS_ON1 view, and suppose that we issue the command to update the PNAME attribute of 'John Smith' from 'ProductX' to 'ProductY'. This view update is shown in UV1:

```
UV1:   UPDATE WORKS_ON1
       SET      Pname = 'ProductY'
       WHERE    Lname = 'Smith' AND Fname = 'John'
                AND Pname = 'ProductX';
```

This query can be mapped into several updates on the base relations to give the desired update effect on the view. In addition, some of these updates will create

additional side effects that affect the result of other queries. For example, here are two possible updates, (a) and (b), on the base relations corresponding to the view update operation in UV1:

```
(a):  UPDATE WORKS_ON
      SET    Pno =    ( SELECT Pnumber
                       FROM   PROJECT
                       WHERE  Pname = 'ProductY' )
      WHERE  Essn IN  ( SELECT Ssn
                       FROM   EMPLOYEE
                       WHERE  Lname = 'Smith' AND Fname = 'John' )
             AND
             Pno =    ( SELECT Pnumber
                       FROM   PROJECT
                       WHERE  Pname = 'ProductX' );

(b):  UPDATE PROJECT   SET    Pname = 'ProductY'
      WHERE  Pname = 'ProductX';
```

Update (a) relates 'John Smith' to the 'ProductY' PROJECT tuple instead of the 'ProductX' PROJECT tuple and is the most likely desired update. However, (b) would also give the desired update effect on the view, but it accomplishes this by changing the name of the 'ProductX' tuple in the PROJECT relation to 'ProductY'. It is quite unlikely that the user who specified the view update UV1 wants the update to be interpreted as in (b), since it also has the side effect of changing all the view tuples with Pname = 'ProductX'.

Some view updates may not make much sense; for example, modifying the Total_sal attribute of the DEPT_INFO view does not make sense because Total_sal is defined to be the sum of the individual employee salaries. This incorrect request is shown as UV2:

```
UV2:  UPDATE   DEPT_INFO
      SET      Total_sal = 100000
      WHERE    Dname = 'Research';
```

Generally, a view update is feasible when only *one possible update* on the base relations can accomplish the desired update operation on the view. Whenever an update on the view can be mapped to *more than one update* on the underlying base relations, it is usually not permitted. Some researchers have suggested that the DBMS have a certain procedure for choosing one of the possible updates as the most likely one. Some researchers have developed methods for choosing the most likely update, whereas other researchers prefer to have the user choose the desired update mapping during view definition. But these options are generally not available in most commercial DBMSs.

In summary, we can make the following observations:

- A view with a single defining table is updatable if the view attributes contain the primary key of the base relation, as well as all attributes with the NOT NULL constraint *that do not have* default values specified.

- Views defined on multiple tables using joins are generally not updatable.
- Views defined using grouping and aggregate functions are not updatable.

In SQL, the clause **WITH CHECK OPTION** should be added at the end of the view definition if a view *is to be updated* by INSERT, DELETE, or UPDATE statements. This allows the system to reject operations that violate the SQL rules for view updates. The full set of SQL rules for when a view may be modified by the user are more complex than the rules stated earlier.

It is also possible to define a view table in the **FROM clause** of an SQL query. This is known as an **in-line view**. In this case, the view is defined within the query itself.

7.3.4 Views as Authorization Mechanisms

We describe SQL query authorization statements (GRANT and REVOKE) in detail in Chapter 30, when we present database security and authorization mechanisms. Here, we will just give a couple of simple examples to illustrate how views can be used to hide certain attributes or tuples from unauthorized users. Suppose a certain user is only allowed to see employee information for employees who work for department 5; then we can create the following view DEPT5EMP and grant the user the privilege to query the view but not the base table EMPLOYEE itself. This user will only be able to retrieve employee information for employee tuples whose Dno = 5, and will not be able to see other employee tuples when the view is queried.

```
CREATE VIEW   DEPT5EMP   AS
SELECT        *
FROM          EMPLOYEE
WHERE         Dno = 5;
```

In a similar manner, a view can restrict a user to only see certain columns; for example, only the first name, last name, and address of an employee may be visible as follows:

```
CREATE VIEW   BASIC_EMP_DATA   AS
SELECT        Fname, Lname, Address
FROM          EMPLOYEE;
```

Thus by creating an appropriate view and granting certain users access to the view and not the base tables, they would be restricted to retrieving only the data specified in the view. Chapter 30 discusses security and authorization in detail, including the GRANT and REVOKE statements of SQL.

7.4 Schema Change Statements in SQL

In this section, we give an overview of the **schema evolution commands** available in SQL, which can be used to alter a schema by adding or dropping tables, attributes, constraints, and other schema elements. This can be done while the database is operational and does not require recompilation of the database schema. Certain

checks must be done by the DBMS to ensure that the changes do not affect the rest of the database and make it inconsistent.

7.4.1 The DROP Command

The DROP command can be used to drop *named* schema elements, such as tables, domains, types, or constraints. One can also drop a whole schema if it is no longer needed by using the DROP SCHEMA command. There are two *drop behavior* options: CASCADE and RESTRICT. For example, to remove the COMPANY database schema and all its tables, domains, and other elements, the CASCADE option is used as follows:

```
DROP SCHEMA COMPANY CASCADE;
```

If the RESTRICT option is chosen in place of CASCADE, the schema is dropped only if it has *no elements* in it; otherwise, the DROP command will not be executed. To use the RESTRICT option, the user must first individually drop each element in the schema, then drop the schema itself.

If a base relation within a schema is no longer needed, the relation and its definition can be deleted by using the DROP TABLE command. For example, if we no longer wish to keep track of dependents of employees in the COMPANY database of Figure 6.1, we can get rid of the DEPENDENT relation by issuing the following command:

```
DROP TABLE DEPENDENT CASCADE;
```

If the RESTRICT option is chosen instead of CASCADE, a table is dropped only if it is *not referenced* in any constraints (for example, by foreign key definitions in another relation) or views (see Section 7.3) or by any other elements. With the CASCADE option, all such constraints, views, and other elements that reference the table being dropped are also dropped automatically from the schema, along with the table itself.

Notice that the DROP TABLE command not only deletes all the records in the table if successful, but also removes the *table definition* from the catalog. If it is desired to delete only the records but to leave the table definition for future use, then the DELETE command (see Section 6.4.2) should be used instead of DROP TABLE.

The DROP command can also be used to drop other types of named schema elements, such as constraints or domains.

7.4.2 The ALTER Command

The definition of a base table or of other named schema elements can be changed by using the ALTER command. For base tables, the possible **alter table actions** include adding or dropping a column (attribute), changing a column definition, and adding or dropping table constraints. For example, to add an attribute for keeping track of jobs of employees to the EMPLOYEE base relation in the COMPANY schema (see Figure 6.1), we can use the command

```
ALTER TABLE COMPANY.EMPLOYEE ADD COLUMN Job VARCHAR(12);
```

We must still enter a value for the new attribute Job for each individual EMPLOYEE tuple. This can be done either by specifying a default clause or by using the UPDATE command individually on each tuple (see Section 6.4.3). If no default clause is specified, the new attribute will have NULLs in all the tuples of the relation immediately after the command is executed; hence, the NOT NULL constraint is *not allowed* in this case.

