

Part 2: Design Concepts 67

Chapter 3: The Relational Database Model 68

3-1 A Logical View of Data 69

3-1a Tables and Their Characteristics 69

3-2 Keys 72

3-2a Dependencies 72

3-2b Types of Keys 73

3-3 Integrity Rules 76

3-4 Relational Algebra 78

3-4a Formal Definitions and Terminology 78

3-4b Relational Set Operators 79

3-5 The Data Dictionary and the System Catalog 87

3-6 Relationships within the Relational Database 89

3-6a The 1:M Relationship 89

3-6b The 1:1 Relationship 91

3-6c The M:N Relationship 93

3-7 Data Redundancy Revisited 97

3-8 Indexes 99

3-9 Codd's Relational Database Rules 100

Summary 102 • Key Terms 103 • Review Questions 103 • Problems 106

Chapter 4: Entity Relationship (ER) Modeling 113

4-1 The Entity Relationship Model 114

4-1a Entities 114

4-1b Attributes 114

4-1c Relationships 120

4-1d Connectivity and Cardinality 121

4-1e Existence Dependence 122

4-1f Relationship Strength 123

4-1g Weak Entities 125

4-1h Relationship Participation 127

4-1i Relationship Degree 131

4-1j Recursive Relationships 133

4-1k Associative (Composite) Entities 136

4-2 Developing an ER Diagram 138

4-3 Database Design Challenges: Conflicting Goals 146

Summary 150 • Key Terms 151 • Review Questions 151 • Problems 154 • Cases 159

Chapter 5: Advanced Data Modeling 167

5-1 The Extended Entity Relationship Model 168

5-1a Entity Supertypes and Subtypes 168

5-1b Specialization Hierarchy 169

5-1c Inheritance 170

5-1d Subtype Discriminator 172

5-1e Disjoint and Overlapping Constraints 172

5-1f Completeness Constraint 174

5-1g Specialization and Generalization 175

5-2 Entity Clustering 175

5-3 Entity Integrity: Selecting Primary Keys 176

5-3a Natural Keys and Primary Keys 177

5-3b Primary Key Guidelines 177

5-3c When to Use Composite Primary Keys 177

5-3d When to Use Surrogate Primary Keys 179

5-4 Design Cases: Learning Flexible Database Design 180

5-4a Design Case 1: Implementing 1:1 Relationships 181

5-4b Design Case 2: Maintaining History of Time-Variant Data 182

5-4c Design Case 3: Fan Traps 185

5-4d Design Case 4: Redundant Relationships 186

Summary 187 • Key Terms 187 • Review Questions 188 • Problems 189 • Cases 190

Chapter 5

Advanced Data Modeling

After completing this chapter, you will be able to:

- Describe the main extended entity relationship (EER) model constructs and how they are represented in ERDs and EERDs
- Use entity clusters to represent multiple entities and relationships in an entity relationship diagram (ERD)
- Describe the characteristics of good primary keys and how to select them
- Apply flexible solutions for special data-modeling cases

Preview

In the previous two chapters, you learned how to use entity relationship diagrams (ERDs) to properly create a data model. In this chapter, you will learn about the extended entity relationship (EER) model. The EER model builds on entity relationship (ER) concepts and adds support for entity supertypes, subtypes, and entity clustering.

Most current database implementations are based on relational databases. Because the relational model uses keys to create associations among tables, it is essential to learn the characteristics of good primary keys and how to select them. Selecting a good primary key is too important to be left to chance, so this chapter covers the critical aspects of primary key identification and placement.

Focusing on practical database design, this chapter also illustrates some special design cases that highlight the importance of flexible designs, which can be adapted to meet the demands of changing data and information requirements. Data modeling is a vital step in the development of databases that in turn provides a good foundation for successful application development. Remember that good database applications cannot be based on bad database designs, and no amount of outstanding coding can overcome the limitations of poor database design.

Data Files and Available Formats

	MS Access	Oracle	MS SQL	My SQL		MS Access	Oracle	MS SQL	My SQL
CH05_AirCo	✓	✓	✓	✓	CH05_GCSdata	✓	✓	✓	✓
CH05_TinyCollege	✓	✓	✓	✓					

Data Files Available on cengagebrain.com



Note

The extended entity relationship model discussed in this chapter includes advanced data modeling constructs such as specialization hierarchies. Although Microsoft Visio 2010 and earlier versions handled these constructs neatly, newer versions of Visio starting with Microsoft Visio 2013 removed support for many database modeling activities, including specialization hierarchies.

5-1 The Extended Entity Relationship Model

As the complexity of the data structures being modeled has increased and as application software requirements have become more stringent, the need to capture more information in the data model has increased. The **extended entity relationship model (EERM)**, sometimes referred to as the enhanced entity relationship model, is the result of adding more semantic constructs to the original ER model. As you might expect, a diagram that uses the EERM is called an **EER diagram (EERD)**. In the following sections, you will learn about the main EER model constructs—entity supertypes, entity subtypes, and entity clustering—and see how they are represented in ERDs or EERDs.

extended entity relationship model (EERM)

Sometimes referred to as the enhanced entity relationship model; the result of adding more semantic constructs, such as entity supertypes, entity subtypes, and entity clustering, to the original entity relationship (ER) model.

EER diagram (EERD)

The entity relationship diagram resulting from the application of extended entity relationship concepts that provide additional semantic content in the ER model.

entity supertype

In a generalization or specialization hierarchy, a generic entity type that contains the common characteristics of entity subtypes.

entity subtype

In a generalization or specialization hierarchy, a subset of an entity supertype. The entity supertype contains the common characteristics and the subtypes contain the unique characteristics of each entity.

5-1a Entity Supertypes and Subtypes

Because most employees possess a wide range of skills and special qualifications, data modelers must find a variety of ways to group employees based on their characteristics. For instance, a retail company could group employees as salaried and hourly, while a university could group employees as faculty, staff, and administrators.

The grouping of employees into various *types* provides two important benefits:

- It avoids unnecessary nulls in attributes when some employees have characteristics that are not shared by other employees.
- It enables a particular employee type to participate in relationships that are unique to that employee type.

To illustrate those benefits, you will explore the case of an aviation business that employs pilots, mechanics, secretaries, accountants, database managers, and many other types of employees. Figure 5.1 illustrates how pilots share certain characteristics with other employees, such as a last name (EMP_LNAME) and hire date (EMP_HIRE_DATE). On the other hand, many pilot characteristics are not shared by other employees. For example, unlike other employees, pilots must meet special requirements such as flight hour restrictions, flight checks, and periodic training. Therefore, if all employee characteristics and special qualifications were stored in a single EMPLOYEE entity, you would have a lot of nulls or you would have to create a lot of needless dummy entries. In this case, special pilot characteristics such as EMP_LICENSE, EMP_RATINGS, and EMP_MED_TYPE will generate nulls for employees who are not pilots. In addition, pilots participate in some relationships that are unique to their qualifications. For example, not all employees can fly airplanes; only employees who are pilots can participate in the “employee flies airplane” relationship.

Based on the preceding discussion, you would correctly deduce that the PILOT entity stores only attributes that are unique to pilots and that the EMPLOYEE entity stores attributes that are common to all employees. Based on that hierarchy, you can conclude that PILOT is a *subtype* of EMPLOYEE and that EMPLOYEE is the *supertype* of PILOT. In modeling terms, an **entity supertype** is a generic entity type that is related to one or more **entity subtypes**. The entity supertype contains common characteristics, and the entity subtypes each contain their own unique characteristics.

FIGURE 5.1 NULLS CREATED BY UNIQUE ATTRIBUTES

Database name: Ch05_AirCo								
EMP_NUM	EMP_LNAME	EMP_FNAME	EMP_INITIAL	EMP_LICENSE	EMP_RATINGS	EMP_MED_TYPE	EMP_HIRE_DATE	
100	Kolmycz	Xavier	T					15-Mar-88
101	Lewis	Marcos		ATP	SEL/MEL/Instr/CFII	1		25-Apr-89
102	Vandam	Jean						20-Dec-93
103	Jones	Victoria	R					28-Aug-03
104	Lange	Edith		ATP	SEL/MEL/Instr	1		20-Oct-97
105	Williams	Gabriel	U	COM	SEL/MEL/Instr/CFI	2		08-Nov-97
106	Duzak	Mario		COM	SEL/MEL/Instr	2		05-Jan-04
107	Dante	Venite	L					02-Jul-97
108	Wiesenbach	Joni						18-Nov-95
109	Travis	Brett	T	COM	SEL/MEL/SES/Instr/CFII	1		14-Apr-01
110	Genkazi	Stan						01-Dec-03

Two criteria help the designer determine when to use subtypes and supertypes:

- There must be different, identifiable kinds or types of the entity in the user's environment.
- The different kinds or types of instances should each have one or more attributes that are unique to that kind or type of instance.

In the preceding example, because pilots meet both criteria of being an identifiable kind of employee and having unique attributes that other employees do not possess, it is appropriate to create PILOT as a subtype of EMPLOYEE. Assume that mechanics and accountants also each have attributes that are unique to them, respectively, and that clerks do not. In that case, MECHANIC and ACCOUNTANT would also be legitimate subtypes of EMPLOYEE because they are identifiable kinds of employees and have unique attributes. CLERK would *not* be an acceptable subtype of EMPLOYEE because it only satisfies one of the criteria—it is an identifiable kind of employee—but none of the attributes are unique to just clerks. In the next section, you will learn how entity supertypes and subtypes are related in a specialization hierarchy.

5-1b Specialization Hierarchy

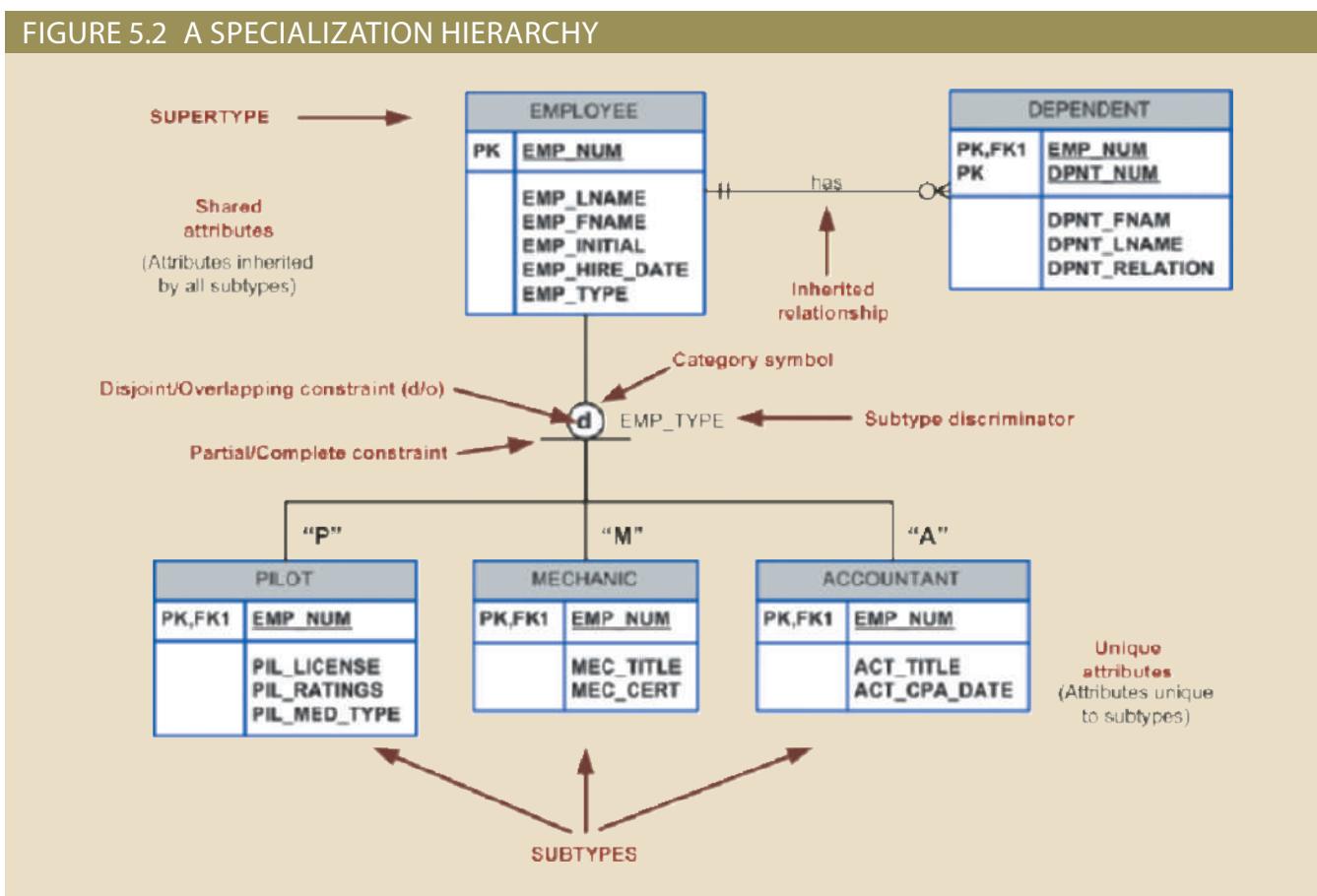
Entity supertypes and subtypes are organized in a **specialization hierarchy**, which depicts the arrangement of higher-level entity supertypes (parent entities) and lower-level entity subtypes (child entities). Figure 5.2 shows the specialization hierarchy formed by an EMPLOYEE supertype and three entity subtypes—PILOT, MECHANIC, and ACCOUNTANT. The specialization hierarchy reflects the 1:1 relationship between EMPLOYEE and its subtypes. For example, a PILOT subtype occurrence is related to one instance of the EMPLOYEE supertype, and a MECHANIC subtype occurrence is related to one instance of the EMPLOYEE supertype. The terminology and symbols in Figure 5.2 are explained throughout this chapter.

