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SCHAUM'S OUTLINE OF

Fundamentals of Relational Databases

RAMON A. MATA-TOLEDO, Ph.D.

Associate Professor of Computer Science
James Madison University

PAULINE K. CUSHMAN, Ph.D.

Associate Professor of Integrated Science and Technology
and Computer Science
James Madison University

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DEDICATION

Dedicated to the memory of my father, Miguel Jesus Mata, the memory of my uncle Alberto Jose Gomez and to the glory and praise of my heavenly Father, the Light of the World for the continuous blessing that He offers me through the love and dedication of my wife Anahis and my children Harold, Lys, and Hayley. I dedicate this book to all of them with my deepest love and affection. Last but not least, I dedicate this work to my mother Mami Nina, my aunt Lys Violeta Mata de Gomez, and my sister Carmen Elena for their love, prayers, and support throughout the years.

RAMT

Relational databases for all my relations. For my parents who are gone now, but always emphasized the importance of *relations*. For my extended family *entities*, my siblings, Theo, Marj, Low, and Beth, along with their assorted spouses, children, and grandchildren. For my children and their spouses, Chuck, Jeni, Matt, Cindy, and Kerry, and my granddaughters Grace and Natalie; they all have great *attributes*. And for my favorite relation, my husband Jim. Our life has been both *integrated* and *shared*.

PKC

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PREFACE

This book was written for anyone who wants a general introduction to relational databases that is both theoretical and practical. Relational databases are the most popular database management systems in the world and are supported by a variety of vendor implementations. Some examples are provided using the RDBMS from Oracle and Microsoft Access.

SQL is the standard computer language used to communicate with relational database management systems, so Chapter 3 provides a brief introduction to SQL. For a more complete explanation of programming in SQL, see the companion book *Schaum's Outline Fundamentals of SQL Programming* by the same authors.

We would like to thank the personnel at McGraw-Hill for their help and support, particularly our sponsor editor Barbara Gilson and editing liaison Maureen Walker. We hope that this book provides a good introduction to relational databases.

RAMON A. MATA-TOLEDO
PAULINE K. CUSHMAN

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CHAPTER 1

An Overview of DBMS and DB Systems Architechture

1.1 Introduction to Database Management Systems

A *Database Management System* (DBMS) is the software system that allows users to define, create and maintain a database and provides controlled access to the data. A database is a logically coherent collection of data with some inherent meaning. The term *database* is often used to refer to the data itself; however, there are other additional components that also form part of a complete database management system. Figure 1-1 shows that a complete DBMS usually consists of hardware, software including utilities, data, users and procedures. These items will be explained in the following paragraphs.

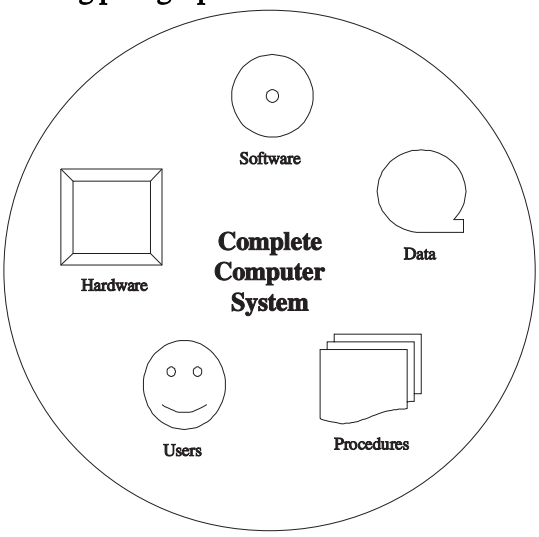

Fig. 1-1. Complete computer system.

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The *hardware* is the actual computer system used for keeping and accessing the database. In large organizations, the hardware for such a system typically consists of a network with a central server and many client programs running on desktops. The server is the central processor where the database is physically located. The server usually has a more powerful processor because it handles the data retrieval operations and most of the actual data manipulation. The clients are the programs that interact with the RDBM and run on the personal desktops at the user's end to access the database. A DBMS and its clients can also reside in a single computer. In that case there is usually only one user at a time accessing the database, either a single user or a single personal database management system accessed by several users at different times. The actual configuration of the network varies from organization to organization. Specific hardware issues will not be addressed in this book.

The *software* is the actual DBMS. In a client/server network, the DBMS allows for data handling programs residing on the server and client programs on each desktop. In a single-user system usually only one piece of software handles everything. The DBMS allows the users to communicate with the database. In a sense, it is the mediator between the database and the users. Each client station or each individual user can be given different levels of access to the data. Some will be allowed to change portions of the database structure, some can change the existing data, and others will only be allowed to view the data. The DBMS controls access and helps maintain the consistency of the data. Utilities are usually included as part of the DBMS. Some of the most common utilities are report writers, application development tools and other design aids. Examples of DBMS software include Microsoft Access™, Oracle Corporation Personal Oracle™, and IBM DB2™. The typical arrangement of all the software modules and how they interact in a DBMS will be explained at the end of this chapter.

The database should contain all the *data* needed by the organization. One of the major features of databases is that the actual data are separated from the programs that use the data. The set of facts represented in a database is called the *Universe of Discourse* (UOD). The UOD should only include facts that form a logically coherent collection and that are relevant to its users. For this reason, a database should always be designed, built and populated for a particular audience and for a specific purpose. Probably as part of the UOD discussion, it is important to point out that only a partial view of the real world can be captured by a DBMS. Emphasis is on the relevant data pertaining to one or more objects, or *entities*. We will define an entity as the thing of significance about which information needs to be known. The characteristics that describe or qualify an entity are called *attributes* of the entity. For instance, in a student database, the basic entity is the student. Information recorded about that entity might be first and last name, major, grade point average, home address, current address, date of birth, and class level. These are the attributes of the student entity. The system would not be interested in the type of clothes, the number of friends, the movies the student attends, and so on. That is, this information is not relevant to the user and should not be part of the UOD. More explanation concerning data will be given in the next section.

Also, for each attribute, the set of possible values that the attribute can take is called the *domain* of the attribute. The domain of the date of birth would be all the dates that might be reasonable in the student body; none in the 1700s would be expected. Undergraduate class levels would probably be restricted to Freshman, Sophomore, Junior, and Senior. No other values would be allowed for that attribute.

There are a number of *users* who can access or retrieve data on demand using the applications and interfaces provided by the DBMS. Each type of user needs different software capabilities.

- The *database administrator* (DBA) is the person or group in charge of implementing the database system within the organization. The DBA has all the system privileges allowed by the DBMS and can assign (grant) and remove (revoke) levels of access (privileges) to and from other users.
- The *end users* are the people who sit at workstations and interact directly with the system. They may need to respond to requests from people outside the organization, to find answers quickly to questions from higher-level management, or to generate periodic reports. In some cases the end users should be allowed to change data within the system, for example addresses or order information. Other end users, such as those at a help desk, would only need privileges to view the data, not to change it.
- The *application programmers* interact with the database in a different manner. They access the data from programs written in high-level languages such as Visual Basic or C++. The application programmers design systems such as payroll, inventory, and billing that normally need to access and change the data.

An integral part of any system is the set of *procedures* that control the behavior of the system, that is, the actual practices the users follow to obtain, enter, maintain, and retrieve the data. For example, in a payroll system, how are the hours worked received by the clerk and entered into the system? Exactly when are monthly reports generated and to whom are they sent? These procedures are often formalized so that users at any level know exactly what to do and how to do the assigned task. In many organizations, if some employees have been there for a long time they may know exactly what to do and when. However, it is important to have procedures clearly articulated and written on record so that the system would not be jeopardized if new employees needed to use the system. Part of the job of the DBA is to verify that all procedures related to the complete system are clearly delineated.

Example 1.1

Indicate which type of user would perform the following functions for a payroll system in a large company: (a) Write an application program to generate and print the checks, (b) change the address in the database for an employee who has moved, (c) create a new user account for a newly hired payroll clerk.

a. Write an application program to generate and print the checks.

An application programmer or a team of programmers would design and implement such an application program.

b. Change the address in the database for an employee who has moved.

An end user might take the information from the employee over the phone and directly access the database to change it. However, changing such information from phone conversations may result in incorrect data because of typographical error or misunderstanding. In order to verify that updates are made correctly, the procedures in many organizations require that database changes be submitted in writing.

c. Create a new user ID for the newly hired payroll clerk.

The DBA or the DBA assistant working under the supervision of the DBA would be the person to create new user IDs. In a small organization, there might be only one person who does all administration of the system. In larger organizations, DBA assistants on the database administration team would be assigned different jobs. One person might handle all user accounts and another might be in charge of database maintenance.

1.1.1 DATA

The data are the heart of the DBMS. There are two kinds of data. First, and most obvious, is the collection of information needed by the organization. The second kind of data, or *metadata*, is information about the database. This information is usually kept in a *data dictionary* or *catalog*. The data dictionary includes information about users, privileges and the internal structure of the database. Careful management of all the data is essential in order that information can be trusted to be up to date and accurate. All levels of users need to have a firm understanding of the database and how it is structured. It is helpful to examine the database from several different perspectives. The system may be multi-user or single-user; the data are usually both integrated and shared; and the database may be centralized or distributed.

First, the configuration of the hardware and the size of the organization will determine whether it is a *multi-user system* or a *single-user system*. In a single-user system, the database resides on one computer and is only accessed by one user at a time. This one user may design, maintain, and write programs for the system, performing all the user roles. On the other hand, someone else, often a consultant, may have been hired to design the system. In this case, the single user may only perform the role of end user and the data may always be accessed interactively through the DBMS without using application programs.

Because of the large amount of data managed even by small organizations, most systems are multi-user. In this situation, the data are both *integrated* and

shared. A database is integrated when the same information is not recorded in two places. For example, both the billing department and the shipping department may need customer addresses. Even though both departments may access different portions of the database, the customers' addresses should only reside in one place. It is the job of the DBA to make sure that the DBMS makes the correct addresses available from one central storage area.

Likewise, the individual pieces of data are shared by both departments. The DBMS must assure that the two users are not changing different portions of the data at the same time. If this happens, the data may not remain accurate. Also, users who share data do not need the same level of access. The shipping department may only need to examine the customer's address for shipping purposes and should have no need to examine the customer's payment history. The billing department needs to be able both to examine the current balance and to change the balance when a payment is made. These permissions are called *privileges* and, as indicated before, are assigned by the DBA.

Example 1.2

Consider a database at a cable company which contains customer names, addresses, service categories (basic cable, premium channels, pay-per-view, etc.) and billing information. Indicate for each user, a billing clerk, a repair person, and a customer service representative, which items that user should be able to access and which items the user should be able to access and change.

User	Permission Level
a. Billing clerk	Should be able to access and change all data.
b. Repair person	Needs to access but not change name, address, and service information. Should not have access to any billing information.
c. Customer service representative	Needs to be able to access and change name, address, and service information. If billing questions are referred to the billing department, the customer service person has no need of any billing information.

A third issue for understanding both the data and the DBMS is whether the system is *centralized* or *distributed*. During the 1970s and 1980s most database management systems resided on large mainframes or minicomputers. The systems were centralized and *single tier*, which means the DBMS and the data reside in one location. The theory was that if data are kept in two places there is a high probability that two items which are supposed to be identical may not in fact be the same. For example, if a customer's address is stored in two separate tables for any reason, it is possible for one to be changed and the other to remain the same. Often dumb terminals were used to access the DBMS through teleprocessing.

The rise of personal computers in businesses during the 1980s, the increased reliability of networking hardware, and the advances of doing business over the Internet during the 1990s led to the newer trend of trying to maintain accuracy of data and still make use of distributed systems. Two-tier and three-tier systems became common. In a *two-tier* system, different software is required for the server and for the client. The *three-tier* system adds middleware, which provides a way for clients of one DBMS to access data from another DBMS. Fig. 1-2 illustrates the difference between single-tier, two-tier and three-tier software systems.

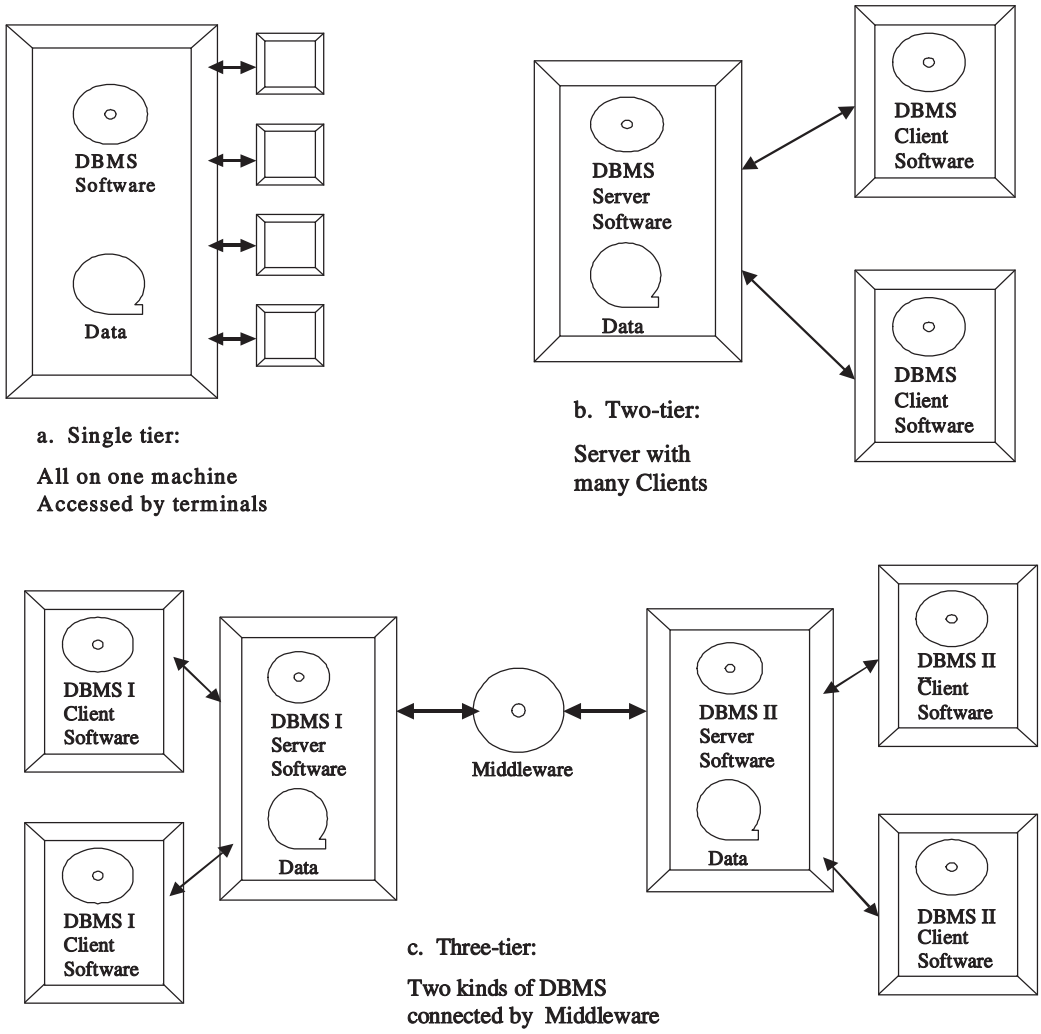


Fig. 1-2. Single-, two- and three-tier configurations.

A distributed DBMS can be implemented in several different ways. A local office network may store the customer data on one server and the supplier data on another. In both cases, the system would allow many client programs to access the data from both servers at the same time. Chapter 6 discusses the security

implications of this configuration. Another method of distribution is to store several equivalent databases in different places. The data are distributed geographically and located closest to where they will be used. However, it is critical in a distributed database that each node of the distributed system should be able to execute a global application or access files at any other node. For example, an organization with branches in several states may store a different customer list at each branch. The tables are distributed but connected, so the DBMS is able to find the information for any customer at any time from any location. The users ask for particular information and the DBMS hides the details of how it locates the requested data. This transparency is an important issue in distributed DBMS software. Remember, even though the database may be distributed, it is not the same as being decentralized. Items of data still reside in only one place and the DBMS knows where to find them. Another advantage of the distributed model is that it results in improved reliability and performance. When both data and the DBMS software are disbursed, if one system goes out, others should still be able to function, and the entire organization is not immobilized.

There are several possible arrangements for connecting the nodes of a distributed system. They may be connected in a star, a ring or a network configuration, as shown in Fig. 1-3. The star configuration is centralized and depends upon the central node for communication among all the nodes. If the central server has problems, the rest of the nodes are inaccessible. In both a ring and a network configuration, the stability of the network does not depend completely upon the stability of any one machine. Particular network issues are beyond the scope of this book.

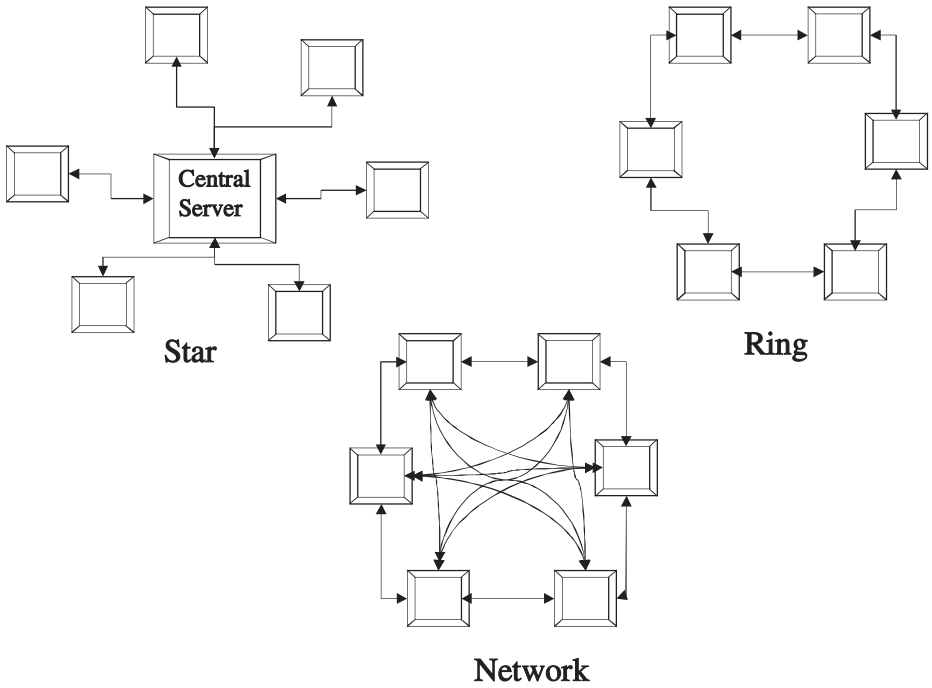


Fig. 1-3. Network configurations.

Example 1.3
Describe how a local medical group of 3 doctors with 2 separate office locations would keep their patient database if it were centralized. How could it be changed to make it a distributed system?

For a centralized system, the entire database would reside on one server at one central location. Client machines at each location would access the central database for patient information. If the central system was down, no patient information could be accessed. In a distributed system, the information for the patients usually seen in location 1 would be kept on a server in that office. Patient information for location 2 patients would be kept on a server in that office. The DBMS would access both locations to find information on any patient. If one of the servers was down, the other could still be accessed.

Example 1.4
Specify whether each system would be single-tiered, two-tiered, or three-tiered.

a. The Happy Nights motel chain allows local managers to purchase a franchise. They can install and use the DBMS of their choice for their reservation system. The only requirement is that they be able to connect and communicate with the central office's system.

b. The Sticky Wicket Company has home offices in Detroit and branches in Chicago and Baltimore. The inventory and parts database is distributed with each branch keeping its own inventory. One central DBMS located in Detroit allows instant ordering of supplies through the central office.

Since both these companies have a number of locations, the systems are obviously not single-tier. The key to the difference is whether there is one central DBMS or whether each local entity runs its own personal database system. Since example (a) allows each franchise to use a different DBMS, middleware will be required to connect these systems with the central office DBMS, resulting in a three-tier system. Because (b) uses one central DBMS with client software at each location, this would be a two-tier system.

1.1.2 WHY WE NEED DBMS

Before continuing with this introduction to DBMS concepts, it is important to specify why we need database management systems. Certainly all readers are aware of the information explosion in today's society. Personal information is stored about each of us in a variety of forms. Anyone who works in any kind of business, either a large or a small organization, knows how important it is to keep accurate records. The advantages of using a DBMS fall into three main categories.

- Proper maintenance of the data
- Providing access to data
- Maintaining security of the data

1.1.2.1 Proper Maintenance of the Data

Proper maintenance of the data will be a recurring theme throughout this book. The users must be able to trust that the data is *accurate* and *up to date*. *Inconsistency* should be avoided and *redundancy* should be minimized. Redundancy occurs when the same information is kept in a variety of places. Inconsistency comes when data are changed in one of those locations and not changed in another. Most database systems provide for *integrity constraints* that must be followed. All these concepts will be considered both explicitly and implicitly in the following chapters. The DBMS is the key to enforcing these characteristics within the database. Each DBMS may manage the data in different ways, but they all are careful to address such data issues.

Example 1.5
In a particular organization, customer names and addresses are kept in one database for the sales department and another database for the billing department. What inconsistency might result from this redundancy?

When a sales person is taking an order, the customer reports a change in address. The sales person might update the record in the sales department. However, when the bill is prepared, it is sent to the old address because the address was not changed in that database.

1.1.2.2 Providing Access to Data

As specified in the previous section, the data are usually shared by a variety of users and programs. Both storage of and access to data should be easy and quick. Concurrent support for all kinds of transactions, both interactive and programmed queries, must be provided by the DBMS. The interactive queries should not have to wait for the application programs to finish. Basically, the data should be accessible precisely when required. It would be unacceptable for the users to wait even a day while the database is updated and checked. The job of the DBMS is to allow for speedy access for all the necessary users while still using proper maintenance procedures.

Another issue surrounding access is the ability to find a particular piece of information from the large amount of data stored. The DBMS must contain flexible methods to access each item in the database while allowing for speedy searches throughout the database to find that item.

1.1.2.3 Maintaining Security of the Data

The DBA is usually the person responsible for the security of the data. Unauthorized access must be prevented, and a variety of levels of permission must be granted to users. Tools are provided for the DBA to enforce all security procedures and meet all the conflicting requirements that arise when many people must access the same database. If two separate users are accessing a

particular table at the same time, the DBMS must not allow them both to make conflicting changes. Such safeguards are part of all systems. The DBMS also provides the tools for easy backup and recovery in case of system failures. Chapter 6 explores a variety of issues surrounding data security.

Example 1.6
Make a list of all the databases you can think of where your name and financial information are kept. How can you check the accuracy of this data?

Information about you is stored by your employer, your school, possibly your religious organization, the government and any banks or credit companies. You can check the accuracy of many of these locations by asking for a credit report or current statement. Many localities have laws requiring schools and government agencies to allow you to see and correct personal information. You will never know if the information is wrong if you don't check it yourself.

It might also be helpful to specify situations when one might not want to use a DBMS. Sometimes these systems result in unnecessary costs when traditional file processing would work just as well. If only one person maintains the data and that person is not skilled in designing a database, the resulting product might also take more time and be less efficient. When you are designing a database, as with any other system, remember that a simple, clear strategy is usually more easily maintained than a complex, confusing design.

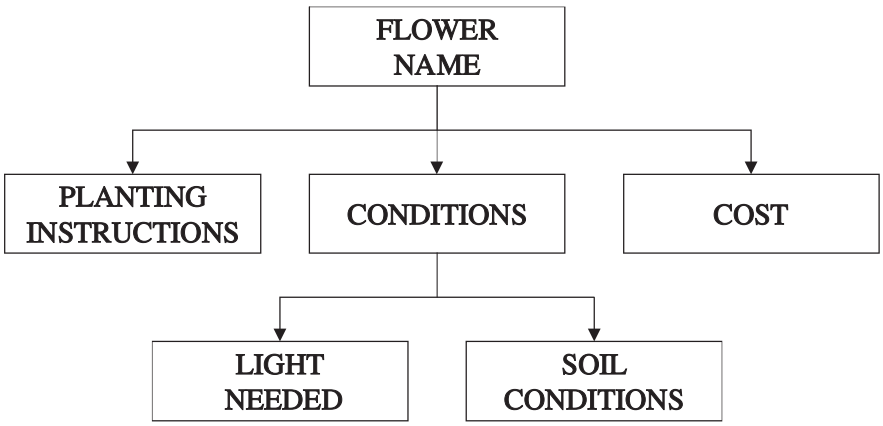
1.2 Data Models

Children build model airplanes or model cars as a way of understanding how a real airplane or car is constructed. Through understanding the models, children expect to see a car with four wheels and an airplane with two wings. Real estate developers take prospective customers on tours of a model home to show them how the house is organized and the relationship between the various rooms of the house. Homebuyers can get a good feel for the flow from kitchen to dining room to living room. Models generally allow people to conceptualize an abstract idea more easily.

A *data model* is a way of explaining the logical layout of the data and the relationship of various parts to each other and the whole. Different data models have been used throughout the years. In the early years often a *flat file* system, or a simple text file with all the data listed in some order, seemed the easiest. The application program accessed the data usually sequentially for batch processing. Not much interactive access was available. Other models used on big mainframes were the *hierarchical* and the *network* model. The hierarchical database is constructed using a tree model, with one root and several levels of subtrees. Each item has just one link leading to it. Data are accessed beginning with the root and traveling down the tree until the desired details are located. The network model contains many links among the various items of data. Interrelated indices allow access to data from a variety of directions.

In 1970, Dr. E. F. Codd described a new kind of model, the *relational* model for database systems.[1] Relational database management systems, where all data are kept in tables or relations, became the new standard. They are much more flexible and easy to use, as almost any item of data can be accessed more quickly than in the other models. Retrieval time is reduced so that interactive access becomes more feasible than in the other models. The use of related tables and views also allows the use of distributed databases that would be difficult in the hierarchical or network models. The data dictionary for the relational model contains the table names, along with column names and data types for each table. In addition, the data dictionary maintains information about all users and privileges. Relational database management systems (RDBMS) will be the model used throughout this book and are explained more fully in Chapter 2.

Example 1.7
Given this model of data for a flower company, would it be hierarchical, network or relational?



This would be a hierarchical model because, though each node can point to several other nodes, each level only has one node pointing to it from above. To find out the amount of light needed, one would need to access first the flower name and then the conditions. It would be difficult to access planting instructions for only those flowers that need to be planted in full sunlight.

Example 1.8
How would the same data be organized in a RDBMS?

In a relational database the data would be kept in a table with one row for each item as shown below. Questions regarding the values in any column are possible any time. For example, the names and planting instructions for each flower that grows in full sunlight would be easily displayed.

[1] E. F Codd, *The Relational Model of Data for Large Shared Data Banks*. This model is further explained in E. F. Codd, *The Relational Model for Database Management Version 2*, Addison-Wesley, Reading, MA, 1990.

Flower Name	Planting Instructions	Conditions	Light Needed	Soil Conditions	Cost

1.3 Database System Architecture

Understanding an abstract model of the data is important in order to describe the architecture of the database system. Recall from earlier in this chapter that one of the major features of databases is that the actual data are separated from the programs that use the data. That fact is important to keep in mind in this entire section which explains database schemas and languages and then describes database system architecture.

Database management systems can also be classified in the way they use their data dictionary. As stated before, the data dictionary contains logical descriptions of the data and its relationships, physical information about data storage, and usually information on users and privileges. Some software vendors also design the data dictionary to keep usage information such as frequencies of queries and other transaction information. Data dictionaries are helpful for all human users, especially the database administrator, as well as invaluable to the application programs and report generators that might access the database.

1.3.1 SCHEMAS AND LANGUAGES

The data model describes the data and the relationships at the abstract level. The *database schema* is used to describe the conceptual organization of the database system. This organization is defined during the design process, usually using the data definition language (*DDL*) provided by the particular software vendor.

The organization of the data can be defined at two levels, logical and physical. The physical organization is related to how the data are actually stored on the disk. The logical organization is the conceptual data model that is being implemented. The DDL allows the user to define the organization of the data at the logical level. The particular DBMS software then takes care of the physical organization of data by mapping from the logical to the physical. In this way, users are protected from having to deal with the hardware level storage of data.

The DDL is used to create the tables and describe the fields within each table. Fig. 1-4 shows the schema diagram for part of a retail store database. The schema shows three tables. Each table contains information about particular objects: customers, orders and employees. The schema contains no information about how the bits of each item are physically organized or exactly where the item is stored on a particular storage device.

ORDER INFORMATION	CUSTOMER INFORMATION	EMPLOYEE INFORMATION
ID	ID	ID
CUSTOMER_ID	NAME	LAST_NAME
DATE_ORDERED	PHONE	FIRST_NAME
DATE_SHIPPED	ADDRESS	USERID
SALES_REP_ID	CITY	START_DATE
TOTAL	STATE	COMMENTS
PAYMENT_TYPE	COUNTRY	MANAGER_ID
ORDER_FILLED	ZIP_CODE	TITLE
	CREDIT_RATING	DEPT_ID
	SALES_REP_ID	SALARY
	REGION_ID	COMMISSION_PCT

Fig. 1-4. Schema diagram for part of retail store database.

It is important to decide on the schema early in the database design process. Once the database has been created and has begun to be populated with data, it is sometimes difficult to change the schema. The actual population of the database with information is accomplished using the data manipulation language (*DML*). The most common language used by many DBMS for this purpose is SQL, which is explained in Chapter 3. The DML allows the user to enter, to retrieve, and to update the data. Some database management systems like Microsoft Access™ allow a graphical interaction with the database, but usually a DML is working in the background.

Example 1.9

Design a possible schema for a doctors' office. The doctors want immediate access to patient medical information. The records clerk needs to be sure all insurance companies are billed and then each patient is billed for the remainder.

One possible simple schema is shown below. The information could be kept in three tables: patient medical history, patient personal information, and insurance company information. The information kept in medical history would be determined by the particular specialty of the doctors. This table would be connected to the personal information through the patient_ID. The insurance company information could be kept in another table connected to each patient by the company_ID. The reader should be aware that this example is not the definition of a complete database. More information would certainly be stored.

PATIENT MEDICAL HISTORY	PATIENT PERSONAL INFORMATION	INSURANCE COMPANY INFORMATION
PATIENT_ID	PATIENT_ID	COMPANY_ID
AGE	NAME	NAME
GENDER	ADDRESS	ADDRESS
PAST_ILLNESS	CITY	CITY
OTHER . . .	STATE	STATE
	ZIP	ZIP
	TOTAL_AMT_DUE	
	INSURANCE_CO_ID	
	AMT_BILLED_INSURANCE	

Example 1.10
Would the user use the DML or the DDL to do each task? (a) Change the customer's address, (b) define an inventory table, (c) enter the information for a new employee.

a. and **c.** Updating a customer address and entering new employee information would be accomplished through the use of the DML. Both these activities entail manipulating data within currently established tables.

b. Defining a new table would entail the use of the DDL. Creating the table and establishing the attributes are part of the data definition.

1.3.2 THREE-LEVEL ARCHITECTURE

The generally accepted method of explaining the architecture of a database system was formalized by a committee in 1975 and more fully explained in 1978.[2]

[2] Dionysios C. Tsichritzis and Anthonly Klug (eds.), *The ANSI/X3/ SPARC DBMS Framework: Report of the Study Group on Data Base Management Systems*, *Information Systems 3*, 1978.

It is known as ANSI/SPARC architecture, named for the Standards Planning and Requirements Committee of the American National Standards Institute. The three levels are internal, conceptual and external.

- The *internal* level is the one that concerns the way the data are physically stored on the hardware. The internal level is described using the actual bytes and machine-level terminology. Usually the DBMS software takes care of this level.
- The *conceptual* level, the logical definition of the database, is sometimes referred to as the community view. The data model and the schema diagram are both explanations of the database on the conceptual level. The DBA and assistants maintain the schema and usually are the ones who use the DDL to define the database.
- The *external* level is the one concerned with the users. Whether the users are application programmers or end users, they still have a view, or mental model, of the database and what it contains.

Fig. 1-5 shows a graphical representation of the three levels. The conceptual level, or the community view, is where the physical interior level is interpreted and changed into external views for the users. This figure demonstrates that the DBMS acts as the "go-between" to manage the system by handling interior storage and protecting the users from hardware issues.

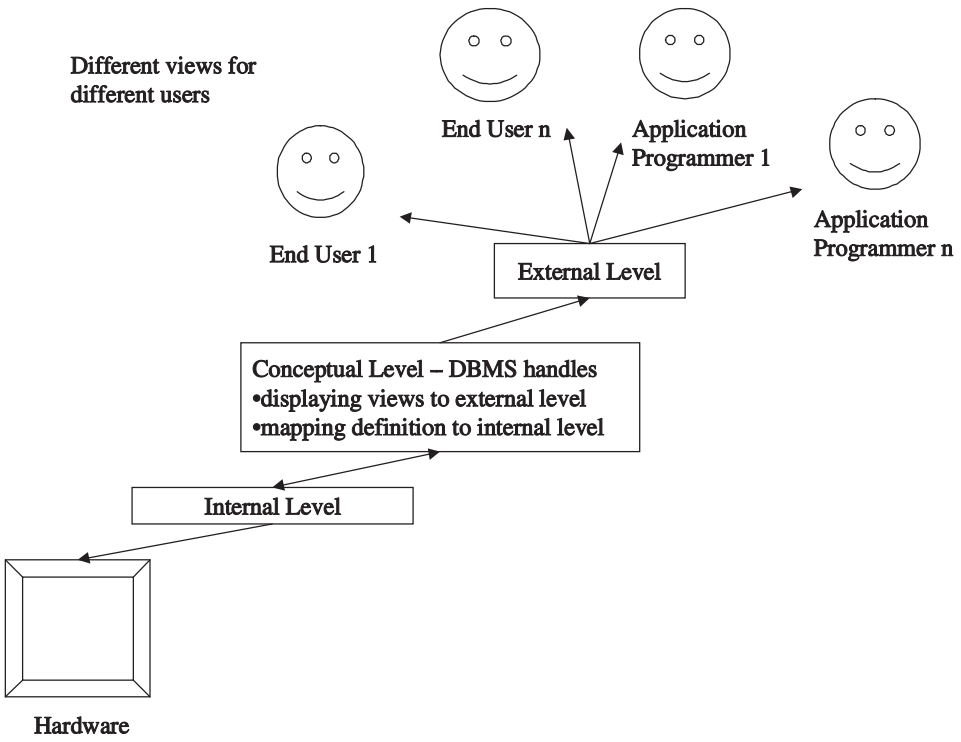


Fig. 1-5. DBMS three-level architecture.

To understand the difference between the three levels, consider again the database schema in Fig. 1-4 that describes customers, orders, and employees. That schema would be the conceptual or community view of the database. Particular information is listed for each entity. The internal level would describe exactly which bytes contain the information and how it can be accessed. If User 1 is the payroll clerk, the external view would contain only the employee information. If Application Programmer 1 is designing billing programs, he or she would need all customer and order information as well as information on the particular sales representative in the external view. Fig. 1-6 shows specific information actually available at each level regarding a particular employee.

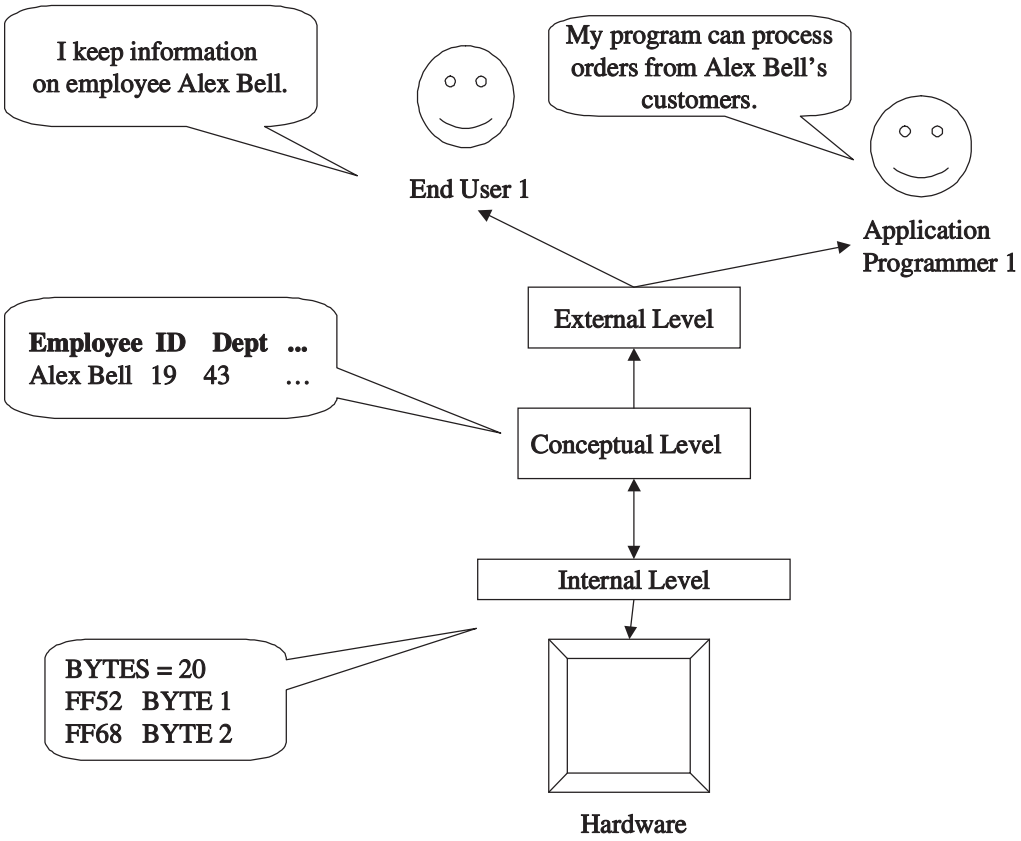


Fig. 1-6. Information at different levels.

Example 1.11

Examine the sample schema in Example 1.9. What would be the internal view, the community view, and the external view of that database?

The tables and the actual contents of each column would be the community view of the database. It might contain such information as

PATIENT_ID	NAME	ADDRESS...
444-44-4444	Sue Jones	345 High St...

The internal view would be the physical location of each element on the disk of the server as well as how many bytes of storage each element needs. The external view would depend upon which user is accessing the database. The doctor would expect to see the patient history. The billing clerk would expect the insurance and billing information.

1.3.3 DATA INDEPENDENCE

The concept of *data independence* is important to address at this time. It has already been stated that the data should be kept separate from the DBMS. At the physical level, the data should be independent of the particular model or architecture. The schema at any of the three levels should be modifiable without interfering with the next higher level. For example, the physical storage of the database might need to be changed. However, this change should not affect either the conceptual view of what is stored or the user's ability to understand and access the data. The data should also be logically independent. Different users and application programs require different information via different logical views. A well-designed system will maintain data independence both physically and logically.

1.3.4 PUTTING THE MODULES TOGETHER

We have discussed all the components of the DBMS. This section focuses on the various software modules usually found in the DBMS and where they can be found with regard to the computer system as a whole. It is probably easiest to approach this environment from the standpoint of the different users explained previously. Fig. 1-7 shows the relationship of users and the various software modules to the actual data.

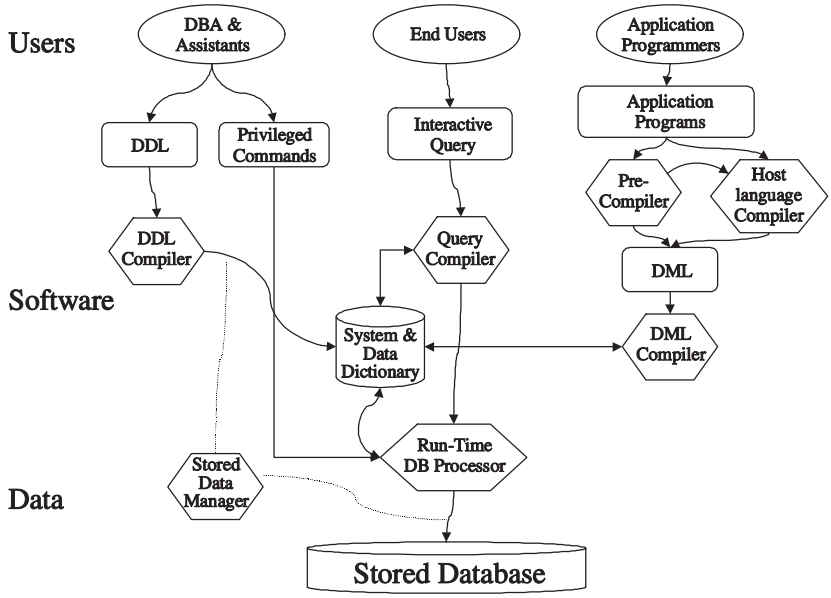


Fig. 1-7. Modules of the DBMS.