To drop a column, we must choose either CASCADE or RESTRICT for drop behavior. If CASCADE is chosen, all constraints and views that reference the column are dropped automatically from the schema, along with the column. If RESTRICT is chosen, the command is successful only if no views or constraints (or other schema elements) reference the column. For example, the following command removes the attribute Address from the EMPLOYEE base table:

```
ALTER TABLE COMPANY.EMPLOYEE DROP COLUMN Address CASCADE;
```

It is also possible to alter a column definition by dropping an existing default clause or by defining a new default clause. The following examples illustrate this clause:

```
ALTER TABLE COMPANY.DEPARTMENT ALTER COLUMN Mgr_ssn
    DROP DEFAULT;
ALTER TABLE COMPANY.DEPARTMENT ALTER COLUMN Mgr_ssn
    SET DEFAULT '333445555';
```

One can also change the constraints specified on a table by adding or dropping a named constraint. To be dropped, a constraint must have been given a name when it was specified. For example, to drop the constraint named EMPSUPERFK in Figure 6.2 from the EMPLOYEE relation, we write:

```
ALTER TABLE COMPANY.EMPLOYEE
DROP CONSTRAINT EMPSUPERFK CASCADE;
```

Once this is done, we can redefine a replacement constraint by adding a new constraint to the relation, if needed. This is specified by using the **ADD CONSTRAINT** keyword in the ALTER TABLE statement followed by the new constraint, which can be named or unnamed and can be of any of the table constraint types discussed.

The preceding subsections gave an overview of the schema evolution commands of SQL. It is also possible to create new tables and views within a database schema using the appropriate commands. There are many other details and options; we refer the interested reader to the SQL documents listed in the Selected Bibliography at the end of this chapter.

7.5 Summary

In this chapter we presented additional features of the SQL database language. We started in Section 7.1 by presenting more complex features of SQL retrieval queries, including nested queries, joined tables, outer joins, aggregate functions, and grouping. In Section 7.2, we described the CREATE ASSERTION statement, which allows the specification of more general constraints on the database, and introduced the

concept of triggers and the CREATE TRIGGER statement. Then, in Section 7.3, we described the SQL facility for defining views on the database. Views are also called *virtual* or *derived tables* because they present the user with what appear to be tables; however, the information in those tables is derived from previously defined tables. Section 7.4 introduced the SQL ALTER TABLE statement, which is used for modifying the database tables and constraints.

Table 7.2 summarizes the syntax (or structure) of various SQL statements. This summary is not meant to be comprehensive or to describe every possible SQL construct; rather, it is meant to serve as a quick reference to the major types of constructs available in SQL. We use BNF notation, where nonterminal symbols

Table 7.2 Summary of SQL Syntax

CREATE TABLE <table name> (<column name> <column type> [<attribute constraint>] { , <column name> <column type> [<attribute constraint>] } [<table constraint> { , <table constraint> }])
DROP TABLE <table name> ALTER TABLE <table name> ADD <column name> <column type>
SELECT [DISTINCT] <attribute list> FROM (<table name> { <alias> } | <joined table>) { , (<table name> { <alias> } | <joined table>) } [WHERE <condition>] [GROUP BY <grouping attributes> [HAVING <group selection condition>]] [ORDER BY <column name> [<order>] { , <column name> [<order>] }]
<attribute list> ::= (* | (<column name> | <function> (([DISTINCT] <column name> | *))) { , (<column name> | <function> (([DISTINCT] <column name> | *)) }))
<grouping attributes> ::= <column name> { , <column name> }
<order> ::= (ASC | DESC)
INSERT INTO <table name> [(<column name> { , <column name> })] (VALUES (<constant value> , { <constant value> }) { , (<constant value> { , <constant value> }) } | <select statement>)
DELETE FROM <table name> [WHERE <selection condition>]
UPDATE <table name> SET <column name> = <value expression> { , <column name> = <value expression> } [WHERE <selection condition>]
CREATE [UNIQUE] INDEX <index name> ON <table name> (<column name> [<order>] { , <column name> [<order>] }) [CLUSTER]
DROP INDEX <index name>
CREATE VIEW <view name> [(<column name> { , <column name> })] AS <select statement>
DROP VIEW <view name>

NOTE: The commands for creating and dropping indexes are not part of standard SQL.

are shown in angled brackets < … >, optional parts are shown in square brackets […], repetitions are shown in braces { … }, and alternatives are shown in parentheses (… | … | …).[7]

Review Questions

7.1. Describe the six clauses in the syntax of an SQL retrieval query. Show what type of constructs can be specified in each of the six clauses. Which of the six clauses are required and which are optional?

7.2. Describe conceptually how an SQL retrieval query will be executed by specifying the conceptual order of executing each of the six clauses.

7.3. Discuss how NULLs are treated in comparison operators in SQL. How are NULLs treated when aggregate functions are applied in an SQL query? How are NULLs treated if they exist in grouping attributes?

7.4. Discuss how each of the following constructs is used in SQL, and discuss the various options for each construct. Specify what each construct is useful for.

a. Nested queries
b. Joined tables and outer joins
c. Aggregate functions and grouping
d. Triggers
e. Assertions and how they differ from triggers
f. The SQL WITH clause
g. SQL CASE construct
h. Views and their updatability
i. Schema change commands

Exercises

7.5. Specify the following queries on the database in Figure 5.5 in SQL. Show the query results if each query is applied to the database state in Figure 5.6.

a. For each department whose average employee salary is more than $30,000, retrieve the department name and the number of employees working for that department.
b. Suppose that we want the number of *male* employees in each department making more than $30,000, rather than all employees (as in Exercise 7.5a). Can we specify this query in SQL? Why or why not?

[7]The full syntax of SQL is described in many voluminous documents of hundreds of pages.

7.6. Specify the following queries in SQL on the database schema in Figure 1.2.

a. Retrieve the names and major departments of all straight-A students (students who have a grade of A in all their courses).

b. Retrieve the names and major departments of all students who do not have a grade of A in any of their courses.

7.7. In SQL, specify the following queries on the database in Figure 5.5 using the concept of nested queries and other concepts described in this chapter.

a. Retrieve the names of all employees who work in the department that has the employee with the highest salary among all employees.

b. Retrieve the names of all employees whose supervisor's supervisor has '888665555' for Ssn.

c. Retrieve the names of employees who make at least $10,000 more than the employee who is paid the least in the company.

7.8. Specify the following views in SQL on the COMPANY database schema shown in Figure 5.5.

a. A view that has the department name, manager name, and manager salary for every department

b. A view that has the employee name, supervisor name, and employee salary for each employee who works in the 'Research' department

c. A view that has the project name, controlling department name, number of employees, and total hours worked per week on the project for each project

d. A view that has the project name, controlling department name, number of employees, and total hours worked per week on the project for each project *with more than one employee working on it*

7.9. Consider the following view, DEPT_SUMMARY, defined on the COMPANY database in Figure 5.6:

```
CREATE VIEW   DEPT_SUMMARY (D, C, Total_s, Average_s)
AS SELECT     Dno, COUNT (*), SUM (Salary), AVG (Salary)
FROM          EMPLOYEE
GROUP BY      Dno;
```

State which of the following queries and updates would be allowed on the view. If a query or update would be allowed, show what the corresponding query or update on the base relations would look like, and give its result when applied to the database in Figure 5.6.

a.
```
SELECT    *
FROM      DEPT_SUMMARY;
```

b.
```
SELECT    D, C
FROM      DEPT_SUMMARY
WHERE     TOTAL_S > 100000;
```

```
c. SELECT   D, AVERAGE_S
   FROM     DEPT_SUMMARY
   WHERE    C > ( SELECT C FROM DEPT_SUMMARY WHERE D = 4);

d. UPDATE   DEPT_SUMMARY
   SET      D = 3
   WHERE    D = 4;

e. DELETE   FROM DEPT_SUMMARY
   WHERE    C > 4;
```

Selected Bibliography

Reisner (1977) describes a human factors evaluation of SEQUEL, a precursor of SQL, in which she found that users have some difficulty with specifying join conditions and grouping correctly. Date (1984) contains a critique of the SQL language that points out its strengths and shortcomings. Date and Darwen (1993) describes SQL2. ANSI (1986) outlines the original SQL standard. Various vendor manuals describe the characteristics of SQL as implemented on DB2, SQL/DS, Oracle, INGRES, Informix, and other commercial DBMS products. Melton and Simon (1993) give a comprehensive treatment of the ANSI 1992 standard called SQL2. Horowitz (1992) discusses some of the problems related to referential integrity and propagation of updates in SQL2.