The relationships depicted within the specialization hierarchy are sometimes described in terms of “is-a” relationships. For example, a pilot *is an* employee, a mechanic *is an* employee, and an accountant *is an* employee. It is important to understand that within a specialization hierarchy, a subtype can exist only within the context of a supertype, and every subtype can have only one supertype to which it is directly related. However, a specialization hierarchy can have many levels of supertype or subtype relationships—that is, you can have a specialization hierarchy in which a supertype has many subtypes. In turn, one of the subtypes is the supertype to other lower-level subtypes.

specialization hierarchy

A hierarchy based on the top-down process of identifying lower-level, more specific entity subtypes from a higher-level entity supertype. Specialization is based on grouping unique characteristics and relationships of the subtypes.

FIGURE 5.2 A SPECIALIZATION HIERARCHY



Online Content

This chapter covers only specialization hierarchies. The EER model also supports specialization *lattices*, in which a subtype can have multiple parents (supertypes). However, those concepts are better covered under the object-oriented model in Appendix G, Object-Oriented Databases. The appendix is available at www.cengagebrain.com.

inheritance

In the EERD, the property that enables an entity subtype to inherit the attributes and relationships of the entity supertype.

As you can see in Figure 5.2, the arrangement of entity supertypes and subtypes in a specialization hierarchy is more than a cosmetic convenience. Specialization hierarchies enable the data model to capture additional semantic content (meaning) into the ERD. A specialization hierarchy provides the means to:

- Support attribute inheritance.
 - Define a special supertype attribute known as the subtype discriminator.
 - Define disjoint or overlapping constraints and complete or partial constraints.
- The following sections cover such characteristics and constraints in more detail.

5-1c Inheritance

The property of **inheritance** enables an entity subtype to inherit the attributes and relationships of the supertype. As discussed earlier, a supertype contains attributes that are common to all of its subtypes. In contrast, subtypes contain only the attributes that are unique to the subtype. For example, Figure 5.2 illustrates that pilots, mechanics, and accountants all inherit the employee number, last name, first name, middle initial, and hire date from the EMPLOYEE entity. However, Figure 5.2 also illustrates that pilots have unique attributes; the same is true for mechanics and accountants. *One important inheritance characteristic is that all entity subtypes inherit their primary key attribute from their supertype.* Note in Figure 5.2 that the EMP_NUM attribute is the primary key for each of the subtypes.

At the implementation level, the supertype and its subtype(s) depicted in the specialization hierarchy maintain a 1:1 relationship. For example, the specialization hierarchy lets you replace the undesirable EMPLOYEE table structure in Figure 5.1 with two tables—one representing the supertype EMPLOYEE and the other representing the subtype PILOT. (See Figure 5.3.)

FIGURE 5.3 THE EMPLOYEE-PILOT SUPERTYPE-SUBTYPE RELATIONSHIP

Database name: Ch05_AirCo

Table name: EMPLOYEE

EMP_NUM	EMP_LNAME	EMP_FNAME	EMP_INITIAL	EMP_HIRE_DATE	EMP_TYPE
100	Koltycz	Xavier	T	15-Mar-88	
101	Lewis	Marcos		25-Apr-89	P
102	Vandam	Jean		20-Dec-93	A
103	Jones	Victoria	R	26-Aug-03	
104	Lange	Edith		20-Oct-97	P
105	Williams	Gabriel	U	08-Nov-97	P
106	Duzak	Mario		05-Jan-04	P
107	Dionte	Venice	L	02-Jul-97	M
108	vMessenbach	Joni		18-Nov-95	M
109	Travis	Brett	T	14-Apr-01	P
110	Genikazi	Stan		01-Dec-03	A

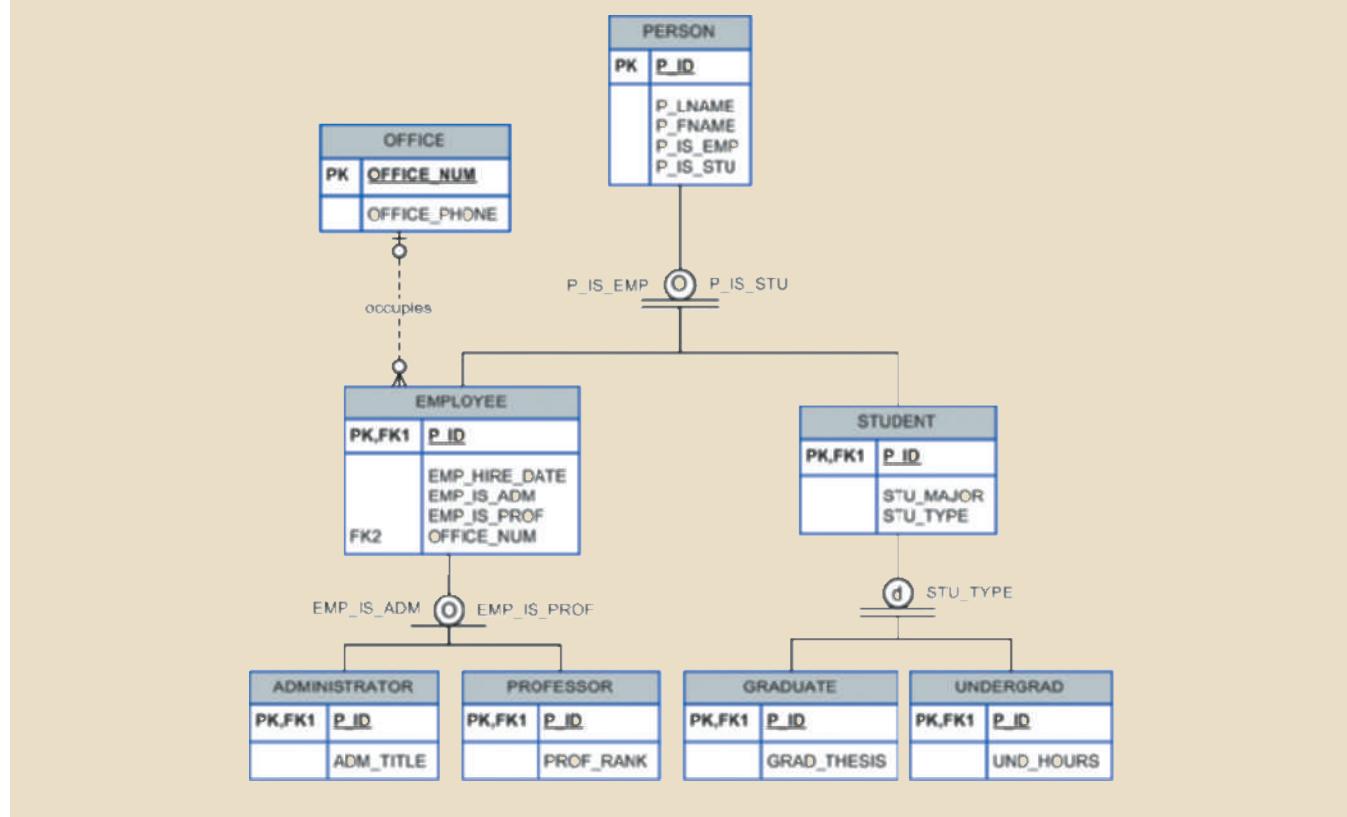
Table name: PILOT

EMP_NUM	PLICENSE	PL_RATINGS	PL_MED_TYPE
101	ATP	SEL/MEL/Instr/CFI	1
104	ATP	SEL/MEL/Instr	1
105	COM	SEL/MEL/Instr/CFI	2
106	COM	SEL/MEL/Instr	2
109	COM	SEL/MEL/SES/Instr/CFI	1

Entity subtypes inherit all relationships in which the supertype entity participates. For example, Figure 5.2 shows the EMPLOYEE entity supertype participating in a 1:M relationship with a DEPENDENT entity. Through inheritance, all subtypes also participate in that relationship. In specialization hierarchies with multiple levels of supertype and subtypes, a lower-level subtype inherits all of the attributes and relationships from all of its upper-level supertypes.

Inheriting the relationships of their supertypes does not mean that subtypes cannot have relationships of their own. Figure 5.4 illustrates a 1:M relationship between EMPLOYEE, a subtype of PERSON, and OFFICE. Because only employees and no other type of person will ever have an office within this system, the relationship is modeled with the subtype directly.

FIGURE 5.4 SPECIALIZATION HIERARCHY WITH OVERLAPPING SUBTYPES





Online Content

For a tutorial on using Visio 2010 to create a specialization hierarchy, see Appendix A, Designing Databases with Visio Professional: A Tutorial, at www.cengagebrain.com.

subtype discriminator

The attribute in the supertype entity that determines to which entity subtype each supertype occurrence is related.

5-1d Subtype Discriminator

A **subtype discriminator** is the attribute in the supertype entity that determines to which subtype the supertype occurrence is related. In Figure 5.2, the subtype discriminator is the employee type (EMP_TYPE).

It is common practice to show the subtype discriminator and its value for each subtype in the ERD, as shown in Figure 5.2. However, not all ER modeling tools follow that practice. For example, Microsoft Visio shows the subtype discriminator but not its value. In Figure 5.2, a text tool was used to manually add the discriminator value above the entity subtype, close to the connector line. Using Figure 5.2 as your guide, note that the supertype is related to a PILOT subtype if the EMP_TYPE has a value of "P." If the EMP_TYPE value is "M," the supertype is related to a MECHANIC subtype. If the EMP_TYPE value is "A," the supertype is related to the ACCOUNTANT subtype.

Note that the default comparison condition for the subtype discriminator attribute is the equality comparison. However, in some situations the subtype discriminator is not necessarily based on an equality comparison. For example, based on business requirements, you might create two new pilot subtypes: pilot-in-command (PIC)-qualified and copilot-qualified only. A PIC-qualified pilot must have more than 1,500 PIC flight hours. In this case, the subtype discriminator would be "Flight_Hours," and the criteria would be $> 1,500$ or $\leq 1,500$, respectively.



Note

In Visio 2010, you select the subtype discriminator when creating a category by using the Category shape from the available shapes. The Category shape is a small circle with a horizontal line underneath that connects the supertype to its subtypes. Newer versions of Visio do not support specialization hierarchy. Professional data modeling tools, such as E/R Studio Data Architect by Idera and Power Designer by Sybase, support specialization hierarchies, but these tools typically cost thousands of dollars for a single user license.

disjoint subtypes

In a specialization hierarchy, these are unique and nonoverlapping subtype entity set.

nonoverlapping subtypes

See *disjoint subtype*.

overlapping subtype

In a specialization hierarchy, a condition in which each entity instance (row) of the supertype can appear in more than one subtype.

5-1e Disjoint and Overlapping Constraints

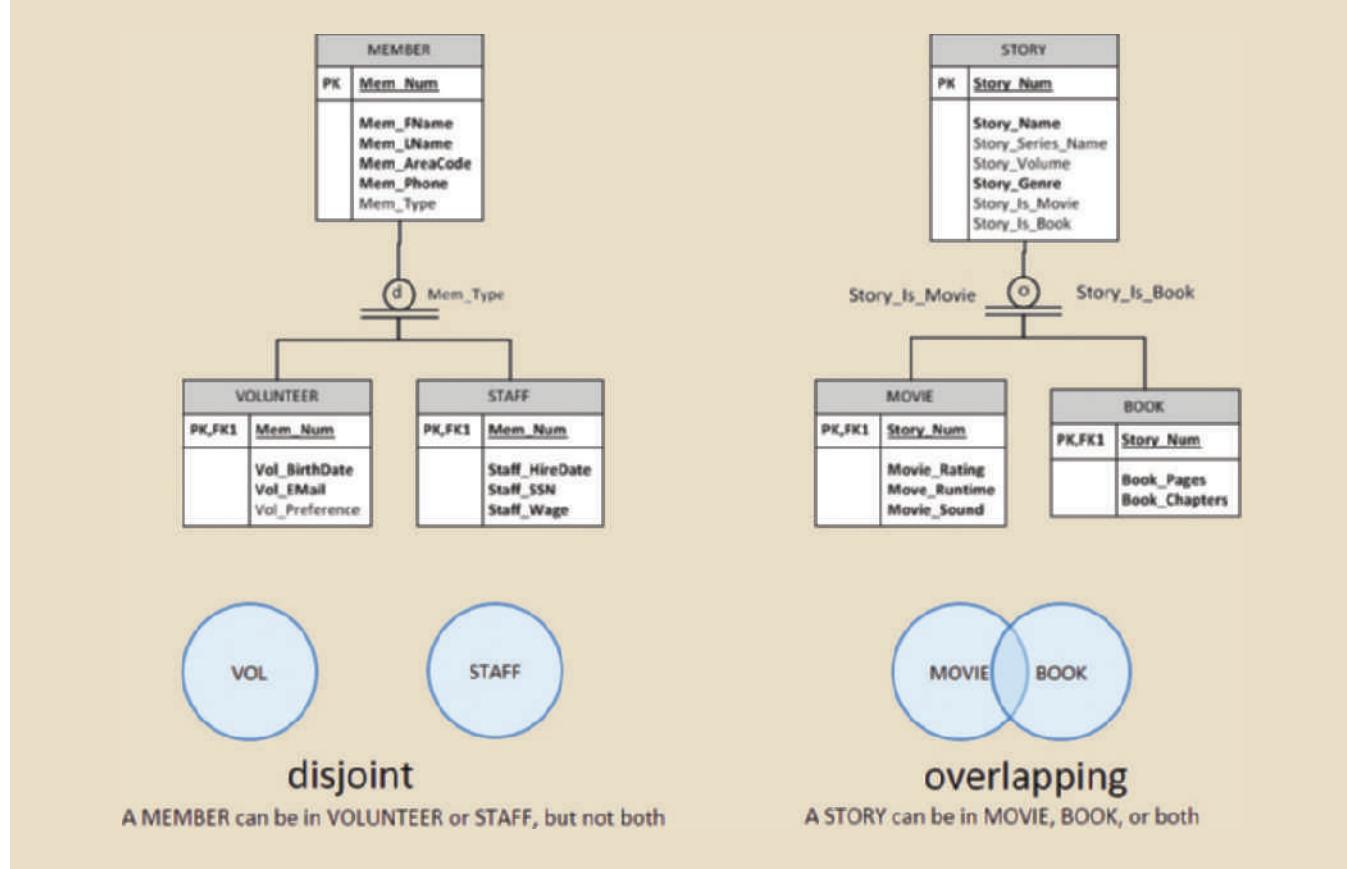
An entity supertype can have disjoint or overlapping entity subtypes. In the aviation example, an employee can be a pilot, a mechanic, or an accountant. Assume that one of the business rules dictates that an employee cannot belong to more than one subtype at a time; that is, an employee cannot be a pilot and a mechanic at the same time. **Disjoint subtypes**, also known as **nonoverlapping subtypes**, are subtypes that contain a *unique* subset of the supertype entity set; in other words, each entity instance of the supertype can appear in only one of the subtypes. For example, in Figure 5.2, an employee (supertype) who is a pilot (subtype) can appear only in the PILOT subtype, not in any of the other subtypes. In an ERD, such disjoint subtypes are indicated by the letter *d* inside the category shape.