The actual data are stored on a disk. The DBA and assistants can issue both privileged commands and DDL statements, which are managed first by the DDL compiler. End users issue interactive queries that are also compiled before processing. The application programmers write the programs that are precompiled to create the DML statements needed, as well as compiled in the host language.

The DBMS provides complete protection for the data through the use of the data dictionary, the run-time database manager, and the stored data manager. Every access to the stored data comes through one or more of these components. The DBMS consistently checks with the data dictionary to be sure all accesses are legal and then processes those commands through the run-time processor. The run-time database manager handles each query, whether retrieval or update. Only the DBA and staff have access to the stored data manager for creation and updating of the actual table structure.

Solved Problems

1.1. Which type of user would usually perform the following functions for an inventory system in a large company?

a. Create a monthly report of current inventory value.
b. Update the number in stock for specific items received in shipment.
c. Cancel the user account for an employee who just retired.
d. Change the structure of the inventory database to include more information on each item.
e. Reply to a phone request regarding the number of a particular item that are currently in stock.

a. Application programmer.
b. End user.
c. DBA or the person on the team designated with that job.
d. DBA or the person on the team designated with that job.
e. End user.

1.2. Consider an inventory database at a kitchen cabinet factory which contains parts information (part number, description, color, size, number in stock, etc.) and vendor information (name, address, purchase order, etc.). Indicate for each user, an accounts payable clerk, a line foreman, and a receiving clerk, which items that user should be able to access and which items the user should be able to access and change.

User	Permission level
a. Accounts payable clerk	Should be able to access and change all data.
b. Line foreman	Needs to access but not change parts information. Probably does not need to have access to any vendor information except maybe name.
c. Receiving clerk	Needs to be able to access and change parts information, such as number in stock. Should be able to access but not change vendor information.

1.3. Why have client/server systems become so prevalent in the business world?

First, the advance of hardware technology allows even small organizations to purchase powerful servers at a reasonable cost. Both easy-to-use software and network resources are also within a reasonable price range. These systems provide a high level of performance while allowing for trusted backup and security capabilities.

1.4. What are some differences in security issues between single-user and multi-user systems?

Single-user systems are often kept secure simply by locking the door to the room containing the computer. Multi-user systems, whether stand-alone or client/server, must employ some kind of password protection allowing different users different levels of access. While backup and recovery issues are similar, having concurrent users results in the necessity for transaction protection, deadlock handling, and locking. These issues are discussed in Chapter 6.

1.5. A county-wide school board wants to create a distributed database for student information. Describe how it might be designed. How would it be different if they wanted a centralized system?

For a distributed system, each local school would keep information on all its students on a server located within the school. All the student databases would be accessible from the central office and from the other schools so that staff in any location could find information on any student. If the school board wanted a centralized system they would need to have one server, probably located at the central office, and then allow access to that database from each local school.

1.6. Specify whether each system would likely be single-tiered, two-tiered, or three-tiered.

a. A woman artist designs and sells jewelry and accessories through mail order or at craft shows. She works out of her home.
b. The school board from the previous example that has a centralized system with each local school accessing data from the server in the central office.

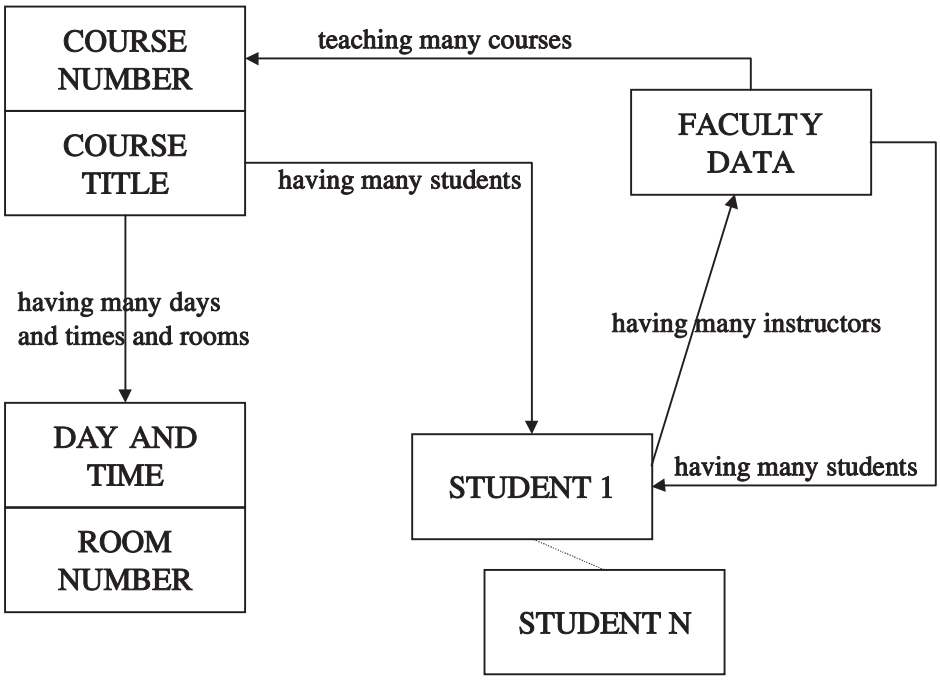
Because the woman in (a) works out of her home, probably she has one computer with the customer and financial information in one DBMS. This would be a single-tier system.

The school board in (b) has one DBMS. Each school would be running the DBMS client software from the central server. This is a two-tier system.

1.7. A woman artist designs and sells jewelry and accessories through mail order or at craft shows. She works out of her home. Currently she has a mailing list in a word processing file she uses for sending out catalogs. She also keeps both supplier and customer names and addresses in word processing files and prepares bills using a spreadsheet and keeps her income and expenses on another spreadsheet. What would be the advantages for her to design and use a DBMS for all her records?

First, she would be helped with proper maintenance of her data. Currently she runs the risk of losing money because she may not record every transaction with every customer on her ledger spreadsheet. It is possible that the address for the same person in the catalog mailing list and the customer mailing list might be different. She may also not be able to demonstrate that she has collected all the required sales tax for the government. If she used a DBMS, she would reduce redundancy and be assured of the accuracy of her records. Second, she would have faster access to her data. She would be able to prepare her tax return more easily with all queries answered quickly. Using the DBMS would improve the completeness of her data. Third, she could maintain the security of her data. The DBMS can limit access through the use of passwords and also provide for easy backup and recovery of her records.

1.8. Given this model for a university database, is it hierarchical, network or relational?



This is a network model because each node can point to several others and can be pointed to by several others.

1.9. How would the data in the previous question be arranged if it were relational?

FACULTY NAME	COURSE 1	COURSE 2	COURSE 3

COURSE NAME	COURSE NUMBER	DAY	TIME	ROOM NUMBER	MAX ENROLLMENT

STUDENT NAME	COURSE 1	COURSE 2	COURSE 3

It would be arranged in a variety of tables as shown above. The items would still be connected by course number.

1.10. Design the schema for a system that keeps information for a youth football league.

A sample schema is shown below. All tables would be connected by team_ID numbers. Using the relational model it would be easy to access the names of players and coaches on any given team.

PLAYER INFORMATION	TEAM INFORMATION	COACH INFORMATION
PLAYER_ID	TEAM_ID	COACH_ID
NAME	TEAM_NAME	NAME
ADDESS	TEAM_SPONSOR	ADDRESS
CITY	PRACTICE_LOCATION	CITY
STATE	WINS	STATE
ZIP	LOSSES	ZIP
PHONE		PHONE
TEAM_ID		TEAM_ID

1.11. Explain the difference between the DDL and the DML.

DDL, or data definition language, is used to handle the structure of the database, to create or remove the tables along with the columns and data types of the columns within the

tables. DDL is usually used only by the DBA and assistants. DML, or data manipulation language, consists of statements to access, retrieve, or update data within existing and predefined tables. DML is used to formulate interactive queries or queries from within application programs.

1.12. Would the user use the DML or the DDL to do each task? (a) Update a student's grade point average, (b) define a new course table, (c) add a column to the student table.

a. Updating a student gpa would be accomplished through the use of the DML. This activity is part of manipulating data within currently defined tables.

b. and **c.** Defining a new table and adding a column to an existing table would entail the use of the DDL. Creating tables and establishing the attributes are part of data definition.

1.13. Give examples of the internal, community, and external view of the team database described in 1.10.

The internal level would be the physical location of the information on the storage medium and the number of bytes used by each item.

The community view would be a conceptual view of the tables and the information contained in them. For example,

COACH_ID	NAME	TEAM_ID
21	Phil Johnson	13

The external view would depend on the user. The record keepers would understand they could calculate standings by examining the win/loss records of each team. The coaches would know they could access the phone numbers of all the players on their team.

1.14. Give examples of the internal, community, and external view of the university database described in 1.9.

The internal level would be the physical location of the information on the storage medium and the number of bytes used by each item.

The community view would be a conceptual view of the tables and the information contained in them. For example,

COURSE NAME	COURSE_ NUMBER	DAY	TIME
Intro to Database	CS474	Tu/Th	1:00

The external view would depend on the user. The faculty members would understand that they could access lists of students in the courses. The registrar's office would know that it should post the list of closed classes.

1.15. Explain the difference between logical and physical data independence.

Physical data independence is related to the actual storage of the data on the storage medium. The way the data are stored in bits and bytes should not affect users' access to that data. Logical data independence usually relates to the different logical views of the data available to different users. If one user sees customer name and address without all the billing information, that does not mean that the billing information is not being stored. Another user should be able to see and even change this information without corrupting the database as a whole.

1.16. What software modules does the DBMS use to protect the accuracy of the database?

The DBMS uses the data dictionary, the run-time manager and the stored data manager. The data dictionary is accessed to verify that requests are legal for that particular database. For example, if the user wants all the parts that are red, the attribute color must actually exist within the table. The run-time manager then processes the actual queries, retrieving the requested information or updating the table. The stored data manager, accessed by the DBA, may use functions of the operating system or may handle tasks on its own. This module also keeps the data dictionary up to date following DDL statements.

Supplementary Problems

1.17. Which type of user would perform the following functions for a billing system in a large company?

a. Respond to call in from customer regarding the current balance due on their account.
b. Write a program to generate monthly bills.
c. Develop schema for new kind of billing system.

1.18. Consider a database at a university which contains information on students (name, ID number, course schedule, grades, etc.), classes (number, name, class list), and faculty (name, ID number, course schedule, salary etc.). Indicate for each user which items that user should be able to access and which items the user should be able to access and change.

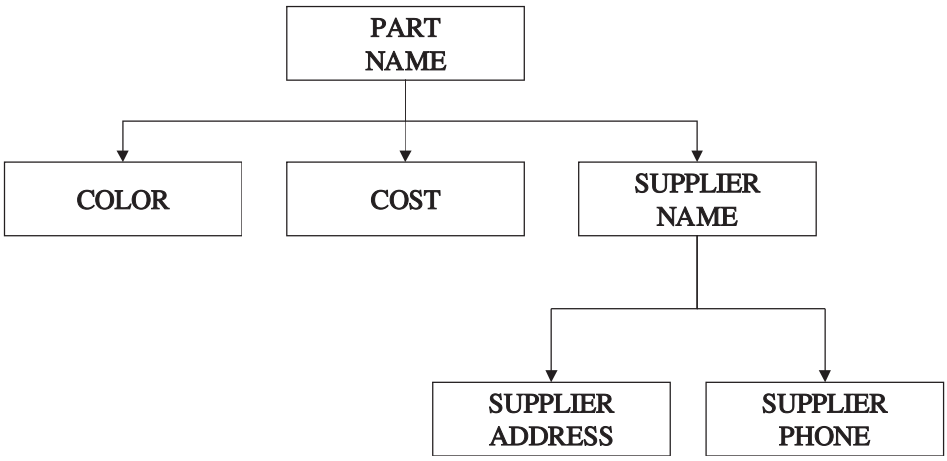
a. Faculty member
b. Clerk in registrar's office
c. Student
d. Payroll clerk

1.19. Consider the university discussed in the previous problem. Would their database likely be centralized or distributed? What unknown factors might make a difference in the design?

1.20. Specify whether each system would be single-tiered, two-tiered, or three-tiered. (a) A mechanic's union allows each local group to keep its own records on its own type of DBMS. The central union headquarters wants to allow access from any local to any local. (b) A medical practice with 3 doctors and 2 locations keeps centralized records accessed by terminals in each location.

1.21. A small private school wants to keep track of students, courses, and faculty. It also has a number of parents and private contributors. Describe the advantages for this school of using a DBMS for all its records.

1.22. Given this model for a parts database, is it hierarchical, network or relational?



1.23. Describe how it would look if it were relational. Why would the relational model be better for this application?

1.24. Design the schema for keeping information on flowers for a mail-order company, including information about each kind of flower, the method of delivery (seeds, bulb, pot, etc.), and the temperature zones in which each flower will grow.

1.25. Would the user use the DML or the DDL to do each task? (a) Define a new table for keeping soil and light needs, (b) add a flower to the inventory, (c) add a new zone to the zone table.

1.26. Give examples of the internal, community, and external view of the flower database described in 1.21.

1.27. Why is it important to maintain data independence in a database?

Answers to Supplementary Problems

1.17. a. End user. b. Application programmer. c. DBA or designee in that department.

1.18. **a.** Faculty member should not be able to change anything. Should have access to class information, but not student information. Should have access only to his or her own faculty data.

b. Clerk in registrar's office should be able to access and change all class information. Should be able to access student information and change only the data surrounding grades. Should be able to access and change faculty class information but not faculty salary data.

c. Student should only be able to access class information with regard to day and time and whether it is open or closed. Should not have access to any class lists or any faculty information. Also, should not have permission to see any student data except his or her own.

d. Payroll clerk probably does not need any access to student data. Should be able to access and change faculty data. In some cases, may need to access but not change class information.

1.19. At first glance, one would think the university database would be centralized with all the course, student, and faculty information kept in one place. However, several factors might change this decision. First, if there are several branch campuses, each campus might want to keep its own student data. Second, for security purposes different offices in different locations might want to keep data. For instance, the human resources office would keep all the faculty information, the registrar's office would keep the course and student grade information, and other student information might be kept by student affairs. With this type of distribution, the DBMS would need to be able to access information at any location with proper authorization.

1.20. **a.** Three-tier because of the required middleware to connect different kinds of DBMS.

b. Two-tier.

1.21. First, the school would be assured of proper maintenance of the data. All tables with personal information would be accurate and up to date. The DBMS would enforce consistency of information on all students, parents, faculty and contributors. Second, the DBMS would provide quick access to data. Items such as student transcripts, course lists, and parent telephone numbers would be instantly accessible. Financial records would be available for scrutiny by contributors. Third, security of the data is maintained. With a DBMS the school officials would be sure that all information remained confidential and secure.

1.22. It is hierarchical because access to each item is only through one path beginning at the top. One could not access the cost without knowing the part name.

1.23. It would be in tables as shown below. The tables would be connected by the supplier ID number. The relational model would be better because any item can be accessed quickly in a variety of ways. For example, the cost of all items from a particular supplier could be listed.

PART NAME	COLOR	COST	SUPPLIER ID

SUPPLIER ID	SUPPLIER ADDRESS	SUPPLIER PHONE

1.24. The schema might look like the table below. Each flower is connected to the type of zone in which it grows and the way it is delivered by the respective IDs.

DELIVERY INFORMATION	FLOWER INFORMATION	ZONE INFORMATION
DELIVERY_ID	ID	ZONE_ID
CATEGORY	COMMON_NAME	LOWEST_TEMP
SIZE	LATIN_NAME	HIGHEST_TEMP
	HIGHEST_TEMP_ZONE_ID	
	LOWEST_TEMP_ZONE_ID	
	DELIVERY_ID	
	LIGHT_NEEDS	
	SOIL_TYPE	

1.25. **a.** Defining a new table would entail the use of the DDL. Creating the table and establishing the attributes are part of the data definition.

b. and **c.** Entering new zone and flower information would be accomplished through the use of the DML. Both these activities entail manipulating data within currently established tables.

1.26. The internal level would be the physical location of the information on the storage medium and the number of bytes used by each item.

The community view would be a conceptual view of the tables and the information contained in them. For example,

DELIVERY_ID	CATEGORY	SIZE
1	pot	1.5 inches

The external view would depend on the user. The shipping clerk would understand that the Thorndale Ivy is delivery type 1, which should be shipped in a pot. The helpdesk personnel would respond to a question that Thorndale Ivy plants can be planted in full sun, partial shade, or shade.

1.27. Data independence is important for three reasons. First, at the physical level, the DBA should be able to change the internal structure of a database without altering the community or the external views. Second, at the logical level, application code or user queries should not need to be altered because of changes in the data representation of storage. Third, the management of the data is easier when the DBMS software is separate from the actual data. Different users can access the data concurrently and feel confident that the DBMS is maintaining integrity and accuracy of the data.

CHAPTER 2

Relational Database Concepts

2.1 Relational Database Management Systems

As indicated in Chapter 1, Database Management Systems are based on data models that allow for a logical or high-level description of the data. A Database Management System based on the relational data model is called a *Relational Database Management System* (RDBMS). In this type of database, the information that comprises the Universe of Discourse is represented as a set of *relations*. In this sense, a RDBMS can then be defined as a collection of relations. Although the notion of a relation can be defined in mathematical terms (see Section 2.2), for all practical purposes, we will represent relations as two-dimensional tables that satisfy certain conditions that will be explained later on. For this reason, in this book we will use the terms tables and relations interchangeably. The reader should keep in mind that in a RDBMS the data is *logically* perceived as tables. That is, tables are logical data structures that we assume hold the data that the database intends to represent. Tables are not physical structures. Each table has a unique name. Tables consist of a given number of *columns* or *attributes*. Every column of a table must have a name and no two columns of the same table may have identical names. The total number of columns or attributes that comprises a table is known as the *degree* of the table. In this book, we use the terms column and attribute interchangeably. The data in the table appears as a set of *rows* or *n-tuples* where n is the number of attributes of the table. Whenever the number of attributes of the table is understood, we can omit the prefix n and refer to the rows of the tables as just rows or tuples. Calling a row an n-tuple (for a fixed n) has the advantage of indicating that the row has n entries (see Example 2.2). However, this terminology is not popular. Most books refer to rows as tuples and vice versa. In this book, unless otherwise stated we will adhere to the most common terminology. All rows of a table have the same format and represent some object

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or relationship in the real world. The total number of rows present in a table *at any one time* is known as the *cardinality* of the table. In legacy systems, the terms *field* and *record* are used as synonyms of the terms attribute and row respectively. Fig. 2-1 shows the general format of the tabular representation of a relation.

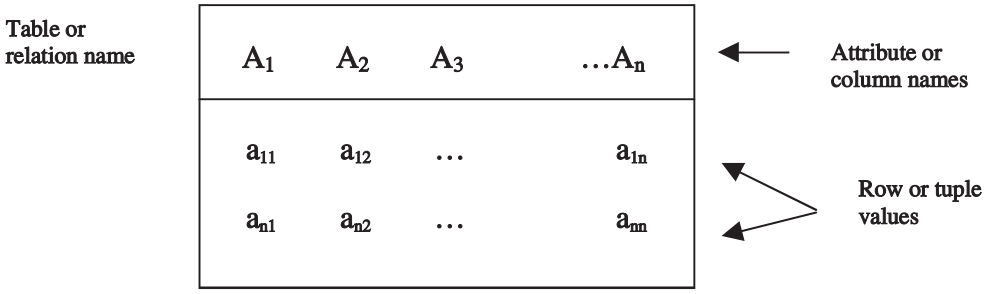

Fig. 2-1. General format of a relation when represented as a table.

We will call the content of a table at any particular point in time a *snapshot* or *instance* of the table. In general, when tables are defined the number of columns remains fixed for the duration of the table. However, the number of rows present in the table is bound to vary since the content of the table reflects the dynamics of the universe that the database intends to capture. New rows may be inserted into the table to represent new facts of the UOD; some rows may be updated to reflect ongoing changes and other rows may be deleted from the table to indicate that some facts are no longer valid or relevant anymore. Notice that tables are required to have at least one column but are not required to have rows. A table with no rows is called an empty table. The process of inserting tuples for the very first time into a table is called *populating the table.*

For *each* column of a table there is a set of possible values called its *domain.* The domain contains all permissible values that can appear under that column. That is, the domain of any column can be viewed as a pool of values from which we can draw values for the column. We will denote the domain of any given column or attribute by *Dom*(*column name*). Observe that any value that appears under a column must belong to its domain. In a table, it is possible that two or more columns may have the same domain. Example 2.1 shows the tabular representation of a relation called EMPLOYEE.

Example 2.1

Given the EMPLOYEE relation shown below, identify its degree and cardinality. For each attribute identify a possible domain.

EMPLOYEE

Id	Last_Name	First_Name	Department	Salary
555294562	Martin	Nicholas	Accounting	55000
397182093	Benakritis	Ben	Marketing	33500
907803123	Adams	Larry	Human Resources	40000

In this table we can identify five attributes or columns: Id, Last_Name, First_Name, Department and Salary. Therefore, the degree of the relation is five.

The table has only three rows or tuples. Therefore, the cardinality of the relation is three.

Possible domains for each of these attributes are as follows:

The domain of the attribute Id, denoted by Dom(Id), is a set of numerical characters. In the United States, for example, it is customary to use the Social Security Number (SSN) of the employee as his or her employee id. Assuming that this is the case in this example, Dom(Id) is the set of nine-digit positive numbers.

The domain of the attribute Last_Name, Dom(Last_Name), is the set of legal last names. In this book we will assume that names consist of a sequence of English alphabetical characters and some other symbols such as a single quote or a hyphen. The number of characters that may comprise a legal last name depends on conventions established by the DBA or the creator of the table. The maximum number of characters typically allowed for names ranges from 20 up to 256 characters.

The domain of the attribute First_Name, Dom(First_Name), is the set of legal first names that a person can have. We will assume that first names follow the same convention used for last names.

For a given company, the domain of the attribute Department, Dom(Department), is the set of names that have been selected as valid department names. In this case, the table shows only three of these values.

The domain of the attribute Salary, Dom(Salary), is a subset of the set of nonnegative real numbers. Notice that a negative salary does not make sense.

In this book, we will assume that every entry of a table or relation has at most a single value.[1] That is, at the intersection of every column and every row there is at most a single value. For any given relation *r*, for any attribute *A* of r, and an arbitrary tuple *t* of r, we will use the notation *t*(*A*) to denote the value of the entry of tuple t under the column A. That is, the value at the intersection of column A and row t.

Example 2.2

For the CUSTOMER_ORDER relation shown below, what are the individual values of t(A) if t is an arbitrary tuple and A is an arbitrary attribute of the relation?

CUSTOMER_ORDER

Id	Date_Ordered	Date_Shipped	Payment_Type
1	08/11/1999	08/12/1999	cash
2	08/12/1999	08/12/1999	purchase order
10	08/14/1999	08/15/1999	credit

[1] This guarantees that the relation can be represented in a RDBMS or equivalently that it is in First Normal Form. See Chapter 5, Section 5.2.

If we call t the first tuple shown in the table, we can say that t(Id) = 1, t(Date_Ordered) = 08/11/1999, t(Date_Shipped) = 08/12/1999 and t(Payment_Type) = cash.

If t is the second tuple, we will have that t(Id) = 2, t(Date_Ordered) = 08/12/1999, t(Date_Shipped) = 08/12/1999 and t(Payment_Type) = purchase order.

If t is the third tuple, we will have that t(Id) = 10, t(Date_Ordered) = 08/14/1999, t(Date_Shipped) = 08/15/1999 and t(Payment_Type) = credit.

Notice that the tuples of this relation are 4-tuples. That is, each tuple has 4 entries; one entry for each of the four columns of the table.

From the definitions considered earlier and the notion of a table, whenever a relation is represented by means of a table, we will assume that the following conditions hold:

- The table has a unique name.[2]
- Each column of the table has a unique name. That is, no two columns of the same table may have identical names.
- The order of the columns within the table is irrelevant.
- All rows of the table have the same format and the same number of entries.
- The values under each column belong to the same domain (strings of characters, integer values, real values, etc).
- Every entry (the intersection of a row and a column) of every tuple of the relation must be a single value. That is, no list or collection of values is allowed.
- The order of the rows is irrelevant since they are identified by their content and not by their position within the table.
- No two rows or tuples are identical to each other in all their entries.[3]

2.2 Mathematical Definition of a Relation

In this section we will formalize the definitions of the previous section. Given a finite set of attributes $A_1, A_2, A_3, \ldots, A_n$ we will call a relational scheme R the set formed by all these attributes. That is, $R = \{A_1, A_2, A_3, \ldots, A_n\}$. Associated with each of these attributes there is a nonempty set D_i, $(1 \leq i \leq n)$ called the domain of the attribute A_i and denoted by $Dom(A_i)$. Let D be a new set defined as the union of all the attribute domains. In other words, $D = D_1 \cup D_2 \ldots \cup D_n$. We define a relation *r* on relational scheme R as a finite set of mappings $\{t_1, t_2, \ldots, t_k\}$ from R to D. The individual mappings t_i are called tuples or n-tuples. For each

[2] This constraint refers to tables within the same tablespace or same database in case of personal databases.

[3] Mathematically, a relation is a set of mappings and therefore there are no duplicate elements. In addition, each record is required to have an attribute whose value uniquely identifies each row.

of these tuples, the value under a particular column A_i, denoted by $t(A_i)$, must be an element of the domain of A_i. That is, if *t* is any tuple of the relation *r* then $t(A_i) \in Dom(A_i)$ where the symbol "$\in$" is read "belongs to". If the schema R of a relation r is understood, we will refer to the relation by its name, otherwise we will denote it as r(R). Although other authors prefer to define a relation as a subset of the Cartesian Product of the domains of the attributes of the relation, we have decided to define relations as sets of mappings to avoid any explicit ordering of the attribute names. This corresponds with the tabular representation of the relation since the order of the columns is irrelevant.

2.3 Candidate Key and Primary Key of Relation

The notion of a *key* is a fundamental concept in the relational model because it provides the basic mechanism for retrieving tuples within any table of the database. Formally, given a relation r and its attributes $A_1, A_2, A_3, \ldots, A_n$, we will call any subset $K = \{A_1, A_2, \ldots, A_k\}$ with $(1 \leq k \leq n)$ of these attributes a *candidate key* if K satisfies the following conditions simultaneously:

(1) For any two distinct tuples t_1 and t_2 of the relation r, there exists an attribute A_j of K such that $t_1(A_j) \neq t_2(A_j)$. This implies that no two different tuples of r will have identical entries in all attributes of K. In other words, *at least one* of the following inequalities will be true $t_1(A_1) \neq t_2(A_1)$, $t_1(A_2) \neq t_2(A_2), \ldots, t_1(A_k) \neq t_2(A_k)$ for any two tuples that we consider in the relation. This condition is known as the *uniqueness property of the key*.[4]

(2) No proper subset K′ of K satisfies the uniqueness property. That is, no element of K can be discarded without destroying the uniqueness property. This condition, called the *minimality property of the key*, guarantees that the number of attributes that comprises the key is minimum.

Since a relation r may have more than one candidate key, one of these candidate keys should be designated as the *primary key* (PK) of the relation. The values of the primary key can then be used as the identification and addressing mechanism of the relation. That is, we will differentiate between the different rows of the relation on the basis of their PK values. We will also uniquely retrieve tuples from a relation based on the values of their PK values. Once a primary key has been selected, the remaining candidate keys, if they exist, are sometimes called *alternate keys*. A RDBMS allows only one primary key per table. A primary key may be composed of one single attribute (*single primary key*) or may be composed of more than one attribute (*composite primary key*). Attributes that are part of any key (primary or alternate) are called *prime*

[4] Some RDBMS allow users to create tables with columns defined with a UNIQUE constraint. This type of constraint forbids duplicate values under any attribute so defined.

attributes. In this book, we will underline the attributes that are part of the primary key. In Example 2.1, attribute Id is underlined because it is the PK of the EMPLOYEE relation. Since Id is the PK of this table no two employees will have identical Id values. Likewise, in Example 2.2, we also underlined the attribute Id of the CUSTOMER_ORDER relation. Since Id is the PK of the CUSTOMER_ORDER relation, no two orders will have the same Id value. Notice that even though these two primary keys (Id of EMPLOYEE and Id of CUSTOMER_ORDER) have identical names they are to be considered different because their underlying meanings are different.

Since the primary key is used to identify uniquely the tuples or rows of a relation, none of its attributes may be *NULL*. This fact imposes an additional condition or *constraint* on the keys known as the *integrity constraint*. In a relation, a NULL value is used to represent missing information, unknown, or inapplicable data. The reader should be aware that a NULL value is not a zero value nor does it represent a particular value within the computer.[5]

Example 2.3

Consider the DEPT table and the rows shown below. Explain whether or not these rows can be inserted into the DEPT table. Notice that DEPARTMENT is the key of the table.

DEPT

DEPARTMENT	NAME	LOCATION	BUDGET
20	Sales	Miami	1700000
10	Marketing	New York	2000000

DEPARTMENT	NAME	LOCATION	BUDGET
10	Research	New York	1500000
	Accounting	Atlanta	1200000
15	Computing	Miami	1500000

10	Research	New York	1500000
	Accounting	Atlanta	1200000
15	Computing	Miami	1500000

No, this row cannot be inserted. It violates the uniqueness property of the key since there is a department 10 already in the table.

No, this row cannot be inserted. It violates the integrity constraint of the key since the department key cannot be NULL.

Yes, this row can be inserted with no problems since no constraint is violated.

[5] In most RDBMS comparisons between nulls are by definition neither true nor false but unknown.

Given a key K of a relation *r*, we will call a *superkey* of *r* any set of attributes K′ of the relation that contains the key. That is, if K′ is a superkey then K′ ⊂ K. The symbol "⊂" reads "subset of". That is, any set of attributes of the relation *r* that contains the key is called a superkey. It should be clear that a superkey satisfies the uniqueness property of the key but not the minimality property of the key (see Solved Problem 2.8).

Keys, as we mentioned before, are the basic mechanism for identifying and retrieving the different tuples of a relation. Therefore, when considering the selection of keys we need to choose attributes that satisfy the uniqueness and minimality condition for all permissible data. What this implies is that we cannot select keys for a table based on a list of possible values that may appear in the table. We also need to consider the underlying meaning of the attributes that we are selecting (see Solved Problem 2.7).

Given a relation r, a subset $X = \{A_1, A_2, \ldots, A_k\}$ of attributes of r, and any tuple t of r, we will call the X-value of t, denoted by $t(A_1, A_2, \ldots, A_k)$ the k-tuple $\{t(A_1), t(A_2), \ldots, t(A_k)\}$. That is, the X-value of a tuple t is a k-tuple whose elements are the individual entries at the intersection of the tuple t and the attributes $A_1, A_2, \ldots, A_k$ respectively. If the order of the attributes is understood, the X-value of t can be denoted by t(X).

Primary keys are defined using DDL statements and are automatically enforced by the RDBMS. They are generally defined at the time the tables are created (see Chapter 3, Section 3.2.1).

2.4 Foreign Keys

Because columns that have the same underlying domain can be used to relate tables of a database, the concept of a foreign key allows the DBMS to maintain consistency among the rows of two relations or between the rows of the same relation. This concept can be formally defined as follows: Given two relations r_1 and r_2 of the same database,[6] a set of attributes FK of relation r_1 is said to be a *foreign key* of r_1 (with respect to r_2) if the following two conditions are satisfied simultaneously:

- The attributes of FK have the same underlying domain as a set of attributes of relation r_2 that have been defined as the PK of r_2.[7] The FK is said to reference the PK attribute(s) of the relation r_2.
- The FK-values in any tuple of relation r_1 are either NULL or must appear as the PK-values of a tuple of relation r_2.

From a practical point of view, the foreign key concept ensures that the tuples of relation r_1 that refer to tuples of relation r_2 must refer to tuples of r_2 that already exist. This condition imposed on foreign keys is called the *referential integrity* constraint. Some authors call the table that contains the foreign key a *child table*; the table that contains the referenced attribute or attributes is called

[6] According to this definition of foreign key, relations r_1 and r_2 could be the same relation.

[7] Some DBMS vendors extend this concept to include attributes of r_2 that have been defined as UNIQUE.

the *parent table*. Using this terminology, we can say that the FK value in each row of a child table is either null or it must match the PK value of a tuple of the parent table.

Example 2.4
Consider the tables indicated below. Assume that the attribute EMP_DEPT is a FK of the EMPLOYEE table that references the attribute ID of DEPARTMENT. Indicate if the rows shown below can be inserted into the EMPLOYEE table.

ID	NAME	LOCATION
10	Accounting	New York
40	Sales	Miami

DEPARTMENT

EMP ID	EMP_NAME	EMP_MGR	TITLE	EMP_DEPT
1234	Green		President	40
4567	Gilmore	1234	Senior VP	40
1045	Rose	4567	Director	10
9876	Smith	1045	Accountant	10

EMPLOYEE

9213	Jones	1045	Clerk	30	No, this row cannot be inserted since it violates the referential integrity constraint. There is no department 30 in the department table.
8997	Grace	1234	Secretary	40	Yes, this row can be inserted with no problem since no constraint is violated.
5932	Allen	4567	Clerk	NULL	Yes, this row can be inserted into the table. NULL values are acceptable in the EMP_DEPT column. The NULL value may indicate that the employee has not yet been assigned to a department.

Notice that in the previous example, we use the keyword[8] `NULL` to indicate explicitly the absence of a department whereas in Example 2.3 the entry for DEPARTMENT was left blank. The reader should be aware that some systems allow both ways to indicate a NULL value whereas some other systems may require that the `NULL` keyword be used explicitly.

Foreign keys are generally defined after all tables have been created and populated. This avoids problems such as the one illustrated in Solved Problem 2.9 or problems of circularity. The latter problem occurs when one table references values in another table, which in turn, may reference the first table. Integrity constraints are defined using DDL statements and are automatically enforced by the RDBMS.

[8] A keyword is a word that has a specific meaning to the system and cannot be used outside a specific context.

2.5 Relational Operators

We call *relational operators* a set of operators that allow us to manipulate the tables of the database. The entire set of operators that allows us to construct new relations from a set of given relations is called a *relational algebra*. Relational operators are said to satisfy the *closure property* since they operate on one or more relations to produce new relations. When a relational operator is used to manipulate a relation, we say that the operator is "applied" to the relation. To define a relational operator we use *relational calculus*. That is, the set of predicate or truth-value statements that, combined with basic logical operations, determine the shape and membership conditions of elements in the resulting relation. To define the relational operators, we will use the logical symbols: $\exists$ (there exists), $\forall$ (for all), $\vee$ (or), $\wedge$ (and), $\sim$ (not), and some set theory symbols that include $\in$ (belongs to), $\subset$ (subset of), $\varnothing$ (empty set), / or $\ni$ (such that), and some of their negated symbols such as $\notin$ (does not belong to), and $\not\subset$ (not a subset of). Since relational operators are defined by means of equalities, the expression on the left-hand side of the equal sign is the relational algebra expression for the operator. The expression on the right-hand side is the relational calculus definition of the operator. In this section, we will discuss only the Selection, the Projection and the Equijoin relational operators. Some other operations, in particular, Boolean operations on relations will be considered later in the chapter. Each operation on a relation answers a question posed to the database. In database lingo, questions to the database are called *queries*. We will use this term to refer to any relational operation performed on relations with the purpose of retrieving information from the database.

2.5.1 THE SELECTION OPERATOR[9]

This operator, when applied to a relation r, produces another relation whose rows are a subset of the rows of r that have a particular value on a specified attribute. The resulting relation and r have the same attributes. More formally, we can define this operator as follows. Let r be a relation on scheme R, A a specified attribute of r, and a particular element a of the Dom(A). The Selection of r on attribute A for the particular element a is the set of tuples t of the relation r such that t(A) − a. That is, all rows of the new relation—the Selection relation—have a under the column A. The *Selection of r on A* is denoted $\sigma_{A\ a}(r)$. Notice that the predicate A − a of $\sigma_{A\ a}(r)$ is meant to be understood as t(A) − a. Mathematically, the Selection operator can be defined as follows:

$\sigma_{A\ a}(r)$ − {t ∈ r/t(A) − a} where the symbol "/" is read "such that".

The scheme of the new relation, $\sigma_{A\ a}(r)$ is the same scheme of the relation r.

[9] This operator is also known as the RESTRICT or SELECT operator. We do not use the word SELECT to avoid any confusion with the SQL command that shares the same name.

That is, as was mentioned before, $\sigma_{A\ \ a}(r)$ and r have the same attributes. The following example illustrates how this Selection operator works. Notice that the Selection operator is a *unary operator*. That is, it operates on one relation at a time. From a practical point of view this operator is applied to a relation whenever we are interested in retrieving all possible information about a tuple or set of tuples that have a given value under a particular column.

Example 2.5
Given the EMPLOYEE relation of the previous example, find all the information contained in the table for all employees who work for department 10.

Since we need to retrieve *all* the information about the employees who work for department 10, it is necessary to determine $\sigma_{EMP_DEPT\ \ 10}$(EMPLOYEE). Notice that in this example the condition that needs to be satisfied by the tuples of the EMPLOYEE relation to appear as tuples of the new SELECTION relation is t(EMP_DEPT) 10. The resulting table is shown below.

$\sigma_{EMP_DEPT\ \ 10}$(EMPLOYEE)

EMP ID	EMP_NAME	EMP_MGR	TITLE	EMP_DEPT
1045	Carson	4567	Director	10
9876	Smith	1045	Accountant	10

Notice that all rows of this new relation have the value of 10 under the column EMP_DPET

2.5.2 THE PROJECTION OPERATOR

The Projection operator is also a unary operator. Whereas the Selection operator chooses a subset of the rows of the relation, the Projection operator chooses a subset of the columns. This operator can be formally defined as follows. The *Projection of relation r onto a set X of its attributes*, denoted by $\pi_X(r)$, is a new relation that we can obtain by first eliminating the columns of r not indicated in X and then removing any duplicate tuple. The attributes of X are the columns of the Projection relation. Mathematically, the Projection relation can be defined as follows: Let r be a relation with relational scheme R and let X $\{A_1, A_2, \ldots, A_k\}$ be a subset of its attributes, then $\pi_X(r)$ $\{t(X)/t \in r\}$. Notice that entries of the rows of the Projection relation are formed by taking from each of the tuples t of r the entries corresponding to the attributes defined in X. That is, the entries for a tuple j of $\pi_X(r)$ are formed by selecting the entries $t_j(A_1)$, $t_j(A_2), \ldots, t_j(A_k)$ from the tuple j of the relation r. Since relations have been defined as sets it is necessary to eliminate all duplicate tuples from $\pi_X(r)$. From a practical point of view, this operator is applied whenever we are interested in the different values currently present under a particular column or

the different combinations of values currently present in two or more columns. The following example illustrates the use of the Projection operator.

Example 2.6
Using the DEPARTMENT table shown below, what are the locations of the different departments? From the answer to the previous question, can we tell the total number of locations that are currently present in the DEPARTMENT table?

DEPARTMENT

ID	NAME	LOCATION
10	Accounting	New York
30	Computing	New York
50	Marketing	Los Angeles
60	Manufacturing	Miami
90	Sales	Miami

Since we need to determine the different values that are currently present in the LOCATION column, we need to find the Projection of the DEPARTMENT table on the attribute LOCATION. That is, we need to find $\pi_{LOCATION}$(DEPARTMENT). In this case, r DEPARTMENT and X {LOCATION}. The tuples of the Projection are obtained by retrieving the value t(LOCATION) for each of the tuples of the relation DEPARTMENT. Since two of the tuples have New York as their locations, only one of these values will appear in the projection. Similar argument can be made for the tuples that have Miami as their locations. The resulting relation is shown next.

$\pi_{LOCATION}$(DEPARTMENT)

LOCATION
New York
Los Angeles
Miami

Observe that LOCATION is the sole attribute of this table.

In general, the projection of this relation on the attribute LOCATION cannot give us the total number of locations present in the DEPARTMENT table since duplicate values are eliminated. Notice that the Projection relation only has three locations whereas the DEPARTMENT relation has a total of five locations.

Example 2.7
Using the table of the previous example, what are the different departments and their locations?

In this case, X {NAME, LOCATION} and r DEPARTMENT. The resulting relation is shown below.

$\pi_{NAME,LOCATION}$(DEPARTMENT)

NAME	LOCATION
Accounting	New York
Computing	New York
Marketing	Los Angeles
Manufacturing	Miami
Sales	Miami

The resulting relation does not contain duplicate values since the different combinations of name and location are unique. Notice that the tuples (Manufacturing, Miami) and (Sales, Miami) are different. Likewise (Accounting, New York) and (Computing, New York) are considered to be two different tuples.