The question of view updates is addressed by Dayal and Bernstein (1978), Keller (1982), and Langerak (1990), among others. View implementation is discussed in Blakeley et al. (1989). Negri et al. (1991) describes formal semantics of SQL queries.

There are many books that describe various aspects of SQL. For example, two references that describe SQL-99 are Melton and Simon (2002) and Melton (2003). Further SQL standards—SQL 2006 and SQL 2008—are described in a variety of technical reports; but no standard references exist.

chapter 8

The Relational Algebra and Relational Calculus

In this chapter we discuss the two *formal languages* for the relational model: the relational algebra and the relational calculus. In contrast, Chapters 6 and 7 described the *practical language* for the relational model, namely the SQL standard. Historically, the relational algebra and calculus were developed before the SQL language. SQL is primarily based on concepts from relational calculus and has been extended to incorporate some concepts from relational algebra as well. Because most relational DBMSs use SQL as their language, we presented the SQL language first.

Recall from Chapter 2 that a data model must include a set of operations to manipulate the database, in addition to the data model's concepts for defining the database's structure and constraints. We presented the structures and constraints of the formal relational model in Chapter 5. The basic set of operations for the formal relational model is the **relational algebra**. These operations enable a user to specify basic retrieval requests as *relational algebra expressions*. The result of a retrieval query is a new relation. The algebra operations thus produce new relations, which can be further manipulated using operations of the same algebra. A sequence of relational algebra operations forms a **relational algebra expression**, whose result will also be a relation that represents the result of a database query (or retrieval request).

The relational algebra is very important for several reasons. First, it provides a formal foundation for relational model operations. Second, and perhaps more important, it is used as a basis for implementing and optimizing queries in the query processing and optimization modules that are integral parts of relational database management systems (RDBMSs), as we shall discuss in Chapters 18 and 19. Third, some of its concepts are incorporated into the SQL standard

query language for RDBMSs. Although most commercial RDBMSs in use today do not provide user interfaces for relational algebra queries, the core operations and functions in the internal modules of most relational systems are based on relational algebra operations. We will define these operations in detail in Sections 8.1 through 8.4 of this chapter.

Whereas the algebra defines a set of operations for the relational model, the **relational calculus** provides a higher-level *declarative* language for specifying relational queries. In a relational calculus expression, there is *no order of operations* to specify how to retrieve the query result—only what information the result should contain. This is the main distinguishing feature between relational algebra and relational calculus. The relational calculus is important because it has a firm basis in mathematical logic and because the standard query language (SQL) for RDBMSs has some of its foundations in a variation of relational calculus known as the tuple relational calculus.[1]

The relational algebra is often considered to be an integral part of the relational data model. Its operations can be divided into two groups. One group includes set operations from mathematical set theory; these are applicable because each relation is defined to be a set of tuples in the *formal* relational model (see Section 5.1). Set operations include UNION, INTERSECTION, SET DIFFERENCE, and CARTESIAN PRODUCT (also known as CROSS PRODUCT). The other group consists of operations developed specifically for relational databases—these include SELECT, PROJECT, and JOIN, among others. First, we describe the SELECT and PROJECT operations in Section 8.1 because they are **unary operations** that operate on single relations. Then we discuss set operations in Section 8.2. In Section 8.3, we discuss JOIN and other complex **binary operations**, which operate on two tables by combining related tuples (records) based on *join conditions*. The COMPANY relational database shown in Figure 5.6 is used for our examples.

Some common database requests cannot be performed with the original relational algebra operations, so additional operations were created to express these requests. These include **aggregate functions**, which are operations that can *summarize* data from the tables, as well as additional types of JOIN and UNION operations, known as OUTER JOINs and OUTER UNIONs. These operations, which were added to the original relational algebra because of their importance to many database applications, are described in Section 8.4. We give examples of specifying queries that use relational operations in Section 8.5. Some of these same queries were used in Chapters 6 and 7. By using the same query numbers in this chapter, the reader can contrast how the same queries are written in the various query languages.

In Sections 8.6 and 8.7 we describe the other main formal language for relational databases, the **relational calculus**. There are two variations of relational calculus. The *tuple* relational calculus is described in Section 8.6 and the *domain* relational calculus is described in Section 8.7. Some of the SQL constructs discussed in

[1]SQL is based on tuple relational calculus, but also incorporates some of the operations from the relational algebra and its extensions, as illustrated in Chapters 6, 7, and 9.

Chapters 6 and 7 are based on the tuple relational calculus. The relational calculus is a formal language, based on the branch of mathematical logic called predicate calculus.[2] In tuple relational calculus, variables range over *tuples*, whereas in domain relational calculus, variables range over the *domains* (values) of attributes. In Appendix C we give an overview of the Query-By-Example (QBE) language, which is a graphical user-friendly relational language based on domain relational calculus. Section 8.8 summarizes the chapter.

For the reader who is interested in a less detailed introduction to formal relational languages, Sections 8.4, 8.6, and 8.7 may be skipped.

8.1 Unary Relational Operations: SELECT and PROJECT

8.1.1 The SELECT Operation

The SELECT operation is used to choose a *subset* of the tuples from a relation that satisfies a **selection condition**.[3] We can consider the SELECT operation to be a *filter* that keeps only those tuples that satisfy a qualifying condition. Alternatively, we can consider the SELECT operation to *restrict* the tuples in a relation to only those tuples that satisfy the condition. The SELECT operation can also be visualized as a *horizontal partition* of the relation into two sets of tuples—those tuples that satisfy the condition and are selected, and those tuples that do not satisfy the condition and are filtered out. For example, to select the EMPLOYEE tuples whose department is 4, or those whose salary is greater than $30,000, we can individually specify each of these two conditions with a SELECT operation as follows:

$$\sigma_{Dno=4}(\text{EMPLOYEE})$$
$$\sigma_{Salary>30000}(\text{EMPLOYEE})$$

In general, the SELECT operation is denoted by

$$\sigma_{<\text{selection condition}>}(R)$$

where the symbol σ (sigma) is used to denote the SELECT operator and the selection condition is a Boolean expression (condition) specified on the attributes of relation R. Notice that R is generally a *relational algebra expression* whose result is a relation—the simplest such expression is just the name of a database relation. The relation resulting from the SELECT operation has the *same attributes* as R.

The Boolean expression specified in <selection condition> is made up of a number of **clauses** of the form

<attribute name> <comparison op> <constant value>

[2]In this chapter no familiarity with first-order predicate calculus—which deals with quantified variables and values—is assumed.

[3]The SELECT operation is **different** from the SELECT clause of SQL. The SELECT operation chooses tuples from a table, and is sometimes called a RESTRICT or FILTER operation.

or

<attribute name> <comparison op> <attribute name>

where <attribute name> is the name of an attribute of *R*, <comparison op> is normally one of the operators {=, <, ≤, >, ≥, ≠}, and <constant value> is a constant value from the attribute domain. Clauses can be connected by the standard Boolean operators *and*, *or*, and *not* to form a general selection condition. For example, to select the tuples for all employees who either work in department 4 and make over $25,000 per year, or work in department 5 and make over $30,000, we can specify the following SELECT operation:

$$\sigma_{(\text{Dno=4 AND Salary>25000}) \text{ OR } (\text{Dno=5 AND Salary>30000})}(\text{EMPLOYEE})$$

The result is shown in Figure 8.1(a).

Notice that all the comparison operators in the set {=, <, ≤, >, ≥, ≠} can apply to attributes whose domains are *ordered values*, such as numeric or date domains. Domains of strings of characters are also considered to be ordered based on the collating sequence of the characters. If the domain of an attribute is a set of *unordered values*, then only the comparison operators in the set {=, ≠} can be used. An example of an unordered domain is the domain Color = { 'red', 'blue', 'green', 'white', 'yellow', …}, where no order is specified among the various colors. Some domains allow additional types of comparison operators; for example, a domain of character strings may allow the comparison operator SUBSTRING_OF.