On the other hand, if the business rule specifies that employees can have multiple classifications, the EMPLOYEE supertype may contain *overlapping* job classification subtypes. **Overlapping subtypes** are subtypes that contain nonunique subsets of the supertype entity set; that is, each entity instance of the supertype may appear in more than one subtype. For example, in a university environment, a person may be an employee, a student, or both. In turn, an employee may be a professor as well as an administrator. Because an employee may also be a student, STUDENT and EMPLOYEE

are overlapping subtypes of the supertype PERSON, just as PROFESSOR and ADMINISTRATOR are overlapping subtypes of the supertype EMPLOYEE. Figure 5.4 illustrates overlapping subtypes with the letter *o* inside the category shape.

Figure 5.5 illustrates more examples of disjoint and overlapping subtypes. At a charity organization, members are either volunteers or they are paid staff. Recall that a subtype must be an identifiable kind or type of instance of the supertype (in this example, identifiable kinds of members), and the subtype must have attributes that are unique to that kind or type of instance. There are attributes that apply to volunteers that do not apply to paid staff, so VOLUNTEER is a valid subtype. There are attributes that apply to paid staff that do not apply to volunteers, so STAFF is also a valid subtype. A single member of the organization cannot be both a volunteer and paid staff, so those subtypes are disjoint. The second example in Figure 5.5 is a website that provides data about popular children's stories and tracks stories that appear in movies and books. Stories in movies have attributes that stories in books do not have, such as a rating and sound type. Stories in books have attributes that do not apply to movies, such as the number of chapters and pages. MOVIE and BOOK are valid subtypes because each is an identifiable kind of story, and each has attributes that do not apply to the other kind of story. However, these subtypes are overlapping because it is possible for a story to appear as both a book and a movie.

FIGURE 5.5 DISJOINT AND OVERLAPPING SUBTYPES



It is common practice to show disjoint and overlapping symbols in the ERD. (See Figures 5.2, 5.4, and 5.5.) However, not all ER modeling tools follow that practice. For example, by default, Visio shows only the subtype discriminator (using the Category shape), but not the disjoint and overlapping symbols. The Visio text tool was used to manually add the *d* and *o* symbols in the previous figures.



Note

Alternative notations exist for representing disjoint and overlapping subtypes. For example, Toby J. Teorey popularized the use of G and Gs to indicate disjoint and overlapping subtypes.

As you learned earlier in this section, the implementation of disjoint subtypes is based on the value of the subtype discriminator attribute in the supertype. However, *implementing* overlapping subtypes requires the use of one discriminator attribute for each subtype. For example, in the case of the Tiny College database design in Chapter 4, Entity Relationship (ER) Modeling, a professor can also be an administrator. Therefore, the EMPLOYEE supertype would have the subtype discriminator attributes and values shown in Table 5.1.

TABLE 5.1

DISCRIMINATOR ATTRIBUTES WITH OVERLAPPING SUBTYPES

DISCRIMINATOR ATTRIBUTES		COMMENT
PROFESSOR	ADMINISTRATOR	
Y	N	The Employee is a member of the Professor subtype.
N	Y	The Employee is a member of the Administrator subtype.
Y	Y	The Employee is both a Professor and an Administrator.

completeness constraint

A constraint that specifies whether each entity supertype occurrence must also be a member of at least one subtype. The completeness constraint can be partial or total.

partial completeness

In a generalization or specialization hierarchy, a condition in which some supertype occurrences might not be members of any subtype.

total completeness

In a generalization or specialization hierarchy, a condition in which every supertype occurrence must be a member of at least one subtype.

5-1f Completeness Constraint

The **completeness constraint** specifies whether each entity supertype occurrence must also be a member of at least one subtype. The completeness constraint can be partial or total. **Partial completeness** means that not every supertype occurrence is a member of a subtype; some supertype occurrences may not be members of any subtype. **Total completeness** means that every supertype occurrence must be a member of at least one subtype.

The ERDs in the previous figures represent the completeness constraint based on the Visio Category shape. A single horizontal line under the circle represents a partial completeness constraint; a double horizontal line under the circle represents a total completeness constraint.



Note

Alternative notations exist to represent the completeness constraint. For example, some notations use a single line (partial) or double line (total) to connect the supertype to the Category shape.

Given the disjoint and overlapping subtypes and completeness constraints, it is possible to have the specialization hierarchy constraint scenarios shown in Table 5.2.

TABLE 5.2

SPECIALIZATION HIERARCHY CONSTRAINT SCENARIOS

TYPE	DISJOINT CONSTRAINT	OVERLAPPING CONSTRAINT
Partial 	Supertype has optional subtypes. Subtype discriminator can be null. Subtype sets are unique.	Supertype has optional subtypes. Subtype discriminators can be null. Subtype sets are not unique.
Total 	Every supertype occurrence is a member of only one subtype. Subtype discriminator cannot be null. Subtype sets are unique.	Every supertype occurrence is a member of at least one subtype. Subtype discriminators cannot be null. Subtype sets are not unique.

5-1g Specialization and Generalization

You can use various approaches to develop entity supertypes and subtypes. For example, you can first identify a regular entity and then identify all entity subtypes based on their distinguishing characteristics. You can also start by identifying multiple entity types and then later extract the common characteristics of those entities to create a higher-level supertype entity.

Specialization is the top-down process of identifying lower-level, more specific entity subtypes from a higher-level entity supertype. Specialization is based on grouping the unique characteristics and relationships of the subtypes. In the aviation example, you used specialization to identify multiple entity subtypes from the original employee supertype. **Generalization** is the bottom-up process of identifying a higher-level, more generic entity supertype from lower-level entity subtypes. Generalization is based on grouping the common characteristics and relationships of the subtypes. For example, you might identify multiple types of musical instruments: piano, violin, and guitar. Using the generalization approach, you could identify a “string instrument” entity supertype to hold the common characteristics of the multiple subtypes.

5-2 Entity Clustering

Developing an ER diagram entails the discovery of possibly hundreds of entity types and their respective relationships. Generally, the data modeler will develop an initial ERD that contains a few entities. As the design approaches completion, the ERD will contain hundreds of entities and relationships that crowd the diagram to the point of making it unreadable and inefficient as a communication tool. In those cases, you can use entity clusters to minimize the number of entities shown in the ERD.

An **entity cluster** is a “virtual” entity type used to represent multiple entities and relationships in the ERD. An entity cluster is formed by combining multiple interrelated entities into a single, abstract entity object. An entity cluster is considered “virtual” or “abstract” in the sense that it is not actually an entity in the final ERD. Instead, it is a temporary entity used to represent multiple entities and relationships, with the purpose of simplifying the ERD and thus enhancing its readability.

Figure 5.6 illustrates the use of entity clusters based on the Tiny College example in Chapter 4. Note that the ERD contains two entity clusters:

- OFFERING, which groups the SEMESTER, COURSE, and CLASS entities and relationships
- LOCATION, which groups the ROOM and BUILDING entities and relationships

specialization

In a specialization hierarchy, the grouping of unique attributes into a subtype entity.

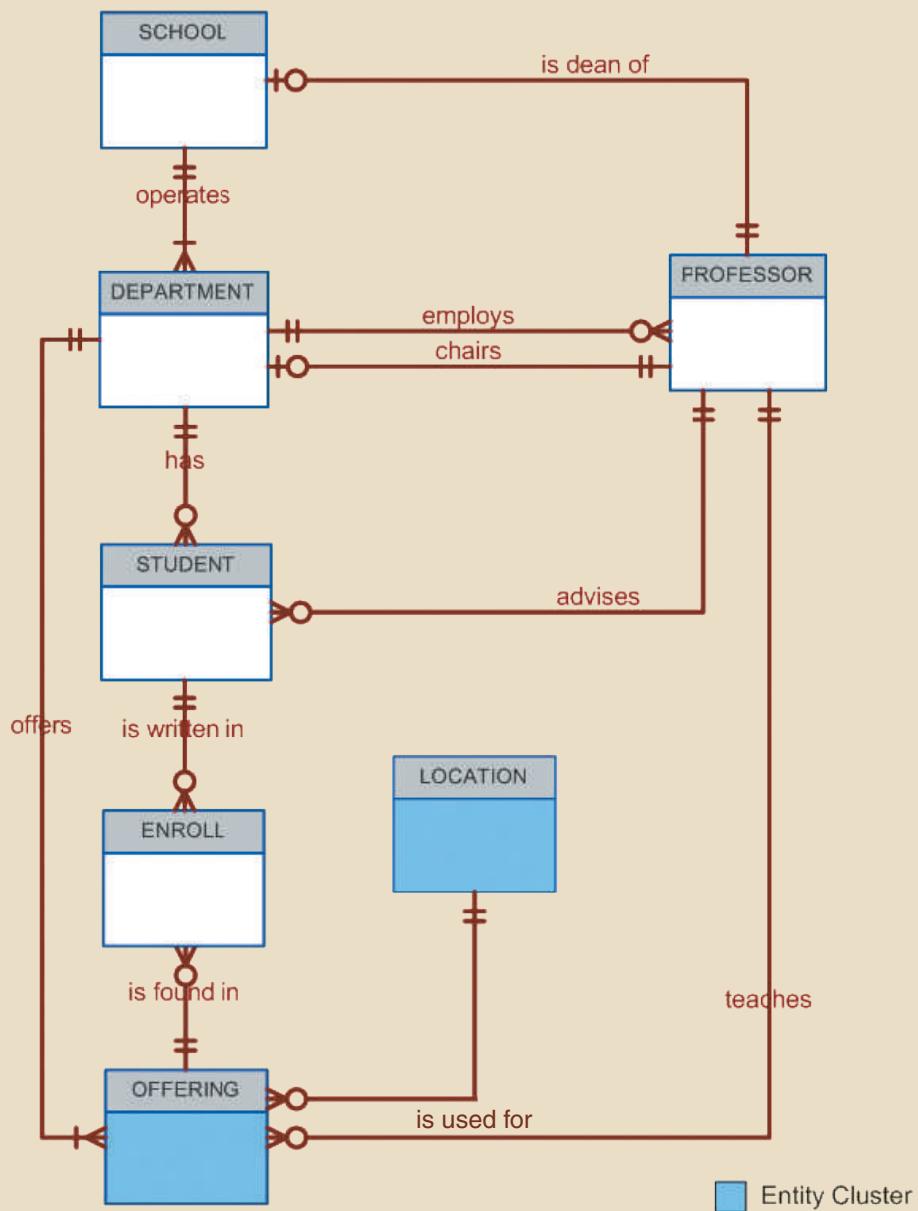
generalization

In a specialization hierarchy, the grouping of common attributes into a supertype entity.

entity cluster

A “virtual” entity type used to represent multiple entities and relationships in the ERD. An entity cluster is formed by combining multiple interrelated entities into a single abstract entity object. An entity cluster is considered “virtual” or “abstract” because it is not actually an entity in the final ERD.

FIGURE 5.6 TINY COLLEGE ERD USING ENTITY CLUSTERS



Note also that the ERD in Figure 5.6 does not show attributes for the entities. When using entity clusters, the key attributes of the combined entities are no longer available. Without the key attributes, primary key inheritance rules change. In turn, the change in the inheritance rules can have undesirable consequences, such as changes in relationships—from identifying to nonidentifying or vice versa—and the loss of foreign key attributes from some entities. To eliminate those problems, the general rule is to *avoid the display of attributes when entity clusters are used*.

5-3 Entity Integrity: Selecting Primary Keys

Arguably, the most important characteristic of an entity is its primary key (a single attribute or some combination of attributes), which uniquely identifies each entity instance. The primary key's function is to guarantee entity integrity. Furthermore, primary keys

and foreign keys work together to implement relationships in the relational model. Therefore, the importance of properly selecting the primary key has a direct bearing on the efficiency and effectiveness of database implementation.