Before considering the next operator, it is necessary to define the *concatenation operator*. This operator is a tuple operator instead of a table operator. Given two tuples s $(s_1, s_2, \ldots, s_n)$ and r $(r_1, r_2, \ldots, r_m)$, the concatenation of r and s is the (m n)-tuple defined as follows:

$\overline{rs}$ $(s_1, s_2, \ldots s_n, r_1, r_2, \ldots r_m)$ where the symbol $\overline{rs}$ is read the "concatenation" of tuples r and s. Notice that the number of entries in the tuples r and s are not necessarily the same. For example, if r = (a, b, c) and s = (1, 2) then $\overline{rs}$ (a, b, c, 1, 2).

2.5.3 THE EQUIJOIN OPERATOR

The Equijoin[10] operator is a binary operator for combining two relations not necessarily different. In general, this operator combines two relations on all their common attributes. That is, the join consists of all the tuples resulting from concatenating the tuples of the first relation with the tuples of the second relation that have identical values for a common set of attributes X. By common attributes we mean attributes that, although they may not have the same name, must have the same domain and underlying meaning. Mathematically, this definition can be expressed as follows: Let r be a relation with a set of attributes R and let s be another relation with a set of attributes S. In addition, let us

[10] This type of join is also called a natural join.

assume that R and S have some common attributes and let X be that set of common attributes. That is, $R \cap S = X$. The join of r and s, denoted by *r Join s*, is a new relation whose attributes are the elements of $R \cup S$. In addition, for *every tuple* t of the *r Join s* relation, the following three conditions must be satisfied simultaneously: (1) $t(R) = t_r$ for some tuple t_r of the relation *r* (2) $t(S) = t_s$ for some tuple t_s of the relation and (3) $t_s(X) = t_r(X)$.

An equivalent definition of the Join operator is as follows:

$$r\,Join\,s = \{\overline{rs} / s \in r \text{ and } s \in s \text{ and } r(R \cap S) = s(R \cap S)\}$$

This definition and the previous one are equivalent. The next example illustrates how this operator works.

Example 2.8

Join the tables shown below on their common attributes DEPARTMENT and NAME. Write a possible user's query that can be satisfied by the result of this operation. Can these two tables be joined on the attribute ID?

DEPARTMENT

ID	NAME	LOCATION
100	Accounting	Miami
200	Marketing	New York
300	Sales	Miami

EMPLOYEE

ID	NAME	DEPT	TITLE
100	Smith	Sales	Clerk
200	Jones	Marketing	Clerk
300	Martin	Accounting	Clerk
400	Bell	Accounting	Sr. Accountant

In this case, the common attributes are the DEPT and NAME attributes. The join of these two tables, denoted by DEPARTMENT *Join* EMPLOYEE, is shown below. Since both tables have an attribute called ID, to avoid confusing the attribute ID of the DEPARTMENT table with the attribute ID of the EMPLOYEE table, it is necessary to qualify each attribute by preceding it with its corresponding table name before joining the tables. For a similar reason, the attribute NAME of the EMPLOYEE and DEPARTMENT tables has to be qualified. Observe that this is consistent with the requirement that in any table the column names must be different. Notice that the common column was not duplicated. The results of this join operation could be used to satisfy a user's request to "display all the information about the employees along with their department's id, name and location".

DEPARTMENT *Join* EMPLOYEE

DEPT ID	DEPARTMENT NAME	LOCATION	EMPLOYEE ID	EMPLOYEE NAME	TITLE
100	Accounting	Miami	300	Martin	Clerk
100	Accounting	Miami	400	Bell	Sr. Accountant
200	Marketing	New York	200	Jones	Clerk
300	Sales	Miami	100	Smith	Clerk

In this Join operation notice that the common attribute is DEPARTMENT NAME. That is, X {DEPARTMENT}. In addition, observe that this join satisfies the three conditions mentioned above. In fact, if r is the DEPARTMENT relation and s is the EMPLOYEE relation we will have that their respective schemes are:

R − {ID, NAME, LOCATION} and
S {ID, NAME, DEPT, TITLE}

Observe also that for every tuple t of the Join relation we must have

t(R) − t(ID, NAME, LOCATION) − t_r for some tuple of r.
t(S) t(ID, NAME, TITLE) t_s for some tuple of s.
t_r(X) − t_s(X)

If we include the attribute names for sake of the explanation and consider the first tuple of the Join relation we have that

DEPT ID	DEPARTMENT NAME	LOCATION	EMPLOYEE ID	EMPLOYEE NAME	TITLE
100	Accounting	Miami	300	Martin	Clerk

If we call t this first tuple notice that

t(DEPARTMENT ID, DEPARTMENT NAME, LOCATION)
(100, Accounting, Miami) – t_r
t(EMPLOYEE ID, EMPLOYEE NAME, DEPT, TITLE) –
(300, Martin, Accounting, Clerk) – t_s
t_r(DEPARTMENT) – t_s(DEPARTMENT) – Accounting

The reader can verify that the three conditions indicated above for the Join are satisfied by the remaining tuples of the relation. We leave this as an exercise for the reader.

The tables DEPARTMENT and EMPLOYEE *cannot* be joined on the attribute ID because the attribute ID of the EMPLOYEE table and the attribute ID of the DEPARTMENT table have different meanings. One is an employee's id while the other is a department's id. This illustrates the fact that two tables cannot be joined just because they have attributes with the same name. To join two tables on their common attributes, these attributes need to have same domain and the same underlying meaning.

In the database literature, there are several types of joins. The equijoin or natural join previously defined requires that the condition to be satisfied by the tuples of the intervening relations be equality. A *composition* is a natural join with the common join attribute or attributes deleted. A *theta join* is a join where the condition that needs to be satisfied by the tuples may be defined by means of one the following logical operators $\leq$, $\geq$, $\neq$, $<$, or $>$. In general, the latter operation is not directly supported by the RDBMS manufacturers but it can be implemented as a combination of Selection and Projection operations (see Solved Problem 2.17).

2.6 Set Operations on Relations

Since relations have been defined as mathematical sets, the basic binary operations that are traditionally considered as "set operations" can also be applied to relations. These operations are: Union, Intersection, Difference and the Cartesian product. Of all these operations the union is perhaps the most powerful and interesting. The first three of these operations require that the attributes of the participating relations be *union compatible*. We will say that two sets of attributes A and B are union compatible if they are of the same degree and the corresponding domains are of the same data type. Notice that this definition does not require that the names of the attributes be the same. In practical terms the purpose of all these operations is to allow the result of the execution of multiple operations to be displayed as a single statement.

As Chapter 3 will show, all these operations are implemented using variations of the SQL statement SELECT. Since the result of each of these operations is a single table and the attributes of the participating tables are not required to be the same, what will be the names of the columns of the "final" table? In this book, we will follow the convention that the result table will have the column names of the "first" table. This will be clarified shortly.

2.6.1 UNION

Given two relations r(R) and s(S) with union compatible schemes, the UNION of these two relations, denoted by $r \cup s$, is the set of all tuples that are currently present in r or are currently present in s or are present in both relations. In mathematical terms, the UNION can be defined as follows:

$r \cup s \quad \{t/t \in r \vee t \in s\}$ where the symbol "$\cup$" is read "union" and the symbol $\vee$ is read "or".

Like in any other relation, there are no duplicate tuples in the UNION relation. The scheme of the UNION, that is, its set of attributes is the scheme of the relation r since this is the relation that is named first in the UNION operation. Observe that if we had written $s \cup r$ the attributes of s would have appeared as column headings of the resulting relation.

Example 2.9

Given the relations shown below, find the union of these two relations. What query will this operation answer?

C_PROGRAMMER

Employee_Id	Last_Name	First_Name	Project	Department
101123456	Venable	Mark	E-commerce	Sales Department
103705430	Cordani	John	Firewall	Information Technology
101936822	Serrano	Areant	E-commerce	Sales Department

JAVA_PROGRAMMER

Employee_Id	Last_Name	First_Name	Project	Department
101799332	Barnes	James	Web Application	Information Technology
101936822	Serrano	Areant	E-commerce	Sales Department

C_PROGRAMMER $\cup$ JAVA_PROGRAMMER

Employee_Id	Last_Name	First_Name	Project	Department
101123456	Venable	Mark	E-commerce	Sales Department
103705430	Cordani	John	Firewall	Information Technology
101799332	Barnes	James	Web Application	Information Technology
101936822	Serrano	Areant	E-commerce	Sales Department

Notice that there are no duplicate tuples in the resulting relation. Observe also that it is not possible by mere examination of the resulting relation to tell which rows were selected from which table. This operation may answer a query that requests information about all employees that are C programmers or Java programmers or both.

The UNION is a commutative operation. That is, for any two relations r and s, we have that $r \cup s = s \cup r$. The observant reader should realize that this is a direct consequence of the commutativity of the Boolean *OR* operator.

2.6.2 INTERSECTION

Given two relations r(R) and s(S) with union compatible schemes, the intersection of these two relations, denoted by $r \cap s$, is the set of tuples currently present in both relations. That is, the set of tuples common to both relations. In mathematical terms, the INTERSECTION can be defined as follows:

$r \cap s = \{t/t \in r \wedge t \in s\}$ where the symbol "$\cap$" is read "intersection" and the symbol "$\wedge$" is read "and". Like in any relation, there are no duplicate tuples in the INTERSECTION relation.

Example 2.10
Given the tables of the previous example, find the intersection of the given relations. What query will this operation answer?

The tuples of the intersection of these two relations are the tuples that are currently present in both relations. In this case there is only one tuple common to both relations. This operation will answer a query that requests information about all employees that are both C and Java programmers.

C_PROGRAMMER $\cap$ JAVA_PROGRAMMER

Employee_Id	Last_Name	First_Name	Project	Department
101936822	Serrano	Areant	E-commerce	Sales Department

The INTERSECTION is a commutative operation. That is, $r \cap s = s \cap r$ for any two relations r and s. This is direct consequence of the commutativity of the Boolean *AND* operator.

2.6.3 DIFFERENCE

Given two relations r(R) and s(S) with union compatible schemes, the DIFFERENCE of relations R and S (in that order), denoted by r s, is the set of tuples that are currently present in r and are not currently present in s. The symbol can be read as a "difference" or as a "minus". In mathematical terms, the difference of these two relations can be defined as follows:

r s $\{t/t \in r \wedge t \notin s\}$ where the symbol "$\notin$" is read "does not belong to" and the symbol "$\wedge$", as we indicated before, is read "and".

Example 2.11
Find the difference of the relations C_PROGRAMMER JAVA_PROGRAMMER and JAVA_PROGRAMMER C_PROGRAMMER. What queries do these operations answer? Use the relations defined in Example 2.10.

The relation C_PROGRAMMER JAVA_PROGRAMMER contains the tuples that are currently present in the relation C_PROGRAMMER and are *not* currently present in the relation JAVA_PROGRAMMER. The Difference relation is shown below.

C_PROGRAMMER JAVA_PROGRAMMER

Employee_Id	Last_Name	First_Name	Project	Department
101123456	Venable	Mark	E-commerce	Sales Department
103705430	Cordani	John	Firewall	Information Technology

This query may answer a request to find all C programmers that are not Java programmers.

The relation JAVA_PROGRAMMER C_PROGRAMMER contains the tuples that are currently present in the relation JAVA_PROGRAMMER and are not currently present in the relation C_PROGRAMMER. The difference relation is shown below.

JAVA_PROGRAMMER C_PROGRAMMER

Employee_Id	Last_Name	First_Name	Project	Department
101799332	Barnes	James	Web Application	Information Technology

This query may answer a request to find all Java programmers that are not C programmers.

Notice that the order in which the relations are named in the difference operation is important. In general, and as this example illustrates, given two relations r and s, we have that $r - s \neq s - r$. This result shows that the DIFFERENCE of relations is not a commutative operation.

2.6.4 CARTESIAN PRODUCT[11]

Given two nonempty relations r(R) and s(S), the CARTESIAN PRODUCT of these two relations, denoted by $r \otimes s$, is defined as the relation whose tuples are formed by concatenating every tuple of relation r with every tuple of relation s. In mathematical terms, the Cartesian product is defined as follows:

$r \otimes s \quad \{\overline{pq}/p \in \mathbf{r} \text{ and } q \in \mathbf{s}\}$ where, as indicated before, the symbol $\overline{pq}$ reads "the concatenation of tuples *p* and *q*".

The degree of the CARTESIAN PRODUCT relation is the sum of the degrees of the original relations with duplicate names qualified if necessary. The cardinality of the CARTESIAN PRODUCT is the product of the cardinality of the original relations. The reader should be careful when applying the Cartesian product because the result relation may make no sense. This operation is sometimes useful if followed by a SELECTION operation that matches values of attributes coming from the component relations (see Solved Problem 2.16). Of all the set operations on relations the Cartesian product is the most time consuming. Therefore, we caution the reader in the use of this operation.

Example 2.12

Given the relations shown below, find the Cartesian product of these two relations.

BUYER

ID_NUMBER	ITEM
100	A
234	B
543	C

[11] This operation is also called the cross product.

PRODUCT

CODE	NAME	PRICE
A	Bike	250
B	Spikes	90
C	Goggles	15
D	Gloves	35

The Cartesian product of these two relations is shown below. As the resulting relation shows, this Cartesian product has 5 attributes = 2 (from BUYER) 3 (from PRODUCT) and 12 tuples 3 (from BUYER) * 4 (from PRODUCT). The Cartesian product is shown below.

ID_NUMBER	ITEM	CODE	NAME	PRICE
100	A	A	Bike	250
100	A	B	Spikes	90
100	A	C	Goggles	15
100	A	D	Gloves	35
234	B	A	Bike	250
234	B	B	Spikes	90
234	B	C	Goggles	15
234	B	D	Gloves	35
543	C	A	Bike	250
543	C	B	Spikes	90
543	C	C	Goggles	15
543	C	D	Gloves	35

Notice that this relation, besides containing tuples that can provide us with some useful information, also contains tuples that are meaningless. For instance, from the first tuple we can see that customer number 100 bought a bike for $250. However, what is the meaning of the second tuple?

2.7 Insertion, Deletion and Update Operations on Relations

As indicated before in Section 2.1, the contents of relations are, in general, time-varying. Some of the most common operations applied to relations that allow them to change over time are: Insertion, Deletion and Update operations. Although these operations can be formally defined in mathematical terms, their definitions are too complicated to be of any practical use. Therefore, to define them we will use a less formal approach that allows us to visualize the effect of the operations.

2.7.1 INSERTING A TUPLE INTO A TABLE

Given a relation r with relation scheme R $\{A_1, A_2, A_3, \ldots, A_n\}$. The format of the INSERT operation is as follows:

INSERT INTO *relation-name* $(A_1 \quad v_1, A_2 \quad v_2, A_3 \quad v_3, \ldots, A_n \quad v_n)$

where the values $v_1, v_2, \ldots, v_n$ belong to the domain of the attributes $A_1, A_2, A_3, \ldots, A_n$ respectively. If the order of the attributes is understood, we will write the INSERT operation as

INSERT INTO *relation-name* $(v_1, v_2, v_3, \ldots, v_n)$

The effect of this operation, as its name indicates, is to add a new tuple *t* to the relation where $t(A_i) \quad v_i$.

Notice that the effect of this operation is not guaranteed to succeed; the INSERT operation may fail for one of the following reasons:

- A given value may not belong to the domain of its corresponding column. That is, $v_i \notin Dom(A_i)$.
- The tuple that is being inserted does not have the appropriate number of entries as determined by the scheme of the relation.
- The key value of the tuple that is being inserted may duplicate the value of the PK of a tuple already present in the relation.
- One or more values of the tuple being inserted may duplicate the values under one or more columns that have been defined as UNIQUE.
- The name of the relation does not exist in the database, or the attributes, as mentioned in the INSERT INTO operation, do not exist in the relation.

In all cases where a violation occurs the system will issue an appropriate error message. The nature of the message depends on the RDBMS being used.

The following example illustrates the use of the INSERT operation.

Example 2.13

Given the PATIENT-ACCOUNT relation shown below, state whether or not the indicated tuples can be inserted into the relation. Assume that character data needs to be enclosed in double quotes within the INSERT operator.

PATIENT-ACCOUNT (ACCOUNT, AMOUNT-DUE, DEPARTMENT, DOCTOR-ID, TREATMENT-CODE)

where the corresponding domains are:

Dom(ACCOUNT) – character string, length 9 characters.
DOM(AMOUNT-DUE) numeric, maximum 9 digits with two optional decimals.
Dom(DEPARTMENT) {G, T, L, X-rays, I}
Dom(DOCTOR-ID) – character, 4 digits maximum, range from 1000 through 2000.
Dom(TREATMENT-CODE) {G100, G110, G120, T130, L140, L150, X160, X170, I180, I190, I200}

PATIENT-ACCOUNT

ACCOUNT	AMOUNT-DUE	DEPARTMENT	DOCTOR-ID	TREATMENT-CODE
980543990	2456	G	1200	X160
804804308	245.45	T	1123	G100
173402644	589.25	L	1111	I180

a. INSERT INTO patient-account (ACCOUNT "890345255", AMOUNT-DUE 256, DEPARTMENT "G", DOCTOR-ID "1500", TREATMENT-CODE "T130")

This tuple can be inserted with no problems since it does not violate any of the restrictions indicated above.

b. INSERT INTO patient-account (ACCOUNT "980543990", AMOUNT-DUE 256, DEPARTMENT "G", DOCTOR-ID "1500", TREATMENT-CODE "T130")

This tuple cannot be inserted because it duplicates the primary key of one of the existing tuples.

c. INSERT INTO patient-account (ACCOUNT "890345255", AMOUNT-DUE 256, DEPARTMENT "G", DOCTOR-ID "1500")

This tuple cannot be inserted because it does not have the appropriate number of entries.

d. INSERT INTO patient-account (ACCOUNT − "564890155", AMOUNT-DUE − 256, DEPARTMENT − "G", DOCTOR-ID − "1500", TREATMENT-CODE − "T130")

This tuple cannot be inserted because one of the columns is not recognized by the system. Column AMOUNT_DUE has been misspelled.

e. INSERT INTO patient-account (ACCOUNT − "721307804", AMOUNT-DUE − 256, DEPARTMENT − "G", DOCTOR-ID = "3500", TREATMENT-CODE = "T130")

This tuple cannot be inserted because the value for the DOCTOR-ID attribute is not within the acceptable range.

2.7.2 DELETING A TUPLE FROM A TABLE

The DELETE operation removes a particular tuple from a relation. To remove a specific tuple it is necessary to identify it by the attributes of its primary key. Given a relation r with relation scheme R $\{A_1, A_2, A_3, \ldots, A_n\}$. The format of the DELETE operation is as follows:

DELETE FROM *relation-name* WHERE *search-condition*

The search-condition generally specifies the values of the key attributes of the particular tuple that we want to delete. However, whenever more than one tuple is to be deleted by the same operation, the search condition may be specified by the value of any other attribute. In this book, we will indicate the search-condition as $(A_1 \quad v_1, A_2 \quad v_2, A_3 \quad v_3, \ldots, A_k \quad v_k)$ where the attributes $A_1, A_2, A_3, \ldots, A_k$ comprise the key of the relation. If the attributes are understood, we will list only the v_i values. The DELETE operation fails if one of the following conditions occurs:

- The indicated tuple is not present in the relation.
- The tuple to be deleted is referenced by a foreign key of another relation. In this case, we say that the operation violates the integrity constraint.
- The relation does not exist or the tuple does not conform to the scheme of the relation.

Deleting the last tuple of a relation is permissible since the empty relation is allowed. That is, a relation with no tuples is legal. In all cases where a violation occurs the system will issue an appropriate error message.

Example 2.14

Using the PATIENT-ACCOUNT relation of the previous example, indicate whether or not it is possible to delete the tuples indicated below.

a. DELETE FROM patient-account WHERE account − "980543990"

This operation successfully removes the tuple whose primary key is 980543990.

b. DELETE FROM patient-account WHERE account − 980543990

This operation fails because the value of the account attribute is not found. Notice that we have made the assumption that character data needs to be enclosed in double quotes. In this case, the RDBMS is looking for a numerical value instead of a character value. Some systems automatically translate character data into numeric data and vice versa. However, the reader should not rely on automatic translations. In this book, we will assume that no automatic translation occurs.

c. DELETE FROM patient-account WHERE accounts = "980543990"

This operation fails because the RDBMS does not recognize the attribute accounts. Notice that the key attribute is singular and not plural.

2.7.3 UPDATING A TUPLE OF A TABLE

To update a tuple is to change the values of one or more of its attributes. The tuple that we want to update needs to be identified by its key or some other search attribute. The format of this operator is as follows:

UPDATE *table-name* SET *column_name* *new-value* WHERE *search-condition*

The reader should be aware that the UPDATE operator is just a convenience offered by the vendors of the RDBMS since we could delete the tuple that we want to change and then add a new tuple with the correct values. The reasons that this operator may fail are the same reasons that the INSERT and DELETE operations may fail.

Example 2.15

Update the PATIENT-ACCOUNT table to show that patient with account 804804308 has made a payment of $45.45 and now owes $200.00. The corresponding UPDATE operation is as follows:

UPDATE patient-account SET amount-due = 200 WHERE account = "804804308"

This operation successfully sets the value of the attribute amount-due to its new value of 200.

2.8 Attribute Domains and Their Implementations

As indicated before, the domain of an attribute defines the characteristics of the values that a table column may contain. In any RDBMS the domain of any given attribute is implemented using a data type. National and international organizations such as the ANSI (American National Standards Institute) and the ISO (International Standard Organization) have defined a set of basic data types. These data types, although supported by most of the RDBMS vendors, have implementation details that vary from vendor to vendor. Table 2-1 shows some of the basic SQL data types and their implementations for selected RDBMS vendors.

Table 2-1. Some standard SQL data types and some of the RDBMS vendors' implementations.

STANDARD SQL	ORACLE	ACCESS	DB2
Character(n) n is number of characters.	*Char(n)* fixed length with up to 255 characters maximum.	*Text* fixed length with up to 255 characters maximum.	*Character(n)* same as ORACLE Char(n).
Character varying (n) n characters. Storage fits the size of content.	*Varchar2(n)* varying length with up to 2000 characters maximum.	*Text* varying length up to 255 characters max or *Memo* varying length up to 64,000 characters maximum.	*Varchar(n)* same as ORACLE varchar2(n).
Float (p), where *p* is total number of digits.	*Number* ranges from 1.0×10^{130} to 38 9s followed by 88 0s.	*Single or Double* depending on range of data values.	*Float* same as ORACLE NUMBER.
Decimal(p,s) at least *p* digits with s defined by vendor.	*Number(p,s) p* ranges from 1 to 38, whereas *s* ranges from 84 to 127.	*Integer or Long Integer* depending on range of data values.	*Integer* same as ORACLE NUMBER(38).

Columns of data type *character(n)* or *character varying(n)*, where n is the maximum number of characters that can be stored in the column, are generally used for data containing text or numbers that are not involved in calculations. Examples of this data type are names, addresses, employee identification numbers, social security numbers, and telephone numbers. The primary difference between the character(n) and character varying(n) data types is how they store strings (sequence of characters) shorter than the maximum column length. When a string with fewer than n characters is stored in a character(n) column, the RDBMS pads blank spaces to the end of the string to create a string that has exactly n characters. When a string with fewer than n characters is stored in a character varying(n) column, the RDBMS stores the string "as is" and does not pad it with blank spaces. For this reason, if we know that the contents of a character column may vary in length, it is better to define the column as character varying since the RDBMS can store this information more efficiently. Text data, whether it is stored as fixed or varying type, is always case sensitive. For example, the string 'abc' is different than the string 'aBc'. Any embedded blank counts as a character. For instance, 'abc' and ' abc ' are different strings since the latter contains at least one embedded blank.

Columns of type *float(n)*, where n is the total numbers of digits, are generally used to represent large numerical quantities or scientific computations. For example, in Oracle we can use float data types to represent numbers in the range between 1.0×10^{-10} and $1.0 \times 10^{+10}$.

Columns of type *decimal(p,s)* are used to represent fixed-point numbers. The *precision*, p, is the total number of digits both to the right and to the left of the decimal point. The *scale*, s, is the number of decimal digits to the right of the decimal point. When the number we are representing is a whole number, the scale is set equal to zero. An example of this data type is the number 123.23 which can be specified as decimal(5,2). Whole numbers such as 125 can be specified as decimal(3,0).

Although not shown on Table 2-1, another data type that is commonly used by all RDBMS is *DATE*. This data type allows users to store date and time information. Date is generally displayed in the default format DD-MM-YY where DD stands for Day, MM stands for month and YY stands for year.

Solved Problems

2.1. What is the degree and cardinality of the SUPPLIER relation shown below?

SUPPLIER

Supplier-Id	Part	Order-Number	Customer-Number	Quantity-Last-Order	Total
S1002	P1898E	18904-01-12-00	119078090	1000	12800
S8948	P3473	12443-10-11-99	232301248	25	1000
S1000	P2354-A	98080-05-08-00	300234732	780	19500
S2993	P1898A	80808-78-08-31	459042354	2	500

Since the table has 5 columns its degree is 5. There are 4 tuples in this table. Therefore, the cardinality is 4.

2.2. Assuming that you have to create the SUPPLIER relation of the previous exercise in a RDBMS, what data types will you choose for the different attributes of the relation? Justify your answer.

The data type of the Supplier-Id attribute should be character. Notice that there are digits and letters as part of the values of this attribute. If all supplier-Id values are 5 characters long then character(5) is an appropriate data type. If the supplier-Id varies in length, then character varying(6) may be appropriate. Notice that in this case, we are allowing for these values to grow up to 6 characters. Similar arguments can be made for the attributes Part, Order-Number, and Customer-Number. All these attributes are, by their nature, character data. Notice that the customer number seems to be "numeric". However, this attribute should not be defined as such because customer numbers are not involved in any type of computation. In their behavior they are very similar to the Social Security numbers.

Attributes Quantity-Last-Order and Total should be numeric since they may be involved in some particular computation. For example, the company may produce a monthly or annual report listing the total dollar amount and the total number of items bought by every customer. Quantity-Last-Order should be an integer, whereas Total should allow for fractional parts.

2.3. So far we have considered the terms table and relation as synonyms. Assume that the table shown below is a partial list of the academic degrees of the instructors of a particular university; can this table be considered a relation?

INSTRUCTORS

Last-Name	First-Name	Academic-Degree	Department
Prieto	Ray	B.S, M.S, Ph.D	Physics
Renton	Joan	B.A	Biology
Perez	Jose	B.A, M.S, Ph.D	PreMed
Bell	Mardre	B.A, M.S, Ph.D	PreMed

No, this table cannot be considered a relation because the entries under the column Academic-Degree are not single values. Notice that with the exception of instructor Renton, each entry contains more than one value. This table is just that, a table; it cannot be considered a relation.

2.4. Consider a relation with a single-attribute key and n ($n > 0$) tuples. If we do a Projection on the key attribute of this relation, what can we say about the cardinality of the Projection relation?

Since there are n different tuples in the relation, there must be n different key values, one per tuple. Therefore, the cardinality of the projection on the key attribute should be equal to n since there are no duplicate values and each value must appear only once.

2.5. Assume that you have two relations, an EMPLOYEE relation and a PROJECT relation. The EMPLOYEE table has an attribute Id. The value of this attribute may range from 1 to 100. The PROJECT relation also has an attribute Id that also ranges from 1 to 100. Since these attributes take values in the same range, can we say that these attributes are the same? Can these two attributes be considered common attributes?

No, we cannot say that these attributes are the same since they have different meaning. Attributes have *roles* that allow us to differentiate them from a logical point of view. The roles of these attributes are different. One of them represents employee Ids, that is, values that uniquely identify each employee. The other attribute represents project Ids. For similar reasons, these two attributes cannot be considered common.

2.6. Given the relations of the previous example, if we were to join these two relations would the RDBMS prevent us from doing the join?

The answer is no. The RDBMS will not prevent us from doing the operation because it is not aware of the semantic meaning of these attributes and, as long as the operation is valid from a syntactical point of view, the RDBMS will execute it. However, the resulting relations are, in general, meaningless.

2.7. The STAFF relation of a medical facility is shown below. Does it make sense to choose the attribute Last-Name as the primary key of this relation?

Last-Name	First-Name	Title	Salary	Department
Kyger	Wendy	X-Ray Tech	28000	Radiology
Dillard	Suzanne	X-Ray Tech	28000	Radiology
Shafiroff	Jean	Secretary	16000	General Office
Carson	Anna-Christie	Medical Assistant	23000	General Medicine
Sutton	Melissa	X-Ray Tech	28000	Radiology
Renton	Hayley	Receptionist	14000	General Office

No, the attribute Last-Name cannot be used as the primary key of this relation even though all the current last names are different. Last names do not satisfy the requirement that keys have to remain keys regardless of the number of tuples that are inserted into the table. That is, the fact that there are no duplicates in the Last-Name column in the current table instance is not a guarantee that there will not be duplicates in the future. In this case, using the attribute Last-Name as the primary key imposes an additional and unnecessary constraint of having to consider, as a pre-employment condition, the last name of a prospective employee. In fact, if Last-Name is chosen as the key there cannot be two people with identical last names working at the same facility.

2.8. Since relations are defined as sets we know that there are no duplicate tuples. Why then can we not use the entire set of attributes of a relation as the primary key of the relation?

It is true that in any relation r the primary key is a subset of the entire set of attributes of the relation. That is, the entire set of attributes of the relation is a superkey of the relation. In addition, it is also true that no two tuples of the relation have identical values in all their attributes. However, we need to keep in mind that keys are used as the primary mechanism for identifying and retrieving tuples from relations. To do so, we would like to use a minimal set of values. For instance, in an EMPLOYEE relation, knowing an employee-id number we would like to know his or her salary. If we need to know all the information about an employee to retrieve his or her corresponding tuple then we do not need to retrieve the tuple. We already know all that we need about the employee! Notice that from the entire set of attributes of the relation we can discard those attributes that are not part of the key and still identify uniquely every tuple of the relation. This shows that a superkey does not satisfy the minimality condition.

2.9. Assume that we are going to populate the EMPLOYEE relation whose scheme is shown below. The arrow indicates that the Manager-Id attribute is a foreign key that refers to the Id attribute of the relation. The meaning of this foreign key is that in order to be a manager you must also be an employee. If the tuples (a), (b) and (c) shown below are the first set of tuples that are going to be inserted into the table, can they be inserted without any problem?

EMPLOYEE

Id	Last-Name	Department	Salary	Manager-Id

a. ("190034890", "Gomez","Lila", "Human Resources", 25000, "355899234")
b. ("123434643", "Tuset", "Agustin", "Marketing", 35000, NULL)
c. (NULL, "Tuset", "Maria Pia", "Sales", 40000, NULL)

If tuple (a) is the first tuple to be inserted into the table, the RDBMS will generate a foreign-key violation error since the Manager-Id 355899234 is not currently present as one of the values of the Id column. Since Manager-Id is a FK that references Id, then any non-null value that is inserted into the Manager-Id column must already appear as a value in the Id column.

Tuple (b) can be inserted into the table with no problem because NULL is acceptable as one of the values of the Manager-Id column. Null may be used to indicate that the employee has not been assigned to any manager.

Tuple (c) cannot be inserted because it violates the integrity constraint of the primary key. That is, the value of the primary key cannot be NULL.

2.10. Prove that the Selection operator is commutative with respect to itself. That is, if r is a relation and A and B are attributes of the relation r with $a \in$ Dom(A) and $b \in$ dom(B) then the following identity holds

$$\sigma_{A=a}(\sigma_{B=b}(r)) = \sigma_{B=b}(\sigma_{A=a}(r))$$

Notice that what this identity is saying is that if we need to select all the tuples of the relation r that have an "a" under column "A" and then from this resulting relation select all the tuples that have "b" under column "B", it does not make any difference if we select first from the original relation r all the tuples that have "b" under "B" and then from this resulting set all the tuples that have "a" under column "A".

To prove that two sets A and B are equal we need to show that $A \subseteq B$ and $B \subseteq A$. Since the Selection relation is also a set, to prove the given statement we need to show that

(a) $\sigma_{A=a}(\sigma_{B=b}(r)) \subseteq \sigma_{B=b}(\sigma_{A=a}(r))$ and (b) $\sigma_{B=b}(\sigma_{A=a}(r)) \subseteq \sigma_{A=a}(\sigma_{B=b}(r))$

To prove part (a), that is, $\sigma_{A=a}(\sigma_{B=b}(r)) \subseteq \sigma_{B=b}(\sigma_{A=a}(r))$ we need to take any arbitrary tuple t of $\sigma_{A=a}(\sigma_{B=b}(r))$ and show that this tuple is also a tuple of $\sigma_{B=b}(\sigma_{A=a}(r))$. We can prove this as follows:

Let $t \in \sigma_{A=a}(\sigma_{B=b}(r))$, according to the definition of the Selection operator, this implies that t is an element of the relation $\sigma_{B=b}(r)$ and that t(A) = a. That is $t \in \sigma_{B=b}(r)$ and t(A) = a. Applying the definition of Selection again to $(\sigma_{B=b}(r))$, we have that $t \in r \wedge t(A) = a \wedge t(B) = b$. Grouping conveniently, using the fact that the $\wedge$ operator is commutative and applying the definition of Selection we have that $t \in \sigma_{A=a}(r) \wedge t(B) = b$. Applying the definition of Selection again, we have that $t \in \sigma_{B=b}(\sigma_{A=a}(r))$. Since we have taken an arbitrary tuple t of $\sigma_{A=a}(\sigma_{B=b}(r))$ and shown that it is also a tuple of $\sigma_{B=b}(\sigma_{A=a}(r))$ then, according to the definition of inclusion of sets, $\sigma_{A=a}(\sigma_{B=b}(r)) \subseteq \sigma_{B=b}(\sigma_{A=a}(r))$. This proves part (a). A similar argument can be made to prove part (b). Since parts (a) and (b) are both true then $\sigma_{A=a}(\sigma_{B=b}(r)) = \sigma_{B=b}(\sigma_{A=a}(r))$.

2.11. Given the EMPLOYEE relation shown below, find the last name, department and salary of all employees.

EMPLOYEES

SSN	Last-Name	First-Name	Department	Sex	Salary
122904934	Gomez	Luis	General Office	M	40000
789009233	Nadeau	Frank	Engineering	M	57000
802341175	Knupp	Carroll	Security	M	23000
123425434	Nichols	Lois	Engineering	F	30000
209354532	Nichols	James	Maintenance	M	30000
894393344	Nadeau	Peggy	General Office	F	40000
823123453	Smith	Donald	Maintenance	M	35000
634890303	Smith	Faith	Maintenance	F	34000

To obtain the required information, it is necessary to find the projection of the relation on the attributes Last-Name, Department and Salary. That is, $\pi_{\text{last-name, department, salary}}$(EMPLOYEE). This projection is shown below.

$\pi_{\text{last-name, department, salary}}$(EMPLOYEE).

Last-Name	Department	Salary
Gomez	General Office	40000
Nadeau	Engineering	57000
Knupp	Security	23000
Nichols	Engineering	30000
Nichols	Maintenance	30000
Nadeau	General Office	40000
Smith	Maintenance	35000
Smith	Maintenance	34000

Notice that tuples such as (Nichols, Engineering, 30000) and (Nichols, Maintenance, 30000) are different since they differ in their Department values. Likewise, the tuples (Smith, Maintenance, 35000) and (Smith, Maintenance, 34000) are different since they differ in their Salary values.

2.12. In addition to the EMPLOYEE table of the previous problem, assume that the DEPARTMENT table shown below is also available. Write a query that allows us to find the budget of the department where the employee Luis Gomez works.

DEPARTMENT

Id	Name	Building	Budget
GOF	General Office	North Tower	2000000
ENG	Engineering	North Tower	3000000
SEC	Security	South Tower	1000000
MAI	Maintenance	East Tower	6000000

To answer this question, first we need to retrieve all the information about the given employee. To do this, we calculate $\sigma_{\text{last-name} = \text{"Gomez"}}$(EMPLOYEE). This resulting relation is:

$\sigma_{\text{last-name} = \text{"Gomez"}}$(EMPLOYEE)

Last-Name	Department	Salary
Gomez	General Office	40000

Using this new relation, we then do a projection on the department attribute to find the department in which the given employee works. That is,

$$\pi_{\text{department}}(\sigma_{\text{last-name} = \text{"Gomez"}}(\text{EMPLOYEE}))$$

The resulting relation is:

$\pi_{\text{department}}(\sigma_{\text{last-name} = \text{"Gomez"}}(\text{EMPLOYEE}))$

Department
General Office

Next, we can use the value returned by this relation to do a Selection on the DEPARTMENT relation. That is, in this relation we try to retrieve all the information about the tuple where department = "General Office":

SELECTION $_{\text{Name} = \pi(\text{department}(\sigma_{\text{last-name} = \text{"Gomez"}}(\text{EMPLOYEE})))}$ (DEPARTMENT)

The result of this relation is:

SELECTION $_{\text{Name} = \pi(\text{department}(\sigma_{\text{last-name} = \text{"Gomez"}}(\text{EMPLOYEE})))}$ (DEPARTMENT)

Name	Building	Budget
General Office	North Tower	2000000

Finally, we can do a projection on the attribute budget to obtain the desired result.

$\pi_{\text{department}}$(SELECTION $_{\text{Name} = (\pi_{\text{department}(\sigma_{\text{last-name} = \text{"Gomez"}}(\text{EMPLOYEE})))}}$)(DEPARTMENT))

Budget
2000000

2.13. Write a query that will display the first and last name of each employee, his or her department and the building in which his or her department is located.

To answer this question we first form an Equijoin between the relations EMPLOYEE and DEPARTMENT on the common attributes department (of EMPLOYEE) and name (of DEPARTMENT). Using the result of the Equijoin we can then do a projection on the resulting relation on the required attributes.

The join operation between these two relations is as follows:

EMPLOYEE Join DEPARTMENT

SSN	Last-Name	First-Name	Sex	Salary	Department	Building	Budget
122904934	Gomez	Luis	M	40000	General Office	North Tower	2000000
789009233	Nadeau	Frank	M	57000	Engineering	North Tower	3000000
802341175	Knupp	Carroll	M	23000	Security	South Tower	1000000
123425434	Nichols	Lois	F	30000	Engineering	North Tower	3000000
209354532	Nichols	James	M	30000	Maintenance	East Tower	6000000
894393344	Nadeau	Peggy	F	40000	General Office	North Tower	2000000
823123453	Smith	Donald	M	35000	Maintenance	East Tower	6000000
634890303	Smith	Faith	F	34000	Maintenance	East Tower	6000000

To obtain the information that we are looking for we do a Projection on the Join relation. This projection is as follows:

$\pi_{\text{first-name,last-name,department,building}}$(EMPLOYEE Join DEPARTMENT)

First-Name	Last-Name	Department	Building
Luis	Gomez	General Office	North Tower
Frank	Nadeau	Engineering	North Tower
Carroll	Knupp	Security	South Tower
Lois	Nichols	Engineering	North Tower
James	Nichols	Maintenance	East Tower
Peggy	Nadeau	General Office	North Tower
Donald	Smith	Maintenance	East Tower
Faith	Smith	Maintenance	East Tower

2.14. The Join operation allows us to display specific rows from two related tables. In all our examples, we have displayed rows from one table that have a "match" in another table. However, we may want rows from one of the tables to appear in the Join table even when these rows do not have a match in the other table. The *Outer Join* is an additional relational operation that allows us to accomplish this. The result of an Outer Join operation will contain the same rows as an Equijoin plus a row

corresponding to each row from the original relations that do not match on the join condition. There are two main variations of the Outer Join: the *Left Outer Join* and the *Right Outer Join*. We will denote these two operations as *lr Ljoin rr* and *lr Rjoin rr* where *lr* and *rr* stand for relation names that we will call the *left relation* and the *right relation* respectively. Given two relations r(R) and s(S) with common attributes X, we will define *r Ljoin s* as a relation that contains all the tuples from the EquiJoin of the relations *plus* a row corresponding to each row of the *left relation*, the r relation, that does not contain a matching row in the right relation, the s relation. Likewise, we will define *r Rjoin s* as a relation that contains all the tuples from the EquiJoin of the relations *plus* a row corresponding to each row of the *right relation*, the s relation, that does not contain a matching row in the left relation, the r relation. In case of the Ljoin the "no match" rows from the left table have null values appended to the right. In the Rjoin, the "no match" rows from the right table have null values appended to the left. An additional relational operation, called the *Full Outer Join*, can be defined as the UNION of the Ljoin and Rjoin.[12] Consider the two tables SalesAssociate and Customer given below. Display the name of the SalesAssociate, his or her id and the customer name for all customers. Include in the result all customer names even if they do not have a designated SalesAssociate.

SalesAssociate

Last_Name	Id
McGee	11
Gilson	12
Segui	13
Nguyen	14
Dumas	15

Customer

SalesAssociateId	Name
11	WomanSport
11	Baseball for All
12	Sport Equipments
13	Sam's Sporting Goods
14	The Little Sporting Shop
14	Equipo Deportivo
15	Sportique
	UniSports

[12] RDBMS vendors rarely support this operation because it can be implemented as a Union operation.