Figure 8.1
Results of SELECT and PROJECT operations. (a) $\sigma_{(\text{Dno=4 AND Salary>25000}) \text{ OR } (\text{Dno=5 AND Salary>30000})}$ (EMPLOYEE). (b) $\pi_{\text{Lname, Fname, Salary}}$(EMPLOYEE). (c) $\pi_{\text{Sex, Salary}}$(EMPLOYEE).

(a)

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston, TX	M	40000	888665555	5
Jennifer	S	Wallace	987654321	1941-06-20	291 Berry, Bellaire, TX	F	43000	888665555	4
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble, TX	M	38000	333445555	5

(b)

Lname	Fname	Salary
Smith	John	30000
Wong	Franklin	40000
Zelaya	Alicia	25000
Wallace	Jennifer	43000
Narayan	Ramesh	38000
English	Joyce	25000
Jabbar	Ahmad	25000
Borg	James	55000

(c)

Sex	Salary
M	30000
M	40000
F	25000
F	43000
M	38000
M	25000
M	55000

In general, the result of a SELECT operation can be determined as follows. The <selection condition> is applied independently to each *individual tuple t* in *R*. This is done by substituting each occurrence of an attribute A_i in the selection condition with its value in the tuple $t[A_i]$. If the condition evaluates to TRUE, then tuple *t* is **selected**. All the selected tuples appear in the result of the SELECT operation. The Boolean conditions AND, OR, and NOT have their normal interpretation, as follows:

- (cond1 **AND** cond2) is TRUE if both (cond1) and (cond2) are TRUE; otherwise, it is FALSE.
- (cond1 **OR** cond2) is TRUE if either (cond1) or (cond2) or both are TRUE; otherwise, it is FALSE.
- (**NOT** cond) is TRUE if cond is FALSE; otherwise, it is FALSE.

The SELECT operator is **unary**; that is, it is applied to a single relation. Moreover, the selection operation is applied to *each tuple individually*; hence, selection conditions cannot involve more than one tuple. The **degree** of the relation resulting from a SELECT operation—its number of attributes—is the same as the degree of *R*. The number of tuples in the resulting relation is always *less than or equal to* the number of tuples in *R*. That is, $|\sigma c\ (R)| \leq |R|$ for any condition *C*. The fraction of tuples selected by a selection condition is referred to as the **selectivity** of the condition.

Notice that the SELECT operation is **commutative**; that is,

$$\sigma_{<\text{cond1}>}(\sigma_{<\text{cond2}>}(R)) = \sigma_{<\text{cond2}>}(\sigma_{<\text{cond1}>}(R))$$

Hence, a sequence of SELECTs can be applied in any order. In addition, we can always combine a **cascade** (or **sequence**) of SELECT operations into a single SELECT operation with a conjunctive (AND) condition; that is,

$$\sigma_{<\text{cond1}>}(\sigma_{<\text{cond2}>}(\ldots(\sigma_{<\text{cond}n>}(R))\ldots)) = \sigma_{<\text{cond1}>\ \textbf{AND}<\text{cond2}>\ \textbf{AND}\ldots\textbf{AND}\ <\text{cond}n>}(R)$$

In SQL, the SELECT condition is typically specified in the *WHERE clause* of a query. For example, the following operation:

$$\sigma_{\text{Dno=4 AND Salary>25000}}\ (\text{EMPLOYEE})$$

would correspond to the following SQL query:

```
SELECT    *
FROM      EMPLOYEE
WHERE     Dno=4 AND Salary>25000;
```

8.1.2 The PROJECT Operation

If we think of a relation as a table, the SELECT operation chooses some of the *rows* from the table while discarding other rows. The **PROJECT** operation, on the other hand, selects certain *columns* from the table and discards the other columns. If we are interested in only certain attributes of a relation, we use the PROJECT operation to *project* the relation over these attributes only. Therefore, the result of the PROJECT operation can be visualized as a *vertical partition* of the relation into two relations:

one has the needed columns (attributes) and contains the result of the operation, and the other contains the discarded columns. For example, to list each employee's first and last name and salary, we can use the PROJECT operation as follows:

$$\pi_{\text{Lname, Fname, Salary}}(\text{EMPLOYEE})$$

The resulting relation is shown in Figure 8.1(b). The general form of the PROJECT operation is

$$\pi_{\text{<attribute list>}}(R)$$

where π (pi) is the symbol used to represent the PROJECT operation, and <attribute list> is the desired sublist of attributes from the attributes of relation *R*. Again, notice that *R* is, in general, a *relational algebra expression* whose result is a relation, which in the simplest case is just the name of a database relation. The result of the PROJECT operation has only the attributes specified in <attribute list> *in the same order as they appear in the list*. Hence, its **degree** is equal to the number of attributes in <attribute list>.

If the attribute list includes only nonkey attributes of *R*, duplicate tuples are likely to occur. The PROJECT operation *removes any duplicate tuples*, so the result of the PROJECT operation is a set of distinct tuples, and hence a valid relation. This is known as **duplicate elimination**. For example, consider the following PROJECT operation:

$$\pi_{\text{Sex, Salary}}(\text{EMPLOYEE})$$

The result is shown in Figure 8.1(c). Notice that the tuple <'F', 25000> appears only once in Figure 8.1(c), even though this combination of values appears twice in the EMPLOYEE relation. Duplicate elimination involves sorting or some other technique to detect duplicates and thus adds more processing. If duplicates are not eliminated, the result would be a **multiset** or **bag** of tuples rather than a set. This was not permitted in the formal relational model but is allowed in SQL (see Section 6.3).

The number of tuples in a relation resulting from a PROJECT operation is always less than or equal to the number of tuples in *R*. If the projection list is a superkey of *R*—that is, it includes some key of *R*—the resulting relation has the *same number* of tuples as *R*. Moreover,

$$\pi_{\text{<list1>}}(\pi_{\text{<list2>}}(R)) = \pi_{\text{<list1>}}(R)$$

as long as <list2> contains the attributes in <list1>; otherwise, the left-hand side is an incorrect expression. It is also noteworthy that commutativity *does not* hold on PROJECT.

In SQL, the PROJECT attribute list is specified in the *SELECT clause* of a query. For example, the following operation:

$$\pi_{\text{Sex, Salary}}(\text{EMPLOYEE})$$

would correspond to the following SQL query:

```
SELECT   DISTINCT Sex, Salary
FROM     EMPLOYEE
```

Notice that if we remove the keyword **DISTINCT** from this SQL query, then duplicates will not be eliminated. This option is not available in the formal relational algebra, but the algebra can be extended to include this operation and allow relations to be multisets; we do not discuss these extensions here.

8.1.3 Sequences of Operations and the RENAME Operation

The relations shown in Figure 8.1 that depict operation results do not have any names. In general, for most queries, we need to apply several relational algebra operations one after the other. Either we can write the operations as a single **relational algebra expression** by nesting the operations, or we can apply one operation at a time and create intermediate result relations. In the latter case, we must give names to the relations that hold the intermediate results. For example, to retrieve the first name, last name, and salary of all employees who work in department number 5, we must apply a SELECT and a PROJECT operation. We can write a single relational algebra expression, also known as an **in-line expression**, as follows:

$$\pi_{\text{Fname, Lname, Salary}}(\sigma_{\text{Dno=5}}(\text{EMPLOYEE}))$$

Figure 8.2(a) shows the result of this in-line relational algebra expression. Alternatively, we can explicitly show the sequence of operations, giving a name to each intermediate relation, and using the **assignment operation,** denoted by ← (left arrow), as follows:

$$\text{DEP5\_EMPS} \leftarrow \sigma_{\text{Dno=5}}(\text{EMPLOYEE})$$
$$\text{RESULT} \leftarrow \pi_{\text{Fname, Lname, Salary}}(\text{DEP5\_EMPS})$$

It is sometimes simpler to break down a complex sequence of operations by specifying intermediate result relations than to write a single relational algebra expression. We can also use this technique to **rename** the attributes in the intermediate and result relations. This can be useful in connection with more complex operations such as UNION and JOIN, as we shall see. To rename the attributes in a relation, we simply list the new attribute names in parentheses, as in the following example:

$$\text{TEMP} \leftarrow \sigma_{\text{Dno=5}}(\text{EMPLOYEE})$$
$$R(\text{First\_name, Last\_name, Salary}) \leftarrow \pi_{\text{Fname, Lname, Salary}}(\text{TEMP})$$

These two operations are illustrated in Figure 8.2(b).