5-3a Natural Keys and Primary Keys

The concept of a unique identifier is commonly encountered in the real world. For example, you use class or section numbers to register for classes, invoice numbers to identify specific invoices, and account numbers to identify credit cards. Those examples illustrate natural identifiers or keys. A **natural key** or **natural identifier** is a real-world, generally accepted identifier used to distinguish—that is, uniquely identify—real-world objects. As its name implies, a natural key is familiar to end users and forms part of their day-to-day business vocabulary.

Usually, if an entity *has* a natural identifier, a data modeler uses it as the primary key of the entity being modeled. Generally, most natural keys make acceptable primary key identifiers. The next section presents some basic guidelines for selecting primary keys.

5-3b Primary Key Guidelines

A primary key is the attribute or combination of attributes that uniquely identifies entity instances in an entity set. However, can the primary key be based on, for example, 12 attributes? And just how long can a primary key be? In previous examples, why was EMP_NUM selected as a primary key of EMPLOYEE and not a combination of EMP_LNAME, EMP_FNAME, EMP_INITIAL, and EMP_DOB? Can a single, 256-byte text attribute be a good primary key? There is no single answer to those questions, but database experts have built a body of practice over the years. This section examines that body of documented practices.

First, you should understand the function of a primary key. Its main function is to uniquely identify an entity instance or row within a table. In particular, given a primary key value—that is, the determinant—the relational model can determine the value of all dependent attributes that “describe” the entity. Note that identification and description are separate semantic constructs in the model. *The function of the primary key is to guarantee entity integrity, not to “describe” the entity.*

Second, primary keys and foreign keys are used to implement relationships among entities. However, the implementation of such relationships is done mostly behind the scenes, hidden from end users. In the real world, end users identify objects based on the characteristics they know about the objects. For example, when shopping at a grocery store, you select products by taking them from a display shelf and reading the labels, not by looking at the stock number. It is wise for database applications to mimic the human selection process as much as possible. Therefore, database applications should let the end user choose among multiple descriptive narratives of different objects, while using primary key values behind the scenes. Keeping those concepts in mind, look at Table 5.3, which summarizes desirable primary key characteristics.

5-3c When to Use Composite Primary Keys

In the previous section, you learned about the desirable characteristics of primary keys. For example, you learned that the primary key should use the minimum number of attributes possible. However, that does *not* mean that composite primary keys are not permitted in a model. In fact, composite primary keys are particularly useful in two cases:

- As identifiers of composite entities, in which each primary key combination is allowed only once in the M:N relationship
- As identifiers of weak entities, in which the weak entity has a strong identifying relationship with the parent entity

natural key (natural identifier)

A generally accepted identifier for real-world objects. As its name implies, a natural key is familiar to end users and forms part of their day-to-day business vocabulary.

TABLE 5.3

DESIRABLE PRIMARY KEY CHARACTERISTICS

PK CHARACTERISTIC	RATIONALE
Unique values	The PK must uniquely identify each entity instance. A primary key must be able to guarantee unique values. It cannot contain nulls.
Nonintelligent	The PK should not have embedded semantic meaning other than to uniquely identify each entity instance. An attribute with embedded semantic meaning is probably better used as a descriptive characteristic of the entity than as an identifier. For example, a student ID of 650973 would be preferred over Smith, Martha L. as a primary key identifier.
No change over time	If an attribute has semantic meaning, it might be subject to updates, which is why names do not make good primary keys. If Vickie Smith is the primary key, what happens if she changes her name when she gets married? If a primary key is subject to change, the foreign key values must be updated, thus adding to the database work load. Furthermore, changing a primary key value means that you are basically changing the identity of an entity. In short, the PK should be permanent and unchangeable.
Preferably single-attribute	A primary key should have the minimum number of attributes possible (irreducible). Single-attribute primary keys are desirable but not required. Single-attribute primary keys simplify the implementation of foreign keys. Having multiple-attribute primary keys can cause primary keys of related entities to grow through the possible addition of many attributes, thus adding to the database workload and making (application) coding more cumbersome.
Preferably numeric	Unique values can be better managed when they are numeric, because the database can use internal routines to implement a counter-style attribute that automatically increments values with the addition of each new row. In fact, most database systems include the ability to use special constructs, such as Autonumber in Microsoft Access, sequence in Oracle, or uniqueidentifier in MS SQL Server to support self-incrementing primary key attributes.
Security-compliant	The selected primary key must not be composed of any attribute(s) that might be considered a security risk or violation. For example, using a Social Security number as a PK in an EMPLOYEE table is not a good idea.

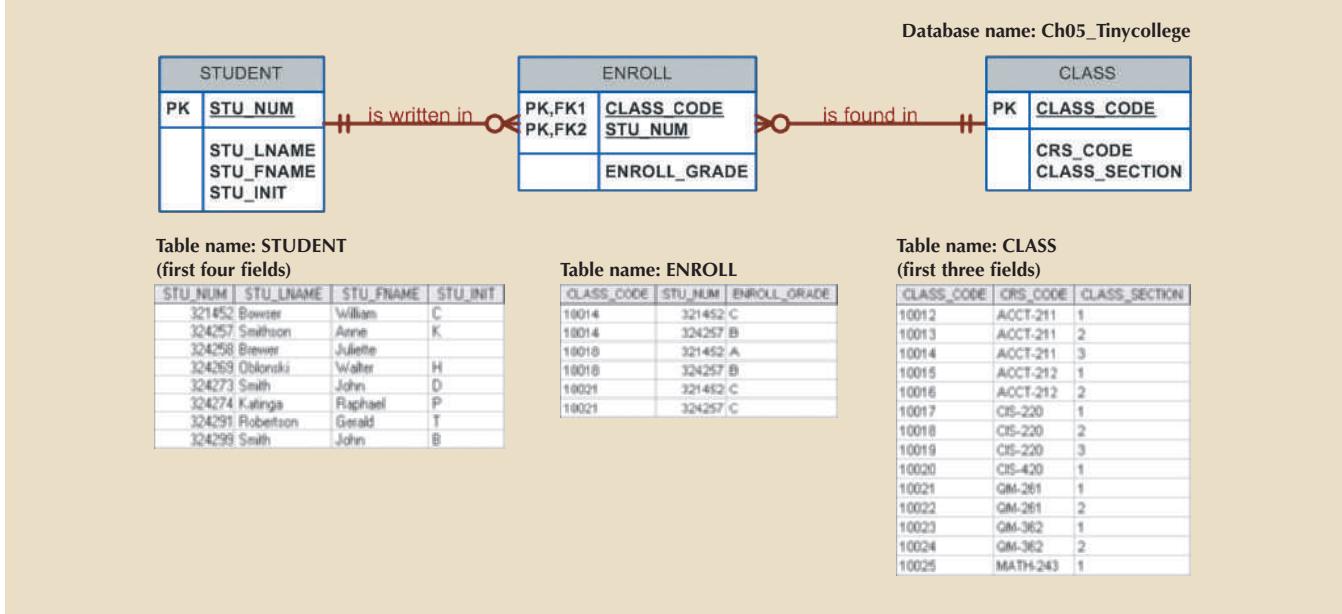
To illustrate the first case, assume that you have a STUDENT entity set and a CLASS entity set. In addition, assume that those two sets are related in an M:N relationship via an ENROLL entity set, in which each student or class combination may appear only once in the composite entity. Figure 5.7 shows the ERD to represent such a relationship.

As shown in Figure 5.7, the composite primary key automatically provides the benefit of ensuring that there cannot be duplicate values—that is, it ensures that the same student cannot enroll more than once in the same class.

In the second case, a weak entity in a strong identifying relationship with a parent entity is normally used to represent one of two situations:

1. *A real-world object that is existence-dependent on another real-world object.* Such objects are distinguishable in the real world. A dependent and an employee are two separate people who exist independently of each other. However, such objects can exist in the model only when they relate to each other in a strong identifying relationship. For example, the relationship between EMPLOYEE and DEPENDENT is one of existence dependency, in which the primary key of the dependent entity is a composite key that contains the key of the parent entity.
2. *A real-world object that is represented in the data model as two separate entities in a strong identifying relationship.* For example, the real-world invoice object is represented by two entities in a data model: INVOICE and LINE. Clearly, the LINE entity does not exist in the real world as an independent object but as part of an INVOICE.

FIGURE 5.7 THE M:N RELATIONSHIP BETWEEN STUDENT AND CLASS



In both situations, having a strong identifying relationship ensures that the dependent entity can exist only when it is related to the parent entity. In summary, the selection of a composite primary key for composite and weak entity types provides benefits that enhance the integrity and consistency of the model.

5-3d When to Use Surrogate Primary Keys

In some instances a primary key doesn't exist in the real world or the existing natural key might not be a suitable primary key. In these cases, it is standard practice to create a surrogate key. A **surrogate key** is a primary key created by the database designer to simplify the identification of entity instances. The surrogate key has no meaning in the user's environment—it exists only to distinguish one entity instance from another (just like any other primary key). One practical advantage of a surrogate key is that because it has no intrinsic meaning, values for it can be generated by the DBMS to ensure that unique values are always provided.

For example, consider the case of a park recreation facility that rents rooms for small parties. The manager of the facility keeps track of all events, using a folder with the format shown in Table 5.4.

surrogate key
A system-assigned primary key, generally numeric and auto-incremented.

TABLE 5.4

DATA USED TO KEEP TRACK OF EVENTS

DATE	TIME_START	TIME_END	ROOM	EVENT_NAME	PARTY_OF
6/17/2018	11:00 a.m.	2:00 p.m.	Allure	Burton Wedding	60
6/17/2018	11:00 a.m.	2:00 p.m.	Bonanza	Adams Office	12
6/17/2018	3:00 p.m.	5:30 p.m.	Allure	Smith Family	15
6/17/2018	3:30 p.m.	5:30 p.m.	Bonanza	Adams Office	12
6/18/2018	1:00 p.m.	3:00 p.m.	Bonanza	Boy Scouts	33
6/18/2018	11:00 a.m.	2:00 p.m.	Allure	March of Dimes	25
6/18/2018	11:00 a.m.	12:30 p.m.	Bonanza	Smith Family	12

Given the data shown in Table 5.4, you would model the EVENT entity as follows:

EVENT (DATE, TIME_START, TIME_END, ROOM, EVENT_NAME, PARTY_OF)

What primary key would you suggest? In this case, there is no simple natural key that could be used as a primary key in the model. Based on the primary key concepts you learned in previous chapters, you might suggest one of these options:

(DATE, TIME_START, ROOM) or (DATE, TIME_END, ROOM)

Assume that you select the composite primary key **(DATE, TIME_START, ROOM)** for the EVENT entity. Next, you determine that one EVENT may use many RESOURCES (such as tables, projectors, PCs, and stands) and that the same RESOURCE may be used for many EVENTS. The RESOURCE entity would be represented by the following attributes:

RESOURCE (RSC_ID, RSC_DESCRIPTION, RSC_TYPE, RSC_QTY, RSC_PRICE)

Given the business rules, the M:N relationship between RESOURCE and EVENT would be represented via the EVNTRSC composite entity with a composite primary key as follows:

EVNTRSC (DATE, TIME_START, ROOM, RSC_ID, QTY_USED)

You now have a lengthy, four-attribute composite primary key. What would happen if the EVNTRSC entity's primary key were inherited by another existence-dependent entity? At this point, you can see that the composite primary key could make the database implementation and program coding unnecessarily complex.

As a data modeler, you probably noticed that the EVENT entity's selected primary key might not fare well, given the primary key guidelines in Table 5.3. In this case, the EVENT entity's selected primary key contains embedded semantic information and is formed by a combination of date, time, and text data columns. In addition, the selected primary key would cause lengthy primary keys for existence-dependent entities. The preferred alternative is to use a numeric, single-attribute surrogate primary key.

Surrogate primary keys are accepted practice in today's complex data environments. They are especially helpful when there is no natural key, when the selected candidate key has embedded semantic contents, or when the selected candidate key is too long or cumbersome. However, there is a trade-off: if you use a surrogate key, you must ensure that the candidate key of the entity in question performs properly through the use of "unique index" and "not null" constraints.



Note

This example shows a case in which entity integrity is maintained but semantic correctness of business rules is not. For example, you could have two events that overlap and whose primary keys are perfectly compliant. The only way to ensure adherence to this type of business rule (two events cannot overlap—occur on the same room at the same time) would be via application programming code.

5-4 Design Cases: Learning Flexible Database Design

Data modeling and database design require skills that are acquired through experience. In turn, experience is acquired through practice—regular and frequent repetition, applying the concepts learned to specific and different design problems. This section presents four special design cases that highlight the importance of flexible designs, proper identification of primary keys, and placement of foreign keys.



Note

In describing the various modeling concepts throughout this book, the focus is on relational models. Also, given the focus on the practical nature of database design, all design issues are addressed with the implementation goal in mind. Therefore, there is no sharp line of demarcation between design and implementation.

At the pure conceptual stage of the design, foreign keys are not part of an ERD. The ERD displays only entities and relationships. Entity instances are distinguished by identifiers that may become primary keys. During design, the modeler attempts to understand and define the entities and relationships. Foreign keys are the mechanism through which the relationship designed in an ERD is implemented in a relational model.