In this case the common attribute is Id (of SalesAssociate) and SalesAssociateId (of Customer). The Rjoin table on this common Id is shown below. Notice that the Customer Unisports shows in the Rjoin table even though it has no SalesAssociate.

SalesAssociate Rjoin Customer

Last_Name	Id	Customer
McGee	11	WomanSport
McGee	11	Baseball for All
Gilson	12	Sport Equipments
Segui	13	Sam's Sporting Goods
Nguyen	14	The Little Sporting Shop
Nguyen	14	Equipo Deportivo
Dumas	15	Sportique
		UniSports

Null values (not shown here) have been appended to the left of the "no match" row of the right.

2.15. Another type of operation that allows us to answer a particular type of query that occurs frequently in databases is the DIVISION operator. The division operator allows us to answer questions such as, what tuples from one table have every value that appears in a particular column of another table? The Division operator can be defined as follows: given two relations r(R) and s(S) with A ⊂ R and B ⊂ S and A and B union compatible. The Division relation will be denoted by $r[A \div B]s$ where the relation r is called the *dividend relation*, s is the *divisor relation*, A the *dividend attribute*(*s*) and B the *divisor attribute*(*s*). The result of this operation can be obtained using the following algorithm:[13]

(1) Consider the dividend relation as a binary relation consisting of the dividend attribute(s) (A) and the nondividend attributes C R A.

(2) Find the Projection of the dividend relation on the nondividend attribute(s). That is, find $\pi_C(R)$. Then for each of the tuples obtained in this Projection repeat the following steps:

a. Form a table with all tuples of the dividend relation that includes the tuple selected in the previous step. Make sure that the scheme of this table is the same as the scheme of the dividend relation.

b. Project the table of the previous step on the dividend attribute. Call this set T_i.

[13] Adapted from *Database Management Systems* by D. Tsichritzis and F. Lochovsky, Academic Press, 1977.

(3) Project the divisor relation on the divisor attribute.

(4) Choose the set T_i that contains all the tuples obtained in step 3.

Using this algorithm and the tables BUYER and PRODUCT shown below, find the buyers who have bought every type of product.[14] The query to answer this request is: BUYER [ITEM ÷ CODE] PRODUCT. Notice that the attributes ITEM and CODE are union compatible. ITEM is the dividend attribute and CODE is the divisor attribute.

BUYER

Name	Item
Smith	A
Jones	B
Adams	A
Smith	B
Jones	A
Smith	C

PRODUCT

CODE	COST	PRICE
A	5	4
B	4	4
C	6	9

Applying the algorithm to the given tables we have that:

(1) Since the dividend relation (BUYER) consists of only two attributes, it can be easily divided into two groups; the dividend attribute (ITEM) and nondividend attribute (NAME).

(2) The Projection of the BUYER relation on the nondividend attribute is shown below:

π_{NAME}(BUYER)

NAME
SMITH
JONES
ADAMS

[14] This exercise appears in *Database Management Systems* by D. Tsichritzis and F. Lochovsky, Academic Press, 1977.

Choose tuple SMITH and form a new table T_1 with the tuples of the dividend relation (BUYER) that contain the tuple SMITH. Include all attributes of the dividend relation. This new table is:

Table T_1

Name	Item
Smith	A
Smith	B
Smith	C

Obtain the Projection of this table on the dividend attribute and call this set T_1. That is, $T_1 - \pi_{ITEM}(T_1) - \{(A), (B), (C)\}$. Notice that this is a set of tuples.

Choose the tuple JONES and form a new table T_2 with the tuples of the dividend relation (BUYER) that contain the tuple JONES. This table is shown below:

T_2

Name	Item
Jones	B
Jones	A

Obtain the Projection of this table on the dividend attribute and call this set T_2. That is, $T_2 \quad \pi_{ITEM}(T_2) \quad \{(A), (B)\}$.

Choose the tuple ADAMS and form a new table T_3 with the tuples of the dividend relation (BUYER) that contain the tuple ADAMS. This new table is:

Name	Item
Adams	A

Obtain the Projection of this table on the dividend attribute and call this set T3. That is, $T_3 - \pi_{ITEM}(T_3) - \{(A)\}$.

(3) Find the Projection of the divisor relation (PRODUCT) on the divisor attribute (CODE). That is, find π_{CODE}(PRODUCT). This relation is shown below:

CODE
A
B
C

(4) T_1 is the only set of tuples that contains the three different tuples obtained in the previous step. Since T_1 was obtained when we chose the tuple SMITH, then SMITH is the buyer who has bought all products.

2.16. Given the tables shown below, find the names of the dependents of all Engineers.

EMP

SSN	Last-Name	Title	Department	No-of-Dependents
123456789	Hopkins	Engineer	Construction	2
987654321	Brando	Architect	Design	1
570345228	Kimball	Engineer	Construction	3
923458004	Housden	Lawyer	Main Office	1

DEP

EMPSSN	DEPSSN	Last-Name	First-Name	DOB
123456789	792323653	Hopkins	Gerald	11/12/90
123456789	970254356	Hopkins	Brenda	05/12/92
987654321	805298992	Brando	Greta	08/12/85
570345228	234497909	Kimball	Silvia	02/02/87
570345228	807325224	Kimball	George	04/08/90
570345228	345098772	Kimball	Alice	05/23/92
923458004	943003993	Housden	David	07/12/81

Let us first identify all the Engineers in the EMP table. To do this, let us find $\sigma_{TITLE \quad Engineer}$(EMP). This table is shown below:

$\sigma_{TITLE \quad Engineer}$(EMP)

SSN	Last-Name	Title	Department	No-of-Dependents
123456789	Hopkins	Engineer	Construction	2
570345228	Kimball	Engineer	Construction	3

From this relation that lists all Engineers let us obtain their SSN, Last-Name and Title. To do this we need to obtain $\pi_{SSN,Last\text{-}Name,Title}(\sigma_{TITLE = Engineer}(EMP))$. This relation is:

$\pi_{SSN,Last\text{-}Name,Title}(\sigma_{TITLE = Engineer}(EMP))$

SSN	Last-Name	Title
123456789	Hopkins	Engineer
570345228	Kimball	Engineer

We can now form the Cartesian product of this relation and the DEP table. Let us rename the previous table $\pi_{SSN,Last\text{-}Name,Title}(\sigma_{TITLE = Engineer}(EMP))$ and call it ENG, short for Engineers. The Cartesian product is shown below. Notice that some attributes had to be qualified to avoid duplicate names within the table.

ENG $\otimes$ DEP

SSN	Eng-Last-Name	Title	EMPSSN	DEPSSN	DEP-Last-Name	First-Name	DOB
123456789	Hopkins	Engineer	123456789	792323653	Hopkins	Gerald	11/12/90
123456789	Hopkins	Engineer	123456789	970254356	Hopkins	Brenda	05/12/92
123456789	Hopkins	Engineer	987654321	805298992	Brando	Greta	08/12/85
123456789	Hopkins	Engineer	570345228	234497909	Kimball	Silvia	02/02/87
123456789	Hopkins	Engineer	570345228	807325224	Kimball	George	04/08/90
123456789	Hopkins	Engineer	570345228	345098772	Kimball	Alice	05/23/92
123456789	Hopkins	Engineer	923458004	943003993	Housden	David	07/12/81
570345228	Kimball	Engineer	123456789	792323653	Hopkins	Gerald	11/12/90
570345228	Kimball	Engineer	123456789	970254356	Hopkins	Brenda	05/12/92
570345228	Kimball	Engineer	987654321	805298992	Brando	Greta	08/12/85
570345228	Kimball	Engineer	570345228	234497909	Kimball	Silvia	02/02/87
570345228	Kimball	Engineer	570345228	807325224	Kimball	George	04/08/90
570345228	Kimball	Engineer	570345228	345098772	Kimball	Alice	05/23/92
570345228	Kimball	Engineer	923458004	943003993	Housden	David	07/12/81

The Cartesian product by itself is not useful, but we can use it to retrieve the "real dependents" of the Engineers. To do this we can select all tuples where SSN = EMPSSN. This operation on the Cartesian product is:

$\sigma_{SSN = EMPSSN}(ENG \bowtie DEP)$

SSN	Eng-Last-Name	Title	EMPSSN	DEPSSN	DEP-Last-Name	First-Name	DOB
123456789	Hopkins	Engineer	123456789	792323653	Hopkins	Gerald	11/12/90
123456789	Hopkins	Engineer	123456789	970254356	Hopkins	Brenda	05/12/92
570345228	Kimball	Engineer	570345228	234497909	Kimball	Silvia	02/02/87
570345228	Kimball	Engineer	570345228	807325224	Kimball	George	04/08/90
570345228	Kimball	Engineer	570345228	345098772	Kimball	Alice	05/23/92

The required list of dependents can then be obtained by doing a Projection on the attributes SSN, Eng-Last-Name, First-Name. This Projection is shown below.

$\pi_{SSN,Eng\text{-}Last\text{-}Name,First\text{-}Name}(\sigma_{SSN = EMPSSN}(ENG \bowtie DEP))$

SSN	Eng-Last-Name	First-Name
123456789	Hopkins	Gerald
123456789	Hopkins	Brenda
570345228	Kimball	Silvia
570345228	Kimball	George
570345228	Kimball	Alice

2.17. The theta-Join operation between two relations r(R) and s(S), generally denoted by $r \bowtie_{\theta} s$, is a generalization of the Equijoin that combines a Selection with a Cartesian product. Using the tables shown below, find the items that each customer can afford based on his or her credit.

Product

Id	Name	Price
00123	Basketball	125
00343	Bike	550
00489	Golf Clubs	980

Customer

Id	Credit
C3920	1500
C563	350
C332	200

The Theta Join can be simulated as follows:

Form the Cartesian product of the two given relations. That is, find Customer $\otimes$ Product. Notice that some attributes had to be qualified.

Customer $\otimes$ Product

CustomerId	Credit	ProductId	Name	Price
C3920	1500	00123	Basketball	125
C3920	1500	00343	Bike	550
C3920	1500	00489	Golf Clubs	980
C563	350	00123	Basketball	125
C563	350	00343	Bike	550
C563	350	00489	Golf Clubs	980
C332	200	00123	Basketball	125
C332	200	00343	Bike	550
C332	200	00489	Golf Clubs	980

Using the result of this Cartesian product, we can now do a SELECTION where the selection criterion is Credit $\geq$ Price. That is, let us find $\sigma_{Credit \geq Price}$(Customer $\otimes$ Product). This relation is shown below.

$\sigma_{Credit \geq Price}$(Customer $\otimes$ Product)

CustomerId	Credit	ProductId	Name	Price
C3920	1500	00123	Basketball	125
C3920	1500	00343	Bike	550
C3920	1500	00489	Golf Clubs	980
C563	350	00123	Basketball	125
C332	200	00123	Basketball	125

Taking the Projection on the attributes CustomerId, ProductId, Name and Price we obtain the required information.

CustomerId	ProductId	Name	Price
C3920	00123	Basketball	125
C3920	00343	Bike	550
C3920	00489	Golf Clubs	980
C563	00123	Basketball	125
C332	00123	Basketball	125

2.18. How can the Join operation be used to simulate a Selection?

To simulate a selection using a join operation, proceed as follows: Given a relation r(R), an attribute A of r and a value a ∈ Dom(A) assume that you want to obtain $\sigma_{A=a}(r)$. To obtain this Selection, create a new relation *s* with a single attribute and a single tuple. Let A be the only attribute of this relation and *a* its only tuple. The new relation is shown below.

$\sigma_{A=a}(r)$

A
a

Then form the Equijon between r and $\sigma_{A=a}(r)$ on the common attribute A. That is, form σ(A) Join r. This join is equivalent to $\sigma_{A=a}(r)$.

2.19. Given the relations DOCTORS and NURSES, find the last names and supervisors of the medical personnel that work in the Cardiology department. What assumptions are necessary to be able to present the result as a single table?

DOCTORS

Id	Last-Name	Department	Supervisor
120534533	Silver	Cardiology	Dr. Jones
380237302	Roswell	Radiology	Dr. Stewart
293982983	Hartman	Oncology	Dr. Smith
727873233	Stanley	Cardiology	Dr. Sing
982391179	Bartley	Pediatrics	Dr. Spresser
425370983	Jones	Rehab	Dr. Sams

NURSES

Id	Last-Name	Department	Supervisor
930272434	Clinton	Pediatrics	Mrs. Alexander
8923903133	Alvarez	Cardiology	Ms. Hussain
321231234	Lewis	Rehab	Mr. Hanson
930111341	Felton	Oncology	Mr. Lenkerd
823907592	Traubaugh	Pediatrics	Ms. Sullivan
392983999	Rissler	Cardiology	Mr. Sanchez

To answer this query we need to proceed as follows:
First find the names of the doctors and nurses that work in the Cardiology department. The queries to find the doctors and nurses who work in the Cardiology department are shown below.

$\sigma_{(DEPARTMENT - CARDIOLOGY}$(DOCTOR)

Id	Last-Name	Department	Supervisor
120534533	Silver	Cardiology	Dr. Jones
727873233	Stanley	Cardiology	Dr. Sing

$\sigma_{(DEPARTMENT - CARDIOLOGY}$(NURSE)

Id	Last-Name	Department	Supervisor
8923903133	Alvarez	Cardiology	Ms. Hussain
392983999	Rissler	Cardiology	Mr. Sanchez

From the two previous relations we can find the Last-Name and Supervisor of both doctors and nurses. The queries to obtain this information are:

$\pi_{Last-Name,Supervisor}(\sigma_{DEPARTMENT \quad CARDIOLOGY}$(DOCTOR))

Last-Name	Supervisor
Silver	Dr. Jones
Stanley	Dr. Sing

$\pi_{\text{Last-Name,Supervisor}}(\sigma_{\text{DEPARTMENT = CARDIOLOGY}}(\text{NURSE}))$

Last-Name	Supervisor
Alvarez	Ms. Hussain
Rissler	Mr. Sanchez

To present the previous two results as a single table, let us form the UNION of these two relations. To be able to do this both relations must have the same number of attributes and the data type of these attributes must be the same.

Last-Name	Supervisor
Silver	Dr. Jones
Stanley	Dr. Sing
Alvarez	Ms. Hussain
Rissler	Mr. Sanchez

2.20. Given relations r(R), s(S) and the operations shown below, what can be said about the cardinality of the resulting relations?

(a) $s \cup r$ (b) $r \cap s$ (c) $r - s$ (d) $r \times s$

(e) $\sigma_{A=a}(r)$ for a $\in$ Dom(A) (f) $\pi_A(r)$ if A is in the scheme of r.

a. The cardinality of a Union operation depends on the number of identical tuples currently present in r and s. If the relations are disjoint, that is, if they do not have common tuples, the cardinality of the Union is equal to the sum of the cardinalities of the relations. If all tuples of relation r are contained in relation s, then the cardinality of the Union is equal to the cardinality of the s. In case the relations have some but not all tuples in common the cardinality of the Union is less or equal to the sum of the cardinalities of the relations.

b. The cardinality of the Intersection may be zero in case the relations do not have any common tuples. If all tuples of one relation are included in the other relation then the cardinality of the Intersection is the minimum of the two cardinalities. In cases where the relations have some but not all tuples in common then the cardinality of the Intersection is less or equal to the minimum of the cardinalities.

c. If the Difference r − s is not the empty relation, then the cardinality of the Difference is less or equal to the cardinality of r. If all the tuples of s are included in r then the cardinality of the Difference relation is the difference of the cardinalities. That is the cardinality of r minus the cardinality of s.

d. The cardinality of the Cartesian product is the product of the cardinalities of the relation.

e. The cardinality of the Selection is less or equal to the cardinality of r.

f. The cardinality of the Projection is less than the cardinality of r if there are duplicate rows in the Projection. If there are not duplicate rows then the cardinality of the Projection is equal to the cardinality of the relation r.

Supplementary Problems

2.21. Given the following tables shown below, determine which of these tables can also represent relations. Explain why.

Table A

A	B	C	D
1	88	80	0
	45	23	89
25	87	23	43
46	26	39	55
53	23	33	43
16	57	48	48

Table B

A	B	C	D
1	88	80	0
16	57	48	48
25	87	23	43
46	26	39	55
53	23	33	43
16	57	48	48

Table C

A	B	C	D
23WEE	88	80	0
16	57	48	48
25WE	87	23	43
46RE	26	39	55
53WT	23	33	43
16E	57	48	48

2.22. Assume that a relation instance has a degree of 7 and a cardinality of 15. How many attributes does this relation have and how many different rows are currently present in the relation?

2.23. Assume that you have a relation r(R) and that you perform a Projection on this relation on the set of attributes X ($X \subseteq R$) of the relation. If you then do a Selection on the Projection relation to retrieve all tuples that satisfy the condition A a, what is the relationship between A and the attributes of the Projection?

2.24. Consider the relations r(ABC) and s(ACDE). Assume also that $a \in Dom(A)$, $b \in Dom(B)$, $c \in Dom(C)$ and $d \in Dom(D)$. Which of the following expressions are legal to carry out?

a. $r \cup s$ **b.** $\pi_B(r) \cap \pi_B(r)$ **c.** $\sigma_{D=d}(r)$

2.25. Find an appropriate key for each of the relational schemes below. Are the keys single or composite? If the current set of attributes is not appropriate explain why and propose a solution.

a. ORDER(Order-No, Order-Date, SalesRep, Total-Amount, Discount, Ship-Date). Assume that order numbers are reset daily. A customer-Id can place more than one order per day.
b. STORE(Location, No-of-Employees, Total-Monthly-Sales, Manager, City). Assume that there may be more than one store located in the same city.
c. PAYMENT(Customer-Id, Account, Amount-Paid, Date-Paid, Type-Payment, Discount). Assume that a customer may have more than one account and that he or she can make several payments on any day but no more than one payment per day can be applied to each account.

2.26. Consider the relations shown below and the attributes that have been selected as PK for these relations. Justify if the choices for PK are appropriate or not.

a. EMPLOYEE (ID, <u>LAST-NAME, SALARY</u>).
b. STUDENT (<u>NAME, ADVISOR</u>, MAJOR). Assume that each student has a unique advisor. An advisor may have more than one advisee.
c. STUDENT (<u>ID, NAME</u>, ADVISOR). Assume that each student has a unique advisor.

2.27. Given the TRAVELER and RESORT tables, find the names of all the customers that have visited all the resorts that currently appear in the RESORT table. What operation will you use?

TRAVELER

Customer	Country
Alton	Mexico
Russell	Mexico
Jones	Mexico
Martin	Mexico
Alton	England
Jones	England
Russell	Brazil
Jones	Brazil
Martin	Brazil
Alton	Spain
Russell	Spain
Jones	Spain

RESORT

Country	Resort Location	Price
Mexico	Cancun	1200
England	Liverpool	1790
Brazil	Rio de Janeiro	1790
Spain	Marbella	2200

2.28. Assume that you have the two relations considered in Example 2.4. What would happen if you try to delete from the DEPARTMENT table the tuple with Id 10? Assume that this department has been eliminated from the company and all its employees have to be laid off. How can you avoid getting any errors from the system when you try to delete the tuple with Id 10?

2.29. Assume that you have two relations r and s defined over the same scheme R and that $X \subset R$. Using tables of your own, write an example to illustrate that in the expressions shown below the left hand of the expression is always included in the right hand but not the other way around.

a. $\pi_X(r \cap s) = \pi_X(r) \cap \pi_B(s)$
b. $\pi_X(r \cup s) = \pi_X(r) \cup \pi_B(s)$

2.30. Using the relations shown below find the following operations:

a. $\sigma_{A=a}(r)$ **b.** $\pi_{A,B}(r)$ **c.** $r \cup s$ **d.** $r \bowtie s$ **e.** $r - s$

r

A	B	C
a	1	a
b	1	b
a	1	c
c	2	d

s

A	B	C
a	1	a
a	3	d

Answers to Supplementary Problems

2.21. Table A cannot represent a relation because the PK cannot be NULL or have no value. Table B cannot represent a relation because two of its rows are identical. Table C may or may not represent a relation. If the data type of the key is character then it is possible for this table to be a relation. However, if the data type is supposed to be numeric then the table is not a relation.

2.22. Since the degree is 7 the relation has 7 attributes. Since the cardinality is 15 there are 15 different tuples currently present in the relation.

2.23. Attribute A must be one of the attributes of the set X on which the Projection is taken.

2.24. a. This Union operation is not legal because the relations do not have the same number of attributes.

b. This operation is legal if the attributes are union compatible.

c. This operation is illegal because the attribute D is not an element of the scheme of relation r.

2.25. a. The PK key for this relation is a composite key. The attributes of the key are: Order-No and Order-Date.

b. The current set of attributes does not allow us to choose a key without imposing unnecessary constraints on the relation. The best solution is to add a new attribute Store-Id and use it to uniquely identify each of stores. The pair Location and Manager-Last-Name is not a viable solution since it imposes on the data the unnecessary condition. Before hiring a new manager the database must be checked to see if there is another manager with similar last name. This does not seem to be a good hiring practice.

c. The key for this relation is a composite key formed by the following attributes: Customer-Id, Account and Date-Paid.

2.26. a. This composite attribute is not an appropriate key. Keys must be keys regardless of the data or for how long the relation is going to be used. In this case, it is possible that two different employees may have the same last-name and salary.

b. This composite key is not an appropriate key either. An advisor may have two different advisees with the same name.

c. This composite key is not appropriate because it violates the minimality property of the key. The attribute Name can be discarded. It is not necessary to uniquely identify the tuples of the relation.

2.27. To find the name of all travelers that have visited all the available resorts currently listed in the RESORT table, you must use a division operator. Jones has visited all the available resorts.

2.28. The system will generate an error because that tuple is being referenced by some tuples in the EMPLOYEE table. Some systems allow you to DELETE a tuple with the CASCADE option; what this does is to drop the tuple and the foreign key constraint that exists with the referencing table. If this not possible try to delete the tuple from the EMPLOYEE table before DELETING the department tuple from the DEPARTMENT table. Obviously, this is not an ideal solution.

2.29. Answers will vary. Each table you make may look different.

2.30. a. $\sigma_{A=a}(r)$

A	B	C
a	1	a
a	1	c

b. $\pi_{A,B}(r)$

A	B
a	1
b	1
c	2

c. $r \bowtie s$

A	B	C
a	1	a
b	1	b
a	1	c
c	2	d
a	3	d

d. $r \times s$

r.A	r.B	r.C	s.A	s.B	s.C
a	1	a	a	1	a
a	1	a	a	3	d
b	1	b	a	1	a
b	1	b	a	3	d
a	1	c	a	1	a
a	1	c	a	3	d
c	2	d	a	1	a
c	2	d	a	3	d

e. $r - s$

A	B	C
b	1	b
a	1	c
c	2	d

CHAPTER 3

An Introduction to SQL

3.1 Introduction to SQL Language

The previous chapter detailed the theoretical and mathematical background for creating, maintaining and retrieving items from tables in relational databases. This chapter presents a general introduction to how these tasks are performed for particular RDBMS systems. We will present only an overview of SQL. For more detailed information on the capabilities of this language, consult other sources that specifically deal with SQL as a language.[1]

SQL is the standard computer language used to communicate with relational database management systems. The SQL standard has been defined by the American National Standard Institute (ANSI) and the International Standards Organization (ISO). The official name of the language is International Standard Database Language SQL (1992). The latest version of this standard is commonly referred to as SQL/92 or SQL2. In this book, we will refer to this standard as the ANSI/ISO SQL standard or just the SQL standard.

The ORACLE Corporation, formerly Relational Software Inc, produced the first commercial implementation of the language in 1979. Although most relational database vendors support SQL/92, compliance with the standard is not 100%. Currently, there exist several flavors of SQL on the market since each RDBMS vendor tries to extend the standard to increase the commercial appeal of its product. In this chapter, we adhere to the SQL/92 standard whenever possible. However, we will illustrate the implementations of these features using

[1] One such book is *Schaum's Outline: Fundamentals of SQL Programming* by the authors of this publication. These two books are intended as companions and together would form a basis for a complete study of relational databases.

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Personal Oracle 8, the PC version of the ORACLE relational database management system. It is important to note that many RDBMS vendors provide more interactive ways to create and maintain databases using tables and/or windows. The examples we will use in this area come from Microsoft Access. Although we will show alternate ways to maintain tables and create queries, the reader should remember that SQL is still the background language used by MS Access. From the MS Access query interface, one can always view the SQL that accomplishes the same purpose.

One of the main characteristics of the SQL language is that it is a *declarative* or *nonprocedural language*. From the programmer's point of view, this implies that the programmer does not need to specify step by step all the operations that the computer needs to carry out to obtain a particular result. Instead, the programmer indicates to the database management system what needs to be accomplished and then lets the system decide on its own how to obtain the desired result.

The statements or commands that comprise the SQL language are generally divided into two major categories or *data sublanguages*, DDL and DML, which were explained in Chapter 1. Each sublanguage is concerned with a particular aspect of the language. DDL includes statements that support the definition or creation of database objects such as tables, indexes, sequences and views. Some of the most commonly used DDL statements are the different forms of the `CREATE`, `ALTER` and `DROP` commands. DML includes statements that allow the processing or manipulation of database objects. Some of the most commonly used DML statements are the different modalities of the `SELECT`, `INSERT`, `DELETE` and `UPDATE` statements. It is important to observe that all objects created in a database are stored in the data dictionary or catalog.

The SQL language can be used interactively or in its embedded form. *Interactive SQL* allows the user to issue commands[2] directly to the DBMS and receive the results back as soon as they are produced. When *embedded SQL* is used, the SQL statements are included as part of a program written in a general-purpose language such as C, C++ or COBOL. In this case, we refer to the general-purpose programming language as the *host language*. The main reason for using embedded SQL is to use additional programming language features that are not generally supported by SQL.

When embedded SQL is used, the user does not observe directly the output of the different SQL statements. Instead, the results are passed back in variables or procedure parameters.

As a general rule, any SQL instruction that can be used interactively can also be used as part of an application program. However, the user needs to keep in mind that there may be some syntactical differences in the SQL statements when they are used interactively or when they are embedded into a program. In this chapter, we only consider SQL in its interactive form.

[2] Some authors refer to instructions used in interactive mode as commands and embedded instructions as statements. In this book, we will use these two terms interchangeably.

3.1.1 NAME CONVENTIONS FOR DATABASE OBJECTS

Database objects, including tables and attribute names, must obey certain rules or conventions that may vary from one RDBMS to another. Failing to follow the naming conventions of a particular RDBMS may cause errors. However, users are generally "safe" if they stay within the following guidelines.

- Names can be from 1 to 30 characters long (64 in MS Access) with the exception that the database's names may be limited to 8 characters as is the case with any ORACLE database.
- Names must begin with a letter (lower or upper-case); the remaining characters can be any combination of upper or lower-case letters, digits or the underscore character. MS Access allows spaces in the name, but then requires the use of square brackets, e.g. [My pets].

Example 3.1

Tell whether these names are usually valid or invalid according to the SQL naming conventions. If invalid, explain the reason.

a. Database names: *Employee, PurchaseOrders, Sales Data*
b. Table names: *PARTS, Employee_Birthdays, Vendor-Names*
c. Attribute names: *Computer_ID_Number, $_Amount_Paid, addresscitystatezipcode*

a. Database names: *Employee* — valid; *PurchaseOrders* — invalid because in many versions of SQL, including Oracle, database names are limited to 8 characters; *Sales Data* — invalid because spaces are not allowed except in MS Access along with square brackets ([Sales Data]).
b. Table names: *PARTS* — valid because the case does not matter — this would be the same as *parts*; *Employee_Birthdays* — valid because table names can be any length up to 30 and may contain the underline character; *Vendor-Names* — invalid because only letters, digits, and the underline character may be used.
c. Attribute names: *Computer_ID_Number* — valid; *$_Amount_Paid* — invalid because characters other than letters, digits, and the underscore character are not allowed; *addresscitystatezipcode* — valid but not very smart. Not only is it hard to read with no underscore characters between the words, but also it implies that many different items would be included in the one column. Choose the columns so that one item of data is stored for each record. This attribute should really be divided into four different columns.

3.1.2 STRUCTURE OF SQL STATEMENTS/SQL WRITING GUIDELINES

Any SQL statement or command is a combination of one or more clauses. *Clauses* are, in general, introduced by keywords. An example of a SQL statement

is shown in Fig. 3-1. At this moment, the reader should not be concerned with the inner working of this statement but only with its structural aspects.

SELECT column-name-1, column-name-2,...column-name-N

FROM table-name

WHERE Boolean-condition

ORDER BY column-name [ASC | DESC][, column-name [ASC | DESC]....];

Fig. 3-1. Keywords and clauses in the structure of a SQL statement.

In this SQL statement, we can distinguish four keywords and four clauses. The keywords are shown in bold in Fig. 3-1. As indicated before, a keyword is a word that has a specific meaning within the language. To use a keyword other than in its specific context will generate errors. The four clauses of this SQL statement are underlined in Fig. 3-1. Notice that each clause starts with a keyword.

In the preceding statement, the first two clauses (SELECT and FROM) are mandatory and the last two (WHERE and ORDER BY) are optional. When describing the syntax of SQL statements we will indicate optional keywords or clauses by enclosing them in square brackets. Using this convention, we can rewrite the preceding statement as shown in Fig. 3-2.

SELECT column-name-1, column-name-2,...column-name-N

FROM table-name

[WHERE condition]

[**ORDER BY** column-name [ASC | DESC][, column-name [ASC | DESC]....]];

Fig. 3-2. Mandatory and optional clauses explicitly indicated in a SQL statement.

Notice that in the ORDER BY clause we have enclosed in square brackets the words ASC (ascending) and DESC (descending) separated by a '|' character. This character, sometimes called the "pipe" character, is used to separate the different options that a user can choose when writing a SQL statement. The user can choose one and only one from each set of options. Notice also that we have underlined the word ASC. This indicates that this word is a *default value*. That is, a value that will be used by the system when the user does not choose a different option from the set of available choices. In Fig. 3-2, whenever the ORDER BY clause is used and the user does not choose the DESC option the RDBMS will use the ASC option by default.

When writing SQL statements or commands it is useful to follow certain rules and guidelines to improve the readability of the statements and to facilitate their editing if this is necessary. Some of the guidelines that the reader should keep in mind are:

- SQL statements are not case sensitive. However, keywords that start a clause are generally written in upper case to improve readability of the SQL statements.
- SQL statements can be written in one or more lines. It is customary to write each clause in its own line.
- Keywords cannot be split across lines and, with very few exceptions, cannot be abbreviated.
- SQL statements end in a semicolon. This semicolon must follow the last clause of the statement but it does not have to be in the same line.

3.2 Table Creation

In any RDBMS, tables are the basic unit of data storage. Tables hold all of the user-accessible data. To create a table it is necessary to name the table and all the attributes that comprise it. In addition, for every attribute the user needs to define its data type and, if necessary, the appropriate constraint or constraints. The name of the table identifies it as a unique object within the RDBMS.[3] Column or attribute names serve to differentiate the attributes from one another. Attribute names must be unique within the table. The data type of each attribute defines the characteristics of its underlying domain. The constraint or constraints that may be defined for a column impose conditions that need to be satisfied by all the values stored in the column. Tables in SQL are created using the **CREATE TABLE** statement or command. Fig. 3-3 shows the basic form of this command. In this section, we will assume that every time a table is created there is no other table by the same name previously created by the same user in his or her *schema*,[4] as explained in Chapter 1. (If a table already exists with that name, and the table is to be redefined, use the **DROP TABLE** command.) In the database lingo, tables created by a user are said to be "owned" by the user.

```
CREATE TABLE table-name
(
  column-name-1        data-type-1     [constraint],
  column-name-2        data-type-2     [constraint],
        ..
  column-name-N        data-type-N     [constraint]
);
```

Fig. 3-3. A basic syntax of the CREATE TABLE command.

[3] Formally, it defines the table as a unique object within the user's tablespace or schema or within the entire system depending upon whether or not the table has been defined as public.

[4] This term refers to a collection of logical structures of data or schema objects. Each user owns a single schema whose name is that of its owner. Any user, with the appropriate privileges, can create objects in his or her own schema. Some schema objects are tables, synonyms, indexes, sequences and views.

When describing the syntax of the CREATE TABLE command we will call a *column definition line* every line of the form

column-name data type [constraint],

where optional elements are enclosed in square brackets. Therefore, according to this notation, every column definition line requires a column name and a data type. Constraints are optional. Usually, when typing a CREATE TABLE command, each column definition line is written in a separate line for readability. Commas separate column definition lines except for the last line which is followed by a parenthesis. As any other SQL command, a semicolon follows the closing parenthesis.

Example 3.2
Write the SQL statements to create a table called SAMPLE TABLE with two attributes: Attribute 1 is text no more than 15 characters long and Attribute 2 is currency. NOTE: Recall from Table 2-1 that in the Oracle implementation of SQL, text of varying length is indicated by Varchar2(max-size) and currency would simply be a number with two decimal places.

```
CREATE TABLE Sample_Table
(
 Attribute_1    Varchar2(15),
 Attribute_2    Number(4,2)
);
```

Notice in this code that the naming rules from Section 3.1.1 have been followed. Spaces in names of tables or attributes are not allowed and usually replaced with the underscore character.

3.2.1 CONSTRAINT IMPLICATIONS

The SQL standard requires that, whenever a constraint is defined, the constraint be given a name. Constraints can be named explicitly by the user at the time a table is created or modified. Otherwise, the constraint is named internally by the RDBMS. Constraints that are named by the user are called *named constraints*. Constraints named by the RDBMS are vendor dependent and are called *unnamed constraints*. Although constraint names can follow the conventions indicated in Section 3.1.1, we will use the following format for *named* constraints:

CONSTRAINT table-name-column-name-suffix

where the clause CONSTRAINT is *mandatory* and the suffix is a one or two letters sequence that indicates the type of the constraint. Table 3-1 shows a list of the suffixes that we will use in this book. Unnamed constraints *must not* be preceded by the CONSTRAINT clause.

Table 3-1. Suffix conventions for named constraints.

SUFFIX	MEANING
PK	Primary key
FK	Foreign key
NN	Not NULL
U	Unique

Some of the constraints that we will consider in this chapter are shown in Table 3-2. A constraint defined as part of a column definition is called a *column constraint*. This type of constraint can be used to impose a single condition on the column in which it is defined. A constraint that is part of a table definition is called a *table constraint*. This type of constraint can be used to define more than one constraint on any column of the table. We will only consider column constraints here. See a SQL reference for an explanation of table constraints.

Table 3-2. Basic column and table constraints.

CONSTRAINT	DEFINITION
NOT NULL (*)	Prevents NULL values from being entered into a column.
UNIQUE (**)	Prevents duplicate values from being entered into a column.
PRIMARY KEY (***)	Requires that all values entered into the column be unique and different than NULL.

* column_constraint.

** column_constraint or table constraint depending upon whether or not it is applied to one or more columns respectively.

*** column_constraint when defining a single PK and a table_constraint when defining a composite PK.

Example 3.3

A university allows students to buy meals using a Flex Card. They purchase a certain amount and each time they use the card the appropriate amount is subtracted from their account. Create the table `Flex_Card` with the attributes and assumptions indicated below. Choose the most appropriate data types.
Attributes: student name, card number, starting value, value left, and pin number.
Assumptions: The attribute student name may have up to 25 characters. The attributes value left and original value are measured in dollars and cents. The attribute card number may have up to 15 digits. The pin number attribute is always 12 characters long.

The SQL instruction to create the `Flex_Card` table is as follows:

```
CREATE TABLE Flex_Card
( Student_Name          VARCHAR2(25),
  Card_Number           VARCHAR2(15),
  Starting_Value        NUMBER(4,2),
  Value_Left            NUMBER(4,2),
  Pin_Number            CHAR(12)
);
```

The attribute `Student_Name` is obviously of type character. Since not all student names are 25 characters long, the data type of this column is `Varchar2(25)`. The `Card_Number` and `Pin_Number` columns are both of character type because they are not involved in any type of computation. Since `Card_Number` may vary in length, its data type is `Varchar2(15)`. The data type of `Pin_Number` is `Char(12)` since this column has a fixed length. The `Starting_Value` and `Value_Left` columns are both numerical quantities that may have up to 4 digits including 2 decimal places. Observe the use of the underscore character to improve the readability of the attribute names.

Example 3.4
Rewrite the `CREATE TABLE` of the previous example with the attribute `Card_Number` defined as the primary key and the attribute `Pin_Number` defined as unique. Use unnamed constraints.

In this case, we may use a column constraint to define the attribute `Card_Number` as the PK. By definition of PK, this attribute is also `UNIQUE` and therefore it is not necessary to define it as such. The attribute `Pin_Number` is only defined as a `UNIQUE` attribute. The reader should be aware that these two constraints behave a little bit differently. The `PRIMARY KEY` constraint, in addition to requiring that the values be unique, also guarantees that the values of the `Card_Number` column cannot be `NULL`. The `UNIQUE` constraint of the `Pin_Number` column does not allow duplicate values in this column but it does allow `NULL` values. The new `CREATE TABLE` command is shown below.

```
CREATE TABLE Flex_Card
( Student_Name          VARCHAR2(25),
  Card_Number           VARCHAR2(15) PRIMARY KEY,
  Starting_Value        NUMBER(4,2),
  Value_Left            NUMBER(4,2),
  Pin_Number            CHAR(12)UNIQUE
);
```

Example 3.5
Rewrite the `CREATE TABLE` of the previous example using named constraints.

Following the convention for naming constraints and using the suffixes of Table 3-1, the constraints associated with the attributes `Card_Number` and `Pin_Number` are respectively

`Calling_Card_Card_Number_PK` and `Calling_Card_Pin_Number_U`

The corresponding `CREATE TABLE` command is shown below:

```
CREATE TABLE Flex_Card
(Student_Name      VARCHAR2(25),
 Card_Number       VARCHAR2(15) CONSTRAINT
                   calling_card_card_number_PK PRIMARY KEY,
 Starting_Value    NUMBER(4,2),
 Value_Left        NUMBER(4,2),
 Pin_Number        CHAR(12) CONSTRAINT
                   calling_card_pin_number_U UNIQUE);
```

Notice that the column definition for the attributes `Card_Number` and `Pin_Number` have been written in more than one line to fit the width of this page.

3.2.2 CREATING TABLES AND CONSTRAINTS IN MS ACCESS

MS Access provides a way to create the table directly through the use of the table design view. Fig. 3-4 shows the window where the user can type in the field names, choose a data type, and give a brief description of the column. The table from Example 3.2 has been defined. Notice that table and attribute names are allowed to contain spaces. In Fig. 3-4, *Attribute 1* is the primary key, as indicated by the picture of the key to the left of the field name. Limits on size, default values, and many other constraints can be indicated through the use of the bottom half of the window. The *Indexed Yes(No duplicates)* will enforce the SQL Unique constraint, and if the line *Required* is set to *Yes* then NULL values are not allowed. Consult a reference on MS Access for a detailed guide to using other sections of this screen.

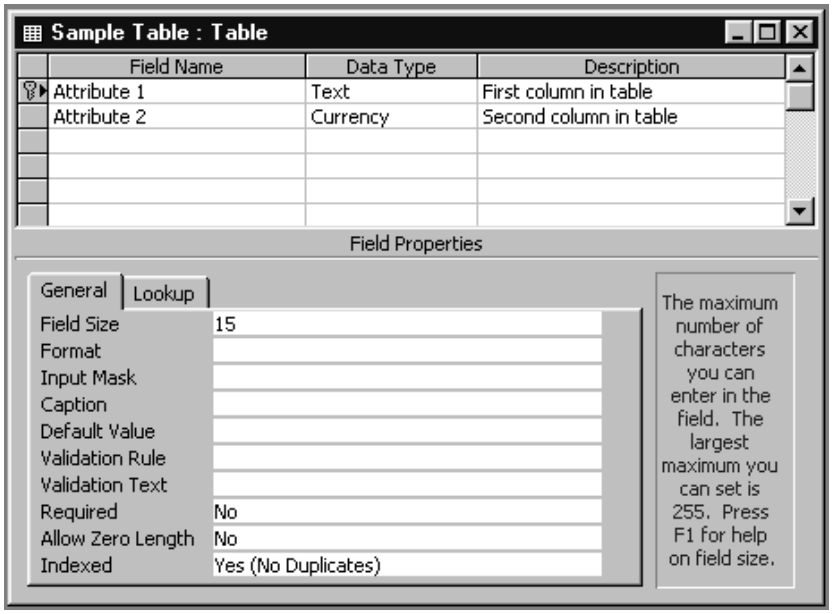
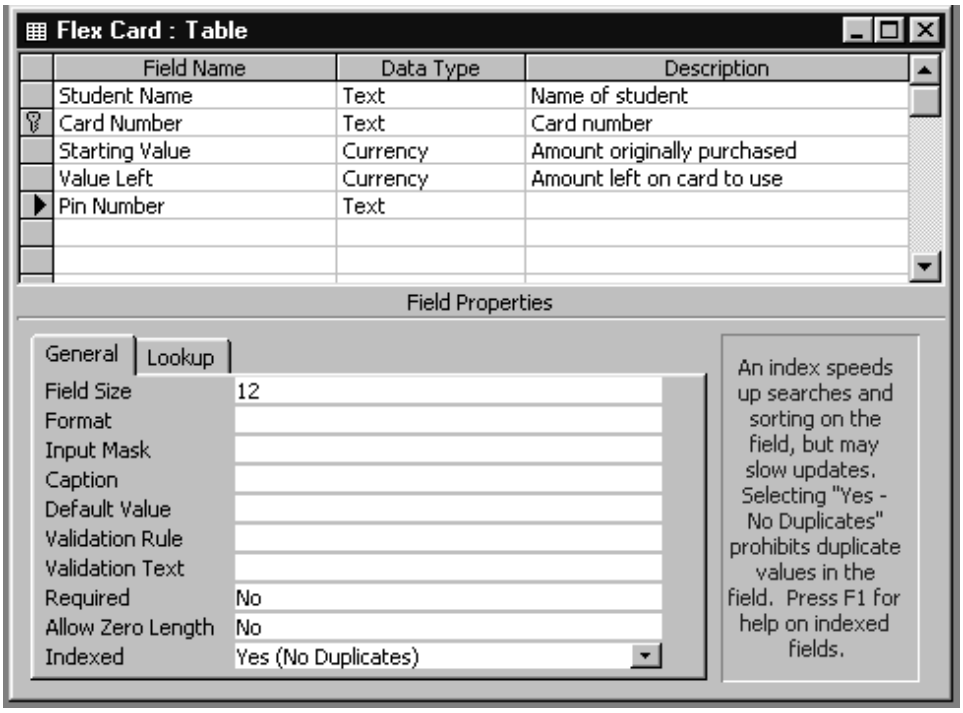


Fig. 3-4. Table design view in MS Access.