If no renaming is applied, the names of the attributes in the resulting relation of a SELECT operation are the same as those in the original relation and in the same order. For a PROJECT operation with no renaming, the resulting relation has the same attribute names as those in the projection list and in the same order in which they appear in the list.

We can also define a formal **RENAME** operation—which can rename either the relation name or the attribute names, or both—as a unary operator. The general RENAME operation when applied to a relation R of degree n is denoted by any of the following three forms:

$$\rho_{S(B1, B2, \ldots, Bn)}(R) \quad \text{or} \quad \rho_{S}(R) \quad \text{or} \quad \rho_{(B1, B2, \ldots, Bn)}(R)$$

(a)

Fname	Lname	Salary
John	Smith	30000
Franklin	Wong	40000
Ramesh	Narayan	38000
Joyce	English	25000

(b)

TEMP

Fname	Minit	Lname	Ssn	Bdate	Address	Sex	Salary	Super_ssn	Dno
John	B	Smith	123456789	1965-01-09	731 Fondren, Houston,TX	M	30000	333445555	5
Franklin	T	Wong	333445555	1955-12-08	638 Voss, Houston,TX	M	40000	888665555	5
Ramesh	K	Narayan	666884444	1962-09-15	975 Fire Oak, Humble,TX	M	38000	333445555	5
Joyce	A	English	453453453	1972-07-31	5631 Rice, Houston, TX	F	25000	333445555	5

R

First_name	Last_name	Salary
John	Smith	30000
Franklin	Wong	40000
Ramesh	Narayan	38000
Joyce	English	25000

Figure 8.2
Results of a sequence of operations. (a) $\pi_{\text{Fname, Lname, Salary}}$ ($\sigma_{\text{Dno=5}}$(EMPLOYEE)).
(b) Using intermediate relations and renaming of attributes.

where the symbol ρ (rho) is used to denote the RENAME operator, S is the new relation name, and $B_1, B_2, \ldots, B_n$ are the new attribute names. The first expression renames both the relation and its attributes, the second renames the relation only, and the third renames the attributes only. If the attributes of R are $(A_1, A_2, \ldots, A_n)$ in that order, then each A_i is renamed as B_i.

In SQL, a single query typically represents a complex relational algebra expression. Renaming in SQL is accomplished by aliasing using **AS**, as in the following example:

```
SELECT   E.Fname AS First_name, E.Lname AS Last_name, E.Salary AS Salary
FROM     EMPLOYEE AS E
WHERE    E.Dno=5,
```

8.2 Relational Algebra Operations from Set Theory

8.2.1 The UNION, INTERSECTION, and MINUS Operations

The next group of relational algebra operations are the standard mathematical operations on sets. For example, to retrieve the Social Security numbers of all

In addition to selecting a subset of tuples, a query can extract a subset of the fields of each selected tuple. We can compute the names and logins of students who are younger than 18 with the following query:

```
SELECT S.name, S.login
FROM   Students S
WHERE  S.age < 18
```

Figure 3.7 shows the answer to this query; it is obtained by applying the selection to the instance 81 of Students (to get the relation shown in Figure 3.6), followed by removing unwanted fields. Note that the order in which we perform these operations does matter-if we remove unwanted fields first, we cannot check the condition *S. age* < 18, which involves one of those fields.

name	*login*
Madayan	madayan@music
Guldu	guldu@music

Figure 3.7 Names and Logins of Students under 18

We can also combine information in the Students and Enrolled relations. If we want to obtain the names of all students who obtained an A and the id of the course in which they got an A, we could write the following query:

```
SELECT S.name, E.cid
FROM   Students S, Enrolled E
WHERE  S.sid = E.studid AND E.grade = 'A'
```

This query can be understood as follows: "If there is a Students tuple S and an Enrolled tuple E such that S.sid = E.studid (so that S describes the student who is enrolled in E) and E.grade = 'A', then print the student's name and the course id." When evaluated on the instances of Students and Enrolled in Figure 3.4, this query returns a single tuple, *(Smith, Topology112)*.

We cover relational queries and SQL in more detail in subsequent chapters.

3.5 LOGICAL DATABASE DESIGN: ER TO RELATIONAL

The ER model is convenient for representing an initial, high-level database design. Given an ER diagram describing a database, a standard approach is taken to generating a relational database schema that closely approximates

the ER design. (The translation is approximate to the extent that we cannot capture all the constraints implicit in the ER design using SQL, unless we use certain SQL constraints that are costly to check.) We now describe how to translate an ER diagram into a collection of tables with associated constraints, that is, a relational database schema.

3.5.1 Entity Sets to Tables

An entity set is mapped to a relation in a straightforward way: Each attribute of the entity set becomes an attribute of the table. Note that we know both the domain of each attribute and the (primary) key of an entity set.

Consider the Employees entity set with attributes *ssn, name,* and *lot* shown in Figure 3.8. A possible instance of the Employees entity set, containing three

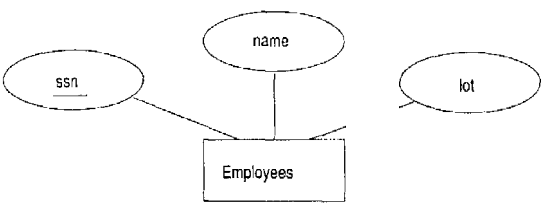

Figure 3.8 The Employees Entity Set

Employees entities, is shown in Figure 3.9 in a tabular format.

ssn	*name*	*lot*
123-22-3666	Attishoo	48
231-31-5368	Smiley	22
131-24-3650	Smethurst	35

Figure 3.9 An Instance of the Employees Entity Set

The following SQL statement captures the preceding information, including the domain constraints and key information:

```
CREATE TABLE Employees ( ssn      CHAR(11),
                         name     CHAR(30) ,
                         lot      INTEGER,
                         PRIMARY  KEY  (ssn) )
```

3.5.2 Relationship Sets (without Constraints) to Tables

A relationship set, like an entity set, is mapped to a relation in the relational model. We begin by considering relationship sets without key and participation constraints, and we discuss how to handle such constraints in subsequent sections. To represent a relationship, we must be able to identify each participating entity and give values to the descriptive attributes of the relationship. Thus, the attributes of the relation include:

- The primary key attributes of each participating entity set, as foreign key fields.
- The descriptive attributes of the relationship set.

The set of nondescriptive attributes is a superkey for the relation. If there are no key constraints (see Section 2.4.1), this set of attributes is a candidate key.

Consider the Works_In2 relationship set shown in Figure 3.10. Each department has offices in several locations and we want to record the locations at which each employee works.