5-4a Design Case 1: Implementing 1:1 Relationships

Foreign keys work with primary keys to properly implement relationships in the relational model. The basic rule is very simple: put the primary key of the “one” side (the parent entity) on the “many” side (the dependent entity) as a foreign key. However, where do you place the foreign key when you are working with a 1:1 relationship? For example, take the case of a 1:1 relationship between EMPLOYEE and DEPARTMENT based on the business rule “one EMPLOYEE is the manager of one DEPARTMENT, and one DEPARTMENT is managed by one EMPLOYEE.” In that case, there are two options for selecting and placing the foreign key:

1. *Place a foreign key in both entities.* This option is derived from the basic rule you learned in Chapter 4. Place EMP_NUM as a foreign key in DEPARTMENT, and place DEPT_ID as a foreign key in EMPLOYEE. However, this solution is not recommended because it duplicates work, and it could conflict with other existing relationships. (Remember that DEPARTMENT and EMPLOYEE also participate in a 1:M relationship—one department employs many employees.)
2. *Place a foreign key in one of the entities.* In that case, the primary key of one of the two entities appears as a foreign key in the other entity. That is the preferred solution, but a question remains: *which* primary key should be used as a foreign key? The answer is found in Table 5.5, which shows the rationale for selecting the foreign key in a 1:1 relationship based on the relationship properties in the ERD.

TABLE 5.5**SELECTION OF FOREIGN KEY IN A 1:1 RELATIONSHIP**

CASE	ER RELATIONSHIP CONSTRAINTS	ACTION
I	One side is mandatory and the other side	Place the PK of the entity on the mandatory side in the entity on the optional side as a FK, and make the FK mandatory.
II	Both sides are optional.	Select the FK that causes the fewest nulls, or place the FK in the entity in which the (relationship) role is played.
III	Both sides are mandatory.	See Case II, or consider revising your model to ensure that the two entities do not belong together in a single entity.

Figure 5.8 illustrates the “EMPLOYEE manages DEPARTMENT” relationship. Note that in this case, EMPLOYEE is mandatory to DEPARTMENT. Therefore, EMP_NUM is placed as the foreign key in DEPARTMENT. Alternatively, you might also argue that the “manager” role is played by the EMPLOYEE in the DEPARTMENT.

FIGURE 5.8 THE 1:1 RELATIONSHIP BETWEEN DEPARTMENT AND EMPLOYEE

A One-to-One (1:1) Relationship:
An EMPLOYEE manages zero or one DEPARTMENT;
each DEPARTMENT is managed by one EMPLOYEE.



As a designer, you must recognize that 1:1 relationships exist in the real world; therefore, they should be supported in the data model. In fact, a 1:1 relationship is used to ensure that two entity sets are not placed in the same table. In other words, EMPLOYEE and DEPARTMENT are clearly separate and unique entity types that do not belong together in a single entity. If you grouped them together in one entity, what would you name that entity?

5-4b Design Case 2: Maintaining History of Time-Variant Data

Company managers generally realize that good decision making is based on the information generated through the data stored in databases. Such data reflects both current and past events. Company managers use the data stored in databases to answer questions such as “How do the current company profits compare to those of previous years?” and “What are XYZ product’s sales trends?” In other words, the data stored in databases reflects not only current data but also historic data.

Normally, data changes are managed by replacing the existing attribute value with the new value, without regard to the previous value. However, in some situations the history of values for a given attribute must be preserved. From a data-modeling point of view, **time-variant data** refers to data whose values change over time and for which you *must* keep a history of the data changes. You could argue that all data in a database is subject to change over time and is therefore time variant. However, some attribute values, such as your date of birth or your Social Security number, are not time variant. On the other hand, attributes such as your student GPA or your bank account balance are subject to change over time. Sometimes the data changes are externally originated and event driven, such as a product price change. On other occasions, changes are based on well-defined schedules, such as the daily stock quote “open” and “close” values.

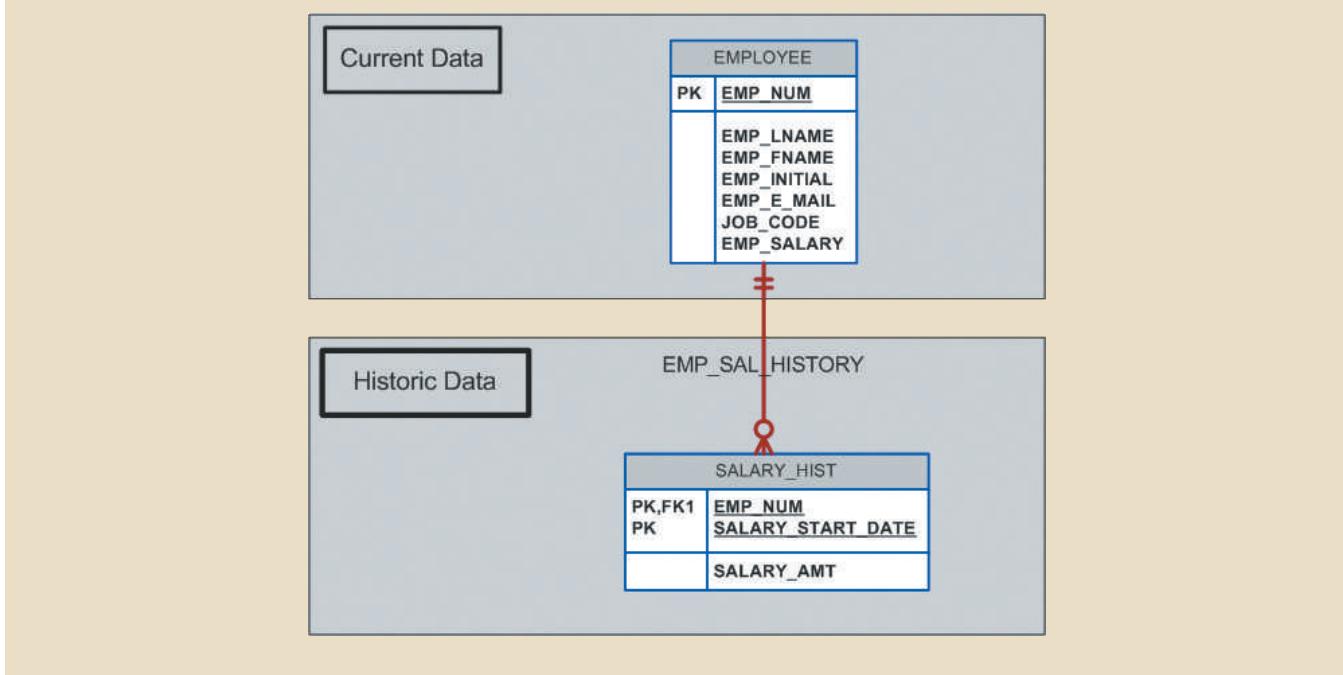
The storage of time-variant data requires changes in the data model; the type of change depends on the nature of the data. Some time-variant data is equivalent to having a multivalued attribute in your entity. To model this type of time-variant data, you must create a new entity in a 1:M relationship with the original entity. This new entity will contain the new value, the date of the change, and any other attribute that is pertinent to the event being modeled. For example, if you want to track salary histories for each employee, then the EMP_SALARY attribute becomes multivalued, as shown in Figure 5.9. In this case, for each employee, there will be one or more records in the SALARY_HIST entity, which stores the salary amount and the date when the new salary goes into effect.

Other time-variant data can turn a 1:M relationship into an M:N relationship. Assume that in addition to employee data, your data model includes data about the different departments in the organization and which employee manages each department. Assuming that each department is managed by only one employee and each employee can manage one department at most, then a 1:1 relationship would exist between EMPLOYEE and DEPARTMENT. This relationship would record the current manager

time-variant data

Data whose values are a function of time. For example, time-variant data can be seen at work when a company’s history of all administrative appointments is tracked.

FIGURE 5.9 MAINTAINING SALARY HISTORY



of each department. However, if you want to keep track of the history of all department managers as well as the current manager, you can create the model shown in Figure 5.10.

Note that in Figure 5.10, the MGR_HIST entity has a 1:M relationship with EMPLOYEE and a 1:M relationship with DEPARTMENT to reflect the fact that an employee could be the manager of many different departments over time, and a department could have many different employee managers. Because you are recording time-variant data, you must store the DATE_ASSIGN attribute in the MGR_HIST entity to provide the date that the employee (EMP_NUM) became the department manager. The primary key of MGR_HIST permits the same employee to be the manager of the same department but on different dates. If that scenario is not the case in your environment—if, for example, an employee is the manager of a department only once—you could make DATE_ASSIGN a nonprime attribute in the MGR_HIST entity.

Note in Figure 5.10 that the “manages” relationship is optional in theory and redundant in practice. At any time, you could identify the manager of a department by retrieving the most recent DATE_ASSIGN date from MGR_HIST for a given department. On the other hand, the ERD in Figure 5.10 differentiates between current data and historic data. The *current* manager relationship is implemented by the “manages” relationship between EMPLOYEE and DEPARTMENT. Additionally, the historic data is managed through EMP_MGR_HIST and DEPT_MGR_HIST. The trade-off with that model is that each time a new manager is assigned to a department, there will be two data modifications: one update in the DEPARTMENT entity and one insert in the MGR_HIST entity.

The flexibility of the model proposed in Figure 5.10 becomes more apparent when you add the 1:M “one department employs many employees” relationship. In that case, the PK of the “1” side (DEPT_ID) appears in the “many” side (EMPLOYEE) as a foreign key. Now suppose you would like to keep track of the job history for each of the company’s employees—you’d probably want to store the department, the job code, the date assigned, and the salary. To accomplish that task, you could modify the model in Figure 5.10 by adding a JOB_HIST entity. Figure 5.11 shows the use of the new JOB_HIST entity to maintain the employee’s history.

FIGURE 5.10 MAINTAINING MANAGER HISTORY

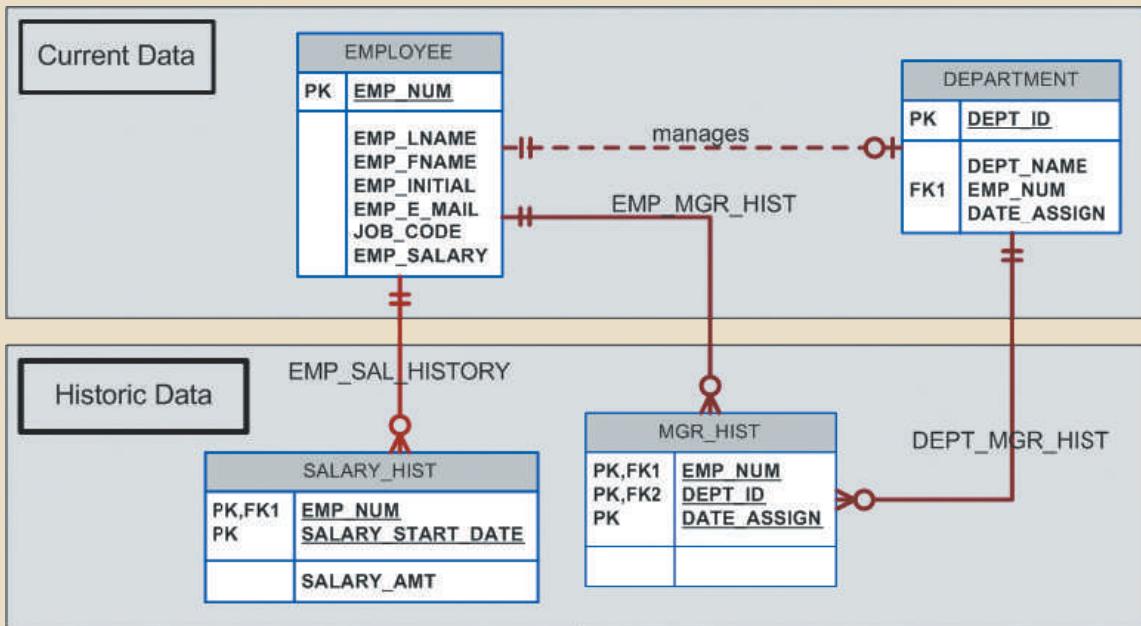
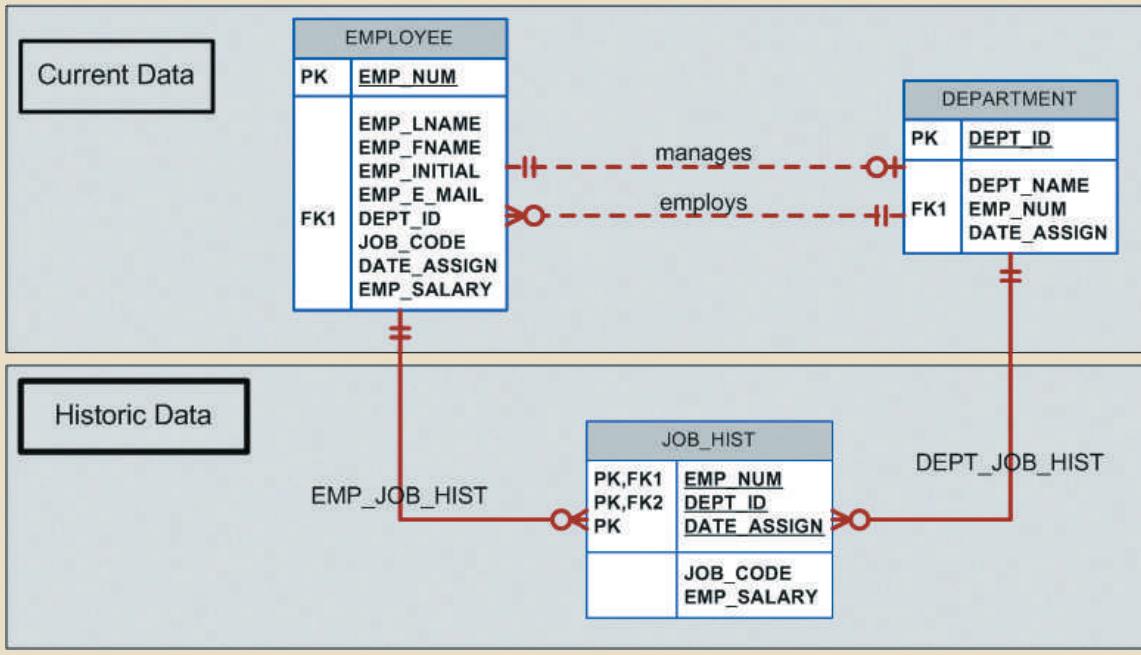