Example 3.6
Show the Flex Card table design as it would be created using MS Access. Be sure to use all the constraints shown in Example 3.4.



The design view of the table shows that the Card Number is the primary key. The Pin Number can be forced to be Unique by selecting the *No Duplicates* value for the property *Indexed*.

3.2.3 POPULATING AND MAINTAINING TABLES

After creating a table, the user may add rows to the table using the **INSERT INTO** command. The process of adding rows to a table is called *populating the table*. In its simplest form, this command allows the user to add rows to a table *one row* at a time. Fig. 3-5 shows the basic syntax of this command. More complex insertion techniques are available, but beyond the scope of this chapter. Section 2.7.1 described the care that must be taken when trying to insert a tuple into a table. The INSERT INTO commands must be formatted correctly and not violate any of the rules listed in Chapter 2. If the INSERT INTO operation fails, an error message will appear.

```
INSERT INTO table-name (column-1, column-2,...column-N)
VALUES (value-1, value-2,...value-N);
```

Fig. 3-5. Basic form of the INSERT statement.

In Fig. 3-5, `column-1`, `column-2`,...`column-N` are the table's columns, and `value-1`, `value-2`, `value-3`,...`value-N` are the values that will be inserted into their corresponding columns. Notice that the value to be inserted into a column must be of the same data type that was specified for that column when its table was created. It is important to keep in mind that we *must* specify a value in the `VALUES` clause for each column that appears in the column list.

Example 3.7
Insert into the Flex_Card table the data indicated below.

Student_Name	Card_Number	Starting_Value	Value_Left	Pin Number
Ann Stephens	1237096435	20.00	12.45	987234569871
John Gilmore	5497443544	15.00	11.37	433809835833

Since the basic form of the `INSERT INTO` command only allows the insertion of one row at a time, it is necessary to use two consecutive `INSERT INTO` commands to add these two tuples to the Flex_Card table. Notice that all character data has been enclosed in single quotes.

```
INSERT INTO Flex_Card (Student_Name, Card_Number,
                        Starting_Value,Value_Left,Pin_Number)
VALUES ('ANN STEPHENS', '1237096435', 20.00, 12.45,
        '987234569871');
INSERT INTO Flex_Card (Student_Name, Card_Number,
                        Starting_Value,Value_Left,Pin_Number)
VALUES ('JOHN GILMORE', '5497443544', 15.00, 11.37,
        '433809835833');
COMMIT;
```

The `COMMIT` command that follows the last `INSERT INTO` command is necessary to make the changes to the table permanently. The `COMMIT` command will be explained in Chapter 6.

The reader should be aware that the order of the columns following the `INTO` clause is immaterial provided that their corresponding values appear in the same order in the `VALUES` clause. This allows us to fill in the columns of a row in any order. Example 3.8 illustrates this.

EXAMPLE 3.8
Insert into the Flex_Card table the rows shown below, and fill in the columns in the following sequence: `Pin_Number`, `Card_Number`, `Student_Name`, `Starting_Value`, and `Value_Left`.

Student_Name	Card_Number	Starting_Value	Value_Left	Pin Number
John Darc	2137096435	20.00	20.00	125234569871
Richard Lion	3817443544	20.00	20.00	632809835833

As in the previous example, we need two consecutive INSERT statements to add these rows to the Flex_Card table. The new INSERT statements are as follows:

```
INSERT INTO Flex_Card (Pin_Number,Card_Number,Student_Name,
                       Starting_Value,Value_Left)
VALUES ('125234569871', '2137096435', 'JOAN DARC', 20.00,
        20.00);
INSERT INTO Flex_Card (Pin_Number, Card_Number, Student_Name,
                       Starting_Value,Value_Left)
VALUES ('632809835833', '3817443544', 'RICHARD LION',
        20.00, 20.00);
COMMIT;
```

As part of the normal maintenance of a database, one or more rows may need to be updated or removed from the database. For instance, in the Flex_Card table, the amount left on the card may change, or the student might leave school. The SQL command that allows the user to delete rows from a table is the DELETE command (see Section 2.7.2). The SQL command that allows the user to update values in existing rows is the UPDATE command (see Section 2.7.3).

The DELETE command can be used to remove rows that meet certain conditions or it can be used to remove all rows from a particular table. The syntax of this command to remove rows that meet certain conditions is shown here:

```
DELETE FROM table-name WHERE condition;
```

The syntax of the DELETE command to remove all rows of a table is

```
DELETE table-name;
```

Example 3.9
Student Joan Darc has left school. Remove her information from the database.

```
DELETE FROM Flex_Card
WHERE student_name = 'JOAN DARC';
```

This DELETE command will remove the entire row from the table. Sometimes, however, information in a row must be changed. As the name of the UPDATE command suggests, its primary function is to update the rows of a table. The basic syntax of this SQL command to update one or more values of a single row is as follows:

```
UPDATE table-name
SET col-1 = new-val1 [...,...col-N = new-valN]
[WHERE condition];
```

where col-1..., col-N stand for column names and new-val1,...new-valN stand for the new values that will be stored in their corresponding columns. The WHERE clause allows us to change the values of selected rows. The following example illustrates the use of this command.

Example 3.10
Richard Lion has spent $7.50 of the value of his flex card. The new amount left on his card is $13.50. Update his row.

```
UPDATE Flex_Card
SET value_left = 13.50
WHERE student_name = 'RICHARD LION';
```

The UPDATE statement sets the specified attribute to the new value. Several columns and rows can be updated at the same time through more complex UPDATE commands.

3.2.4 POPULATING TABLES IN MS ACCESS

MS Access provides a way to enter items into the table from the table view without the use of SQL. Rows can be inserted, deleted, or individual values can be updated directly. Fig. 3-6 shows this view of the table. Items can simply be updated or typed into each column. During the editing process, constraints are enforced as the user is typing in the information. The editor flags the error and does not allow the row to be recorded until unique or required items are correct.

Sample Table : Table

Attribute 1	Attribute 2
Item 1	$2.00
Item 2	$5.00
	$0.00

Record: 2 of 2

Fig. 3-6. Table view in MS Access.

Example 3.11
Show the screen that would be used to type into the Flex_Card table the data from both Example 3.7 and Example 3.8 above.

Flex Card : Table

Student Name	Card Number	Starting Value	Value Left	Pin Number
ANN STEPHENS	1237096435	$20.00	$12.45	987234569871
JOAN DARC	2137096435	$20.00	$20.00	125234569871
RICHARD LION	3817443544	$20.00	$20.00	632809835833
JOHN GILMORE	5497443544	$15.00	$11.37	433809835833
		$0.00	$0.00	

Record: 4 of 4

After the data is typed directly into the table, when the user closes the screen MS Access asks if the changes to the table should be saved. However, the user should be aware of the need to save frequently as data are entered. Saving is the equivalent of the COMMIT in Oracle.

3.3 Selections, Projections, and Joins Using SQL

The **SELECT** statement is the most frequently used SQL statement. The SELECT statement is used primarily to *query* or retrieve data from the database. For this reason, it is customary to call a SELECT statement a *query*. In this book, we will refer to any SELECT statement by this name. The basic syntax of this statement is shown once again in Fig. 3-7.

```
SELECT column-1, column-2, column-3,...,column-N
FROM table-1,..., table-N
[WHERE condition]
[ORDER BY column-name [ASC|DESC][,column-name [ASC|DESC]...]];
```

Fig. 3-7. Basic structure of the SELECT statement.

The SELECT statement is formed by at least two *clauses*: the **SELECT** clause and the **FROM** clause. The clauses **WHERE** and **ORDER BY** are optional. Observe that the SELECT statement, like any other SQL statement, ends in a semicolon. The functions of each of these clauses are summarized below.

- The **SELECT** clause lists the subset of attributes or columns to retrieve. (See Projection in Section 2.5.2.) The attributes listed in this clause are the columns of the resulting relation.
- The **FROM** clause lists the tables from which to obtain the data. The columns mentioned in the SELECT clause must be columns of the tables listed in the FROM clause. (To accomplish Equijoins, as explained in Section 2.5.3, several tables may be used.)
- The **WHERE** clause specifies the condition or conditions that need to be satisfied by the tuples or rows of the tables indicated in the FROM clause. (See Selection in Section 2.5.1.)
- The **ORDER BY** clause indicates the criterion or criteria used to sort rows that satisfy the WHERE clause. The ORDER BY clause only affects the display of the data retrieved, not the internal ordering of the rows within the tables.

As a mnemonic aid to the basic structure of the SELECT statement some authors summarize its functionality by saying that "you **SELECT** columns **FROM** tables **WHERE** the rows satisfy certain conditions and the result is **ORDERED BY** specific columns".

The WHERE clause is what gives real power to the SELECT command since it provides the ability to display data that meets a specified condition. For instance,

you might want to print out all the names of people in a certain zip code area or you might want to see the names of all employees that work for a given department. The condition that accompanies the where clause defines the criterion to be met. The types of condition that we consider in this chapter are of the following form:

```
Column-name    comparison-operator    single-value
```

`Column-name` is the name of one of the columns of the table indicated in the `FROM` clause. The comparison operator is one of the operators shown in Table 3-5. By a single value we mean a numeric quantity or a character string. It is possible to construct other more complex queries using compound conditions using the Boolean operators `AND`, `OR` and `NOT`.

Table 3-5. Comparison operators for the `WHERE` clause.

Comparison Operator	Description
	equal to
<>	not equal to
<	less than
<=	less than or equal to
>	greater than
>=	greater than or equal to

The following example illustrates the use of the `SELECT` command.

Example 3.12
Recall the EMPLOYEE table from Example 2.8.

EMPLOYEE

ID	NAME	DEPT	TITLE
100	Smith	Sales	Clerk
200	Jones	Marketing	Clerk
300	Martin	Accounting	Clerk
400	Bell	Accounting	Sr. Accountant

Using the EMPLOYEE table, display the name and title of all the employees who work in the accounting department.

To retrieve this data from the EMPLOYEE table we use the following statement

```
SELECT name, title, dept      ← Columns to retrieve
FROM employee                 ← Table from which to retrieve the data
WHERE dept = 'Accounting';    ← Criterion to be satisfied
```

The resulting table is shown below.

NAME	TITLE	DEPT
Martin	Clerk	Accounting
Bell	Sr. Accountant	Accounting

Notice that in the resulting table the attribute names and their corresponding values are displayed in the same order in which they were listed in the SELECT statement. All the retrieved tuples satisfy the condition indicated in the WHERE clause. That is, for any tuple t of the resulting relation, t(DEPT) − Accounting. Observe that the rows retrieved are not sorted by alphabetical name. However, if we want to display the table with the names ordered in alphabetical order, we can proceed as indicated in Example 3.13. Observe also that in the SELECT clause the attribute names are not case sensitive. That is, we can write the attributes in either lower or upper case and obtain the same result. However, the condition indicated in the WHERE clause requires some consideration. Since DEPT is a character column, the condition has been enclosed in single quotes. In addition, we need to remember that character data is case sensitive. Had the condition of the WHERE clause been written as DEPT='ACCOUNTING' then no tuple would have satisfied it. Observe that the strings 'Accounting' and 'ACCOUNTING' are different strings.

Example 3.13
Display the result of the previous query in alphabetical order by the employee's name.

In this case, the SELECT statement needs to indicate to the RDBMS that the results need to be sorted in alphabetical order. Since we want to sort the resulting table according to the attribute NAME, it is necessary to mention this attribute in the ORDER BY clause. By default, the sorting of rows is done in ascending order[5] according to the column or columns that define the order, in this case, the attribute NAME. The SELECT statement to accomplish the desired result is shown next.

[5] By ascending order, we mean from lower values to higher values according to the coalescence sequence of the ASCII characters.

```
SELECT name, title, dept
FROM employee
WHERE dept = 'Accounting'
ORDER BY name;
```

The resulting table is shown here:

NAME	TITLE	DEPT
Bell	Sr. Accountant	Accounting
Martin	Clerk	Accounting

The rows of this table have been sorted in alphabetical order by last name.

The SELECT statement allows the use of the asterisk as a wildcard character. The use of SELECT * is the same as asking for all the columns of the table to be shown in the resulting chart.

Example 3.14
Display all the information for everyone in the EMPLOYEE table who is a clerk.

```
SELECT *
FROM employee
WHERE title = 'Clerk';
```

ID	NAME	DEPT	TITLE
100	Smith	Sales	Clerk
200	Jones	Marketing	Clerk
300	Martin	Accounting	Clerk

Once again the resulting table would not be displayed alphabetically unless we used the ORDER BY clause.

The SELECT statement can accomplish the Equijoin operation as explained in Chapter 2 by accessing columns from two or more tables. As stated in Section 2.5.3, a join consists of all the tuples resulting from concatenating the tuples of the first relation with the tuples of the second relation that have identical values for a common set of attributes. Recall the second table, DEPARTMENT, from Example 2.8.

DEPARTMENT

ID	DEPT	LOCATION
100	Accounting	Miami
200	Marketing	New York
300	Sales	Miami

Example 3.15
Display all the information about the employees along with their department's ID, name and location. For this, you will need two tables, DEPARTMENT and EMPLOYEE.

```
SELECT department.id, department.dept, department.location,
     employee.id, employee.name, employee.title
FROM department, employee
WHERE department.dept = employee.dept;
```

This query requires the join of two separate tables, as evident in the `FROM` clause. The resulting chart from this query would produce the same table below as shown in Example 2.8.

DEPT ID	DEPARTMENT NAME	LOCATION	EMPLOYEE ID	EMPLOYEE NAME	TITLE
100	Accounting	Miami	300	Martin	Clerk
100	Accounting	Miami	400	Bell	Sr. Accountant
200	Marketing	New York	200	Jones	Clerk
300	Sales	Miami	100	Smith	Clerk

Since for a true join we only wanted the row for each employee matched with his or her department, we needed to use the `WHERE` clause to connect columns in each table. If the `WHERE` clause had been omitted, the resulting chart would have contained twelve rows, one for each row in DEPARTMENT matched with each row in EMPLOYEE. This resulting table, shown below, is the Cartesian product of the two relations. This Cartesian product has 6 attributes, 3 (from EMPLOYEE) 3 (from DEPARTMENT) 6, and 12 tuples, 4 (from EMPLOYEE) * 3 (from DEPARTMENT) 12.

```
ID  DEPT           LOCATION     ID  NAME           TITLE
--- -------------- ------------ --- -------------- ------------
100 Accounting     Miami        100 Smith          Clerk
200 Marketing      New York     100 Smith          Clerk
300 Sales          Miami        100 Smith          Clerk
100 Accounting     Miami        200 Jones          Clerk
200 Marketing      New York     200 Jones          Clerk
300 Sales          Miami        200 Jones          Clerk
100 Accounting     Miami        300 Martin         Clerk
200 Marketing      New York     300 Martin         Clerk
300 Sales          Miami        300 Martin         Clerk
100 Accounting     Miami        400 Bell           Sr. Accountant
200 Marketing      New York     400 Bell           Sr. Accountant
300 Sales          Miami        400 Bell           Sr. Accountant
```

Remember to use caution when finding the Cartesian product of two tables because often some of the tuples make no sense. For example, the first tuple shows that Smith is a Clerk in the Accounting department, 100, which is located in Miami. The second tuple, however, says that Smith is a Clerk in Department 100, and the Marketing Department, 200, is in New York. Ordinarily, one would have no use for that information.

3.3.1 SET OPERATIONS IN SQL

Section 2.6 explained the mathematical basis of set operations performed on relations. This section will demonstrate the use of SQL to perform these operations. The first example is a union of two relations, or the set of all tuples in both relations with no duplicate tuples listed. The `UNION` operator is shown in Fig. 3-8. Recall from the definition of union in Chapter 2 that the tables must have the same structures.

```
SELECT *
FROM table_1
UNION
SELECT *
FROM table_2;
```

Fig. 3-8. UNION operator in SQL.

Example 3.16

Recall these tables from Chapter 2. Write the SQL code that will perform the UNION of the two tables, or show all the programmers in the organization.

C_PROGRAMMER

Employee_Id	Last_Name	First_Name	Project	Department
101123456	Venable	Mark	E-commerce	Sales Department
103705430	Cordani	John	Firewall	Information Technology
101936822	Serrano	Areant	E-commerce	Sales Department

JAVA_PROGRAMMER

Employee_Id	Last_Name	First_Name	Project	Department
101799332	Barnes	James	Web Application	Information Technology
101936822	Serrano	Areant	E-commerce	Sales Department

```
SELECT *
FROM c_programmer
UNION
SELECT *
FROM java_programmer;
```

The resulting chart demonstrates the union of the two tables. All the tuples from each relation are included with no duplicate rows.

```
EMP_ID    LAST    FIRST  PROJECT         DEPARTMENT
--------- ------- ------ --------------- ----------------------
101123456 Venable Mark   E-commerce      Sales
101799332 Barnes  James  Web Application Information Technology
101936822 Serrano Areant E-commerce      Sales
103705430 Cordani John   Firewall        Information Technology
```

Intersection of relations can also be performed in SQL. The intersection is the set of tuples present in both relations. The SQL syntax is shown in Fig. 3-9.

```
SELECT *
FROM table_1
INTERSECT
SELECT *
FROM table_2;
```

Fig. 3-9. INTERSECTION operator in SQL.

Example 3.17
Write the SQL code that will perform the INTERSECTION of the two programmer tables, or show which programmers can program in both C and JAVA.

```
SELECT *
FROM c_programmer
INTERSECT
SELECT *
FROM java_programmer;
```

The resulting chart shows that only one programmer is listed in both tables.

```
EMP_ID    LAST_NAME   FIRST_NAME      PROJECT         DEPARTMENT
--------- ----------- --------------- --------------- ----------
101936822 Serrano     Areant          E-commerce      Sales
```

A third set operation explained in Chapter 2 is the DIFFERENCE between two relations, or the set of tuples contained in the first that are not present in the second. The `MINUS` operator in SQL allows us to determine the rows that are present in one table but not in another. Unlike the `UNION` and `INTERSECT` operators, the `MINUS` operator is not commutative. That is, the result of table A `MINUS` table B is in general different than the result of table B `MINUS` table A. The syntax for this operator is shown in Fig. 3-10.

```
SELECT *
FROM table_1
MINUS
SELECT *
FROM table_2;
```

Fig. 3-10. DIFFERENCE operator in SQL.

Example 3.18
Write the SQL code that will perform the DIFFERENCE of the two programmer tables, or find all the C programmers that are not also JAVA programmers.

```
SELECT *
FROM c_programmer
MINUS
SELECT *
FROM java_programmer;
```

The resulting chart shows the tuples that were present in the C_PROGRAMMER table that were not also present in the JAVA_PROGRAMMER table.

```
EMP_ID    LAST_NAME  FIRST_NAME   PROJECT        DEPARTMENT
--------- ---------- ------------ -------------- ----------------------
101123456 Venable    Mark         E-commerce     Sales
103705430 Cordani    John         Firewall       Information Technology
```

3.3.2 QUERIES IN MS ACCESS

The screen for constructing queries in MS Access provides a way to select the columns from specific tables where columns have specific names. It is even possible to sort the resulting chart. All this can be done without writing SQL statements through the use of the query design view, shown in Fig. 3-11. The tables are shown in the top half of the screen with all the attributes listed and the primary key indicated in bold font. The attributes selected to appear in the resulting table and their order are shown in the bottom half. Sorts can be ascending or descending. Criteria to be used (as the `WHERE` clause) can also be entered directly. Compound criteria will be demonstrated at the end of this chapter in Solved Problems.

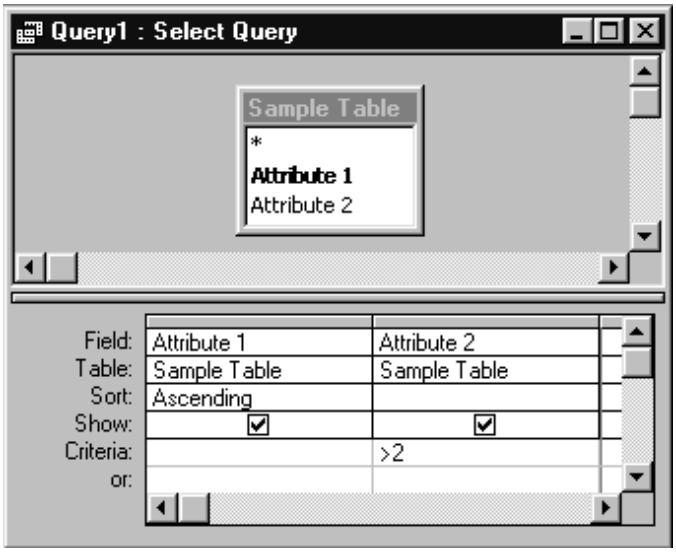


Fig. 3-11. Query design view in MS Access.

In Fig. 3-11, the resulting table would correspond to the following `SELECT` statement:

```
SELECT attribute_1, attribute_2
FROM sample_table
WHERE attribute_2 > 2
ORDER BY attribute_1;
```

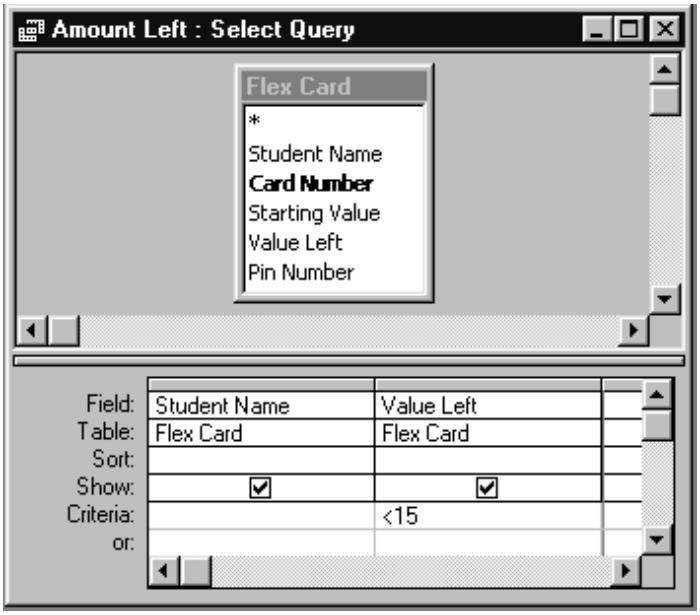
In the design view of this query, choose View=>SQL View, and this statement will appear:

```
SELECT [Sample Table].[Attribute 1], [Sample Table].[Attribute 2]
FROM [Sample Table]
WHERE ((([Sample Table].[Attribute 2])>2))
ORDER BY [Sample Table].[Attribute 1];
```

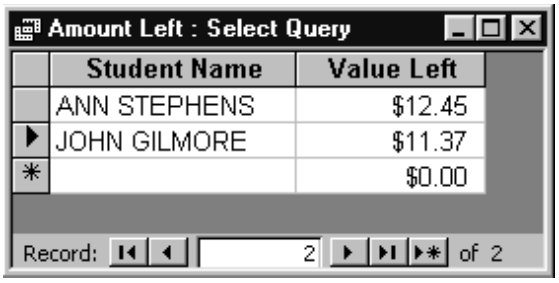
Because MS Access allows the use of spaces in names, the names are enclosed in square brackets. For the sake of clarity, the table name is always used to identify each column. This can be done in any SQL statement, but is usually omitted except in statements that join two tables. See Example 3.15.

Example 3.19

Recall the `Flex_Card` table introduced earlier in the chapter in Example 3.3. Show the MS Access design view of the query to list the names of everyone who has less than $15 left on the card.

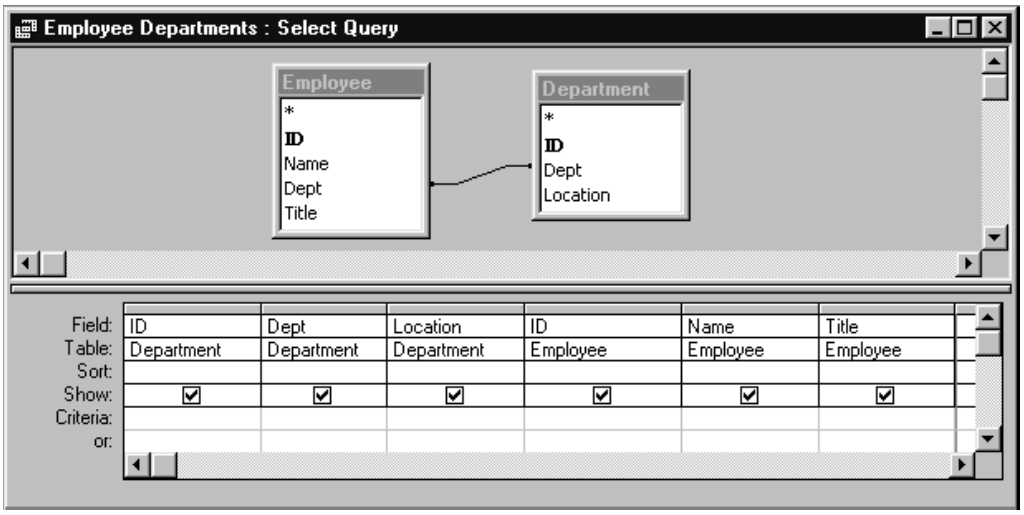


The fields listed in the lower portion of the design view are the only columns that will appear in the resulting chart. This particular query would result in this chart:



Example 3.20

It is also possible to perform a join in MS Access queries. You can include columns from any number of related tables. Consider the DEPARTMENT and EMPLOYEE tables used in Example 3.15. Show the MS Access design view for the query that would display all the information about the employees along with their department's ID, name and location.



Notice that both tables are shown in the upper section of the design view connected by a line. The line from department.dept to employee.dept coincides with the `WHERE` clause from Example 3.15.

```
WHERE department.dept = employee.dept
```

Any of the tables in the database may be used in queries. It is important to connect the columns that you want to use for the join process.

Performing other set operations in MS Access cannot be accomplished from the design view. SQL statements are needed. Consult the MS Access Help or other MS Access books to find out how to perform these operations.

Solved Problems

3.1. What is the difference between the use of SQL in Personal Oracle and in MS Access?

Personal Oracle has an interactive, command line interface. A prompt waits for the SQL commands to be typed and then the DBMS responds to the command. MS Access employs a graphical user interface through the use of dialog windows. However, when constructing a query using the design view, it is always possible to see the SQL that is working in the background through the use of menus, View=> SQL View.

3.2. Tell whether these names are usually valid or invalid according to the SQL naming conventions. If invalid, explain the reason.

a. Database names: Parts1, Chicago_Office, Emp_data.
b. Table names: Emp_data, All_the_books_I_want_to_read_in_the_world, 1_potato_2_potato.
c. Attribute names: Letter_Grade, Grade%, Mom'sPhoneNumber.

a. Database names: Parts1 — valid; Chicago_Office — invalid in Oracle, as database names in Oracle should be 8 characters or less; Emp_data valid, but it sounds more like a table name. Databases contain many tables and usually have more than one kind of related data.
b. Table names: Emp_data — valid; All_the_books_I_want_to_read_in_the_world — invalid, as most names should be limited to 30 characters. However, in MS Access, a name this long would be valid; 1_potato_2_potato — valid, as letters, digits, and the underscore character can all be used.
c. Attribute names: Letter_Grade — valid; Grade% — invalid because of incorrect percent character; Mom'sPhoneNumber — invalid because of apostrophe.

3.3. A flower vendor wants to market flowers that can be grown in a variety of zones. These zones have a range for the lowest possible temperature during the year. Create the table ZONE with the attributes and assumptions indicated below. *Attributes*: ID, the lowest possible low temperature, and the highest possible low temperature. *Assumptions*: the ID will be the primary key and have one or two characters, the temperatures will be at most two digits and a possible minus sign. Use unnamed constraints.

```
CREATE TABLE Zone
(
 ID        Char(2) PRIMARY KEY,
 LowerTemp Number(3),
 UpperTemp Number(3)
);
```

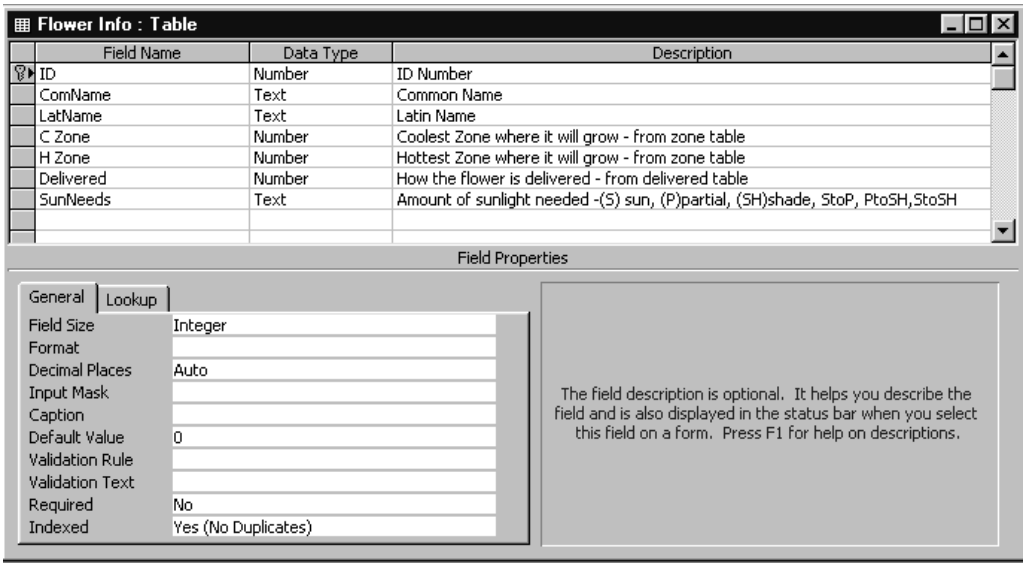
3.4. The same flower vendor wants to use a code to explain type of delivery. Create the table DELIVERY with the attributes and assumptions indicated below. *Attributes*: ID, the category or type of delivery and the size of the delivery. *Assumptions*: the ID will be the primary key and have one character, the category will be at most five characters (pot, plant, hedge, shrub, tree) and the delivery size will be up to five digits with three decimal spaces. Use unnamed constraints.

```
CREATE TABLE Delivery
(
 ID            Char(1) PRIMARY KEY,
 Category      VARCHAR2(5),
 DelSize       Number(5,3)
);
```

3.5. The flower vendor wants to market certain types of flowers. Create the table FLOWERINFO with the attributes and assumptions indicated below. Choose the most appropriate data types. *Attributes*: ID with three characters, common name, Latin name, the coolest and hottest zones where it can be grown, the delivery category, and the sun needs. *Assumptions*: The ID will be the primary key, the attribute common name may have up to thirty characters and the Latin name up to twenty-five characters. The attributes coolest zone, hottest zone and delivery category will match the IDs from other tables, and the sun needs will be up to five characters, S for Sun, SH for Shade, P for Partial sun and any combination (StoP, StoSH, etc.). Use named constraints for this table for the primary key.

```
CREATE TABLE FlowerInfo
(
 ID              Char(3) CONSTRAINT
                 flowerinfo_id_PK PRIMARY KEY,
 ComName         VARCHAR2(25),
 LatName         VARCHAR2(30),
 CZone           Number ,
 HZone           Number ,
 Delivered       Number ,
 SunNeeds        VARCHAR2(5)
);
```

3.6. Show the design view for creating the FLOWERINFO table in MS Access. Be sure to indicate the primary key.



3.7. Write the code to insert into the ZONE table the data indicated below:

```
ID LOWERTEMP UPPERTEMP
-- --------- ---------
2        -50       -40
3        -40       -30
4        -30       -20
5        -20       -10
6        -10         0
7          0        10
8         10        20
9         20        30
10        30        40
```

```
INSERT INTO Zone (ID, LowerTemp, UpperTemp)
VALUES ('2', -50, -40);
INSERT INTO Zone (ID, LowerTemp, UpperTemp)
VALUES ('3', -40, -30);
INSERT INTO Zone (ID, LowerTemp, UpperTemp)
VALUES ('4', -30, -20);
INSERT INTO Zone (ID, LowerTemp, UpperTemp)
VALUES ('5', -20, -10);
INSERT INTO Zone (ID, LowerTemp, UpperTemp)
VALUES ('6', -10, 0);
INSERT INTO Zone (ID, LowerTemp, UpperTemp)
VALUES ('7', 0, 10);
INSERT INTO Zone (ID, LowerTemp, UpperTemp)
VALUES ('8', 10, 20);
INSERT INTO Zone (ID, LowerTemp, UpperTemp)
VALUES ('9', 20, 30);
INSERT INTO Zone (ID, LowerTemp, UpperTemp)
VALUES ('10', 30, 40);
```

Notice that the ID is character data and must be enclosed with single quotation marks. Numbers do not have quotation marks.

3.8. Write the code to insert into the DELIVERY table the data indicated below:

```
ID CATEG   DELSIZE
-- ----- ---------
1  pot         1.5
2  pot        2.25
3  pot       2.625
4  pot        4.25
5  plant
6  bulb
7  hedge        18
8  shrub        24
9  tree         36
```

```
INSERT INTO Delivery (ID, Category, DelSize)
VALUES ('1','pot', 1.5);
INSERT INTO Delivery (ID, Category, DelSize)
VALUES ('2','pot', 2.25);
INSERT INTO Delivery (ID, Category, DelSize)
VALUES ('3','pot',2.625 );
INSERT INTO Delivery (ID, Category, DelSize)
VALUES ('4','pot',4.25 );
INSERT INTO Delivery (ID, Category, DelSize)
VALUES ('5','plant',NULL );
INSERT INTO Delivery (ID, Category, DelSize)
VALUES ('6','bulb', NULL);
INSERT INTO Delivery (ID, Category, DelSize)
VALUES ('7','hedge', 18);
INSERT INTO Delivery (ID, Category, DelSize)
VALUES ('8','shrub', 24);
INSERT INTO Delivery (ID, Category, DelSize)
VALUES ('9','tree', 36);
```

Notice that in the required data, plant and bulb do not have any information in the `DelSize` column. Therefore, the value inserted is `NULL`. Remember that `NULL` is not the same as zero.

3.9. Write the code to insert into the FLOWERINFO table the data indicated below:

ID	COMNAME	LATNAME	CZONE	HZONE	DELIVER	SUNNE
101	Lady Fern	Atbyrium filix-femina	2	9	5	SH
102	Pink Caladiums	C.x bortulanum	10	10	6	PtoSH
103	Lily-of-the-Valley	Convallaria majalis	2	8	5	PtoSH
105	Purple Liatris	Liatris spicata	3	9	6	StoP
106	Black Eyed Susan	Rudbeckia fulgida var. specios	4	10	2	StoP
107	Nikko Blue Hydrangea	Hydrangea macrophylla	5	9	4	StoSH
108	Variegated Weigela	W. florida Variegata	4	9	8	StoP
110	Lombardy Poplar	Populus nigra Italica	3	9	9	S
111	Purple Leaf Plum Hedge	Prunus x cistena	2	8	7	S
114	Thorndale Ivy	Hedera belix Thorndale	3	9	1	StoSH

```
INSERT INTO FlowerInfo(ID, ComName, LatName, CZone, HZone, Delivered,
SunNeeds)
VALUES ('101', 'Lady Fern', 'Atbyrium filix-femina',2, 9, 5, 'SH');
INSERT INTO FlowerInfo(ID, ComName, LatName, CZone, HZone, Delivered,
SunNeeds)
VALUES ('102', 'Pink Caladiums', 'C.x bortulanum',10, 10, 6, 'PtoSH');
INSERT INTO FlowerInfo(ID, ComName, LatName, CZone, HZone, Delivered,
SunNeeds)
```

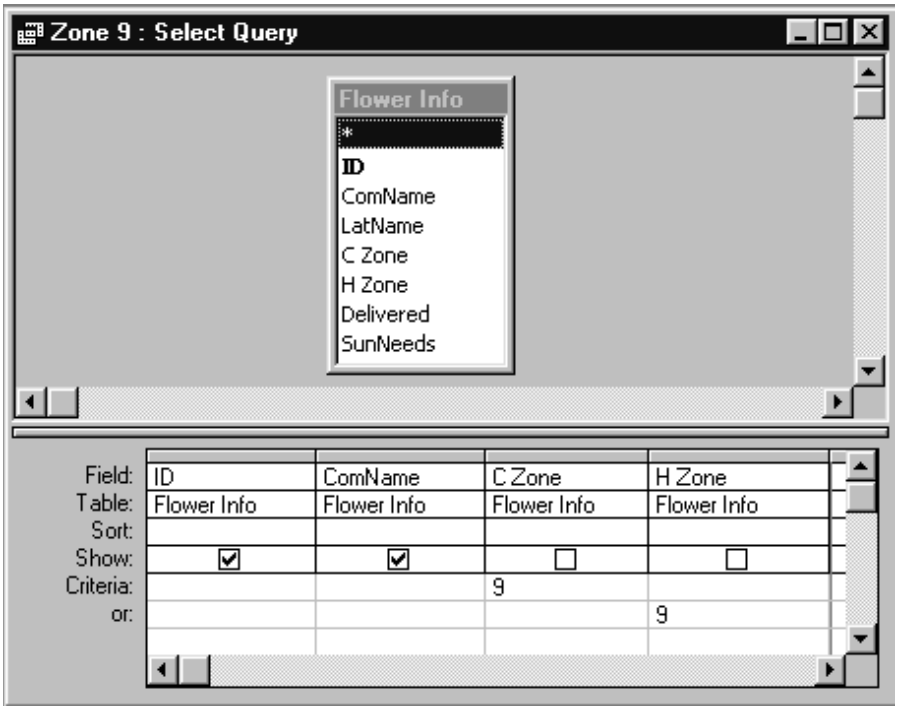
```
VALUES ('103', 'Lily-of-the-Valley', 'Convallaria majalis',2, 8, 5,
'PtoSH');
INSERT INTO FlowerInfo(ID, ComName, LatName, CZone, HZone, Delivered,
SunNeeds)
VALUES ('105', 'Purple Liatris', 'Liatris spicata',3, 9, 6, 'StoP');
INSERT INTO FlowerInfo(ID, ComName, LatName, CZone, HZone, Delivered,
SunNeeds)
VALUES ('106', 'Black Eyed Susan', 'Rudbeckia fulgida var. specios',4, 10,
2, 'StoP');
INSERT INTO FlowerInfo(ID, ComName, LatName, CZone, HZone, Delivered,
SunNeeds)
VALUES ('107', 'Nikko Blue Hydrangea', 'Hydrangea macrophylla',5, 9, 4,
'StoSH');
INSERT INTO FlowerInfo(ID, ComName, LatName, CZone, HZone, Delivered,
SunNeeds)
VALUES ('108', 'Variegated Weigela', 'W. florida Variegata',4, 9, 8,
'StoP');
INSERT INTO FlowerInfo(ID, ComName, LatName, CZone, HZone, Delivered,
SunNeeds)
VALUES ('110', 'Lombardy Poplar', 'Populus nigra Italica',3, 9, 9, 'S');
INSERT INTO FlowerInfo(ID, ComName, LatName, CZone, HZone, Delivered,
SunNeeds)
VALUES ('111', 'Purple Leaf Plum Hedge', 'Prunus x cistena',2, 8, 7, 'S');
INSERT INTO FlowerInfo(ID, ComName, LatName, CZone, HZone, Delivered,
SunNeeds)
VALUES ('114', 'Thorndale Ivy', 'Hedera belix Thorndale',3, 9, 1, 'StoSH');
```

3.10. Write the SQL query and show the resulting table that lists the ID and common name of all the flowers that can grow in zone 9. Remember that 9 can be the coolest zone or the hottest zone.

```
SELECT id, comname
FROM flowerinfo
WHERE czone = 9 OR hzone = 9;
ID  COMNAME
--- ---------------------
101 Lady Fern
105 Purple Liatris
107 Nikko Blue Hydrangea
108 Variegated Weigela
110 Lombardy Poplar
114 Thorndale Ivy
```

Remember that AND, OR and NOT can be used to create compound WHERE clauses.