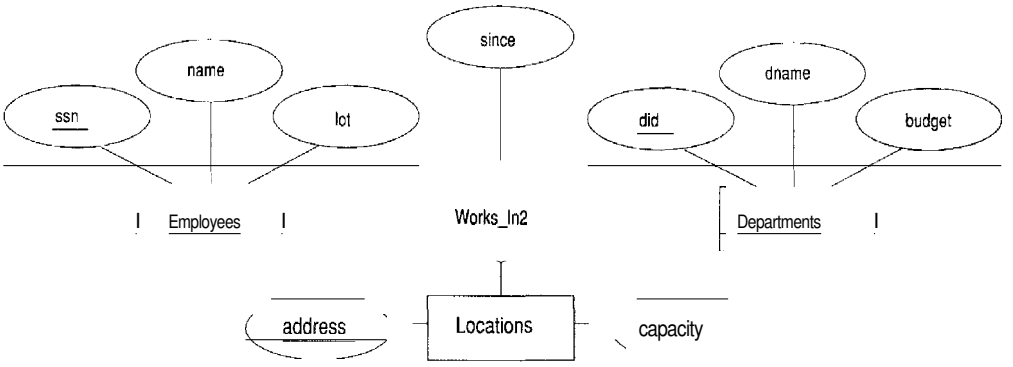

Figure 3.10 A Ternary Relationship Set

All the available information about the Works_In2 table is captured by the following SQL definition:

```
CREATE TABLE Works_In2 ( ssn       CHAR(11),
                         did       INTEGER,
                         address   CHAR(20),
                         since     DATE,
                         PRIMARY KEY (8sn, did, address),
                         FOREIGN KEY (ssn) REFERENCES Employees,
```

```
                    FOREIGN KEY (address) REFERENCES Locations,
                    FOREIGN KEY (did) REFERENCES Departments)
```

Note that the *address, did.* and *ssn* fields cannot take on *n'ull* values. Because these fields are part of the primary key for \Vorks_In2, a NOT NULL constraint is implicit for each of these fields. This constraint ensures that these fields uniquely identify a department, an employee, and a location in each tuple of WorksJn. We can also specify that a particular action is desired when a referenced Employees, Departments, or Locations tuple is deleted, as explained in the discussion of integrity constraints in Section 3.2. In this chapter, we assume that the default action is appropriate except for situations in which the semantics of the ER diagram require some other action.

Finally, consider the Reports_To relationship set shown in Figure 3.11. The

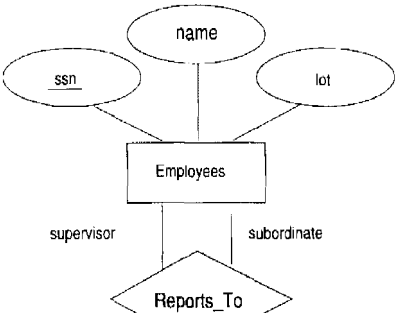

Figure 3.11 The Reports_To Relationship Set

role indicators *supervisor* and *subordinate* are used to create meaningful field names in the CREATE statement for the Reports_To table:

```
CREATE TABLE Reports_To (
        supervisor...ssn    CHAR(11),
        subordinate...ssn   CHAR(11),
        PRIMARY KEY (supervisor_ssn, subordinate_ssn),
        FOREIGN KEY (supervisor...ssn) REFERENCES Employees(ssn),
        FOREIGN KEY (subordinate...ssn) REFERENCES Employees(ssn) )
```

Observe that we need to explicitly name the referenced field of Employees because the field name differs from the name(s) of the referring field(s).

3.5.3 Translating Relationship Sets with Key Constraints

If a relationship set involves n entity sets and somem of them are linked via arrows in the ER diagTam, the key for anyone of these m entity sets constitutes a key for the relation to which the relationship set is mapped. Hence we have m candidate keys, and one of these should be designated as the primary key. The translation discussed in Section 2.3 from relationship sets to a relation can be used in the presence of key constraints, taking into account this point about keys.

Consider the relationship set Manages shown in Figure 3.12. The table cor-

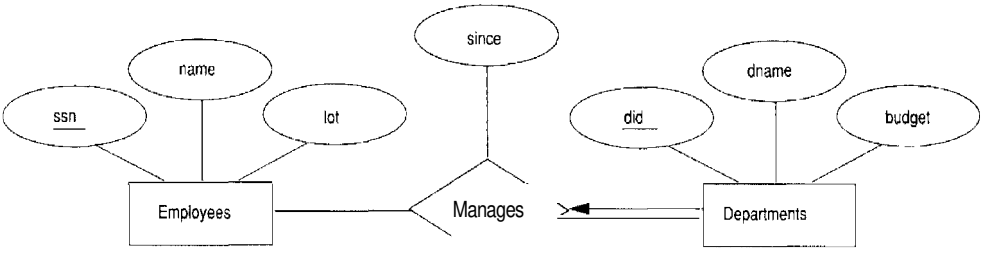

Figure 3.12 Key Constraint on Manages

responding to Manages has the attributes *ssn, did, since.* However, because each department has at most one manager, no two tuples can have the same *did* value but differ on the *ssn* value. A consequence of this observation is that *did* is itself a key for Manages; indeed, the set *did, ssn* is not a key (because it is not minimal). The Manages relation can be defined using the following SQL statement:

```
CREATE TABLE Manages (ssn      CHAR(11),
                      did      INTEGER,
                      since    DATE,
                      PRIMARY KEY (did),
                      FOREIGN KEY (ssn) REFERENCES Employees,
                      FOREIGN KEY (did) REFERENCES Departments)
```

A second approach to translating a relationship set with key constraints is often superior because it avoids creating a distinct table for the relationship set. The idea is to include the information about the relationship set in the table corresponding to the entity set with the key, taking adyantage of the key constraint. In the Manages example, because a department has at most one manager, we can add the key fields of the Employees tuple denoting the Inanager and the *since* attribute to the Departments tuple.

This approach eliminates the need for a separate Manages relation, and queries asking for a department's manager can be answered without combining information from two relations. The only drawback to this approach is that space could be wasted if several departments have no managers. In this case the added fields would have to be filled with *null* values. The first translation (using a separate table for Manages) avoids this inefficiency, but some important queries require us to combine information from two relations, which can be a slow operation.

The following SQL statement, defining a DepLMgr relation that captures the information in both Departments and Manages, illustrates the second approach to translating relationship sets with key constraints:

```
CREATE TABLE DepLMgr ( did       INTEGER,
                       dname     CHAR(20),
                       budget    REAL,
                       ssn       CHAR(11),
                       since     DATE,
                       PRIMARY KEY (did),
                       FOREIGN KEY (ssn) REFERENCES Employees)
```

Note that *ssn* can take on *null* values.

This idea can be extended to deal with relationship sets involving more than two entity sets. In general, if a relationship set involves n entity sets and some m of them are linked via arrows in the ER diagram, the relation corresponding to anyone of the m sets can be augmented to capture the relationship.

We discuss the relative merits of the two translation approaches further after considering how to translate relationship sets with participation constraints into tables.

3.5.4 Translating Relationship Sets with **Participation** Constraints

Consider the ER diagram in Figure 3.13, which shows two relationship sets, Manages and Works_In.

Every department is required to have a manager, due to the participation constraint, and at most one manager, due to the key constraint. The following SQL statement reflects the second translation approach discussed in Section 3.5.3, and uses the key constraint:

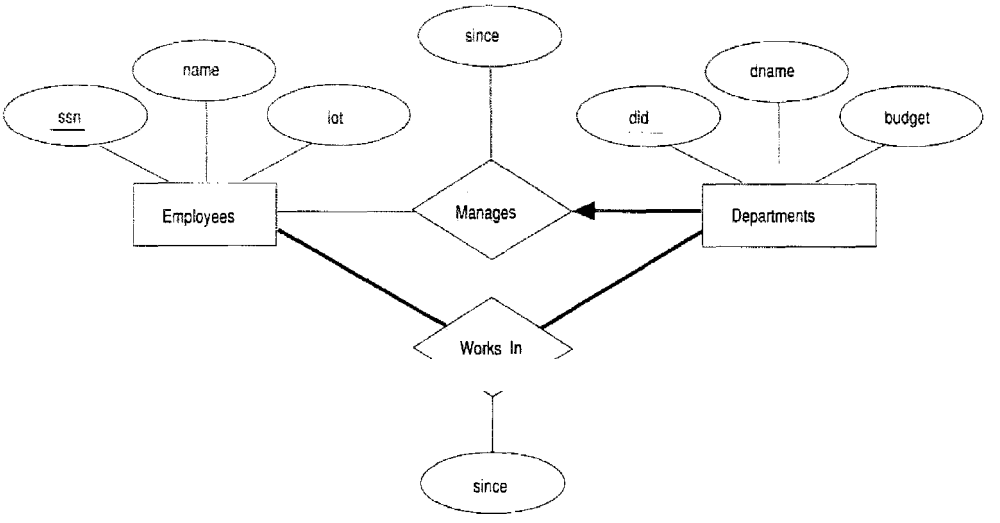

Figure 3.13 Manages and WorksJn

```
CREATE TABLE Dept_Mgr ( did       INTEGER,
                        dname     CHAR(20) ,
                        budget    REAL,
                        ssn       CHAR(11) NOT NULL,
                        since     DATE,
                        PRIMARY KEY (did),
                        FOREIGN KEY (ssn) REFERENCES Employees
                                ON DELETE NO ACTION)
```