FIGURE 5.11 MAINTAINING JOB HISTORY



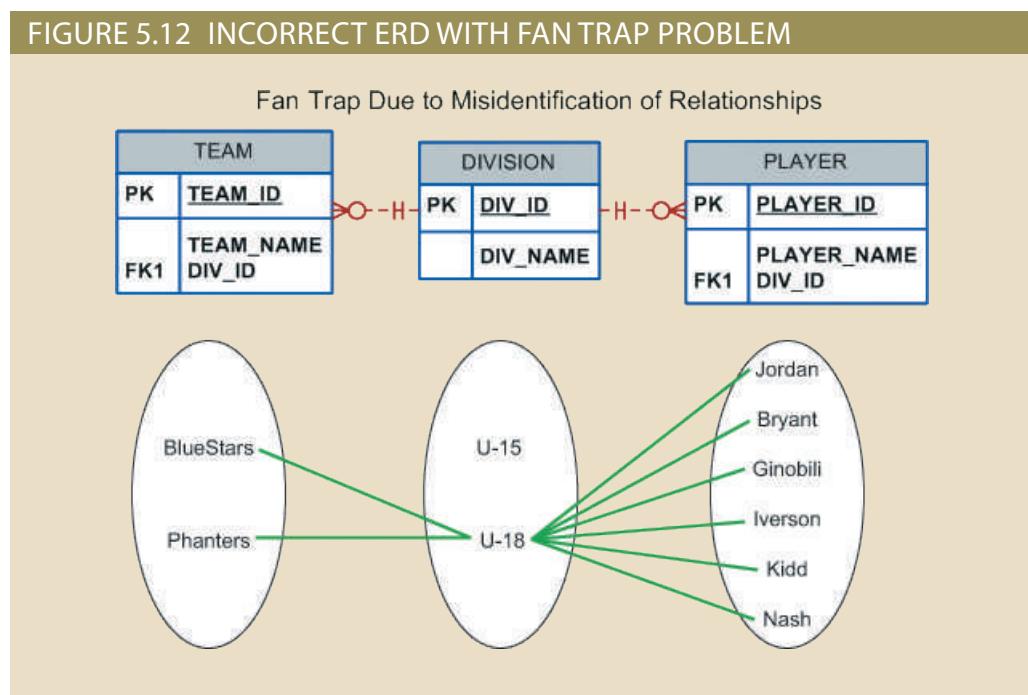
Again, it is worth emphasizing that the “manages” and “employs” relationships are theoretically optional and redundant in practice. You can always find out where each employee works by looking at the job history and selecting only the most current data row for each employee. However, as you will discover in Chapter 7, Introduction to Structured Query Language (SQL), and in Chapter 8, Advanced SQL, finding where each employee works is not a trivial task. Therefore, the model represented in Figure 5.11

includes the admittedly redundant but unquestionably useful “manages” and “employs” relationships to separate current data from historic data.

5-4c Design Case 3: Fan Traps

Creating a data model requires proper identification of the data relationships among entities. However, due to miscommunication or incomplete understanding of the business rules or processes, it is not uncommon to misidentify relationships among entities. Under those circumstances, the ERD may contain a design trap. A **design trap** occurs when a relationship is improperly or incompletely identified and is therefore represented in a way that is not consistent with the real world. The most common design trap is known as a *fan trap*.

A **fan trap** occurs when you have one entity in two 1:M relationships to other entities, thus producing an association among the other entities that is not expressed in the model. For example, assume that the JCB basketball league has many divisions. Each division has many players, and each division has many teams. Given those “incomplete” business rules, you might create an ERD that looks like the one in Figure 5.12.



As you can see in Figure 5.12, DIVISION is in a 1:M relationship with TEAM and in a 1:M relationship with PLAYER. Although that representation is semantically correct, the relationships are not properly identified. For example, there is no way to identify which players belong to which team. Figure 5.12 also shows a sample instance relationship representation for the ERD. Note that the relationship lines for the DIVISION instances fan out to the TEAM and PLAYER entity instances—thus the “fan trap” label.

Figure 5.13 shows the correct ERD after the fan trap has been eliminated. Note that, in this case, DIVISION is in a 1:M relationship with TEAM. In turn, TEAM is in a 1:M relationship with PLAYER. Figure 5.13 also shows the instance relationship representation after eliminating the fan trap.

Given the design in Figure 5.13, note how easy it is to see which players play for which team. However, to find out which players play in which division, you first need to see what teams belong to each division, and then you need to find out which players play on each team. In other words, there is a transitive relationship between DIVISION and PLAYER via the TEAM entity.

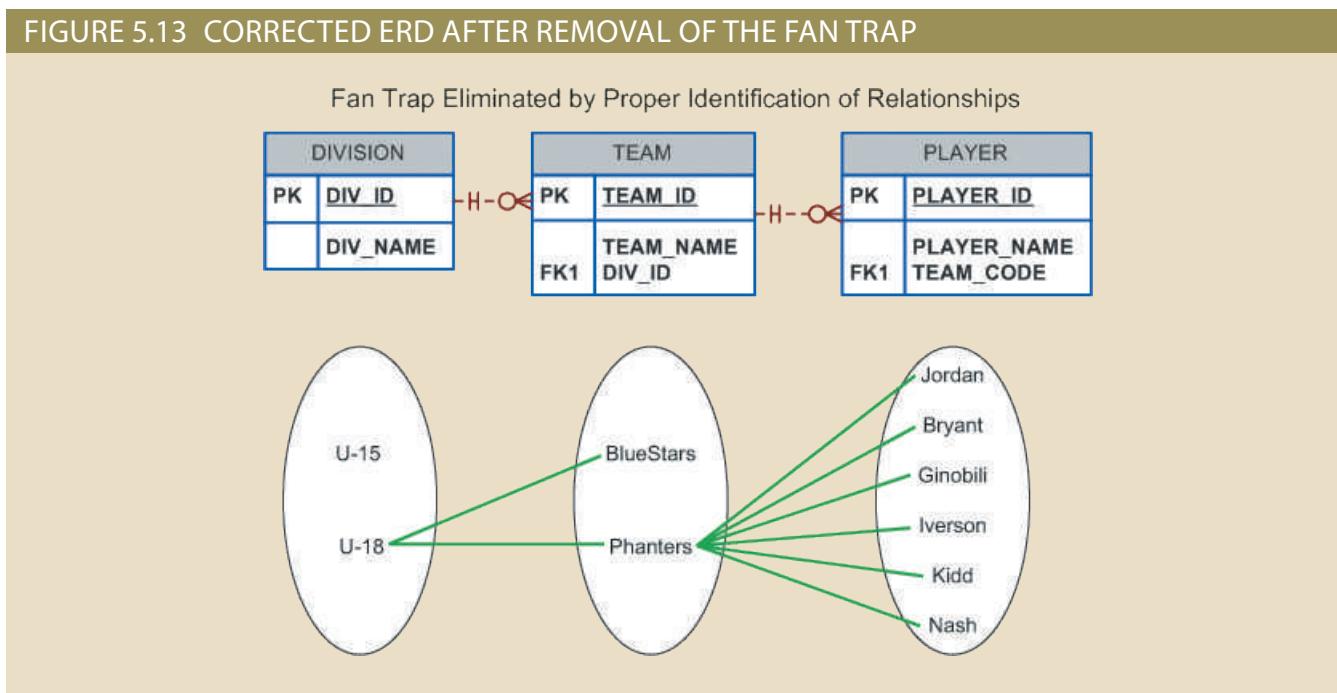
design trap

A problem that occurs when a relationship is improperly or incompletely identified and therefore is represented in a way that is not consistent with the real world. The most common design trap is known as a *fan trap*.

fan trap

A design trap that occurs when one entity is in two 1:M relationships with other entities, thus producing an association among the other entities that is not expressed in the model.

FIGURE 5.13 CORRECTED ERD AFTER REMOVAL OF THE FAN TRAP



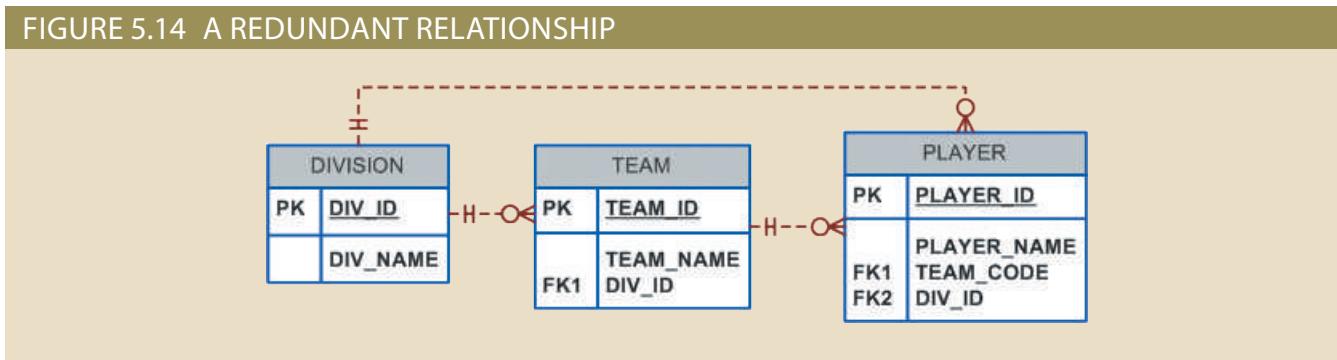
5-4d Design Case 4: Redundant Relationships

Although redundancy is often good to have in computer environments (multiple backups in multiple places, for example), redundancy is seldom good in the database environment. (As you learned in Chapter 3, The Relational Database Model, redundancies can cause data anomalies in a database.) Redundant relationships occur when there are multiple relationship paths between related entities. The main concern with redundant relationships is that they remain consistent across the model. However, it is important to note that some designs use redundant relationships as a way to simplify the design.

An example of redundant relationships was first introduced in Figure 5.10 during the discussion of maintaining a history of time-variant data. However, the use of the redundant “manages” and “employs” relationships was justified by the fact that such relationships dealt with current data rather than historic data. Another more specific example of a redundant relationship is represented in Figure 5.14.

In Figure 5.14, note the transitive 1:M relationship between DIVISION and PLAYER through the TEAM entity set. Therefore, the relationship that connects DIVISION and PLAYER is redundant, for all practical purposes. In that case, the relationship could be safely deleted without losing any information-generation capabilities in the model.

FIGURE 5.14 A REDUNDANT RELATIONSHIP



Summary

- The extended entity relationship (EER) model adds semantics to the ER model via entity supertypes, subtypes, and clusters. An entity supertype is a generic entity type that is related to one or more entity subtypes.
- A specialization hierarchy depicts the arrangement and relationships between entity supertypes and entity subtypes. Inheritance means that an entity subtype inherits the attributes and relationships of the supertype. Subtypes can be disjoint or overlapping. A subtype discriminator is used to determine to which entity subtype the supertype occurrence is related. The subtypes can exhibit partial or total completeness. There are basically two approaches to developing a specialization hierarchy of entity supertypes and subtypes: specialization and generalization.
- An entity cluster is a “virtual” entity type used to represent multiple entities and relationships in the ERD. An entity cluster is formed by combining multiple interrelated entities and relationships into a single, abstract entity object.
- Natural keys are identifiers that exist in the real world. Natural keys sometimes make good primary keys, but not always. Primary keys must have unique values, they should be nonintelligent, they must not change over time, and they are preferably numeric and composed of a single attribute.
- Composite keys are useful to represent M:N relationships and weak (strong identifying) entities.
- Surrogate primary keys are useful when there is no natural key that makes a suitable primary key, when the primary key is a composite primary key with multiple data types, or when the primary key is too long to be usable.
- In a 1:1 relationship, place the PK of the mandatory entity as a foreign key in the optional entity, as an FK in the entity that causes the fewest nulls, or as an FK where the role is played.
- Time-variant data refers to data whose values change over time and require that you keep a history of data changes. To maintain the history of time-variant data, you must create an entity that contains the new value, the date of change, and any other time-relevant data. This entity maintains a 1:M relationship with the entity for which the history is to be maintained.
- A fan trap occurs when you have one entity in two 1:M relationships to other entities, and there is an association among the other entities that is not expressed in the model. Redundant relationships occur when there are multiple relationship paths between related entities. The main concern with redundant relationships is that they remain consistent across the model.