3.11. Show the MS Access design view to create the same query from the previous exercise.



In the design view, you can create compound conditions. Putting both conditions on the CRITERIA: line indicates the AND relationship, while putting one of the conditions on the OR line will create the OR relationship. You can also use a column for the `WHERE` condition without printing the column in the resulting query by removing the check from the SHOW: box as seen above.

3.12. Write the query that would print out the entire DELIVERY table.

```
SELECT *
FROM delivery;
```

Recall that the asterisk (`*`) means to list all the columns. This command is a short cut to printing the entire table.

3.13. Write the query that will print the ID and common name of the flowers delivered in pots, along with the size of the pot. Print the resulting table in alphabetical order of common name. NOTE: This query needs data from two tables. You need to figure out how they will be connected.

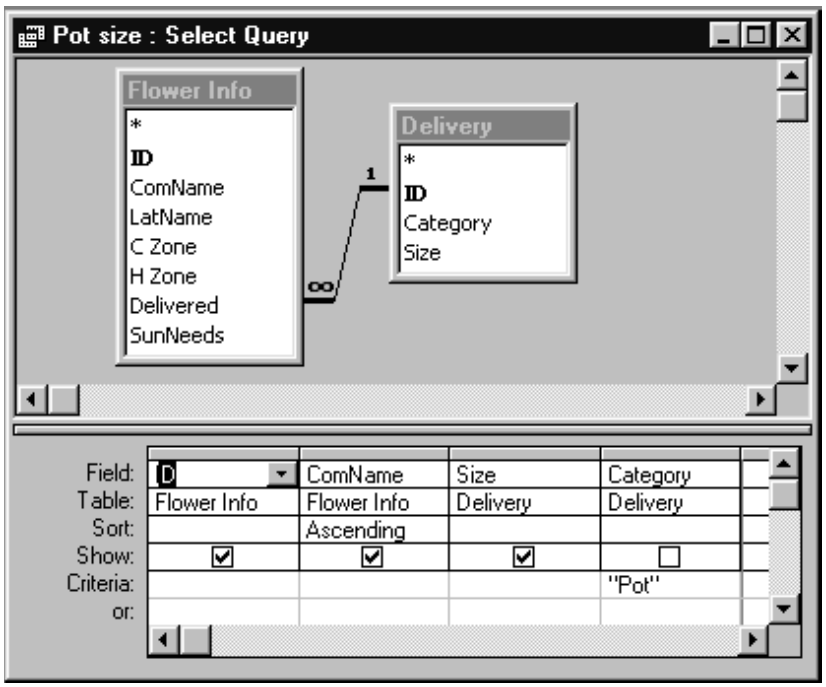
```
SELECT flowerinfo.id, flowerinfo.comname, delivery.delsize
FROM flowerinfo, delivery
WHERE flowerinfo.delivered = delivery.id
      AND delivery.category = 'pot'
```

```
ORDER BY flowerinfo.comname;

ID  COMNAME                       DELSIZE
--- ------------------------- ---------
106 Black Eyed Susan                 2.25
107 Nikko Blue Hydrangea             4.25
114 Thorndale Ivy                     1.5
```

The `WHERE` clause of this query included the category '`pot`' as well as the columns in each table that are connected, `flowerinfo.delivered` and `delivery.id`.

3.14. Show the MS Access design view for the query in the previous example. Remember to connect the correct columns.



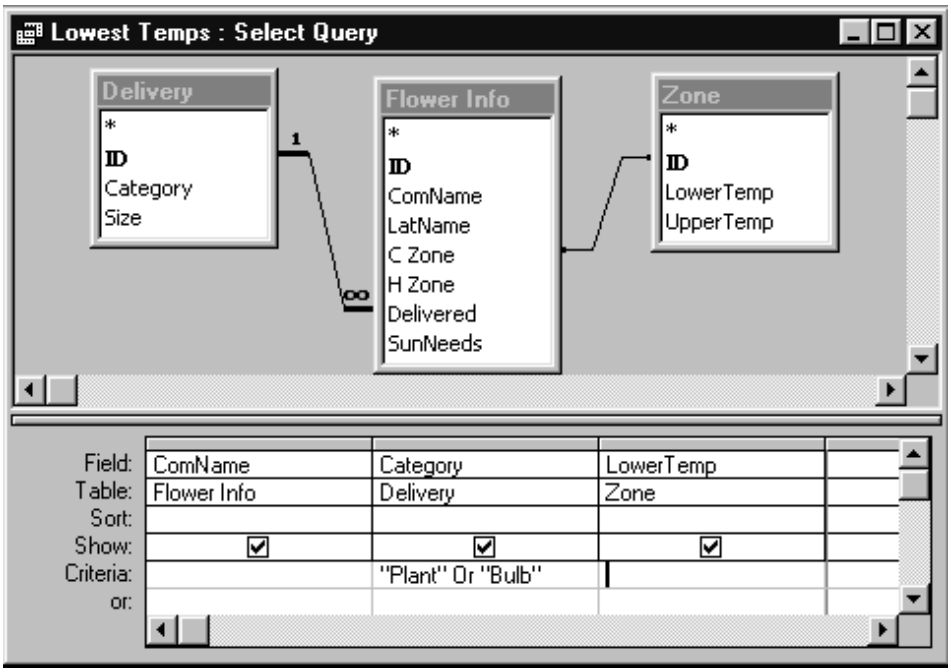
Notice that in MS Access, sorting is indicated in the Sort: row and can be ascending or descending. Criteria including text data must be enclosed in double quotation marks instead of single.

3.15. Write the SQL statement and the resulting table that gives the common name and the lowest possible temperature for growing the flowers delivered as plants or bulbs. HINT: This query requires information from all three tables. The `WHERE` clause is very complex. Be sure to use parentheses around the `OR` section.

```
SELECT flowerinfo.comname, delivery.category, zone.lowertemp
FROM flowerinfo, zone, delivery
WHERE delivery.ID = flowerinfo.delivered AND
flowerinfo.czone = zone.id AND
(delivery.category = 'plant' OR delivery.category = 'bulb');
COMNAME                    CATEG LOWERTEMP
-------------------------- ----- ---------
Lady Fern                  plant       -50
Lily-of-the-Valley         plant       -50
Purple Liatris             bulb        -40
Pink Caladiums             bulb         30
```

When using AND and OR, AND is always executed first. Therefore, parentheses are needed to allow the results to pertain to plants or bulbs. The connecting columns must use the AND to make the result a true join.

3.16. Show the MS Access design view to accomplish the query in the previous problem.



Notice that all the connecting information is accomplished using the lines in the upper section. OR criteria within the same column can be on the Criteria line and the Or line, or it can be on the same line using the word "Or".

3.17. The flower company is discontinuing the sale of Lady Fern. Write the SQL statements to delete that tuple from the table.

```
DELETE FROM flowerinfo
WHERE comname = 'Lady Fern';
```

3.18. The flower company is getting a new product, but they don't have all the information.

a. Insert this information into the table: ID is 104, common name is "White Edged Hosta" and the Latin name is "Hosta undulata."

b. Now the company has got the rest of the information. Update that row to include Czone – 3, Hzone – 8, Delivery – 5, and Sun needed – PtoSH.

a. You can insert a row into the table without having all the information. The primary key must be included, but other attributes may be ignored. In most RDBMs they will be treated as if the contents are NULL. The code to insert part of a tuple looks like this.

```
INSERT INTO FlowerInfo(ID, ComName, LatName)
VALUES ('104', 'White Edged Hosta', 'Hosta undulata');
```

b. Updating the table by setting new values is the same as changing existing values. Use the `UPDATE` command. The `WHERE` clause is included to specify which row is to be changed.

```
UPDATE flowerinfo
SET czone = 3, hzone = 8, delivered = 5, sunneeds = 'PtoSH'
WHERE id = '104';
```

3.19. Look at the TRAVELER table and the RESORT table below.

TRAVELER

Customer	Country
Alton	Mexico
Jones	England
Russell	Spain

RESORT

Country	Resort Location	Price
Mexico	Cancun	1200
England	Liverpool	1790
Brazil	Rio de Janeiro	1790
Spain	Marbella	2200

Write the SQL code to display the Cartesian product of the two tables.

```
SELECT *
FROM traveler, resort;
```

Examine the resulting table to see that this kind of join makes no sense in this situation. If Alton visited Mexico, the fact that Liverpool is in England is irrelevant.

```
CUSTOMER   COUNTRY    COUNTRY       RESORTLOC      PRICE
---------- ---------- ------------- -------------- ---------
Alton      Mexico     Mexico        Cancun         1200
Jones      England    Mexico        Cancun         1200
Russell    Spain      Mexico        Cancun         1200
Alton      Mexico     England       Liverpool      1790
Jones      England    England       Liverpool      1790
Russell    Spain      England       Liverpool      1790
Alton      Mexico     Brazil        Rio de Janeiro 1790
Jones      England    Brazil        Rio de Janeiro 1790
Russell    Spain      Brazil        Rio de Janeiro 1790
Alton      Mexico     Spain         Marbella       2200
Jones      England    Spain         Marbella       2200
Russell    Spain      Spain         Marbella       2200
```

3.20. Write the SQL code to display the true equijoin of the tables.

```
SELECT *
FROM traveler, resort
WHERE traveler.country = resort.country;
```

The resulting table shows that the information on the resort in Brazil never appears. For a true join, only the attributes with matching values are considered.

```
CUSTOMER   COUNTRY    COUNTRY       RESORTLOC      PRICE
---------- ---------- ------------- -------------- ---------
Alton      Mexico     Mexico        Cancun         1200
Russell    England    England       Liverpool      1790
Jones      Spain      Spain         Marbella       2200
```

3.21. Consider the two tables below, Golf Resorts and Beach Resorts.

GOLF

Country	Resort Location	Price
US	Greenbrier	2100
US	Myrtle Beach	1400
Mexico	Cancun	1200

BEACH

Country	Resort Location	Price
Mexico	Cancun	1200
US	Myrtle Beach	1400
Brazil	Rio de Janeiro	1790
Spain	Marbella	2200

Write the SQL code to list all the resorts, or perform the UNION of the two tables.

```
SELECT *
FROM golf
UNION
SELECT *
FROM beach;
```

The resulting chart shows all the resorts.

```
COUNTRY          RESORTLOC        PRICE
---------------- ---------------- ---------
Brazil           Rio de Janeiro        1790
Mexico           Cancun                1200
Spain            Marbella              2200
US               Greenbrier            2100
US               Myrtle Beach          1400
```

3.22. Write the SQL code to display the resorts that are both golf and beach destinations, or the INTERSECTION of the two tables.

```
SELECT *
FROM golf
INTERSECT
SELECT *
FROM beach;
```

The resulting table shows only Cancun and Myrtle Beach because they are the only resorts listed in both tables.

3.23. Write the SQL code to display the beach resorts that are NOT also golf resorts, or the DIFFERENCE between the beach and the golf resorts.

```
SELECT *
FROM beach
MINUS
SELECT *
FROM golf;
```

The resulting chart displays the resorts in Spain and in Brazil. If the query had asked for the golf resorts that were not beach resorts, the two select statements would have been reversed. If the `SELECT *FROM golf` clause were first, then the resulting chart would have displayed only Greenbrier.

Supplementary Problems

3.24. Tell whether these names are usually valid or invalid according to the SQL naming conventions. If invalid, explain the reason.

a. Database names: Flowers, CansAndBoxes, Part_Num
b. Table names: Cars&Trucks, Shade_Flowers, Light Needed To Grow In To Tallest Possible
c. Attribute names: Card#, Zip Code, Amount_Due

3.25. A bookstore wants to stock mystery stories from particular publishers. Create the table PUBINFO with the attributes and assumptions indicated below. *Attributes*: ID, name, and city. *Assumptions*: the ID will be the primary key and have four characters. The publisher's name and city may be a maximum of thirty and fifteen characters respectively. Use unnamed constraints.

3.26. To help the mystery bookstore, create the table BOOKINFO with the attributes and assumptions indicated below. *Attributes*: ID, title, author, publisher ID and copyright year. *Assumptions*: the ID will be the primary key and have four characters. The title and author will have thirty and twenty-five characters respectively. The publisher's ID will have four characters. The copyright year will be an integer. Use named constraints for the primary key.

3.27. Show the MS Access design view to create the BOOKINFO table from the previous problem.

3.28. Write the SQL to insert into the PUBINFO table the data indicated below.

ID	NAME	CITY
AB01	Avon Books	New York
MMC1	MacMillan Company	New York
NAL1	New American Library	New York
PB01	Pocket Books	New York
PNB1	Penguin Books	Baltimore
SBS1	Scholastic Book Services	New York
WP01	World Publishing	Cleveland

3.29. Write the SQL to insert into the BOOKINFO table the data indicated below.

ID	TITLE	AUTHOR	PUBI	CYEAR
C200	Poirot Loses a Client	Agatha Christie	WP01	1937
D300	The Hound of the Baskervilles	Sir Arthur Conan Doyle	SBS1	1964
G600	Cosmopolitan Crimes	Hugh Greene (ED)	PNB1	1971
J100	Lying in Wait	J.A. Jance	AB01	1994
L400	A Stitch in Time	Emma Lathen	MMC1	1968
Q500	The Player on the Other Side	Ellery Queen	PB01	1963
Q501	Face to Face	Ellery Queen	NAL1	1967
S100	Strong Poison	Dorothy L. Sayers	AB01	1930
S101	Have His Carcase	Dorothy L. Sayers	AB01	1932
S102	Gaudy Night	Dorothy L. Sayers	AB01	1936

3.30. Write the SQL code and show the resulting table to display the ID, title, author, and copyright year for all the books published before 1950.

3.31. Write the SQL code and show the resulting table to display all the publishers which are not located in New York.

3.32. Show the MS Access Design View for the query in the previous problem.

3.33. Write the SQL code and show the resulting table to display the book title and the name and location of all the publishers of books for books published after 1950.

3.34. Show the MS Access Design View for the query in the previous problem.

3.35. Write the SQL code to delete the J.A. Jance book from the table.

3.36. Instead of listing the location as "New York", the entry should include the state also, and be "New York, NY". Write the SQL code to change the locations in the publishers table to include the state.

3.37. Look at the DOCTORS and NURSES tables below. Write the SQL code to display the Cartesian product of these two tables. Examine the resulting chart to convince yourself that this particular join makes no sense.

DOCTORS

Id	LastName	Department	Supervisor
120	Silver	Cardiology	Dr. Jones
727	Stanley	Cardiology	Dr. Sing
982	Bartley	Pediatrics	Dr. Spresser

NURSES

Id	LastName	Department	Supervisor
930	Clinton	Pediatrics	Mrs. Alexander
892	Alvarez	Cardiology	Ms. Hussain

3.38. Write the SQL code to display the equijoin of the DOCTORS and NURSES table.

3.39. Consider the tables for two sporting goods stores below.

Store 1

Id	Name	Price
00123	Basketball	125
00343	Bike	550
00489	Golf Clubs	980

Store 2

Id	Name	Price
00652	Football	99
00123	Basketball	125
00489	Golf Clubs	980
00245	Tent	640

Write the SQL code to list all the products, or perform the UNION of the two tables.

3.40. Write the SQL code to display the resorts that are sold at both stores, or the INTERSECTION of the two tables.

3.41. Write the SQL code to display the items sold in store 2 that are NOT also sold in store 1, or the DIFFERENCE between store 2 and store 1.

Answers to Supplementary Problems

3.24. Answers:

a. Database names: Flowers — valid; CansAndBoxes — invalid in Oracle because database names longer than 8 characters are not allowed; Part_Num — valid.

b. Table names: Cars&Trucks — invalid because ampersand is not allowed; Shade_Flowers — valid; Light Needed To Grow In To Tallest Possible — valid in MS Access (with square brackets) but invalid elsewhere because it is longer than 30 characters and also contains spaces.

c. Attribute names: Card# — invalid because of pound sign (or hash); Zip Code — invalid because of space except in MS Access with square brackets; Amount_Due — valid.

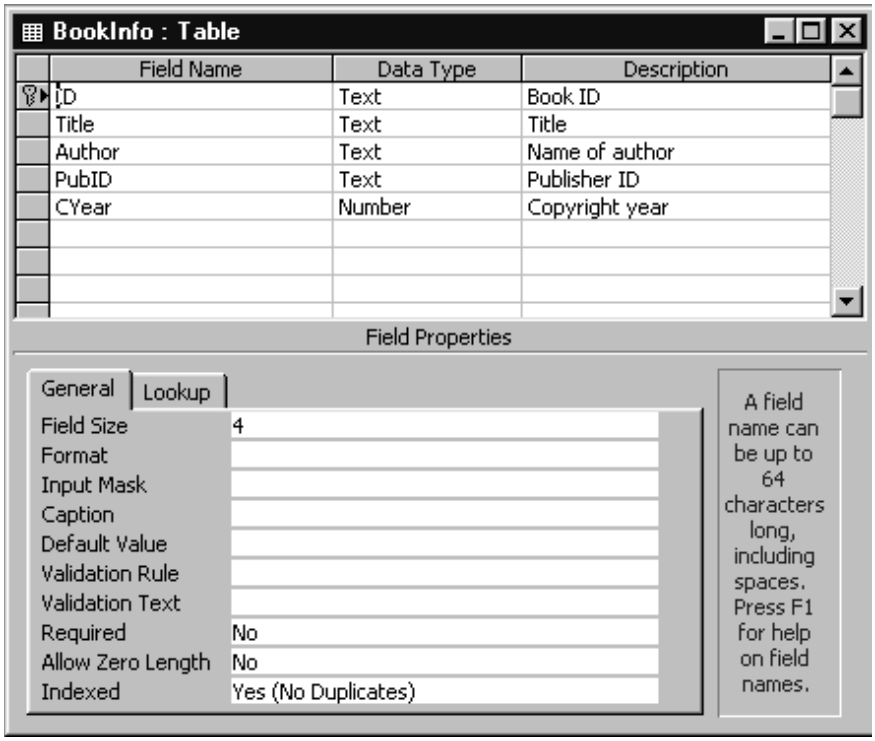
3.25. Code:

```
CREATE TABLE PubInfo
(
 ID     Char(4) PRIMARY KEY,
 Name   VARCHAR2(30),
 City   VARCHAR2(15)
);
```

3.26. Code:

```
CREATE TABLE BookInfo
(
 ID       Char(4) CONSTRAINT
              bookinfo_id_PK PRIMARY KEY,
 Title    VARCHAR2(30),
 Author   VARCHAR2(25),
 PubID    Char(4),
 CYear    Number
);
```

3.27. MS Access:



3.28. Code:

```
INSERT INTO PubInfo(ID, Name, City)
VALUES ('AB01', 'Avon Books', 'New York');
INSERT INTO PubInfo(ID, Name, City)
VALUES ('MMC1', 'MacMillan Company', 'New York');
INSERT INTO PubInfo(ID, Name, City)
VALUES ('NAL1', 'New American Library', 'New York');
INSERT INTO PubInfo(ID, Name, City)
VALUES ('PB01', 'Pocket Books', 'New York');
INSERT INTO PubInfo(ID, Name, City)
VALUES ('PNB1', 'Penguin Books', 'Baltimore');
INSERT INTO PubInfo(ID, Name, City)
VALUES ('SBS1', 'Scholastic Book Services', 'New York');
INSERT INTO PubInfo(ID, Name, City)
VALUES ('WP01', 'World Publishing', 'Cleveland');
```

3.29. Code:

```
INSERT INTO BookInfo(ID, title, author, pubid, cyear)
VALUES ('C200', 'Poirot Loses a Client', 'Agatha Christie', 'WP01', 1937);
INSERT INTO BookInfo(ID, title, author, pubid, cyear)
VALUES ('D300', 'The Hound of the Baskervilles', 'Sir Arthur Conan Doyle',
'SBS1', 1964);
INSERT INTO BookInfo(ID, title, author, pubid, cyear)
VALUES ('G600', 'Cosmopolitan Crimes', 'Hugh Greene (ED)', 'PNB1', 1971);
INSERT INTO BookInfo(ID, title, author, pubid, cyear)
VALUES ('J100', 'Lying in Wait', 'J.A. Jance', 'AB01', 1994);
INSERT INTO BookInfo(ID, title, author, pubid, cyear)
VALUES ('L400', 'A Stitch in Time', 'Emma Lathen', 'MMC1', 1968);
INSERT INTO BookInfo(ID, title, author, pubid, cyear)
VALUES ('Q500', 'The Player on the Other Side', 'Ellery Queen', 'PB01',
1963);
INSERT INTO BookInfo(ID, title, author, pubid, cyear)
VALUES ('Q501', 'Face to Face', 'Ellery Queen', 'NAL1', 1967);
INSERT INTO BookInfo(ID, title, author, pubid, cyear)
VALUES ('S100', 'Strong Poison', 'Dorothy L. Sayers', 'AB01', 1930);
INSERT INTO BookInfo(ID, title, author, pubid, cyear)
VALUES ('S101', 'Have His Carcase', 'Dorothy L. Sayers', 'AB01', 1932);
INSERT INTO BookInfo(ID, title, author, pubid, cyear)
VALUES ('S102', 'Gaudy Night', 'Dorothy L. Sayers', 'AB01', 1936);
```

3.30. Code:

```
SELECT id, title, author, cyear
FROM bookinfo
WHERE cyear < 1950;
```

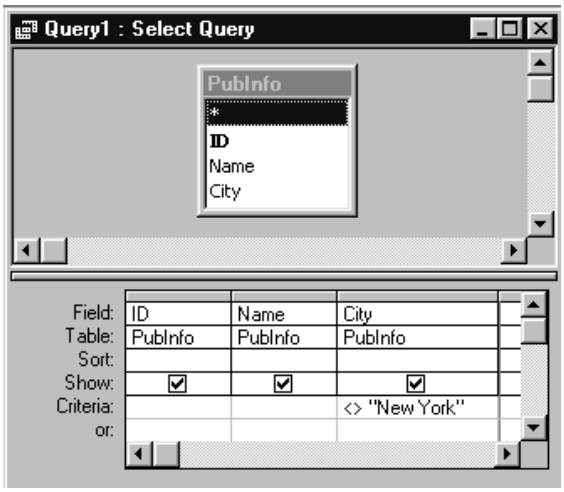
```
ID   TITLE                      AUTHOR                    CYEAR
---- -------------------------- --------------------- ---------
C200 Poirot Loses a Client      Agatha Christie            1937
S100 Strong Poison              Dorothy L. Sayers          1930
S101 Have His Carcase           Dorothy L. Sayers          1932
S102 Gaudy Night                Dorothy L. Sayers          1936
```

3.31. Code:

```
SELECT *
FROM pubinfo
WHERE city <> 'New York';
```

```
ID   NAME                           CITY
---- ------------------------------ -----------
PNB1 Penguin Books                  Baltimore
WP01 World Publishing               Cleveland
```

3.32. MS Access:

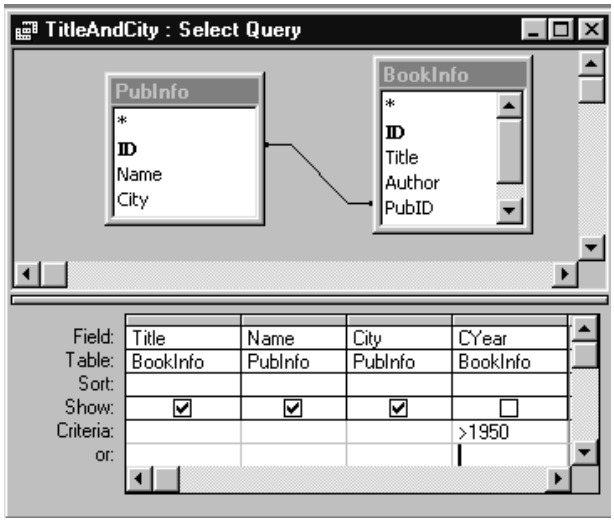


3.33. Code:

```
SELECT bookinfo.title, pubinfo.name, pubinfo.city
FROM bookinfo, pubinfo
WHERE bookinfo.pubid = pubinfo.id
   AND bookinfo.cyear > 1950;
```

```
TITLE                          NAME                           CITY
------------------------------ ------------------------------ -----------
The Hound of the Baskervilles  Scholastic Book Services       New York
Cosmopolitan Crimes            Penguin Books                  Baltimore
Lying in Wait                  Avon Books                     New York
A Stitch in Time               MacMillan Company              New York
The Player on the Other Side   Pocket Books                   New York
Face to Face                   New American Library           New York
```

3.34. MS Access:



3.35. Code:

```
DELETE FROM bookinfo
WHERE author = 'J.A. Jance';
```

3.36. Code:

```
UPDATE pubinfo
SET city = 'New York, NY'
WHERE city = 'New York';
```

The resulting chart shows the update has been made:

```
ID   NAME                            CITY
---- ------------------------------- -------------
AB01 Avon Books                      New York, NY
MMC1 MacMillan Company               New York, NY
NAL1 New American Library            New York, NY
PB01 Pocket Books                    New York, NY
PNB1 Penguin Books                   Baltimore
SBS1 Scholastic Book Services        New York, NY
WP01 World Publishing                Cleveland
```

3.37. Code:

```
SELECT *
FROM doctors, nurses;
```

Table:

```
ID  LASTNAME DEPARTMENT SUPERVISOR  ID  LASTNAME DEPARTMENT SUPERVISOR
--- -------- ---------- ----------- --- -------- ---------- -------------
120 Silver   Cardiology Dr. Jones   930 Clinton  Pediatrics Mrs. Alexander
727 Stanley  Cardiology Dr. Sing    930 Clinton  Pediatrics Mrs. Alexander
982 Bartley  Pediatrics Dr. Spresser 930 Clinton  Pediatrics Mrs. Alexander
120 Silver   Cardiology Dr. Jones   892 Alvarez  Cardiology Ms. Hussain
727 Stanley  Cardiology Dr. Sing    892 Alvarez  Cardiology Ms. Hussain
982 Bartley  Pediatrics Dr. Spresser 892 Alvarez  Cardiology Ms. Hussain
```

3.38. Code:

```
SELECT *
FROM doctors, nurses
WHERE doctors.department = nurses.department;
```

Table:

```
ID  LASTNAME DEPARTMENT SUPERVISOR  ID  LASTNAME DEPARTMENT SUPERVISOR
--- -------- ---------- ----------- --- -------- ---------- -------------
120 Silver   Cardiology Dr. Jones   892 Alvarez  Cardiology Ms. Hussain
727 Stanley  Cardiology Dr. Sing    892 Alvarez  Cardiology Ms. Hussain
982 Bartley  Pediatrics Dr. Spresser 930 Clinton  Pediatrics Mrs. Alexander
```

3.39. Code:

```
SELECT *
FROM store1
UNION
SELECT*
FROM store2;
```

```
ID    NAME                 PRICE
----- --------------- ---------
00123 Basketball            125
00245 Tent                  640
00343 Bike                  550
00489 Golf Clubs            980
00652 Football               99
```

3.40. Code:

```
SELECT *
FROM store1
INTERSECT
SELECT*
FROM store2;
```

```
ID    NAME                 PRICE
----- --------------- ---------
00123 Basketball            125
00489 Golf Clubs            980
```

3.41. Code:

```
SELECT *
FROM store2
MINUS
SELECT*
FROM store1;
```

```
ID    NAME                 PRICE
----- --------------- ---------
00245 Tent                  640
00652 Football               99
```

CHAPTER 4

Functional Dependencies

4.1 Introduction

In any relational database, controlling the redundancy and preserving the consistency of data are two of the most important issues that any database designer or data administrator has to face. *Data redundancy* occurs when a piece of data is stored in more than one place in the database. If the content of that piece of data is changed to a particular value, then it is necessary to ensure that every copy of the same piece of data is changed to the same value. This piece of data is said to be consistent in the database. If some, but not all, copies of this piece of data are changed to the same value, the data is said to be inconsistent. A database is said to be in a *consistent state* if all its data is consistent. Otherwise it is said to be in an *inconsistent state*. Since relations are the logical entities that store data in any RDBMS, to achieve the goal of controlling data redundancy and maintaining its correctness and accuracy it is necessary to be aware of all constraints that apply to the database relations.

One way to learn more about the different types of constraints imposed on all permissible data of a relation or set of relations is through the use of functional dependencies (FDs). *Functional dependencies* arise naturally in many ways due to requirements or restrictions that exist in the real world and that have to be captured by the database. In general, these restrictions or constraints can be classified into two general groups: semantic constraints and agreement constraints. Semantic constraints depend on the meaning or understanding of the attributes of a relation. For instance in an EMPLOYEE relation no employee may have a negative salary or a negative age. Agreement or concordance

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constraints do not depend on the particular values of the attributes of a tuple, but on whether or not tuples that agree on certain attributes agree also in the values of some of their other attributes. For instance, consider the attributes Department and Supervisor of an EMPLOYEE relation. If we assume that employees only work for one department, that there is only one supervisor per department and that every department has a supervisor then two tuples with the same value under the Supervisor column must have the same value under the Department column. Functional dependencies are the most important of the agreement or concordance constraints. We will consider this topic next.

4.2 Definition of Functional Dependencies

Given a relation r(R) and two sets of its attributes A and B. We will say that *attribute(s) A functionally determines attribute(s) B with respect to r*, denoted by $A \rightarrow B$, if and only if for any two tuples t_1 and t_2 of r whenever $t_1(A) = t_2(A)$ then $t_1(B) = t_2(B)$. That is, if A functionally determines B, then whenever two tuples of r have identical values in column A their respective values in column B must also be identical. If the relation r is understood, we will just say that A functionally determines B. In the notation $A \rightarrow B$, attribute A, the left-hand side of the functional dependency, is called the *determinant*; attribute B is called the right-hand side of the functional dependency. If $A \rightarrow B$ (with respect to a relation r), we will say the relation r "satisfies the functional dependency" or that the "functional dependency is satisfied by the relation". Observe that in the definition given above, both A and B have been defined as sets of attributes and not necessarily as single attributes. In other words, A and B may be composite attributes. When more than one attribute are explicitly indicated in a functional dependency, it is customary to use concatenation to stand for set union between sets of operators. That is, in the functional dependency $AB \rightarrow X$, AB is shorthand for $A \cup B$. In addition, the notation $A \not\rightarrow B$ is used to denote that a set of attributes A does not functionally determine a set of attributes B. Functional dependencies where the right-hand side consists of only one attribute are called *simple* FDs.

Example 4.1

Given the Lakes-Of-The-World relation shown below, state whether or not the functional dependencies (a) Continent $\rightarrow$ Name and (b) Name $\rightarrow$ Length are satisfied by this relation. Assume that the Area attribute is measured in square miles and that the Length attribute is measured in miles.[1]

[1] Reference: *The World Almanac and Book of Facts 2000*, World Almanac Books.

Lakes-Of-The-World

Name	Continent	Area	Length
Caspian Sea	Asia-Europe	143244	760
Superior	North America	31700	350
Victoria	Africa	26828	250
Aral Sea	Asia	24904	280
Huron	North America	23000	206
Michigan	North America	22300	307
Tanganyika	Africa	12700	420

a. The functional dependency Continent $\rightarrow$ Name *is not* satisfied by the relation. We can verify this because according to the definition of functional dependency, if Continent $\rightarrow$ Name, then for any two tuples of the relation that have the same value under the Continent attribute their values under the Name attribute must also be the same. For example, in the Lakes-Of-The-World relation consider the following tuples:

t_1: (Superior, North America, 31700, 350) and t_2: (Huron, North America, 23000 206).

Notice that

t_1(Continent) = t_2(Continent) = North America but
t_1(Name) = Superior $\neq$ t_2(Name) = Huron.

Since these two tuples agree on their values under the Continent attribute but not on their values under the Name attribute, we have that Continent $\not\rightarrow$ Name.

b. The functional dependency Name $\rightarrow$ Length is satisfied by the relation. In this case, the relation is obviously satisfied because for any given lake there is only one length associated with it.

The reader should keep in mind that determining whether or not an attribute functionally determines another attribute is based only on the meaning of the attributes. In this sense, functional dependencies can be considered assertions about the real world that should hold at any point in time. That is, they should be true for all instances of the relation. Since functional dependencies depend on the semantics of their attributes they should not be inferred from the current content of a relation. That is, we cannot look at the current content of a relation and based on the values of the attributes A and B decide that A $\rightarrow$ B. Notice also that from the definition of functional dependency (FD) and the previous discussion it is *always* possible to determine if a *given* functional dependency is

or is not satisfied by an instance of a relation. However, it is not valid to infer functional dependencies from a particular instance of a relation without first taking into account the meaning of the intervening attributes. The Satisfies algorithm shown below can be used to determine if a relation r satisfies or does not satisfy a given functional dependency $A \rightarrow B$. The input to the algorithm is a given relation r and a functional dependency $A \rightarrow B$. The output of the algorithm is True if r satisfies $A \rightarrow B$; otherwise the output is False.

The Satisfies Algorithm[2]

(1) Sort the tuples of the relation r on the A attribute(s) so that tuples with equal values under A are next to each other.

(2) Check that tuples with equal values under attribute(s) A also have equal values under attribute(s) B.

(3) If any two tuples of r meet condition 1 but fail to meet condition 2 the output of the algorithm is False. Otherwise, the relation satisfies the functional dependency and the output of the algorithm is True.

Example 4.2

Using the relation of the previous example, apply the Satisfies algorithm to show that the attribute Continent does not determine the attribute Name.

Lakes-Of-The-World

Name	Continent	Area	Length
Victoria	Africa	26828	250
Tanganyika	Africa	12700	420
Aral Sea	Asia	24904	280
Superior	North America	31700	350
Huron	North America	23000	206
Michigan	North America	22300	307

At least two of the values of this attribute are different from each other for identical values of the Continent attribute.

At least two of the values of this attribute are equal to each other.

[2] Adapted from *The Theory of Relational Databases* by D. Maier, Computer Science Press, 1983.

After sorting the tuples of the relation on the Continent attribute, notice that the use of the algorithm makes it obvious that the relation does not satisfy the functional dependency that is Continent → Name. The output of the algorithm is False.

4.3 Functional Dependencies and Keys

Given a relation r(R) and its primary key K, for any particular value of K we can always determine whether or not there is a tuple in the relation with that K value. In addition, if the tuple is present in the relation we can not only uniquely identify the tuple but also the value of any of its attributes. Using the notion of functional dependency we can say that the key K functionally determines any attribute of the relation. That is, $K \rightarrow A_i$ where A_i is any set of attribute(s) of the relation. Since keys are particular cases of FDs all properties that are true for FDs are also valid for keys. Some of these properties are considered in the next and following sections. As we indicated in Chapter 2, Section 2.3, we call prime attributes any set of attributes that comprises a PK or an alternate key.

4.4 Inference Axioms for Functional Dependencies

A relation r may satisfy more than one set of functional dependencies. In theory, it is possible to use the Satisfies algorithm with all possible combinations of attributes of the relation r to determine which FDs are satisfied by the relation. Although this method may indicate all FDs that are satisfied by the relation, from a practical point of view, it is obviously a tedious and time-consuming task. The *inference axioms* offer an alternate method that allows us to infer the FDs that are satisfied by a relation without the use of any algorithm. Given a set F of FDs, the inference axioms are a set of rules that tell us that if a relation satisfies the FDs of F the relation must satisfy certain other FDs. The latter set of FDs that the relation must satisfy are said to be *derived* or *logically deduced* from the FDs of F.

The inference axioms are said to be *complete* and *sound*. By complete we mean that, given a relation r(R) and a set F of functional dependencies satisfied by r, the axioms allow us to derive all valid functional dependencies that are satisfied by r. By sound we mean that if the axioms are correctly applied they cannot derive false dependencies.

Assume that r(R) is a relation and that X, Y, Z and W are subsets of R. The set of inference axioms[3] is shown below. We have enclosed in parentheses the most common name or names for each of the individual axioms. Whenever two or more names are listed we will generally use the first one in the list.

[3] This set of axioms is sometimes called Armstrong's Axioms after W. W. Armstrong who initially proposed a set of somewhat similar axioms.

Inference Axioms

(1) If $Y \subseteq X$, then $X \rightarrow Y$ (Reflexivity*)
(2) If $X \rightarrow Y$, then $XW \rightarrow Y$ and/or $XW \rightarrow YW$ (Augmentation*)
(3) If $X \rightarrow Y$ and $Y \rightarrow Z$, then $X \rightarrow Z$ (Transitivity)
(4) If $X \rightarrow Y$ and $YW \rightarrow Z$, then $XW \rightarrow Z$ (Pseudotransitivity*)
(5) If $X \rightarrow Z$ and $X \rightarrow Y$, then $X \rightarrow YZ$ (Additivity or Union)
(6) If $X \rightarrow YZ$, $X \rightarrow Y$ and $X \rightarrow Z$ (Projectivity or Decomposition)

* This axiom is considered a basic axiom. Any other inference rule can be derived from a set that contains all the basic axioms.

Notice that when there are more than one attribute in either the left or right or both sides of a functional dependency the order in which these attributes are written is immaterial since the union set operation is commutative. That is, $AB \rightarrow CD$ can be written as $AB \rightarrow DC$ or $BA \rightarrow DC$ or $BA \rightarrow CD$ without altering the meaning of the functional dependency.

The axiom of *Reflexivity* indicates that given a set of attributes the set itself functionally determines any of its own subsets. As a particular case of this axiom we have that $X \rightarrow X$ for any set of attributes X. This is an immediate consequence of $X \subset X$. Functional dependencies of the form $X \rightarrow Y$ where $Y \subset X$ are called *trivial dependencies*.

The axiom of *Augmentation* indicates that we can augment or enlarge the left side of an FD or both sides conveniently with one or more attributes. Notice that the axiom does not allow augmenting the right-hand side alone.

The axiom of *Transitivity* indicates that if one attribute uniquely determines a second attribute and this, in turn, uniquely determines a third one, then the first attribute determines the third one.

The axiom of *Pseudotransitivity* is a generalization of the Transitivity axiom (see Supplementary Problem 4.16). Notice that for this axiom to be applied it is required that the entire right-hand side of a FD appears as attribute(s) of the determinant of another FD.

The axiom of *Additivity* indicates that if there are two FDs with the *same* determinant it is possible to form a new FD that preserves the determinant and has as its right-hand side the union of the right-hand sides of the two FDs.

The axiom of *Projectivity* or *Decomposition* is the inverse of the additivity axiom. This axiom indicates that the determinant of any FD can uniquely determine any individual attribute or any combination of attributes of the right-hand side of the FD.

The reader should keep in mind that the inference axioms allow us to discover new FDs that are present or satisfied by a relation even if they are not explicitly stated. For example, if a relation r satisfies $X \rightarrow Y$ and $Y \rightarrow Z$ it also satisfies $X \rightarrow Z$ even if the latter FD is not explicitly indicated as being satisfied by the relation.

As indicated before, the set of inference axioms allows us to derive new functional dependencies from a given set of FDs. The next example illustrates the use of the inference axioms and how they are applied to derive FDs.

Example 4.3
Given the set F – {A → B, C → X, BX → Z} derive AC → Z using the inference axioms. Assume that all these attributes belong to a relational scheme R not shown here.

(1) With A → B (given) and BX → Z (given) and by application of the axiom of Pseudotransitivity we have that AX → Z. Notice that we were able to apply this axiom because the attribute B appears on the right-hand side of a functional dependency and on the left-hand side of another as required by the Pseudotransitivity axiom.

(2) Using AX → Z (from the previous step) and C → X (given) and by application of the Pseudotransitivity axiom we have that AC → Z.

Example 4.3 illustrates the notion of logical implication between functional dependencies. In fact, this result shows that if a relation r satisfies the functional dependencies of the set F given above then it must satisfy the functional dependency AC → Z. We can formalize this concept as follows: Given a set F of functional dependencies of a relational scheme R, and a functional dependency X → Y. We say that F *logically implies* X → Y, denoted by F ⊨ X → Y, if every relation r(R) that satisfies the dependencies in F also satisfies X → Y.