It also captures the participation constraint that every department must have a manager: Because *ssn* cannot take on *null* values, each tuple of Dept_Mgr identifies a tuple in Employees (who is the manager). The NO ACTION specification, which is the default and need not be explicitly specified, ensures that an Employees tuple cannot be deleted while it is pointed to by a Dept_Mgr tuple. If we wish to delete such an Employees tuple, we must first change the Dept_Mgr tuple to have a new employee as manager. (We could have specified CASCADE instead of NO ACTION, but deleting all information about a department just because its manager has been fired seems a bit extreme!)

The constraint that every department must have a manager cannot be captured using the first translation approach discussed in Section 3.5.3. (Look at the definition of Manages and think about what effect it would have if we added NOT NULL constraints to the *ssn* and *did* fields. *Hint:* The constraint would prevent the firing of a manager, but does not ensure that a manager is initially appointed for each department!) This situation is a strong argument

in favor of using the second approach for one-to-many relationships such as Manages, especially when the entity set with the key constraint also has a total participation constraint.

Unfortunately, there are many participation constraints that we cannot capture using SQL, short of using *table constraints* or *assertions*. Table constraints and assertions can be specified using the full power of the SQL query language (as discussed in Section 5.7) and are very expressive but also very expensive to check and enforce. For example, we cannot enforce the participation constraints on the Works_In relation without using these general constraints. To see why, consider the Works_In relation obtained by translating the ER diagram into relations. It contains fields *ssn* and *did,* which are foreign keys referring to Employees and Departments. To ensure total participation of Departments in Works_In, we have to guarantee that every *did* value in Departments appears in a tuple of Works_In. We could try to guarantee this condition by declaring that *did* in Departments is a foreign key referring to Works_In, but this is not a valid foreign key constraint because *did* is not a candidate key for Works_In.

To ensure total participation of Departments in Works_In using SQL, we need an assertion. We have to guarantee that every *did* value in Departments appears in a tuple of Works_In; further, this tuple of Works_In must also have *non-null* values in the fields that are foreign keys referencing other entity sets involved in the relationship (in this example, the *ssn* field). We can ensure the second part of this constraint by imposing the stronger requirement that *ssn* in Works_In cannot contain *null* values. (Ensuring that the participation of Employees in Works_In is total is symmetric.)

Another constraint that requires assertions to express in SQL is the requirement that each Employees entity (in the context of the Manages relationship set) must manage at least one department.

In fact, the Manages relationship set exemplifies most of the participation constraints that we can capture using key and foreign key constraints. Manages is a binary relationship set in which exactly one of the entity sets (Departments) has a key constraint, and the total participation constraint is expressed on that entity set.

We can also capture participation constraints using key and foreign key constraints in one other special situation: a relationship set in which all participating entity sets have key constraints and total participation. The best translation approach in this case is to map all the entities as well as the relationship into a single table; the details are straightforward.

3.5.5 Translating Weak Entity Sets

A weak entity set always participates in a one-to-many binary relationship and has a key constraint and total participation. The second translation approach discussed in Section 3.5.3 is ideal in this case, but we must take into account that the weak entity has only a partial key. Also, when an owner entity is deleted, we want all owned weak entities to be deleted.

Consider the Dependents weak entity set shown in Figure 3.14, with partial key *pname*. A Dependents entity can be identified uniquely only if we take the key of the *owning* Employees entity and the *pname* of the Dependents entity, and the Dependents entity must be deleted if the owning Employees entity is deleted.

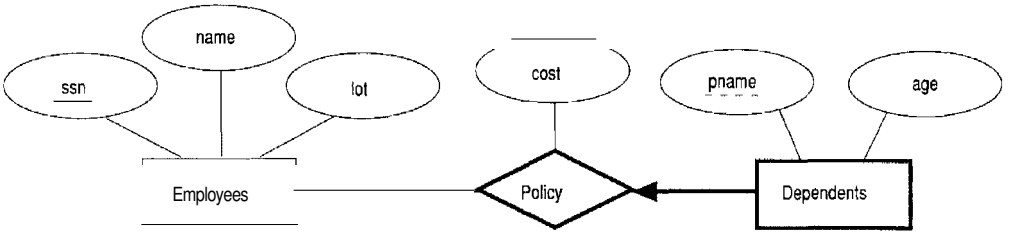

Figure 3.14 The Dependents Weak Entity Set

We can capture the desired semantics with the following definition of the Dep_Policy relation:

```
CREATE TABLE Dep_Policy (pname   CHAR(20),
                         age     INTEGER,
                         cost    REAL,
                         ssn     CHAR(11),
                         PRIMARY KEY (pname, ssn),
                         FOREIGN KEY (ssn) REFERENCES Employees
                                 ON DELETE CASCADE )
```

Observe that the primary key is *(pna:me, ssn)*, since Dependents is a weak entity. This constraint is a change with respect to the translation discussed in Section 3.5.3. \Ve have to ensure that every Dependents entity is associated with an Employees entity (the owner), as per the total participation constraint on Dependents. That is, *ssn* cannot be *null*. This is ensured because *SST/,* is part of the primary key. The CASCADE option ensures that information about an employee's policy and dependents is deleted if the corresponding Employees tuple is deleted.

3.5.6 Translating Class Hierarchies

We present the two basic approaches to handling ISA hierarchies by applying them to the ER diagram shown in Figure 3.15:

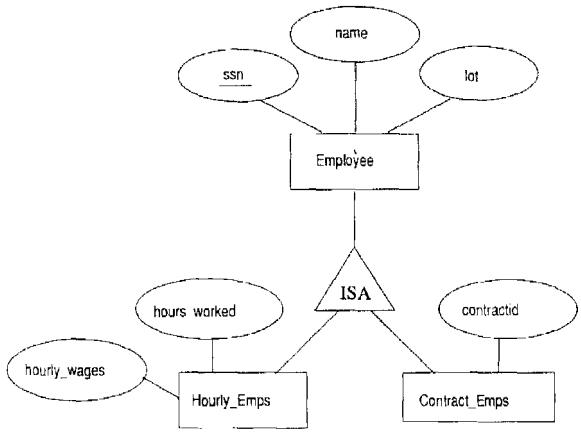

Figure 3.15 Class Hierarchy

1. We can map each of the entity sets Employees, Hourly_Emps, and ContracLEmps to a distinct relation. The Employees relation is created as in Section 2.2. We discuss Hourly_Emps here; ContracLEmps is handled similarly. The relation for Hourly_Emps includes the *hourly_wages* and *hours_worked* attributes of Hourly_Emps. It also contains the key attributes of the superclass *(ssn,* in this example), which serve as the primary key for Hourly_Emps, as well as a foreign key referencing the superclass (Employees). For each Hourly_Emps entity, the value of the *name* and *lot* attributes are stored in the corresponding row of the superclass (Employees). Note that if the superclass tuple is deleted, the delete must be cascaded to Hourly_Emps.

2. Alternatively, we can create just two relations, corresponding to Hourly_Emps and ContracLEmps. The relation for Hourly_Emps includes all the attributes of Hourly_Emps as well as all the attributes of Employees (i.e., *ssn, name, lot, hourly_wages, hours_worked*).