Key Terms

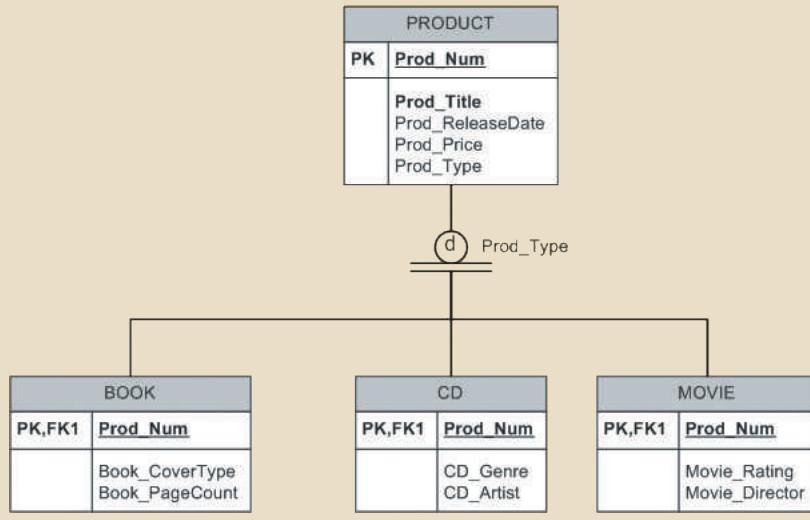
completeness constraint	extended entity relationship model (EERM)	partial completeness
design trap		specialization
disjoint subtype	fan trap	specialization hierarchy
EER diagram (EERD)	generalization	subtype discriminator
entity cluster	inheritance	
entity subtype	natural key (natural identifier)	surrogate key
entity supertype	nonoverlapping subtype	time-variant data
	overlapping subtype	total completeness

Review Questions

1. What is an entity supertype, and why is it used?
2. What kinds of data would you store in an entity subtype?
3. What is a specialization hierarchy?
4. What is a subtype discriminator? Give an example of its use.
5. What is an overlapping subtype? Give an example.
6. What is a disjoint subtype? Give an example.
7. What is the difference between partial completeness and total completeness?

For Questions 8–10, refer to Figure Q5.8.

FIGURE Q5.8 THE PRODUCT DATA MODEL



8. List all of the attributes of a movie.
9. According to the data model, is it required that every entity instance in the PRODUCT table be associated with an entity instance in the CD table? Why, or why not?
10. Is it possible for a book to appear in the BOOK table without appearing in the PRODUCT table? Why, or why not?
11. What is an entity cluster, and what advantages are derived from its use?
12. What primary key characteristics are considered desirable? Explain *why* each characteristic is considered desirable.
13. Under what circumstances are composite primary keys appropriate?
14. What is a surrogate primary key, and when would you use one?
15. When implementing a 1:1 relationship, where should you place the foreign key if one side is mandatory and one side is optional? Should the foreign key be mandatory or optional?

16. What is time-variant data, and how would you deal with such data from a database design point of view?
17. What is the most common design trap, and how does it occur?

Problems



1. Given the following business scenario, create a Crow's Foot ERD using a specialization hierarchy if appropriate. Two-Bit Drilling Company keeps information on employees and their insurance dependents. Each employee has an employee number, name, date of hire, and title. If an employee is an inspector, then the date of certification and certification renewal date should also be recorded in the system. For all employees, the Social Security number and dependent names should be kept. All dependents must be associated with one and only one employee. Some employees will not have dependents, while others will have many dependents.
2. Given the following business scenario, create a Crow's Foot ERD using a specialization hierarchy if appropriate. Tiny Hospital keeps information on patients and hospital rooms. The system assigns each patient a patient ID number. In addition, the patient's name and date of birth are recorded. Some patients are resident patients who spend at least one night in the hospital, and others are outpatients who are treated and released. Resident patients are assigned to a room. Each room is identified by a room number. The system also stores the room type (private or semiprivate) and room fee. Over time, each room will have many patients. Each resident patient will stay in only one room. Every room must have had a patient, and every resident patient must have a room.
3. Given the following business scenario, create a Crow's Foot ERD using a specialization hierarchy if appropriate. Granite Sales Company keeps information on employees and the departments in which they work. For each department, the department name, internal mail box number, and office phone extension are kept. A department can have many assigned employees, and each employee is assigned to only one department. Employees can be salaried, hourly, or work on contract. All employees are assigned an employee number, which is kept along with the employee's name and address. For hourly employees, hourly wages and target weekly work hours are stored; for example, the company may target 40 hours/week for some employees, 32 for others, and 20 for others. Some salaried employees are salespeople who can earn a commission in addition to their base salary. For all salaried employees, the yearly salary amount is recorded in the system. For salespeople, their commission percentage on sales and commission percentage on profit are stored in the system. For example, John is a salesperson with a base salary of \$50,000 per year plus a 2 percent commission on the sales price for all sales he makes, plus another 5 percent of the profit on each of those sales. For contract employees, the beginning date and end date of their contracts are stored along with the billing rate for their hours.
4. In Chapter 4, you saw the creation of the Tiny College database design, which reflected such business rules as "a professor may advise many students" and "a professor may chair one department." Modify the design shown in Figure 4.35 to include these business rules:
 - An employee could be staff, a professor, or an administrator.
 - A professor may also be an administrator.

- Staff employees have a work-level classification, such as Level I or Level II.
- Only professors can chair a department. A department is chaired by only one professor.
- Only professors can serve as the dean of a college. Each of the university's colleges is served by one dean.
- A professor can teach many classes.
- Administrators have a position title.

Given that information, create the complete ERD that contains all primary keys, foreign keys, and main attributes.

5. Tiny College wants to keep track of the history of all its administrative appointments, including dates of appointment and dates of termination. (*Hint:* Time-variant data is at work.) The Tiny College chancellor may want to know how many deans worked in the College of Business between January 1, 1960, and January 1, 2018, or who the dean of the College of Education was in 1990. Given that information, create the complete ERD that contains all primary keys, foreign keys, and main attributes.
6. Some Tiny College staff employees are information technology (IT) personnel. Some IT personnel provide technology support for academic programs, some provide technology infrastructure support, and some provide support for both. IT personnel are not professors; they are required to take periodic training to retain their technical expertise. Tiny College tracks all IT personnel training by date, type, and results (completed versus not completed). Given that information, create the complete ERD that contains all primary keys, foreign keys, and main attributes.
7. The FlyRight Aircraft Maintenance (FRAM) division of the FlyRight Company (FRC) performs all maintenance for FRC's aircraft. Produce a data model segment that reflects the following business rules:
 - All mechanics are FRC employees. Not all employees are mechanics.
 - Some mechanics are specialized in engine (EN) maintenance. Others are specialized in airframe (AF) maintenance or avionics (AV) maintenance. (Avionics are the electronic components of an aircraft that are used in communication and navigation.) All mechanics take periodic refresher courses to stay current in their areas of expertise. FRC tracks all courses taken by each mechanic—date, course type, certification (Y/N), and performance.
 - FRC keeps an employment history of all mechanics. The history includes the date hired, date promoted, and date terminated.

Given those requirements, create the Crow's Foot ERD segment.

Cases



8. "Martial Arts R Us" (MARU) needs a database. MARU is a martial arts school with hundreds of students. The database must keep track of all the classes that are offered, who is assigned to teach each class, and which students attend each class. Also, it is important to track the progress of each student as they advance. Create a complete Crow's Foot ERD for these requirements:
 - Students are given a student number when they join the school. The number is stored along with their name, date of birth, and the date they joined the school.

- All instructors are also students, but clearly not all students are instructors. In addition to the normal student information, for all instructors, the date that they start working as an instructor must be recorded along with their instructor status (compensated or volunteer).
 - An instructor may be assigned to teach any number of classes, but each class has one and only one assigned instructor. Some instructors, especially volunteer instructors, may not be assigned to any class.
 - A class is offered for a specific level at a specific time, day of the week, and location. For example, one class taught on Mondays at 5:00 p.m. in Room 1 is an intermediate-level class. Another class taught on Mondays at 6:00 p.m. in Room 1 is a beginner-level class. A third class taught on Tuesdays at 5:00 p.m. in Room 2 is an advanced-level class.
 - Students may attend any class of the appropriate level during each week, so there is no expectation that any particular student will attend any particular class session. Therefore, the attendance of students at each individual class meeting must be tracked.
 - A student will attend many different class meetings, and each class meeting is normally attended by many students. Some class meetings may not be attended by any students. New students may not have attended any class meetings yet.
 - At any given meeting of a class, instructors other than the assigned instructor may show up to help. Therefore, a given class meeting may have a head instructor and many assistant instructors, but it will always have at least the one instructor who is assigned to that class. For each class meeting, the date of the class and the instructors' roles (head instructor or assistant instructor) need to be recorded. For example, Mr. Jones is assigned to teach the Monday, 5:00 p.m., intermediate class in Room 1. During a particular meeting of that class, Mr. Jones was the head instructor and Ms. Chen served as an assistant instructor.
 - Each student holds a rank in the martial arts. The rank name, belt color, and rank requirements are stored. Most ranks have numerous rank requirements, but each requirement is associated with only one particular rank. All ranks except white belt have at least one requirement.
 - A given rank may be held by many students. While it is customary to think of a student as having a single rank, it is necessary to track each student's progress through the ranks. Therefore, every rank that a student attains is kept in the system. New students joining the school are automatically given the rank of white belt. The date that a student is awarded each rank should be kept in the system. All ranks have at least one student who has achieved that rank at some time.
9. The *Journal of E-commerce Research Knowledge* is a prestigious information systems research journal. It uses a peer-review process to select manuscripts for publication. Only about 10 percent of the manuscripts submitted to the journal are accepted for publication. A new issue of the journal is published each quarter. Create a complete ERD to support the business needs described below.
- Unsolicited manuscripts are submitted by authors. When a manuscript is received, the editor assigns it a number and records some basic information about it in the system, including the title of the manuscript, the date it was received, and a manuscript status of "received." Information about the author(s) is also recorded, including each author's name, mailing address, email address, and affiliation (the author's school or company). Every manuscript must have an author. Only authors who have submitted manuscripts are kept in the system.

It is typical for a manuscript to have several authors. A single author may have submitted many different manuscripts to the journal. Additionally, when a manuscript has multiple authors, it is important to record the order in which the authors are listed in the manuscript credits.

- At his or her earliest convenience, the editor will briefly review the topic of the manuscript to ensure that its contents fall within the scope of the journal. If the content is not appropriate for the journal, the manuscript's status is changed to "rejected," and the author is notified via email. If the content is within the scope of the journal, then the editor selects three or more reviewers to review the manuscript. Reviewers work for other companies or universities and read manuscripts to ensure their scientific validity. For each reviewer, the system records a reviewer number, name, email address, affiliation, and areas of interest. Areas of interest are predefined areas of expertise that the reviewer has specified. An area of interest is identified by an IS code and includes a description (e.g., IS2003 is the code for "database modeling"). A reviewer can have many areas of interest, and an area of interest can be associated with many reviewers. All reviewers must specify at least one area of interest. It is unusual, but possible, to have an area of interest for which the journal has no reviewers. The editor will change the status of the manuscript to "under review" and record which reviewers received the manuscript and the date it was sent to each reviewer. A reviewer will typically receive several manuscripts to review each year, although new reviewers may not have received any manuscripts yet.
 - The reviewers will read the manuscript at their earliest convenience and provide feedback to the editor. The feedback from each reviewer includes rating the manuscript on a 10-point scale for appropriateness, clarity, methodology, and contribution to the field, as well as a recommendation for publication (accept or reject). The editor will record all of this information in the system for each review received, along with the date the feedback was received. Once all of the reviewers have provided their evaluations, the editor will decide whether to publish the manuscript and change its status to "accepted" or "rejected." If the manuscript will be published, the date of acceptance is recorded.
 - Once a manuscript has been accepted for publication, it must be scheduled. For each issue of the journal, the publication period (fall, winter, spring, or summer), publication year, volume, and number are recorded. An issue will contain many manuscripts, although the issue may be created in the system before it is known which manuscripts will be published in that issue. An accepted manuscript appears in only one issue of the journal. Each manuscript goes through a typesetting process that formats the content, including fonts, font size, line spacing, justification, and so on. Once the manuscript has been typeset, its number of pages is recorded in the system. The editor will then decide which issue each accepted manuscript will appear in and the order of manuscripts within each issue. The order and the beginning page number for each manuscript must be stored in the system. Once the manuscript has been scheduled for an issue, the status of the manuscript is changed to "scheduled." Once an issue is published, the print date for the issue is recorded, and the status of each manuscript in that issue is changed to "published."
10. Global Unified Technology Sales (GUTS) is moving toward a "bring your own device" (BYOD) model for employee computing. Employees can use traditional

desktop computers in their offices. They can also use a variety of personal mobile computing devices such as tablets, smartphones, and laptops. The new computing model introduces some security risks that GUTS is attempting to address. The company wants to ensure that any devices connecting to their servers are properly registered and approved by the Information Technology department. Create a complete ERD to support the business needs described below:

- Every employee works for a department that has a department code, name, mail box number, and phone number. The smallest department currently has 5 employees, and the largest department has 40 employees. This system will only track in which department an employee is currently employed. Very rarely, a new department can be created within the company. At such times, the department may exist temporarily without any employees. For every employee, an employee number and name (first, last, and middle initial) are recorded in the system. It is also necessary to keep each employee's title.
- An employee can have many devices registered in the system. Each device is assigned an identification number when it is registered. Most employees have at least one device, but newly hired employees might not have any devices registered initially. For each device, the brand and model need to be recorded. Only devices that are registered to an employee will be in the system. While unlikely, it is possible that a device could transfer from one employee to another. However, if that happens, only the employee who currently owns the device is tracked in the system. When a device is registered in the system, the date of that registration needs to be recorded.
- Devices can be either desktop systems that reside in a company office or mobile devices. Desktop devices are typically provided by the company and are intended to be a permanent part of the company network. As such, each desktop device is assigned a static IP address, and the MAC address for the computer hardware is kept in the system. A desktop device is kept in a static location (building name and office number). This location should also be kept in the system so that, if the device becomes compromised, the IT department can dispatch someone to remediate the problem.
- For mobile devices, it is important to also capture the device's serial number, which operating system (OS) it is using, and the version of the OS. The IT department is also verifying that each mobile device has a screen lock enabled and has encryption enabled for data. The system should support storing information on whether or not each mobile device has these capabilities enabled.
- Once a device is registered in the system, and the appropriate capabilities are enabled if it is a mobile device, the device may be approved for connections to one or more servers. Not all devices meet the requirements to be approved at first, so the device might be in the system for a period of time before it is approved to connect to any server. GUTS has a number of servers, and a device must be approved for each server individually. Therefore, it is possible for a single device to be approved for several servers but not for all servers.
- Each server has a name, brand, and IP address. Within the IT department's facilities are a number of climate-controlled server rooms where the physical servers can be located. Which room each server is in should also be recorded. Further, it is necessary to track which operating system is being used on each server.