Example 4.4
Given F {A → B, C → D} with C ⊂ B, show that F A → D.

(1) Knowing that C ⊂ B and using the axiom of Reflexivity we have that B → C.

(2) Using A → B (given) and B → C (from the previous step) and by application of the Transitivity axiom we have that A → C.

(3) From A → C (from step 2) and C → D (given) and by application of the Transitivity axiom we have that A → D.

Since A → D can be derived from the set of FDs of F then F A → D.

4.5 Redundant Functional Dependencies

Given a set F of FDs, a functional dependency A → B of F is said to be *redundant with respect to the FDs of F* if and only if A → B can be derived from the set of FDs F {A → B}. That is, if A → B can be derived from the FDs of F not including A → B. Redundant functional dependencies, as their name indicates, are extra and unnecessary and can be safely removed from the set F. If the set

F of FDs is understood, we will say that the functional dependency $A \rightarrow B$ is redundant. Eliminating redundant functional dependencies allows us to minimize the set of FDs. The concept of minimality will be further explored in Section 4.6.4. Determining which FDs are redundant in a given set can be a tedious and long process, particularly when there are a large number of FDs in the set. The Membership algorithm shown below provides us with a more systematic procedure to determine redundant FDs; however, the algorithm is still lengthy if applied to a large number of FDs. The input to this algorithm is a set F of FDs and a particular FD of F that is being tested for redundancy. This algorithm is shown next.

The Membership Algorithm

Assume that F is a set of functional dependencies with $A \rightarrow B \in F$. To determine if $A \rightarrow B$ is redundant with respect to the other FDs of the set F proceed as follows:

(1) Remove temporarily $A \rightarrow B$ from F and initialize the set of functional dependencies G to F. That is, set G F $\{A \rightarrow B\}$. If G / $\varnothing$ proceed to step 2; otherwise stop executing the algorithm since $A \rightarrow B$ is nonredundant.

(2) Initialize the set of attributes T_i (with i = 1) with the set of attribute(s) A (the determinant of the FD under consideration). That is, set T_i T_1 $\{A\}$. The set T_1 is the current T_i.

(3) In the set G, search for functional dependencies $X \rightarrow Y$ such that all the attributes of the determinant X are elements of the current set T_i. There are two possible outcomes to this search:

(3-a) If such functional dependency is found, add the attributes of Y(the right-hand side of the FD whose determinant is in T_i) to the set T_i and form a new set $T_{i\ 1}$ $T_i \cup Y$. The set $T_{i\ 1}$ is now the current T_i.
Check if all the attributes of B (the right-hand side of the functional dependency under consideration) are members of $T_{i\ 1}$. If this is the case, stop executing the algorithm because the FD: $A \rightarrow B$ is redundant. If not all attributes of B are members of $T_{i\ 1}$, remove $X \rightarrow Y$ from G and repeat step 3.

(3-b) If G $\varnothing$ or there are no FDs in G that have all the attributes of its determinant in the current T_i then $A \rightarrow B$ is not redundant.

As indicated before, if a functional dependency $A \rightarrow B \in F$ is found to be redundant, we can remove it permanently from the set F.

The following example illustrates the use of the Membership algorithm.

Example 4.5
Given the set F $\{X \rightarrow YW, XW \rightarrow Z, Z \rightarrow Y, XY \rightarrow Z\}$, determine if the functional dependency $XY \rightarrow Z$ is redundant in F.

Step (1) Temporarily remove the functional dependency $XY \rightarrow Z$ from the set F.

$$\text{Set } G \quad \{X \rightarrow YW, XW \rightarrow Z, Z \rightarrow Y\}$$

Step (2) Initialize a set of attributes T_1 with the attribute(s) of the determinant of the FD under consideration. In this particular case, since XY is the determinant of $XY \rightarrow Z$, we have that $T_1 \quad \{XY\}$.

Step (3/3-a) In the set G, look for functional dependencies such that all the attributes of their determinants are elements of the set T_1. Notice that the determinant of $X \rightarrow YW$ is an element of T_1. That is, $X \subseteq T_1$. Adding to T_1 the attributes that appear on the right-hand side of this FD we form the new set shown below.

$$T_2 \quad T_1 \cup \{YW\} \quad \{XY\} \cup \{YW\} \quad \{XYW\}$$

Since Z, the right-hand side of $XY \rightarrow Z$ is not an element of T_2 ($Z \notin T_2$) remove $X \rightarrow YW$ from G. Set $G - \{XW \rightarrow Z, Z \rightarrow Y\}$ and repeat step 3.

Step (3/3-a) (2nd time) Observe now that all the attributes of the determinant of $XW \rightarrow Z$ are elements of T_2. Adding the attribute of the right-hand side of this FD to the set T_2 produces a new set $T_3 - T_2 \cup \{Z\} - \{XYWZ\}$. Since $Z \in T_3$ the algorithm stops and $XY \rightarrow Z$ is a redundant FD. That is, $XY \rightarrow Z$ can be safely removed from F.

To verify that $XY \rightarrow Z$ is redundant, we need to exclude this FD from F before attempting to derive it from the FDs of F using the inference axioms.

$$F \quad \{X \rightarrow YW, XW \rightarrow Z, Z \rightarrow Y\}$$

a. Using $X \rightarrow YW$ (given) and by application of the Projectivity axiom we have that $X \rightarrow Y$ and $X \rightarrow W$.

b. With $X \rightarrow W$ (from step a) and $XW \rightarrow Z$ (given) and by application of the Pseudotransitivity axiom we obtain $XX \rightarrow Z$.

c. Since the concatenation of attributes is equivalent to their union we have that $X \cup X \quad X$. Using this result and rewriting the determinant of the functional dependency of step b, we obtain $X \rightarrow Z$.

Therefore, the functional dependency $XY \rightarrow Z$ is redundant because we have shown that it can be derived from the FDs of F.

4.6 Closures, Cover and Equivalence of Functional Dependencies

Given a set F of FDs we are interested in determining all the FDs that can be logically implied by F. The set of all FDs that can be logically implied from F sees its most important application in the normalization process of relations (see Chapter 5). The following subsections provide the definitions and algorithms to generate a set of FDs or to test if a given set F of FDs implies a particular FD.

4.6.1 CLOSURE OF A SET F OF FUNCTIONAL DEPENDENCIES

Given a set F of functional dependencies for a relation scheme R, we define F^+, the *closure of F*, to be the set of all functional dependencies that are logically implied by F. In mathematical terms, $F^+ = \{X \rightarrow Y / F \vdash X \rightarrow Y\}$. The closure set satisfies the two following properties simultaneously:

(1) F^+ is the smallest set that contains F and satisfies property 2.

(2) Any application of the inference axioms to the FDs of F only produces FDs that are already in F^+.

The following example illustrates this concept.

Example 4.6
Given set $F = \{XY \rightarrow Z\}$ determine all the elements of F^+. Assume that the scheme is comprised by all attributes mentioned in the FDs of F.

To generate all FDs that can be derived from F we proceed as follows: First, apply the inference axioms to all single attributes. Second, apply the inference axioms to all combinations of two attributes and use the functional dependencies of F whenever it is applicable. Next apply the inference axioms to all combinations of three attributes and use the FDs of F when necessary. Proceed in this fashion for as many different attributes as there are in F. The resulting set is shown below.

$F^+ = \{X \rightarrow X, Y \rightarrow Y, Z \rightarrow Z, XY \rightarrow X, XY \rightarrow Y, XY \rightarrow XY, XZ \rightarrow X, XZ \rightarrow Z, XZ \rightarrow XZ, YZ \rightarrow Y, YZ \rightarrow Z, YZ \rightarrow YZ, XYZ \rightarrow XY, XYZ \rightarrow XZ, XYZ \rightarrow YZ, XYZ \rightarrow XYZ\}$

4.6.2 CLOSURE OF A SET OF ATTRIBUTES

As the previous example illustrates, the number of elements in F can be considerably larger than the number of attributes of F. Notice that F only has one FD but F has 16 different FDs.

For any given functional dependency $X \rightarrow Y$, F can be used to determine whether or not $F \vdash X \rightarrow Y$; however, the computation of F can be a very lengthy process. To simplify this task we can use an alternate method that consists of finding X , the *closure of the set of attributes X under F*. This concept can be formally defined as follows:

Given a set of attributes X and a set F of functional dependencies, the closure of the set of attributes X under F, written as X , is the set of attributes A that can be derived from X by applying the inference axioms to the functional dependencies of F. The closure of X is always a nonempty set because $X \rightarrow X$ by the axiom of Reflexivity. Whenever the set F of functional dependencies is understood we will refer to X as the closure of X. Notice that we are assuming that X and all the attributes of the FDs of F are defined over the same scheme R.

The reader may wonder if there is any relationship between the FDs that can be derived from X and the FDs of F that have X as the determinant. In fact, if X $= \{A_1 A_2 A_3 \ldots A_n\}$ then, by definition of the closure of X, any attribute of this set can be derived from X. That is, $X \rightarrow A_1$, $X \rightarrow A_2$, $X \rightarrow A_3, \ldots,$ $X \rightarrow A_n$. Using these FDs and by repeated application of the axiom of additivity, we can form the FD $X \rightarrow A_1 A_2 A_3 \ldots A_n$ that has in its right-hand side all attributes $A_i \in X$. The right-hand side of this production turns out to be a *maximal* set of attributes in F with respect to the attributes that can be derived from X. That is, if $X \rightarrow Z \in F$ then $Z \subset A_1 A_2 A_3 \ldots A_n$. Observe that in this inclusion statement the set on the right-hand side is nothing more than X . This result provides us with a criterion to determine whether or not $F \vdash X \rightarrow Y$ for a given $X \rightarrow Y$. In fact, to verify that $F \vdash X \rightarrow Y$ it is only necessary to show that $Y \in X$.

To calculate X systematically we can use an algorithm that somewhat resembles the Membership Algorithm. We will call this algorithm the Closure Algorithm.

The Closure Algorithm

The input to this algorithm is a set F of FDs and a set of attributes X defined over the same scheme. The output of the algorithm is X .

(1) Initialize a set G of FDs with the attributes of F. That is, set G F.

(2) Initialize the set of attributes T_i (with i 1) with the attributes of X. That is, set T_i T_1 {X}. The set T_1 is the current T_i.

(3) In the set G, look for functional dependencies $X \rightarrow Y$ such that all the attributes of the determinant X are elements of the current set T_i. There are two possible outcomes to this search:

(3-a) If such functional dependency is found, add the attributes of Y to the set T_i to form the set $T_{i\ 1} = T_i \cup Y$ and remove $X \rightarrow Y$ from G since its right-hand side no longer contributes new attributes to future T_is. $T_{i\ 1}$ is now the current T_i. Repeat step 3.

(3-b) If $G = \varnothing$ or there are no FDs in G with all the attributes of their determinants as elements of T_i stop the execution of the algorithm.

When the algorithm finishes the current set T_i has all the attributes that can be derived from X. That is, T_i X . The following example illustrates this.

Example 4.7

Given the set of functional dependencies $F - \{A \rightarrow B, B \rightarrow C, BC \rightarrow D, DA \rightarrow B\}$ find X where X {A}. What is the meaning of this set? Is it true that $A \rightarrow DA$?

Step (1) Set $G - \{A \rightarrow B, B \rightarrow C, BC \rightarrow D, DA \rightarrow B\}$.

Step (2) Set $T_i = T_1 = \{A\}$.

Step (3/3-a) Since the determinant of $A \rightarrow B$ is an element of T_1 we form T_2 $T_1 \cup \{B\}$ {AB}. We can remove $A \rightarrow B$ from G since it can no longer contribute any of the attributes of its right-hand side to future T_is. We are now working with the following set G $\{B \rightarrow C, BC \rightarrow D, DA \rightarrow B\}$. Repeat step 3.

Step (3/3-a) (2nd time) With this new set G we find that the determinant of $B \rightarrow C$ is now an element of T_2. Adding the attributes of the right-hand side of this FD to T_2 we form a new T_3 $T_2 \cup \{C\}$ {ABC}. Removing $B \rightarrow C$ from G we now have that G $\{BC \rightarrow D, DA \rightarrow B\}$. Repeat step 3.

Step (3/3-a) (3rd time) Considering T_3 we find that the determinant of $BC \rightarrow D$ is an element of this set. Adding the attributes of the right-hand side of this functional dependency to T_3 we have that $T_4 = T_3 \cup \{ABC\} \cup \{D\} = \{ABCD\}$. Removing $BC \rightarrow D$ from G we now have that $G = \{DA \rightarrow B\}$. Repeat step 3.

Step (3/3-a) (4th time) Considering T_4 we find that the determinant of $DA \rightarrow B$ is an element of this set. Adding the attributes of the right-hand side of this functional dependency to T_4 we have that T_5 $T_4 \cup \{ABC\} \cup \{B\}$ {ABCD}. Removing $DA \rightarrow B$ from G we now have that $G = \varnothing$. Repeat step 3.

Step (3/3-b) (1st time) Since $G - \varnothing$ the algorithm stops and the current T_i T_5 {ABCD} X .

This result indicates that the attribute A may be the determinant of an FD that has as its right-hand side any of the individual attributes of X or any combination of attributes of this set.

Attributes AD are elements of X , therefore it is true that $A \rightarrow DA$. We can verify this as shown below. The set of FDs is $F = \{A \rightarrow B, B \rightarrow C, BC \rightarrow D, DA \rightarrow B\}$.

(1) With $A \rightarrow B$ (given) and $B \rightarrow C$ (given) we obtain $A \rightarrow C$ (Axiom of Transitivity)

(2) Using $A \rightarrow B$ (given) and $BC \rightarrow D$ (given) we obtain $AC \rightarrow D$ (Axiom of Pseudotransitivity)

(3) With $AC \rightarrow D$ (from step 2) and $A \rightarrow C$ (from step 1) we have $AA \rightarrow D$ (Axiom of Pseudotransitivity)

(4) Knowing that $A \cup A$ A and using the convention that concatenation stands for union, we can rewrite the FD obtained in the previous step as $A \rightarrow D$

(5) Knowing that $A \rightarrow A$ (Axiom of Reflexivity) and $A \rightarrow D$ (from step 4) we have that $A \rightarrow AD$ (Axiom of Additivity)

Therefore, it is true that $A \rightarrow DA$.

4.6.3 COVERS AND EQUIVALENCE OF SET OF FUNCTIONAL DEPENDENCIES

As we indicated before, for a given set F of FDs, the set F may contain a large number of FDs. This is particularly true for any set F that also has a large number of FDs. Therefore, it is desirable to be able to find sets that contain smaller number of FDs than F and still generate all the FDs of F . Sets of FDs that satisfy this condition are said to be *equivalent sets*. We can formalize this definition as follows:

Given two sets F and G of FDs defined over the same relational scheme. We will say that F and G are equivalent if and only if F = G . We will indicate that F and G are equivalent sets by writing $F = G$. Whenever F = G , we will say that F *covers* G and vice versa. If G covers F and no proper subset[4] H of G is such that H = G we say that G is a *nonredundant cover* of F.

The algorithm to find a nonredundant cover G is shown below. The input to this algorithm is a set F of FDs; the output is a nonredundant cover for F.

[4] H is a proper subset of F if and only if $H \subseteq F$ and $F \neq H$.

The NonRedundant Cover Algorithm

(1) Initialize G to F. That is, set G F.

(2) Test every FD of G for redundancy using the Membership Algorithm of Section 4.5 until there are no more FDs of G to be tested.

(3) The set G is a nonredundant cover of F.

The reader should keep in mind that for a given set F there may be more than one nonredundant cover since the order in which the FDs are considered is relevant. In other words, the presence or absence of particular FDs may determine whether or not other FDs become redundant. In addition, if we can find a nonredundant cover, this cover may not be minimal. That is, there may be some other nonredundant covers with fewer FDs. An additional basic type of minimality is covered in Section 4.6.4. However, advanced issues of minimality of covers are out of the scope of this book and will not be considered here.

Example 4.8

Find a nonredundant cover G for the set F {X → YZ, ZW → P, P → Z, W → XPQ, XYQ → YW, WQ → YZ}.

(1) Set G − F.

(2) **a.** Test X → YZ for redundancy. G {ZW → P, P → Z, W → XPQ, XYQ → YW, WQ → YZ}
T_1 {X}. No FD of G has all the attributes of its determinant in T_1. Therefore, X → YZ is nonredundant. Notice that {YZ} ⊄ T.

b. Test ZW → P for redundancy. G {X → YZ, P → Z, W → XPQ, XYQ → YW, WQ → YZ}
T_1 {ZW}. The determinant of W → XPQ has all its attributes in T_1. Therefore T_2 T_1 ∪ {XPQ} {ZWXPQ}. Since P, the right-hand side of ZW → P, is an element of T_2, we have that ZW → P is redundant and can be safely removed from the set G.

c. Test P → Z for redundancy. G {X → YZ, W → XPQ, XYQ → YW, WQ → YZ}
T_1 {P}. No FD has all the attributes of its determinant in T_1. Therefore, P → Z is nonredundant. Notice that {Z} ⊄ T_1.

d. Test W → XPQ for redundancy. G {X → YZ, P → Z, XYQ → YW, WQ → YZ}
T_1 {W}. No FD has all the attributes of its attributes in T_1. Therefore, W → XPQ is nonredundant. Notice that {XPQ} ⊄ T_1.

e. Test XYZ → YW for redundancy. G {X → YZ, P → Z, W → XPQ, WQ → YZ}
T_1 {XYZ}. The determinant of X → YZ has all its attributes in T_1. Therefore, T_2 T_1 ∪ {YZ} {XYZ}. No other FD has all the attributes of its determinant in T_2. Therefore, XYZ → YW is nonredundant. Notice that {YW} ⊄ T_2.

f. Test $WQ \rightarrow YZ$ for redundancy. $G = \{X \rightarrow YZ, P \rightarrow Z, W \rightarrow XPQ, XYQ \rightarrow YW\}$
$T_1 = \{WQ\}$. The determinant of $W \rightarrow XPQ$ has all its attributes in T_1. Therefore, $T_2 = T_1 \cup \{XPQ\} = \{WQXP\}$. The determinant of $X \rightarrow YZ$ is an element of T. Therefore, $T_3 = T_2 \cup \{YZ\} = \{WQXPYZ\}$. Since the right-hand side of $WQ \rightarrow YZ$ has all its attributes in T_3, we have that $WQ \rightarrow YZ$ is redundant and it can be removed from the set G.

(3) There are no more FDs of G that can be tested, therefore, the nonredundant cover of F is the set $G = \{X \rightarrow YZ, P \rightarrow Z, W \rightarrow XPQ, XYQ \rightarrow YW\}$.

4.6.4 EXTRANEOUS ATTRIBUTES

If F is a nonredundant set of FDs then F cannot be made smaller by removing any of its FDs. If we were to do so, the resulting set would no longer be equivalent to F. However, it may be possible to reduce the size of the FDs of F by removing either *extraneous left attributes with respect to F* or *extraneous right attributes with respect to F*. These two concepts can be formalized as follows: Let F be a set of FDs over scheme R and let $A_1A_2 \rightarrow B_1B_2$ be a functional dependency in F. *Attribute A_1 is an extraneous left attribute* in $A_1A_2 \rightarrow B_1B_2$ with respect to F if and only $F \equiv F - \{A_1A_2 \rightarrow B_1B_2\} \cup \{A_2 \rightarrow B_1B_2\}$. In other words, attribute A_1 is an extraneous left attribute in $A_1A_2 \rightarrow B_1B_2$ if the attribute A_1 can be removed from the determinant of the FD: $A_1A_2 \rightarrow B_1B_2$ without changing the closure of F. Likewise, we can define B_1 as being an *extraneous right attribute* in the FD: $A_1A_2 \rightarrow B_1B_2$ if and only if $F \equiv F - \{A_1A_2 \rightarrow B_1B_2\} \cup \{A_1A_2 \rightarrow B_2\}$. In other words, attribute B_1 is an *extraneous right attribute* in $A_1A_2 \rightarrow B_1B_2$ with respect to F if and only if the attribute B_1 can be removed from the right-hand side of the FD: $A_1A_2 \rightarrow B_1B_2$ without changing the closure of F. If the set F is understood, we will refer to extraneous attributes as either extraneous right attributes or extraneous left attributes. Functional dependencies that have no extraneous left attributes are called *left-reduced* FDs. Likewise, functional dependencies that have no extraneous right attributes are called *right-reduced* FDs. If *all* FDs of F are left-reduced the set F is said to be a *left-reduced set*. Likewise, if *all* FDs of F are right-reduced the set F is said to be a *right-reduced set*. In this book, we will only consider left-reduced FDs because, from a practical point of view, they are the most useful.

The algorithm for removing extraneous left attributes is shown below. The input to this algorithm is a set F of FDs. The output of the algorithm is a left-reduced cover for G.

The LeftReduce Algorithm

(1) Initialize a set G of FDs to F. That is, set G = F.

(2) For every $A_1 A_2 \ldots A_i \ldots . A_n \rightarrow Y$ in G do step 3 until there are no more FDs in G to which this step can be applied. The algorithm stops when all FDs of G have executed step 3.

(3) For each attribute A_i in the determinant of the FD selected in the previous step do step 4 until all attributes have been tested. After finishing testing all attributes of a particular FD repeat step 2.

(4) Test if all attributes of Y (the right-hand side of the FD under consideration) are elements of the closure of $A_1 A_2 \ldots A_n$ (notice that we have removed attribute A_i from the determinant of the FD) with respect to the FDs of G. If this is the case remove attribute A_i from the determinant of the FD undergoing testing because A_i is an extraneous left attribute. If not all attributes of Y are elements of the closure of $A_1 A_2 \ldots A_n$ then attribute A_i is not an extraneous left attribute and should remain in the determinant of the FD under consideration.

When the algorithm finishes the set G contains a left-reduced cover set for T.

Note: The algorithm can be executed a little bit faster if the reader realizes that step 2 can only be applied to FDs with a determinant of two or more attributes.

The following example illustrates the use of this algorithm.

Example 4.9

Reduce the set F – {X → Z, XY → WP, XY → ZWQ, XZ → R} by removing extraneous left attributes.

$$F - \{X \rightarrow Z, XY \rightarrow WP, XY \rightarrow ZWQ, XZ \rightarrow R\}$$

There is no need to consider FDs with determinants that consist of a single attribute since there cannot be extraneous left attributes.

Step (1)	Set G {X → Z, XY → WP, XY → ZWQ, XZ → R}
Step (2) 1st time	Select XY → WP and do step 3. [We need to repeat this step for all FDs in G.]
Steps (3–4) 1st time	From the previous FD choose one attribute of the determinant. Let's choose X and test if the right-hand side of Y → WP is in the closure of Y with respect to G. The closure of Y {Y}. Since {WP} ⊄ Y , the X attribute is not an extraneous left attribute.
Steps (3–4) 2nd time	Choosing the Y attribute of the determinant of the FD: XY → WP and testing if the right-hand side of X → WP is in the closure of X with respect to G, we have that X = (XZR). Since {WP} ⊄ X , the Y attribute is not an extraneous left attribute.
Step (2) 2nd time	Select XY → ZWQ and do step 3.

Steps (3–4) 1st time	From the previous FD choose one attribute of the determinant. Let's choose X and test if the right-hand side of $Y \rightarrow ZWQ$ is in the closure of Y with respect to G. The closure of Y $^{-}$ {Y}. Since $\{ZWQ\} \not\subset Y^{+}$, the X attribute is not an extraneous left attribute.
Steps (3–4) 2nd time	Choosing the Y attribute of the determinant of $XY \rightarrow ZWQ$ and testing if the right-hand side of $X \rightarrow ZWQ$ is in the closure of X with respect to G, we have that X (XZR). Since $\{ZWQ\} \not\subset X^{+}$, the Y attribute is not an extraneous left attribute.
Step (2) 3rd time	Select $XZ \rightarrow R$
Steps (3–4) 1st time	From the previous FD choose one attribute of the determinant. Let's choose X and test if the right-hand side of $Z \rightarrow R$ is in the closure of Z with respect to G. The closure of Z {Z}. Since $\{R\} \not\subset Z^{+}$, the X attribute is not an extraneous left attribute.
Steps (3–4) 2nd time	Choosing the Z attribute of the determinant of the FD: $XZ \rightarrow R$ and testing if the right-hand side of $X \rightarrow R$ is in the closure of X with respect to G, we have that X (XZR). Since $\{R\} \subset X^{+}$, the X attribute is an extraneous left attribute. Therefore, this attribute can be removed from the FD.

Since there are no more FDs to be tested in the set G, we have that a left-reduce cover for F is G $\{X \rightarrow Z, XY \rightarrow WP, XY \rightarrow ZWQ, X \rightarrow R\}$.

4.6.5 CANONICAL COVER

For a given set F of FDs, a *canonical cover*, denoted by F_c, is a set of FDs where the following conditions are simultaneously satisfied:

(1) Every FD of F_c is simple. That is, the right-hand side of every functional dependency of F_c has only one attribute.

(2) F_c is left-reduced.

(3) F_c is nonredundant.

Example 4.10

Given the set F of FDs shown below, find a canonical cover for F. Let's call F_c $\{X \rightarrow Z, XY \rightarrow WP, XY \rightarrow ZWQ, XZ \rightarrow R\}$.

From the previous exercise we know that a left-reduced cover for set F is F_c $\{X \rightarrow Z, XY \rightarrow WP, XY \rightarrow ZWQ, X \rightarrow R\}$. By repeated application of the Projectivity axiom, we can rewrite this set as follows:

$$F_c \quad \{X \rightarrow Z, XY \rightarrow W, XY \rightarrow P, XY \rightarrow Z, XY \rightarrow W, XY \rightarrow Q, X \rightarrow R\}.$$

Notice that in this set, $XY \rightarrow Z$ is redundant. Observe that we can derive that FD from $X \rightarrow Z$ (given) and by application of the Axiom of Augmentation. Therefore, $XY \rightarrow Z$ can be eliminated from F_c. In addition, since F is a set we can eliminate all its duplicate FDs and obtain $F_c = \{X \rightarrow Z, XY \rightarrow W, XY \rightarrow P, XY \rightarrow Q, X \rightarrow R\}$. This resulting set where all FDs are simple, left-reduced and nonredundant, is the canonical cover of F.

Solved Problems

4.1. Given the relation r(R) shown below. State whether or not the following functional dependencies are satisfied by the relation.

a. $A \rightarrow B$ **b.** $A \rightarrow C$ **c.** $AB \rightarrow C$ **d.** $C \rightarrow A$ **e.** $BC \rightarrow A$
f. $AC \rightarrow B$

r

A	B	C
1	4	2
3	5	6
3	4	6
7	3	8
9	1	0

a. FD: $A \rightarrow B$ *is not* satisfied by r because for tuples (3,5,6) and (3,4,6) we have that $t_1(A) = 3 = t_2(A)$ but $t_1(B) = 5 \neq t_2(B) = 4$.
b. FD: $A \rightarrow C$ is satisfied by all tuples of r that have unique values under column A. These tuples are said to satisfy the FD vacuously. In addition, the only two tuples that have equal values in column A also have equal values under column C. That is, $t_1(A) = 3 = t_2(A)$ and $t_1(C) = 6 = t_2(C)$. The relation r satisfies the FD: $A \rightarrow C$ because all its tuples satisfy the FD.
c. FD: $AB \rightarrow C$ is satisfied by the relation r. There are no tuples with equal entries under columns A and B. All tuples satisfy the FD vacuously. Therefore, r satisfies the given FD.
d. FD: $C \rightarrow A$ is satisfied by the relation r. In fact, $t_1(C) = 6 = t_2(C)$ and $t_1(A) = 3 = t_2(A)$. The remaining tuples of the relation satisfy the FD vacuously.
e. FD: $BC \rightarrow A$ is satisfied by the relation r. All tuples satisfy the FD vacuously.
f. FD: $AC \rightarrow B$ is not satisfied by the relation r. Consider the following two tuples where $t_1(AC) = (3,6) = t_2(AC)$ but $t_1(B) = 5 \neq t_2(B) = 4$.

4.2. Show that inference rule "if AB → C and C → A then C → B" is invalid for any relation r(R). Assume that A, B, C, D are all attributes of a relational scheme not shown here.

To disprove the validity of this or any given inference rule we only need to construct a 2-tuple relation r that satisfies AB → C and C → A but not C → B. An instance of a relation r that disproves this inference rule is:

r

A	B	C	D
a_1	b_1	c_1	d_1
a_1	b_2	c_1	d_2

Notice that AB → C is satisfied vacuously by the relation r because the values under attributes AB are different. In addition, notice that C → A is satisfied by the relation because $t_1(C) = t_2(C) = c_1$ and $t_1(A) = t_2(A) = a_1$. However, C → B is not satisfied by the relation because $t_1(C) = t_2(C) = c_1$ but $t_1(B) = b_1 \neq t_2(B) = b_2$.

4.3. Assume that conditions 1 and 2 shown below are satisfied simultaneously by a relation r(X, Y, Z), what can we say about the cardinality of $\pi_Y(\sigma_{X=x}(r))$?

(1) X → Y is satisfied by r

(2) $\sigma_{X=x}(r)$ is a nonempty relation.

Without loss of generalization, let's assume that X and Y are single attributes, that X → Y is not vacuously satisfied by all tuples of r and that every tuple of r has a value under attribute Y. According to the definition of Selection, $\sigma_{X=x}(r)$) will retrieve all tuples of r that have an X-value = x. That is, all tuples of r that have an x under the attribute X. Since X → Y all tuples of $\sigma_{X=x}(r)$) that have equal X-values must also have equal Y-values. Therefore, the Projection of $\sigma_{X=x}(r)$) onto the attribute Y will have a single tuple. If we denote the cardinality of a relation as $|r|$, then using this notation, we can say that $|\pi_Y(\sigma_{X=x}(r))| = 1$. If we assume that $\sigma_{X=x}(r)$) may be empty then $0 \leq |\pi_Y(\sigma_{X=x}(r))| \leq 1$.

4.4. Assume that AB → C, C → D and D → A are simultaneously satisfied by a relation r(R). What are the candidate keys of this relation? Which one is the PK? What are the prime attributes? Are there any superkeys for this relation?

A set of attributes of r is a candidate key of r if and only if the set functionally determines every attribute of the relation. In this particular example, any candidate key must functionally determine attributes A, B, C, and D. The set of attributes that can be selected as candidate keys of the relation r are: AB and DB. Let's see why.

AB is a candidate key (The given FDs are: AB → C, C → D and D → A)

If AB is a key of r then it must be true that AB → A, AB → B, AB → C and AB → D. Using the inference axioms and the FDs of F we have that:

(1) AB → *A* and AB → *B* (Reflexivity axiom)

(2) AB → *C* (given)

(3) AB → C (given) and C → D (given) then AB → *D* (Transitivity axiom).

Therefore, AB is a candidate key of the relation r because it functionally determines any other attribute of the relation r.

DB is a candidate key (The given FDs are: $AB \rightarrow C$, $C \rightarrow D$ and $D \rightarrow A$)

If DB is a key of r then it must be true that $DB \rightarrow A$, $DB \rightarrow B$, $DB \rightarrow C$ and $DB \rightarrow D$. Using the inference axioms and the FDs of F we have that:

(1) $DB \rightarrow D$ and $DB \rightarrow B$ (Reflexivity axiom)

(2) $DB \rightarrow D$ (previous step) and $D \rightarrow A$ (given) we have that $DB \rightarrow A$ (Transitivity axiom)

(3) $DB \rightarrow A$ (from previous step) and $AB \rightarrow C$ (given) then $DBB \rightarrow C$ (Pseudotransitivity axiom)

(4) Knowing that concatenation stands for union and that $B \cup B = B$ we can rewrite $DBB \rightarrow C$ as $DB \rightarrow C$.

Therefore, DB is a candidate key of the relation r because it functionally determines all other attributes of the relation r.

Notice that there are two candidate keys. However, only one can be selected as the PK of the relation. The database designer or the DBA should choose the one that makes more sense or is more convenient for the application.

The prime attributes of this relation are: A, B and D. Remember that a prime attribute is any attribute that is part of a PK or an alternate key.

There are several superkeys. They are: ABC, ABD, ABCD, DBA, DBC and DBAC.

4.5. Given the relational scheme R(A,B,C,D) and the FDs $A \rightarrow B$ and $BC \rightarrow D$. Determine which of the dependencies shown below can be derived from these FDs by application of the inference axioms.

a. $AC \rightarrow D$ **b.** $B \rightarrow D$ **c.** $AD \rightarrow B$

a. $AC \rightarrow D$ can be derived from $A \rightarrow B$ and $BC \rightarrow D$ by application of the Pseudotransitivity axiom.

b. $B \rightarrow D$ cannot be derived from the given FDs. Notice that from the given $BC \rightarrow D$ we cannot deduce that $B \rightarrow D$. The following instance of r confirms this.

A	B	C	D
a_1	b_1	c_1	d_1
a_2	b_1	c_2	d_2

Observe that in this instance $BC \rightarrow D$ but $B \not\rightarrow D$.

c. $AD \rightarrow B$ can be immediately derived from $A \rightarrow B$ by an application of the Augmentation axiom. Notice that this axiom states that if we only need A to determine B then having extra information, in this case, D, does not change the fact that we only need A to determine B. Attributes such as D are sometimes called redundant attributes.

4.6. Show that the axiom of Transitivity is a particular case of the Pseudotransitivity axiom.

If $W = \emptyset$ in the Pseudotransitivity axiom ($X \rightarrow Y$ and $YW \rightarrow Z$, then $XW \rightarrow Z$) we can rewrite this axiom as follows: if $X \rightarrow Y$ and $Y\emptyset \rightarrow Z$, then $X\emptyset \rightarrow Z$. Since concatenation stands for union and $X \cup \emptyset = X$ for any set X, we have that if $X \rightarrow Y$ and $Y \rightarrow Z$, then $X \rightarrow Z$.

4.7. Given the relation r(A,B,C) and the set F – {AB → C, B → D, D → B} of functional dependencies, find the candidate keys of the relation. How many candidate keys are in this relation? What are the prime attributes?

AB and AD are the two candidate keys of this relation. That is, either one of these two sets of attributes functionally determines any other attribute in the relation.

AB is a candidate key

(1) AB → *A* and AB → *B* (Reflexivity axiom)

(2) AB → *C* (given)

(3) AB → B (from step 1) and B → D (given) then AB → *D* (Transitivity axiom)

Since AB determines every other attribute of the relation we have that AB is a candidate key.

AD is a candidate key

(1) AD → *A* and AD → *D* (Reflexivity axiom)

(2) AD → D (from previous step) and D → B (given) then AD → *B* (Transitivity axiom)

(3) AD → B (from previous step) and AB → C (given) then AAD → C (Pseudotransitivity axiom). Keeping in mind that concatenation stands for union and A ∪ A A, we can rewrite AAD → C as A → *C*.

Since AD determines every other attribute in the relation we have that AD is a candidate key.

The prime attributes are: A, B, and D.

4.8. Given F { XY → W, Y → Z, WZ → P, WP → QR, Q → X} show that F XY → P using the inference axioms.

(1) XY → W (given) and WZ → P (given) we have XYZ → P (Pseudotransitivity axiom)

(2) XYZ → P (from previous step) and Y → Z (given) we have XYY → P (Pseudotransitivity axiom). Since concatenation stands for union and Y ∪ Y Y, we can rewrite the last FD as follows: XY → P.

4.9. Given the set F of FDs of the previous exercise, show that F XY → P using $(XY)^{-}$.

Step (1)	G – {XY → W, Y → Z, WZ → P, WQ → QR, Q → X}
Step (2)	T_1 – {XY}
Steps (3/3-a)	All attributes of the determinant of XY → W are members of T_1. Therefore, we form a new set T_2 by adding to T_1 the right-hand side of this FD. Therefore, T_2 T_1 ∪ {W} {XYW}. G G (XY → W} {Y → Z, WZ → P, WQ → QR, Q → X }.
Steps (3/3-a) (2nd time)	The determinant of Y → Z is a member of T_2, therefore, T_3 – T_2 ∪ {Z} – {XYWZ}. G – G (Y → Z} – {WZ → P, WQ → QR, Q → X }.
Steps (3/3-a) (3rd time)	Observe now that all the attributes of the determinant of WZ → P are members of T_3. Therefore, T_4 T_3 ∪ {P} {XYWZP}. G – G (WZ → P} – {WQ → QR, Q → X}.
Step (3/3-b)	There are no FDs in G that have all their attributes as elements of T_4. Therefore, the algorithm terminates and $(XY)^{+}$ – {XYZWP}. Since P, the right-hand side of XY → P is a member of (XY) this implies that we can derive P from the attributes XY using the inference axioms.

Another way of showing that $XY \rightarrow P$ using the inference axioms is as follows:

$$F \quad \{XY \rightarrow W, Y \rightarrow Z, WZ \rightarrow P, WP \rightarrow QR, Q \rightarrow X\}$$

(1) $Y \rightarrow Z$ (given) therefore $XY \rightarrow Z$ (Augmentation axiom)

(2) $XY \rightarrow Z$ (from previous step) and $WZ \rightarrow P$ (given) we have $WXY \rightarrow P$ (Pseudotransitivity axiom)

(3) $WXY \rightarrow P$ (from previous step) and $XY \rightarrow W$ (given) we have that $XYXY \rightarrow P$ (Pseudotransitivity axiom)

(4) $XYXY \rightarrow P$ can be rewritten as $XY \rightarrow P$ knowing that concatenation stands for union, that the union of set is commutative and $X \cup X - X$ and $Y \cup Y - Y$.

4.10. Eliminate redundant FDs from $F \quad \{X \rightarrow Y, Y \rightarrow X, Y \rightarrow Z, Z \rightarrow Y, X \rightarrow Z, Z \rightarrow X\}$ using the membership algorithm.

Testing $X \rightarrow Y$ for redundancy ($X \rightarrow Y$ has been temporarily removed from F)

Step (1) $G - \{Y \rightarrow X, Y \rightarrow Z, Z \rightarrow Y, X \rightarrow Z, Z \rightarrow X\}$

Step (2) $T_1 - \{X\}$

Steps (3/3-a) The determinant of $X \rightarrow Z$ is an element of T_1. Adding the right-hand side of this FD to T_1 we have that $T_2 - T_1 \cup \{Z\} - \{XZ\}$. Notice that $Y \notin T_2$. Therefore, removing $X \rightarrow Z$ from G we have that $G \quad G \quad \{X \rightarrow Z\} \quad \{Y \rightarrow X, Y \rightarrow Z, Z \rightarrow Y, Z \rightarrow X\}$.

Steps (3/3-a) (2nd time) The determinant of $Z \rightarrow Y$ is an element of T_2. Therefore, $T_3 - T_2 \cup \{Y\} - \{XZY\}$. Since $Y \subseteq T_3$ we have that $X \rightarrow Y$ is redundant in the set G and can be safely removed from it.

Testing $Y \rightarrow X$ ($Y \rightarrow X$ has been temporarily removed from F)

Step (1) $G \quad \{Y \rightarrow Z, Z \rightarrow Y, X \rightarrow Z, Z \rightarrow X\}$

Step (2) $T_1 \quad \{Y\}$

Steps (3/3-a) The determinant of $Y \rightarrow Z$ is an element of T_1. Therefore, $T_2 \quad T_1 \cup \} \quad \{YZ\}$. $G \quad \{Z \rightarrow Y, X \rightarrow Z, Z \rightarrow X\}$.

Steps (3/3-a) (2nd time) The determinant of $Z \rightarrow X$ is now an element of T_2. Therefore, $T_3 \quad T_2 \cup \{X\} \quad \{YZX\}$. Since the right-hand side of the FD that we are testing, $Y \rightarrow X$, is an element of T_3 we can conclude that $Y \rightarrow X$ is redundant and can be safely removed from the set G. This new set is then $G \quad \{Y \rightarrow Z, Z \rightarrow Y, X \rightarrow Z, Z \rightarrow X\}$.

Testing $Y \rightarrow Z$ ($Y \rightarrow Z$ has been temporarily removed from F)

Step (1) $G - \{Z \rightarrow Y, X \rightarrow Z, Z \rightarrow X\}$

Step (2) $T_1 - \{Y\}$

Steps (3/3-b) None of the FDs of G has all their attributes as elements of T_1. Therefore, $Y \rightarrow Z$ is nonredundant.

Testing $Z \rightarrow Y$ ($Z \rightarrow Y$ has been temporarily removed from F)

Step (1) $G \quad \{Y \rightarrow Z, X \rightarrow Z, Z \rightarrow X\}$

Step (2) $T_1 \quad \{Z\}$

Steps (3/3-a) The determinant of $Z \rightarrow X$ is an element of T_1. Therefore, $T_2 \quad T_1 \cup \{X\} \quad \{ZX\}$. Removing $Z \rightarrow X$ from G we have that now $G \quad \{Y \rightarrow Z, X \rightarrow Z\}$.