The first approach is general and always applicable. Queries in which we want to examine all employees and do not care about the attributes specific to the subclasses are handled easily using the Employees relation. However, queries in which we want to examine, say, hourly employees, may require us to combine Hourly_Emps (or ContracLEmps, as the case may be) with Employees to retrieve *name* and *lot.*

The second approach is not applicable if we have employees who are neither hourly employees nor contract employees, since there is no way to store such employees. Also, if an employee is both an Hourly_Emps and a ContracLEmps entity, then the *name* and *lot* values are stored twice. This duplication can lead to some of the anomalies that we discuss in Chapter 19. A query that needs to examine all employees must now examine two relations. On the other hand, a query that needs to examine only hourly employees can now do so by examining just one relation. The choice between these approaches clearly depends on the semantics of the data and the frequency of common operations.

In general, overlap and covering constraints can be expressed in SQL only by using assertions.

3.5.7 Translating ER Diagrams with Aggregation

Consider the ER diagram shown in Figure 3.16. The Employees, Projects,

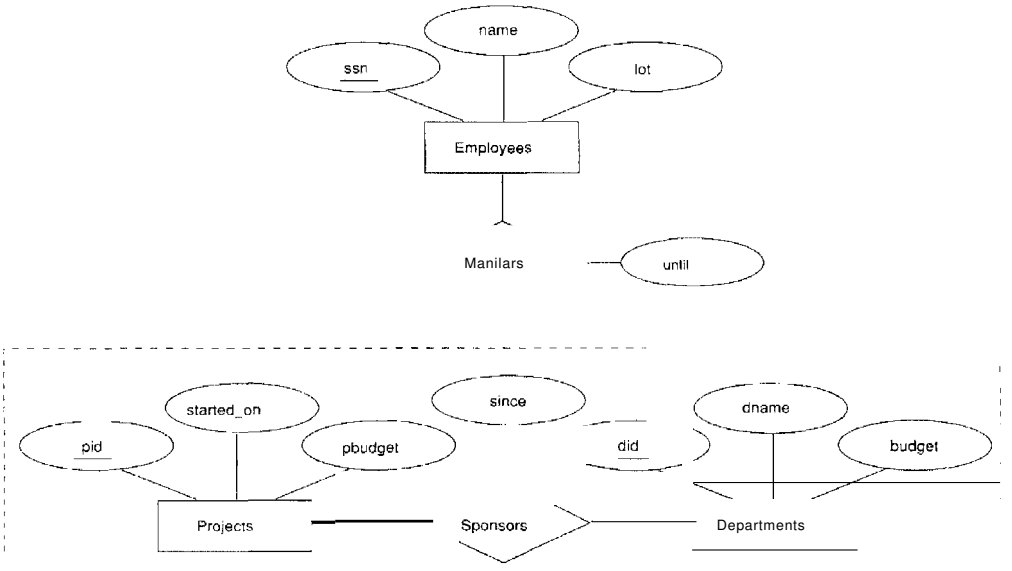

Figure 3.16 Aggregation

and Departments entity sets and the Sponsors relationship set are mapped as described in previous sections. For the Monitors relationship set, we create a relation with the following attributes: the key attributes of Employees *(88n),* the key attributes of Sponsors (*did, pid*), and the descriptive attributes of Monitors (*until*). This translation is essentially the standard mapping for a relationship set, as described in Section 3.5.2.

There is a special case in which this translation can be refined by dropping the Sponsors relation. Consicler the Sponsors relation. It has attributes *pid, did,* and *since;* and in general we need it (in addition to l\rlonitors) for two reasons:

1. \Ve have to record the descriptive attributes (in our example, *since)* of the Sponsors relationship.
2. Not every sponsorship has a monitor, and thus some $\langle pid, did \rangle$ pairs in the Sponsors relation may not appear in the Monitors relation.

However, if Sponsors has no descriptive attributes and has total participation in Monitors, every possible instance of the Sponsors relation can be obtained from the $\langle pid, did \rangle$ columns of Monitors; Sponsors can be dropped.

3.5.8 ER to Relational: Additional Examples

Consider the ER diagram shown in Figure 3.17. We can use the key constraints

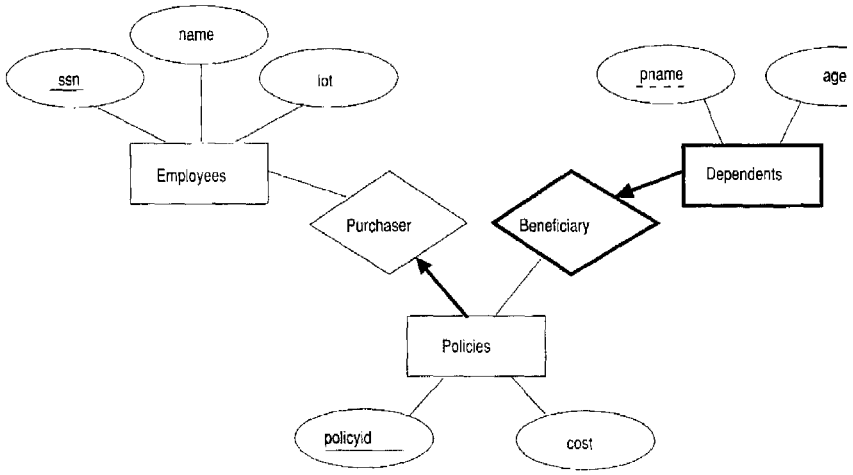

Figure 3.17 Policy Revisited

to combine Purchaser information with Policies and Beneficiary information with Dependents, and translate it into the relational model as follows:

```
CREATE TABLE Policies ( policyid  INTEGER,
                        cost      REAL,
                        ssn       CHAR(11) NOT NULL,
                        PRIMARY KEY (policyid),
                        FOREIGN KEY (ssn) REFERENCES Employees
                                ON DELETE CASCADE )
```

```
CREATE TABLE Dependents (pname    CHAR(20),
                         age      INTEGER,
                         policyid INTEGER,
                         PRIMARY KEY (pname, policyid),
                         FOREIGN KEY (policyid) REFERENCES Policies
                                 ON DELETE CASCADE)
```

Notice how the deletion of an employee leads to the deletion of all policies owned by the employee and all dependents who are beneficiaries of those policies. Further, each dependent is required to have a covering policy-because *policyid* is part of the primary key of Dependents, there is an implicit NOT NULL constraint. This model accurately reflects the participation constraints in the ER diagram and the intended actions when an employee entity is deleted.

In general, there could be a chain of identifying relationships for weak entity sets. For example, we assumed that *policyid* uniquely identifies a policy. Suppose that *policyid* distinguishes only the policies owned by a given employee; that is, *policyid* is only a partial key and Policies should be modeled as a weak entity set. This new assumption about *policyid* does not cause much to change in the preceding discussion. In fact, the only changes are that the primary key of Policies becomes *(policyid, ssn)*, and as a consequence, the definition of Dependents changes-a field called *ssn* is added and becomes part of both the primary key of Dependents and the foreign key referencing Policies:

```
CREATE TABLE Dependents (pname    CHAR(20),
                         ssn      CHAR(11),
                         age      INTEGER,
                         policyid INTEGER NOT NULL,
                         PRIMARY KEY (pname, policyid, ssn),
                         FOREIGN KEY (policyid, ssn) REFERENCES Policies
                                 ON DELETE CASCADE )
```

3.6 INTRODUCTION TO VIEWS

A view is a table whose rows are not explicitly stored in the database but are computed as needed from a view definition. Consider the Students and Enrolled relations. Suppose we are often interested in finding the names and student identifiers of students who got a grade of B in some course, together with the course identifier. We can define a view for this purpose. Using SQL notation:

```
CREATE VIEW B-Students (name, sid, course)
        AS SELECT S.sname, S.sid, E.cid
```