Some servers are virtual servers and some are physical servers. If a server is a virtual server, then the system should track which physical server it is running on. A single physical server can host many virtual servers, but each virtual server is hosted on only one physical server. Only physical servers can host a virtual server. In other words, one virtual server cannot host another virtual server. Not all physical servers host a virtual server.

- A server will normally have many devices that are approved to access the server, but it is possible for new servers to be created that do not yet have any approved devices. When a device is approved for connection to a server, the date of that approval should be recorded. It is also possible for a device that was approved for a server to lose its approval. If that happens, the date that the approval was removed should be recorded. If a device loses its approval, it may regain that approval at a later date if whatever circumstance that lead to the removal is resolved.
 - A server can provide many user services, such as email, chat, homework managers, and others. Each service on a server has a unique identification number and name. The date that GUTS began offering that service should be recorded. Each service runs on only one server although new servers might not offer any services initially. Client-side services are not tracked in this system, so every service must be associated with a server.
 - Employees must get permission to access a service before they can use it. Most employees have permissions to use a wide array of services, but new employees might not have permission on any service. Each service can support multiple approved employees as users, but new services might not have any approved users at first. The date on which the employee is approved to use a service is tracked by the system. The first time an employee is approved to access a service, the employee must create a username and password. This will be the same username and password that the employee will use for every service for which the employee is eventually approved.
11. Global Computer Solutions (GCS) is an information technology consulting company with many offices throughout the United States. The company's success is based on its ability to maximize its resources—that is, its ability to match highly skilled employees with projects according to region. To better manage its projects, GCS has contacted you to design a database, so GCS managers can keep track of their customers, employees, projects, project schedules, assignments, and invoices.

The GCS database must support all of GCS's operations and information requirements. A basic description of the main entities follows:

- The *employees* of GCS must have an employee ID, a last name, a middle initial, a first name, a region, and a date of hire recorded in the system.
- Valid *regions* are as follows: Northwest (NW), Southwest (SW), Midwest North (MN), Midwest South (MS), Northeast (NE), and Southeast (SE).
- Each employee has many skills, and many employees have the same skill.
- Each *skill* has a skill ID, description, and rate of pay. Valid skills are as follows: Data Entry I, Data Entry II, Systems Analyst I, Systems Analyst II, Database Designer I, Database Designer II, Java I, Java II, C++ I, C++ II, Python I, Python II, ColdFusion I, ColdFusion II, ASP I, ASP II, Oracle DBA, MS SQL Server

TABLE P5.11A

SKILL	EMPLOYEE
Data Entry I	Seaton Amy; Williams Josh; Underwood Trish
Data Entry II	Williams Josh; Seaton Amy
Systems Analyst I	Craig Brett; Sewell Beth; Robbins Erin; Bush Emily; Zebras Steve
Systems Analyst II	Chandler Joseph; Burklow Shane; Robbins Erin
DB Designer I	Yarbrough Peter; Smith Mary
DB Designer II	Yarbrough Peter; Pascoe Jonathan
Java I	Kattan Chris; Ephenor Victor; Summers Anna; Ellis Maria
Java II	Kattan Chris; Ephenor Victor; Batts Melissa
C++ I	Smith Jose; Rogers Adam; Cope Leslie
C++ II	Rogers Adam; Bible Hanah
Python I	Zebras Steve; Ellis Maria
Python II	Zebras Steve; Newton Christopher
ColdFusion I	Duarte Miriam; Bush Emily
ColdFusion II	Bush Emily; Newton Christopher
ASP I	Duarte Miriam; Bush Emily
ASP II	Duarte Miriam; Newton Christopher
Oracle DBA	Smith Jose; Pascoe Jonathan
SQL Server DBA	Yarbrough Peter; Smith Jose
Network Engineer I	Bush Emily; Smith Mary
Network Engineer II	Bush Emily; Smith Mary
Web Administrator	Bush Emily; Smith Mary; Newton Christopher
Technical Writer	Kilby Surgena; Bender Larry
Project Manager	Paine Brad; Mudd Roger; Kenyon Tiffany; Connor Sean

DBA, Network Engineer I, Network Engineer II, Web Administrator, Technical Writer, and Project Manager. Table P5.11a shows an example of the Skills Inventory.

- GCS has many *customers*. Each customer has a customer ID, name, phone number, and region.
- GCS works by *projects*. A project is based on a contract between the customer and GCS to design, develop, and implement a computerized solution. Each project has specific characteristics such as the project ID, the customer to which the project belongs, a brief description, a project date (the date the contract was signed), an estimated project start date and end date, an estimated project budget, an actual start date, an actual end date, an actual cost, and one employee assigned as the manager of the project.
- The actual cost of the project is updated each Friday by adding that week's cost to the actual cost. The week's cost is computed by multiplying the hours each employee worked by the rate of pay for that skill.
- The employee who is the manager of the project must complete a *project schedule*, which effectively is a design and development plan. In the project schedule (or plan), the manager must determine the tasks that will be performed to take the project from beginning to end. Each task has a task ID, a brief task description, starting and ending dates, the types of skills needed, and the number of employees (with the required skills) needed to complete the task. General tasks are the initial interview, database and system design, implementation, coding, testing, and final evaluation and sign-off. For example, GCS might have the project schedule shown in Table P5.11b.

TABLE P5.11B

PROJECT ID: 1		DESCRIPTION: SALES MANAGEMENT SYSTEM		
COMPANY: SEE ROCKS		CONTRACT DATE: 2/12/2018		REGION: NW
START DATE: 3/1/2018		END DATE: 7/1/2018		BUDGET: \$15,500
START DATE	END DATE	TASK DESCRIPTION	SKILL(S) REQUIRED	QUANTITY REQUIRED
3/1/18	3/6/18	Initial interview	Project Manager Systems Analyst II DB Designer I	1 1 1
3/11/18	3/15/18	Database design	DB Designer I	1
3/11/18	4/12/18	System design	Systems Analyst II Systems Analyst I	1 2
3/18/18	3/22/18	Database implementation	Oracle DBA	1
3/25/18	5/20/18	System coding and testing	Java I Java II Oracle DBA	2 1 1
3/25/18	6/7/18	System documentation	Technical Writer	1
6/10/18	6/14/18	Final evaluation	Project Manager Systems Analyst II DB Designer I Java II	1 1 1 1
6/17/18	6/21/18	On-site system online and data loading	Project Manager Systems Analyst II DB Designer I Java II	1 1 1 1
7/1/18	7/1/18	Sign-off	Project Manager	1

- GCS pools all of its employees by region; from this pool, employees are assigned to a specific task scheduled by the project manager. For example, in the first project's schedule, you know that a Systems Analyst II, Database Designer I, and Project Manager are needed for the period from 3/1/18 to 3/6/18. The project manager is assigned when the project is created and remains for the duration of the project. Using that information, GCS searches the employees who are located in the same region as the customer, matches the skills required, and assigns the employees to the project task.
- Each project schedule task can have many employees assigned to it, and a given employee can work on multiple project tasks. However, an employee can work on only one project task at a time. For example, if an employee is already assigned to work on a project task from 2/20/18 to 3/3/18, the employee cannot work on another task until the current assignment is closed (ends). The date that an assignment is closed does not necessarily match the ending date of the project schedule task because a task can be completed ahead of or behind schedule.
- Given all of the preceding information, you can see that the assignment associates an employee with a project task, using the project schedule. Therefore, to keep track of the *assignment*, you require at least the following information: assignment ID, employee, project schedule task, assignment start date, and assignment end date. The end date could be any date, as some projects run ahead of or behind schedule. Table P5.11c shows a sample assignment form.

TABLE P5.11C

PROJECT ID: 1 COMPANY: SEE ROCKS		DESCRIPTION: SALES MANAGEMENT SYSTEM CONTRACT DATE: 2/12/2018			AS OF: 03/29/18		
SCHEDULED				ACTUAL ASSIGNMENTS			
PROJECT TASK	START DATE	END DATE	SKILL	EMPLOYEE	START DATE	END DATE	
Initial interview	3/1/18	3/6/18	Project Mgr. Sys. Analyst II DB Designer I	101-Connor S. 102-Burklow S. 103-Smith M.	3/1/18 3/1/18 3/1/18	3/6/18 3/6/18 3/6/18	
Database design	3/11/18	3/15/18	DB Designer I	104-Smith M.	3/11/18	3/14/18	
System design	3/11/18	4/12/18	Sys. Analyst II Sys. Analyst I Sys. Analyst I	105-Burklow S. 106-Bush E. 107-Zebras S.	3/11/18 3/11/18 3/11/18		
Database implementation	3/18/18	3/22/18	Oracle DBA	108-Smith J.	3/15/18	3/19/18	
System coding and testing	3/25/18	5/20/18	Java I Java I Java II Oracle DBA	109-Summers A. 110-Ellis M. 111-Ephanor V. 112-Smith J.	3/21/18 3/21/18 3/21/18 3/21/18		
System documentation	3/25/18	6/7/18	Tech. Writer	113-Kilby S.	3/25/18		
Final evaluation	6/10/18	6/14/18	Project Mgr. Sys. Analyst II DB Designer I Java II				
On-site system online and data loading	6/17/18	6/21/18	Project Mgr. Sys. Analyst II DB Designer I Java II				
Sign-off	7/1/18	7/1/18	Project Mgr.				

(Note: The assignment number is shown as a prefix of the employee name—for example, 101 or 102.) Assume that the assignments shown previously are the only ones as of the date of this design. The assignment number can be any number that matches your database design.

- Employee work hours are kept in a *work log*, which contains a record of the actual hours worked by employees on a given assignment. The work log is a form that the employee fills out at the end of each week (Friday) or at the end of each month. The form contains the date, which is either the current Friday of the month or the last workday of the month if it does not fall on a Friday. The form also contains the assignment ID, the total hours worked either that week or up to the end of the month, and the bill number to which the work-log entry is charged. Obviously, each work-log entry can be related to only one bill. A sample list of the current work-log entries for the first sample project is shown in Table P5.11d.
- Finally, every 15 days, a *bill* is written and sent to the customer for the total hours worked on the project during that period. When GCS generates a bill, it uses the bill number to update the work-log entries that are part of the bill. In summary, a bill can refer to many work-log entries, and each work-log entry can be related to only

TABLE P5.11D

EMPLOYEE NAME	WEEK ENDING	ASSIGNMENT NUMBER	HOURS WORKED	BILL NUMBER
Burklow S.	3/1/18	1-102	4	xxx
Connor S.	3/1/18	1-101	4	xxx
Smith M.	3/1/18	1-103	4	xxx
Burklow S.	3/8/18	1-102	24	xxx
Connor S.	3/8/18	1-101	24	xxx
Smith M.	3/8/18	1-103	24	xxx
Burklow S.	3/15/18	1-105	40	xxx
Bush E.	3/15/18	1-106	40	xxx
Smith J.	3/15/18	1-108	6	xxx
Smith M.	3/15/18	1-104	32	xxx
Zebras S.	3/15/18	1-107	35	xxx
Burklow S.	3/22/18	1-105	40	
Bush E.	3/22/18	1-106	40	
Ellis M.	3/22/18	1-110	12	
Ephanor V.	3/22/18	1-111	12	
Smith J.	3/22/18	1-108	12	
Smith J.	3/22/18	1-112	12	
Summers A.	3/22/18	1-109	12	
Zebras S.	3/22/18	1-107	35	
Burklow S.	3/29/18	1-105	40	
Bush E.	3/29/18	1-106	40	
Ellis M.	3/29/18	1-110	35	
Ephanor V.	3/29/18	1-111	35	
Kilby S.	3/29/18	1-113	40	
Smith J.	3/29/18	1-112	35	
Summers A.	3/29/18	1-109	35	
Zebras S.	3/29/18	1-107	35	

Note: xxx represents the bill ID. Use the one that matches the bill number in your database.

one bill. GCS sent one bill on 3/15/18 for the first project (SEE ROCKS), totaling the hours worked between 3/1/18 and 3/15/18. Therefore, you can safely assume that there is only one bill in this table and that the bill covers the work-log entries shown in the preceding form.

Your assignment is to create a database that fulfills the operations described in this problem. The minimum required entities are employee, skill, customer, region, project, project schedule, assignment, work log, and bill. (There are additional required entities that are not listed.)

- Create all of the required tables and required relationships.
- Create the required indexes to maintain entity integrity when using surrogate primary keys.
- Populate the tables as needed, as indicated in the sample data and forms.