Steps (3/3-a) (2nd time) The determinant of $X \rightarrow Z$ is an element of T_2. Therefore, $T_3 = T_2 \cup \{Z\} = \{ZX\}$. Removing $Z \rightarrow Y$ from G produces a new set $G = \{Y \rightarrow Z\}$.

Steps (3/3-b) None of the FDs of G has all their attributes as elements of T_3. Therefore, $Z \rightarrow Y$ is nonredundant.

Testing $X \rightarrow Z$ ($X \rightarrow Z$ has been temporarily removed from F)

Step (1) $G = \{Y \rightarrow Z, Z \rightarrow Y, Z \rightarrow X\}$

Step (2) $T_1 = \{X\}$

Step (3) None of the FDs of G has all their attributes as elements of T_1. Therefore, $X \rightarrow Z$ is nonredundant.

Testing $Z \rightarrow X$ ($Z \rightarrow X$ has been temporarily removed from F)

Step (1) $G = \{Y \rightarrow Z, Z \rightarrow Y, X \rightarrow Z\}$

Step (2) $T_1 = \{Z\}$

Steps (3/3-a) The determinant of $Z \rightarrow Y$ has all its attributes in T_1. Therefore, $T_2 = T_1 \cup \{Y\} = \{ZY\}$. Removing $Z \rightarrow Y$ from G produces a new $G = \{Y \rightarrow Z, X \rightarrow Z\}$.

Steps (3/3-a) The determinant of $Y \rightarrow Z$ has all its attributes in T_2. Therefore, $T_3 = T_2 \cup \{Z\} = \{ZY\}$. Removing $Y \rightarrow Z$ from G we have $G = \{X \rightarrow Z\}$.

Steps (3/3-b) None of the FDs of G has all their attributes as elements of T_1. Therefore, $Z \rightarrow X$ is nonredundant.

The nonredundant set F is as follows: $\{Y \rightarrow Z, Z \rightarrow Y, X \rightarrow Z, Z \rightarrow X\}$.

4.11. Reduce the set $F = \{X \rightarrow YW, XW \rightarrow Z, Z \rightarrow Y, XY \rightarrow Z\}$ by removing left extraneous attributes.

No need to consider FDs with single determinants.

Step (1) Set $G = \{X \rightarrow YW, XW \rightarrow Z, Z \rightarrow Y, XY \rightarrow Z\}$

Step (2) (1st time) Select $XW \rightarrow Z$ and do step 3. [We need to repeat this step for all FDs of G.]

Steps (3–4) (1st time) From the determinant of the previous FD let's choose attribute X and test if $Z \subseteq (W)^+$ with respect to G.
$(W)^+ = \{W\}$. Since $\{Z\} \not\subseteq (W)^+$ we have that the attribute X is not an extraneous attribute.

Step (2) (2nd time) From the determinant of $XW \rightarrow Z$, let's choose attribute W and test if $Z \subseteq (X)^+$ with respect to G. Since $(X)^+ = \{XYWZ\}$ and $\{Z\} \subseteq (X)^+$ we have that attribute W is an extraneous left attribute and can be removed from the determinant of $XW \rightarrow Z$.

Step (2) (1st time) Select $XY \rightarrow Z$. The new set $G = \{X \rightarrow YW, X \rightarrow Z, Z \rightarrow Y, XY \rightarrow Z\}$.

Steps (3–4) (1st time) From the determinant of $XY \rightarrow Z$ let's choose attribute X and test if $\{Z\} \subseteq (Y)^+$. Since $(Y)^+ = \{Y\}$ we have that $\{Z\} \not\subseteq (Y)^+$. Therefore, attribute X is not an extraneous left attribute.

Steps (3–4) (2nd time) From the determinant of $XY \rightarrow Z$ let's choose attribute Y and test if $\{Z\} \subseteq (X)^+$. In this case, $(X)^+ = \{XYWZ\}$. Therefore, $\{Z\} \subseteq (X)^+$. Attribute Y is an extraneous left attribute and can be removed from $XY \rightarrow Z$.

The algorithm stops executing since there are no more FDs in G that can be tested. After removing duplicate FDs, the set $F = \{X \rightarrow YW, X \rightarrow Z, Z \rightarrow Y\}$ is a left-reduced set.

4.12. Transform the left reduced set of the previous example to a canonical cover for F.

To obtain a canonical cover for F, it is necessary that all FDs be simple. That is, that all FDs of F must have a single attribute in their right-hand sides. Using the Projectivity axiom we can rewrite F as follows: F $\{X \rightarrow Y, X \rightarrow W, X \rightarrow Z, Z \rightarrow Y\}$. $X \rightarrow Y$ is a redundant FD since it can be derived from $X \rightarrow Z$ and $Z \rightarrow Y$ using the Transitivity axiom. Eliminating $X \rightarrow Y$ from F we have that $F_c - \{X \rightarrow W, X \rightarrow Z, Z \rightarrow Y\}$.

Supplementary Problems

4.13. For each of the FDs shown below give an instance of a relation r(R) that shows that these FDs are not valid inference rules.

a. If $A \rightarrow B$ then $B \rightarrow A$ **b.** If $AB \rightarrow C$ then $A \rightarrow C$

c. If $AB \rightarrow C$ then $B \rightarrow C$

4.14. Assume that there is a set of FDs that satisfy a relation r(A,B,C). An instance of this relation is shown below. Find the functional dependencies that are satisfied by r.

r

A	B	C
f	e	e
d	e	e
b	c	e
a	c	d
a	b	c

4.15. Find the candidate keys for the relation r(X, Y, Z, W, P) if all FDs of the set $F - \{Y \rightarrow Z, Z \rightarrow Y, Z \rightarrow W, Y \rightarrow P\}$ hold for all instances of r.

4.16. Using the inference axioms show that F $XY \rightarrow Q$ where F $\{XY \rightarrow W, Y \rightarrow Z, WZ \rightarrow P, WP \rightarrow QR, Q \rightarrow X\}$.

4.17. Using $(XY)^{-}$ show that F $XY \rightarrow Q$ where F $\{XY \rightarrow W, Y \rightarrow Z, WZ \rightarrow P, WP \rightarrow QR, Q \rightarrow X\}$. Find a derivation for $XY \rightarrow Q$ using the inference axioms. Make sure that this derivation is different than the one obtained in the previous problem.

4.18. Remove any extraneous left attributes from F – {A → BC, E → C, D → AEF, ABF → BD}.

4.19. Find a canonical cover for the set F of the previous example.

Answers to Supplementary Problems

4.13. a. The given FD is not a valid inference rule as the instance shown below indicates. Notice that A → B but it is not true that B → A.

r

A	B
a_1	b_1
a_2	b_1

b. The given FD is not a valid inference rule as the instance shown below indicates. Observe that AB → C holds true but A → C does not.

r

A	B	C
a_1	b_1	c_1
a_1	b_2	c_2

c. The given FD is not a valid inference rule as the instance shown below indicates. Notice that AB → C holds true but B → C does not.

r

A	B	C
a_1	b_1	c_1
a_2	b_1	c_2

4.14. $AB \rightarrow C$ and $AC \rightarrow B$ are the only FDs satisfied by the relation r.

4.15. XY and XZ are the only candidate keys of the relation r.

4.16. **a.** From $WZ \rightarrow P$ (given) and $WP \rightarrow QR$ (given) results $WWZ \rightarrow QR$ (Pseudotransitivity axiom). The latter FD can be rewritten as $WZ \rightarrow QR$ (concatenation stands for union and $W \cup W = W$)

b. From $WZ \rightarrow QR$ (previous step) and $Y \rightarrow Z$ (given) results $WY \rightarrow QR$ (Pseudotransitivity axiom)

c. From $WY \rightarrow QR$ (previous step) and $XY \rightarrow W$ (given) results $XYY \rightarrow QR$ (Pseudotransitivity axiom). The latter FD can be rewritten as $XY \rightarrow QR$ (concatenation stands union and $Y \cup Y = Y$)

d. From $XY \rightarrow QR$ (previous result) results $XY \rightarrow Q$ (Projectivity axiom)

4.17. $(XY)^+ = \{XYWZPQR\}$. $Q \in (XY)^+$, therefore $F \models XY \rightarrow Q$.

Using $Y \rightarrow Z$ (given) and $WZ \rightarrow P$ (given) we obtain $WY \rightarrow P$ (Pseudotransitivity axiom). Using this last result and $WP \rightarrow QR$ (given) we obtain $WWY \rightarrow QR$. Knowing that $W \cup W = W$, we can rewrite the latter FD as follows: $WY \rightarrow QR$. Using this last result and $XY \rightarrow W$ (given) we have that $XYY \rightarrow QR$. The determinant of this FD can be rewritten as $XY \rightarrow QR$ since $Y \cup Y = Y$. Using $XY \rightarrow QR$ and the axiom of Projectivity we have $XY \rightarrow Q$.

4.18. Attribute B of the determinant of $ABF \rightarrow BD$ is an extraneous left attribute. This FD can be written as $AF \rightarrow BD$.

4.19. $AF \rightarrow B$ is redundant since $A \rightarrow B$ is in F. $F_c = \{A \rightarrow B, A \rightarrow C, E \rightarrow C, D \rightarrow A, D \rightarrow E, D \rightarrow F, AF \rightarrow D\}$.

CHAPTER 5

The Normalization Process

5.1 Introduction

In relational databases the term *normalization*[1] refers to a reversible step-by-step process in which a given set of relations is replaced by successive collections of relations that have a progressively simpler and more regular structure. Each step, referred to as a *normal form*, defines a set of criteria (the normal form test) that needs to be met by the different tables of the database. In this sense, to say that a relation is in a particular normal form is an indication of the conditions that the table has met. Since the process is reversible, the original set of relations can be recovered with no loss of information. As the normalization progresses to higher forms, the individual collection of relations becomes progressively more restricted on the type of functional dependencies that they can satisfy and the data anomalies that they can experience. Data anomalies will be explained in Section 5.3.

The objectives of the normalization process are:[2]

- To make it feasible to represent any relation in the database.
- To obtain powerful relational retrieval algorithms based on a collection of primitive relational operators.
- To free relations from undesirable insertion, update, and deletion anomalies.
- To reduce the need for restructuring the relations as new data types are introduced.

[1] This process was initially defined by E. F. Codd in "Normalized Data Base Structure: A Brief Tutorial," *Proc. ACM SIGFIDET Workshop on Data Description, Access and Control* pp. 1–17, 1971.

[2] Adapted from *Database Management Systems* by D. Tsichritzis and F. Lochovsky, Academic Press, 1977.

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The first two objectives apply specifically to the First Normal Form; the last two apply to all normal forms. These terms will be defined shortly.

The entire normalization process is based upon the analysis of relations, their schemes, their primary keys and their functional dependencies. Whenever a relation does not meet a normal form test, the relation must be *decomposed* or broken into some other relations that individually meet the criteria of the normal form test. Initially, E. F. Codd proposed three normal forms that he called first, second, and third normal form. These forms are generally abbreviated and referred to as 1NF, 2NF, and 3NF respectively. In addition to these original normal forms there exist others such as the Boyce-Codd Normal Form[3] (BCNF), Fourth Normal Form (4NF), and Fifth Normal Form (5NF). The relationship between some of these normal forms is shown in Fig. 5-1. This figure is sometimes referred to as the normal form "onion". In this book we will only address the following forms: 1NF, 2NF, 3NF, and BCNF. A discussion of these forms follows.

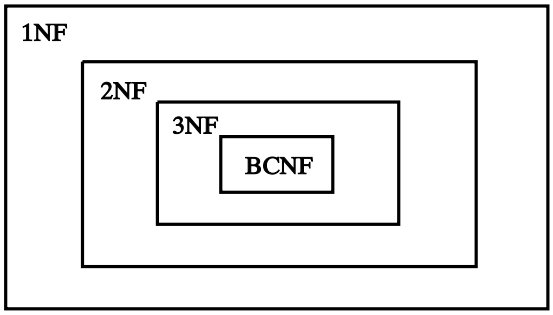


Fig. 5-1. Hierarchy of the Normal Forms.

5.2 First Normal Form

Sometimes, during the process of designing a database it may be necessary to transform into a relation a given table that in some of its entries (the intersection of a row and a column) may have more than one value. For example, consider the PROJECT table shown in Fig. 5-2 where one or more employees may be assigned to a project. Notice that for each Project id (Proj-ID) every "row" of the table has more than one value under the columns Emp-ID, Emp-Name, Emp-Dpt, Emp-Hrly-Rate, and Total-Hrs.

[3] Originally proposed in E. F. Codd; "Recent Investigations into Relational Data Base Systems," *Proc. IFIP Congress*, Stockholm, Sweden, 1974.

Proj-ID	Proj-Name	Proj-Mgr-ID	Emp-ID	Emp-Name	Emp-Dpt	Emp-Hrly-Rate	Total-Hrs
100	E-commerce	789487453	123423479	Heydary	MIS	65	10
			980808980	Jones	TechSupport	45	6
			234809000	Alexander	TechSupport	35	6
			542298973	Johnson	TechDoc	30	12
110	Distance-Ed	820972445	432329700	Mantle	MIS	50	5
			689231199	Richardson	TechSupport	35	12
			712093093	Howard	TechDoc	30	8
120	Cyber	980212343	834920043	Lopez	Engineering	80	4
			380802233	Harrison	TechSupport	35	11
			553208932	Olivier	TechDoc	30	12
			123423479	Heydary	MIS	65	07
130	Nitts	550227043	340783453	Shaw	MIS	65	07

Fig. 5-2. The PROJECT table.

To refer to this type of table and how tables relate to relations some new terminology is necessary. Table entries that have more than one value are called *multivalue* entries. Tables with multivalue entries are called *unnormalized* tables. Within an unnormalized table, we will call a *repeating group* an attribute or group of attributes that may have multivalue entries for single occurrences of the table identifier. This last term refers to the attribute that allows us to distinguish the different rows of the unnormalized table. Using this terminology we can describe the PROJECT table shown above as an unnormalized table where attributes Emp-ID, Emp-Name, Emp-Dpt, Emp-Hrly-Rate, and Total-Hrs are repeating groups. As we indicated before in Section 2.1, this type of table cannot be considered a relation because there are entries with more than one value.

To be able to represent this table as a relation and to implement it in a RDBMS, it is necessary *to normalize the table*. In other words, we need to put the table in first normal form. We can formally define the latter term as follows: A relation r(R) is said to be in *First Normal Form (1NF)* if and only if every entry of the relation (the intersection of a tuple and a column) has at most a single value. Some authors prefer to say that a relation is in 1NF if and only if all its attributes are based upon a simple domain. These two definitions are equivalent. If all relations of a database are in 1NF we will say that the database is in 1NF.

The objective of normalizing a table is to remove its repeating groups and ensure that all entries of the resulting table have at most a single value. The reader should be aware that by simply removing their repeating groups unnormalized tables do not become relations automatically. Some further manipulation of the resulting table(s) may be necessary to ensure that they are indeed relations. In general, there are two basic approaches to normalize tables. We will consider these two approaches next.

The first approach, known as "flattening the table", removes repeating groups by filling in the "missing" entries of each "incomplete row" of the table with copies of their corresponding nonrepeating attributes. The following example illustrates this.

Example 5.1
Flatten the table of Fig. 5-2. Is the resulting table a relation? If not, how can you transform it to a 1NF relation?

In the PROJECT table, for each individual project, under the Emp-ID, Emp-Name, Emp-Dpt, Emp-Hrly-Rate, and Total-Hrs attributes there is more than one value per entry. To normalize this table, we just fill in the remaining entries by copying the corresponding information from the nonrepeating attributes. For instance, for the row that contains the employee Jones, we fill in the remaining "blank" entries by copying the values of the Proj-ID, Proj-Name, and Proj-Mgr-ID columns. This row has now a single value in each of its entries. In the new table shown below, we have grayed all the new set of tuples for the employees of the E-commerce project. We have repeated a similar process for the employees of the remaining two projects. The normalized representation of the PROJECT table is:

Proj-ID	Proj-Name	Proj-Mgr-ID	Emp-ID	Emp-Name	Emp-Dpt	Emp-Hrly-Rate	Total-Hrs
100	E-commerce	789487453	123423479	Heydary	MIS	65	10
100	E-commerce	789487453	980808980	Jones	TechSupport	45	6
100	E-commerce	789487453	234809000	Alexander	TechSupport	35	6
100	E-commerce	789487453	542298973	Johnson	TechDoc	30	12
110	Distance-Ed	820972445	432329700	Mantle	MIS	50	5
110	Distance-Ed	820972445	689231199	Richardson	TechSupport	35	12
110	Distance-Ed	820972445	712093093	Howard	TechDoc	30	8
120	Cyber	980212343	834920043	Lopez	Engineering	80	4
120	Cyber	980212343	380802233	Harrison	TechSupport	35	11
120	Cyber	980212343	553208932	Olivier	TechDoc	30	12
120	Cyber	789487453	123423479	Heydary	MIS	65	10
130	Nitts	550227043	340783453	Shaw	Cabling	40	27

This normalized PROJECT table *is not* a relation because it does not have a primary key. The attribute Proj-ID no longer identifies uniquely any row. Notice that all rows in the grayed area have the same Proj-ID. To transform this table into a relation a primary key needs to be defined. A suitable PK for this table is the composite key (Proj-ID, Emp-ID). Observe that any other combination of the attributes of the table will not work as a PK.

The second approach for normalizing a table requires that the table be decomposed into two new tables that will replace the original table. Decomposition of a relation involves separating the attributes of the relation to create the schemes of two new relations. However, before decomposing the original table it is necessary to identify an attribute or a set of its attributes that can be used as table identifiers. Assuming that this is the case, one of the two tables contains the table identifier of the original table and *all the nonrepeating* attributes. The other table contains a copy of the table identifier and *all the repeating* attributes. To transform these tables in relations, it may be necessary to identify a PK for each table. If one of the tables has more than one repeating group or if the repeating groups have other repeating groups within themselves this process can be repeated as many times as necessary. The tuples of the new relations are the projection of the original relation into their respective schemes. The following example illustrates this second approach for normalizing tables.

Example 5.2

Normalize the table of Fig. 5-2 using the second approach of normalization.

To normalize the PROJECT table we need to replace it by two new tables. The first table contains the table attribute and the nonrepeating groups. These attributes are: Proj-ID (the table identifier), Proj-Name, and Proj-Mgr-ID. The second table contains the table identifier and all the repeating groups. Therefore, the attributes of this table are: Proj-ID, Emp-ID, Emp-Name, Emp-Dpt, Emp-Hrly-Rate, and Total-Hrs. To transform the latter table into a relation, it is necessary to assign it a PK. These two new 1NF relations are shown below. Notice that for the PROJECT-EMPLOYEE table the composite attribute (Proj-ID, Emp-ID) is an appropriate PK.

PROJECT

Proj-ID	**Proj-Name**	**Proj-Mgr-ID**
100	E-commerce	789487453
110	Distance-Ed	820972445
120	Cyber	980212343
130	Nitts	550227043

PROJECT-EMPLOYEE

Proj-ID	Emp-ID	Emp-Name	Emp-Dpt	Emp-Hrly-Rate	Total-Hrs
100	123423479	Heydary	MIS	65	10
100	980808980	Jones	TechSupport	45	6
100	234809000	Alexander	TechSupport	45	6
100	542298973	Johnson	TechDoc	30	12
110	432329700	Mantle	MIS	65	5
110	689231199	Richardson	TechSupport	45	12
110	712093093	Howard	TechDoc	30	8
120	834920043	Lopez	Engineering	80	4
120	380802233	Harrison	TechSupport	45	11
120	553208932	Olivier	TechDoc	30	12
120	123423479	Heydary	MIS	65	10
130	340783453	Shaw	Cabling	40	27

At this point the reader may ask which of these two approaches is better to use. Actually, both approaches are correct because they transform any unnormalized table into a 1NF relation. However, the authors consider the second approach more efficient because the relations produced are less redundant. In addition, as we will see in the next section, the single table obtained using the first approach will be eventually broken into the same two tables obtained in the second approach.

5.3 Data Anomalies in 1NF Relations

Redundancies in 1NF relations lead to a variety of *data anomalies*. By this latter term we mean side effects that the data experience as a result of some relational operations. Data anomalies are divided into three general categories: *insertion*, *deletion* and *update* anomalies. They are named respectively after the relational operations of INSERT, DELETE and UPDATE because it is during the application of these operations that a relation may experience anomalies. In reality there are only two types of anomalies: update and insertion/deletion anomalies. The latter category can be considered as only one category because

a relation that experiences deletion anomalies will also have insertion anomalies. One cannot exist without the other. However, for explanation purposes we will consider these data anomalies as divided into three categories.

To help us understand the concept of data anomalies in 1NF relations, let's consider the functional dependency EMP-ID → EMP-DPT of the PROJECT-EMPLOYEE relation of the previous section. *Insertion anomalies* occur in this relation because we cannot insert information about any new employee that is going to work for a particular department unless that employee is already assigned to a project. Remember that the composite key of this relation is (Proj-ID, Emp-ID). Notice also that the integrity constraint prevents any attribute of a composite key from being NULL. Likewise, the relation experiences *deletion anomalies* whenever we delete the last tuple of a particular employee. In this case, we not only delete the project information that connects that employee to a particular project but also lose other information about the department for which this employee works. Consider the information that is lost if employee Shaw is deleted. In addition to these two types of anomalies, the relation is also susceptible to *update anomalies* because the department for which an employee works may appear many times in the table. It is this redundancy of information that causes the anomaly because if an employee moves to another department, we are now faced with two problems: we either search the entire table looking for that employee and update his or her Emp-Dpt value or we miss one or more tuples of that employee and end up with an inconsistent database. For small tables, this type of anomaly may not seem to be much of a problem, but it is easy to imagine situations where there may be thousands of tuples that experience similar anomaly.

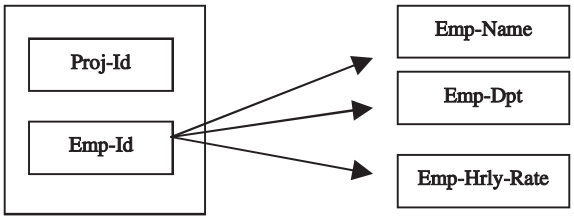
5.4 Partial Dependencies

Given a relation r(R), the sets of attributes X and Y ($X, Y \subset R$), and $X \rightarrow Y$, we will say that attribute *Y is fully dependent on attribute X* if and only if there is no proper subset W of X such that $W \rightarrow Y$. If there is a proper subset W of X such that $W \rightarrow Y$ then attribute Y is said to be *partially dependent on attribute X*. Another way of expressing the concept of partial and full dependency is as follows: Given $A_1A_2A_3 \ldots A_m \rightarrow B_1B_2 \ldots B_n$ with ($m > n$), the set of attributes $B_1B_2 \ldots B_n$ is said to be partially dependent on attributes $A_1A_2A_3 \ldots A_m$ if and only if there exists a proper subset of attributes $A_cA_dA_e \ldots A_k \subset A_1A_2A_3 \ldots A_m$ such that $A_cA_dA_e \ldots A_k \rightarrow B_1B_2 \ldots B_n$. In other words, attributes $B_1B_2 \ldots B_n$ are partially dependent on the determinant if there is a subset of the attributes of the determinant that functionally determine the right-hand side of the FD. If no such a subset of attributes of the determinant exist then we say that attributes $B_1B_2 \ldots B_n$ are fully dependent on the determinant of the FD.

The identification of partial dependencies is a critical aspect of transforming relations to 2NF as we will see in Section 5.5. Example 5.3 illustrates this concept of partial dependency.

Example 5.3
Identify any partial dependencies in the PROJECT-EMPLOYEE relation.

As indicated before, the PK of this relation is formed by the attributes Proj-ID and Emp-ID. This implies that *Proj-ID, Emp-ID* functionally determines any individual attribute or any combination of attributes of the relation. However, we only need attribute Emp-ID to functionally determine the following attributes: Emp-Name, Emp-Dpt, Emp-Hrly-Rate, and Total-Hrs. In other words, attributes Emp-Name, Emp-Dpt, and Emp-Hrly-Rate are partially dependent on the key. A diagram representing the partial dependency of these attributes on the composite key is shown below.



Example 5.4
Find the partial dependencies in the PROJECT table of Example 5.2.

There are no partial dependencies in this table because the determinant of the key only has a single attribute.

5.5 Second Normal Form

A relation r(R) is in *Second Normal Form* (2NF) if and only if the following two conditions are met simultaneously:

(1) r(R) is already in 1NF.

(2) No nonprime attribute is partially dependent on any key or, equivalently, each nonprime attribute in R is fully dependent upon every key (including candidate keys).

Notice that in order to find the nonprime attributes of R we need to identify *all* prime attributes of R. As a consequence of this we need to identify first *all* possible keys of the relation. The nonprime attributes are then calculated as R P where P is the set of all prime attributes and R is the relational scheme of R.

If all relations of a database are in 2NF we will say that the database is in 2NF.

To transform a relation into a 2NF relation we will follow the approach illustrated in Fig. 5-3. In this diagram,[4] the prime attributes are indicated with asterisks and functional dependencies with arrows. The composite key is indicated with a curly bracket.

[4] Adapted from *Computer Data-Base Organization*, 2nd edn, by James Martin, Prentice-Hall, 1975.

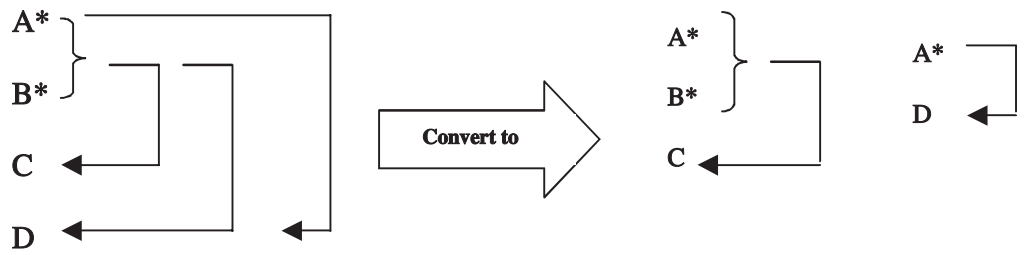


Fig. 5-3. Conversion to 2NF.

Notice that in Fig. 5-3, the PK consists of attributes A and B. These two attributes determine all other attributes. Attributes A and B are the only prime attributes. Attribute C is fully dependent on the key. Attribute D is partially dependent on the key because we only need attribute A to functionally determine it. Attributes C and D are nonprime. Observe that in the diagram the original relation gets replaced by two new relations. The first new relation has three attributes: A, B, and C. The PK of this relation is AB (the PK of the original relation). The second relation has A and D as its only two attributes. Observe that attribute A has been designated as the PK of the second relation and that attribute D is now fully dependent on the key. Although the diagram only shows four attributes, we can generalize this procedure for any relation that we need to transform to 2NF if we assume that C stands for the collection of attributes that are fully dependent on the key and D stands for the collection of attributes that are partially dependent on the key. The next example illustrates how to transform a relation into 2NF using this general procedure.

Example 5.5
Transform the PROJECT-EMPLOYEE relation into a 2NF relation.

The general procedure calls for breaking this relation into two new relations. The first relation has as its PK the PK of PROJECT-EMPLOYEE (Proj-ID, Emp-ID), and the remaining attributes of this relation are all the attributes that fully depend on this key. In this case, the only attribute that fully depends on this composite key is Total-Hours. The scheme of this new relation that we have named HOURS-ASSIGNED is as follows:

HOURS-ASSIGNED (<u>Proj-ID, Emp-ID</u>, Total-Hours)

The second relation contains as its key the Emp-ID attribute since this attribute fully determines the Emp-Name, Emp-Dpt, and Emp-Hrly-Rate. The scheme of this relation is as follows:

EMPLOYEE (<u>Emp-ID</u>, Emp-Name, Emp-Dpt, Emp-Hrly-Rate)

5.6 Data Anomalies in 2NF Relations

Relations in 2NF are still subject to data anomalies. For sake of explanation, let us assume that the department in which an employee works functionally determines the hourly rate charged by that employee. That is, Emp-Dpt → Emp-Hrly-Rate. This fact was not considered in the explanation of the previous normal form but it is not an unrealistic situation. *Insertion anomalies* occur in the EMPLOYEE relation. For example, consider a situation where we would like to set in advance the rate to be charged by the employees of a new department. We cannot insert this information until there is an employee assigned to that department. Notice that the rate that a department charges is independent of whether or not it has employees. The EMPLOYEE relation is also susceptible to *deletion anomalies*. This type of anomaly occurs whenever we delete the tuple of an employee who happens to be the only employee left in a department. In this case, we will also lose the information about the rate that the department charges. *Update anomalies* will also occur in the EMPLOYEE relation because there may be several employees from the same department working on different projects. If the department rate changes, we need to make sure that the corresponding rate is changed for all employees that work for that department. Otherwise, the database may end up in an inconsistent state.

5.7 Transitive Dependencies

Assume that A, B, and C are the set of attributes of a relation r(R). Further assume that the following functional dependencies are satisfied simultaneously: A → B, B ↛ A, B → C, and C ↛ A and A → C. Observe that C → B is neither prohibited nor required. If all these conditions are true, we will say that attribute *C is transitively dependent on attribute A*. It should be clear that these FDs determine the conditions for *having* a transitive dependency of attribute C on A. If any of these FDs are not satisfied then attribute C is not transitively dependent on attribute A. The diagram shown in Fig. 5-4 summarizes these conditions. In this diagram the arrows are equivalent to the symbol "→" that we use for denoting FDs. Notice that the functional dependency A → C may not be explicitly indicated but it holds true due to the Transitivity axiom. The requirements that B ↛ C and C ↛ A are necessary to ensure that attributes A and B are nonprime attributes.

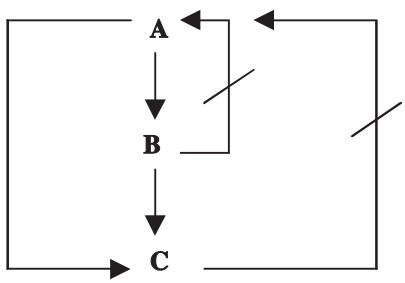


Fig. 5-4. Conditions that define the transitive dependency of attribute C on attribute A.

5.8 Third Normal Form

A relation r(R) is in Third Normal Form (3NF) if and only if the following conditions are satisfied simultaneously:

(1) r(R) is already in 2NF.
(2) No nonprime attribute is transitively dependent on the key.

The reader should not get confused with the conditions stated in Fig. 5-4 and the second condition of the definition of 3NF. Notice that Fig. 5-4 states the conditions that need to be met so that the nonprime attribute C can be transitively dependent on key A. The definition of 3NF requires that these conditions are not met if A is the key attribute and C is a nonprime attribute.

Another way of expressing the conditions for Third Normal Form is as follows:

(1) r(R) is already in 2NF.
(2) No nonprime attribute functionally determines any other nonprime attribute.

Since these two sets of conditions are equivalent (see Solved Problem 5.5), we will use the one that is most convenient for the particular problem at hand.

As these two definitions of 3NF imply, the objective of transforming relations into 3NF is to remove all transitive dependencies. To transform a 2NF relation into a 3NF we will follow the approach indicated by Fig. 5-5. In this figure, assume that any FD not implicitly indicated does not hold. An asterisk indicates the key attribute and the arrows denote functional dependencies. The dashed line indicates that the FD A → C may not be explicitly given but it is always present because it can be derived using the inference axioms.

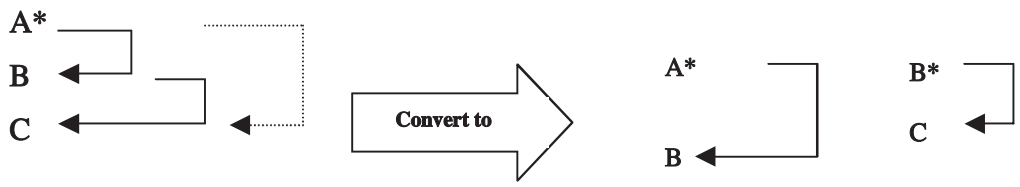


Fig. 5.5. Conversion to Third Normal Form.

The next example illustrates how to transform a relation into 3NF using this general procedure.

Example 5.6
Convert to 3NF the EMPLOYEE relation of Example 5.5 using the first definition of 3NF.

The relation EMPLOYEE of Example 5.5 is not in 3NF because there is a transitive dependency of a nonprime attribute on the primary key of the relation. In this case, the nonprime attribute Emp-Hrly-Rate is transitively dependent on

the key through the functional dependency Emp-Dpt → Emp-Hrly-Rate. Notice that all other conditions required by the definition are met by this set of FDs. In particular, we have that Emp-Dpt ↛ Emp-ID and Emp-Hrly-Rate ↛ Emp-ID. To transform this relation into a 3NF relation, it is necessary to remove any transitive dependency of a nonprime attribute on the key. According to the diagram of Fig. 5-5, it is necessary to create two new relations. The scheme of the first relation is EMPLOYEE (Emp-ID, Emp-Name, Emp-Dpt). The scheme of the second relation is CHARGES (Emp-Dpt, Emp-Hrly-Rate). Observe that in the second relation, the Emp-Dpt attribute has been made the PK of the relation as required by the diagram.

Example 5.7
Using the second definition of 3NF, how can we determine that the EMPLOYEE relation of Example 5.5 is not in 3NF? If we use the second definition for 3NF, do we need to use a different procedure to transform the relation to 3NF?

We can determine that the relation is not in 3NF by noticing that Emp-Dpt → Emp-Hrly-Rate and both attributes are nonprime. To transform this relation to 3NF we use the same general procedure of Fig. 5-5.

The new set of relations that we have obtained through this normalization process does not exhibit any of the anomalies of the previous forms. That is, we can insert, delete and update tuples without any of the side effects that were present in 1NF and 2NF.

5.9 Data Anomalies in 3NF Relations

The Third Normal Form helped us to get rid of the data anomalies caused either by transitive dependencies on the PK or by dependencies of a nonprime attribute on another nonprime attribute. However, relations in 3NF are still susceptible to data anomalies particularly when the relations have two overlapping candidate keys or when a nonprime attribute functionally determines a prime attribute. The following two examples will illustrate this.

Example 5.8
Consider the CERTIFICATION-PROGRAM (Area, Course, Section, Time, Location)

Area	Course	Section	Time	Location
East Coast	SQL 101	Introduction	8:00–10:00	Atlanta Educational Center
East Coast	SQL 101	Intermediate	10:00–12:00	New York Educational Center
West Coast	SQL 101	Advanced	8:00–10:00	Los Angeles Educational Center

This relation is in 3NF because neither of the nonprime attributes functionally determines the other attributes. However, if there is only one instructional center per city then we will have that Location → Area. This dependency does not violate the 3NF condition but there are some anomalies in the data. For example, assume that if we delete the last tuple of the relation we may lose information about the location of the educational center.

Example 5.9
Consider the MANUFACTURER relation shown below where each manufacturer has a unique ID and name. Manufacturers produce items (identified by their unique item numbers) in the amounts indicated. Manufacturers may produce more than one item and different manufacturers may produce the same items.

MANUFACTURER

ID	Name	Item-No	Quantity
M101	Electronics USA	H3552	1000
M101	Electronics USA	J08732	500
M101	Electronics USA	Y23490	200
M322	Electronics-R-Us	H3552	900

This MANUFACTURER relation has two candidate keys: (ID, Item-No) and (Name, Item-No) that overlap on the attribute Item-No. The relation is in 3NF because there is only one nonprime attribute and therefore it is impossible that this attribute can determine another nonprime attribute.

The relation MANUFACTURER is susceptible to update anomalies. Consider for example the case in which one of the manufacturers changes its name. If the value of this attribute is not changed in all of the corresponding tuples there is the possibility of having an inconsistent database.

5.10 Boyce-Codd Normal Form

To eliminate these anomalies in 3NF relations, it is necessary to carry out the normalization process to the next higher step, the Boyce-Codd Normal Form. This concept is formalized next.

A relation r(R) is in Boyce-Codd Normal Form (BCNF) if and only if the following conditions are met simultaneously:

(1) The relation is in 1NF.

(2) For every functional dependency of the form $X \rightarrow A$, we have that either $A \subset X$ or X is a superkey of r. In other words, every functional dependency is either a trivial dependency or in the case that the functional dependency is not trivial then X must be a superkey.

Notice that the definition of BCNF does not make any reference to the concepts of full or partial dependency. However, from this definition we can make the following assertions about the prime and nonprime attributes of the relational scheme:

- All nonprime attributes must be fully dependent on every key.
- All prime attributes must be fully dependent on all keys of which they are not part.

In Fig. 5-1, we can observe that the set of 3NF relations are a proper subset of the BCNF relations. That is, all BCNF are in 3NF but not all 3NF are in BCNF. In this sense, the definition of BCNF is said to be more restrictive. The following example illustrates this.

Example 5.10
Using the MANUFACTURER relation of the previous example, transform it to BCNF.

To transform this relation into BCNF we can decompose it into the following set of relational schemes:

<u>Set No. 1</u>
MANUFACTURER(ID, Name)
MANUFACTURER-PART(ID, Item-No, Quantity)
or
<u>Set No. 2</u>
MANUFACTURER(ID, Name)
MANUFACTURER-PART(Name, Item-No, Quantity)

Notice that both relations are in BCNF and that the update data anomaly is no longer present. In this example, we have decomposed the relation in a manner that is convenient for purpose of the explanation. In Solved Problem 5.16 we will consider a more systematic procedure to transform relations into BCNF.

5.11 Lossless or Lossy Decompositions

So far we have decomposed a relation using either a general procedure (Sections 5.5 and 5.8) or an ad-hoc method (Section 5.10). However, whenever a relation is decomposed it is necessary to ensure that the data in the original relation is represented faithfully by the data in the relations that are the result of the decomposition; that is, we need to make sure that we can recover the original relation from the new relations that have replaced it. Generally the original relation is recovered by forming the natural join of the new relations. If we can recover the original relation we say that the decomposition is *lossless* with respect to D or that the relation has a lossless-join decomposition with respect to D where D is a set of FDs satisfied by the original relation. If the relation cannot be recovered we say that the decomposition is *lossy*. We can formalize this concept as follows:

Assume that a relation r(R) has been replaced by a collection or relation $r_1(R_1)$, $r_2(R_2), \ldots r_n(R_n)$ such that $R = R_1 \cup R_2 \cup \ldots \cup R_n$ and D is a set of dependencies satisfied by r. We say that the decomposition is *lossless with respect to D* or is a *lossless-join decomposition with respect to D* if and only if $r = \pi_{R1}(r)$ join $\pi_{R2}(r)$ join ... join $\pi_{Rn}(r)$. That is, the relation r is lossless if it is the natural join of its projections onto the R_i's. If the relation *cannot* be recovered from the natural projection the *decomposition is said to be lossy with respect to D*. The following example illustrates this concept.

Example 5.11

Consider the relation r shown below and its decomposition R_1 and R_2. Assume that $X \rightarrow Y$ and $Z \rightarrow Y$. Is this decomposition lossless or lossy?

r

X	Y	Z
x_1	y_1	z_1
x_2	y_2	z_2
x_3	y_2	z_3
x_4	y_3	z_4

Decompose

R_1

X	Y
x_1	y_1
x_2	y_2
x_3	y_2
x_4	y_3

R_2

Y	Z
y_1	z_1
y_2	z_2
y_2	z_3
y_3	z_3

R_1 Join R_2

X	Y	Z
x_1	y_1	z_1
x_2	y_2	z_2
x_2	y_2	z_3
x_3	y_2	z_2
x_3	y_2	z_3
x_4	y_3	z_4

Notice that the natural join of relations R_1 and R_2 has tuples that were not present in the original relations. These additional tuples that were not in the original relation are called *spurious tuples* because they represent spurious or false information that is not valid. We have grayed the spurious tuples in the join relation. Since the natural join of relation R_1 and R_2 does not recover the original relation the decomposition is lossy.

5.11.1 TESTING FOR LOSSLESS JOINS

As indicated before, a lossless-join decomposition is necessary to ensure that the relation is recoverable. Determining whether or not a decomposition is lossless or lossy with respect to a set of FDs is a fairly easy procedure if we use the Lossless Join Algorithm. This algorithm is shown next.

The Lossless-Join Algorithm

The algorithm has two inputs. The first input is a set of relations $r_1(R_1)$, $r_2(R_2), \ldots, r_n(R_k)$ that have replaced a relation $r(A_1, A_2, A_3, \ldots, A_n)$ where $R \quad \{A_1, A_2, A_3, \ldots, A_n\} \quad R_1 \cup R_2 \cup \ldots \cup R_k$. The second input to the algorithm is a set F of functional dependencies satisfied by r. The output of the algorithm is a decision stating that the decomposition is lossless or lossy. To apply this algorithm proceed as follows:

(1) Construct a table with n columns (n is the number of attributes of the original relation) and k rows (k is the number of relations in which the original relation has been decomposed). Label the columns of this table $A_1, A_2, A_3, \ldots, A_n$ respectively. Label the rows $R_2, R_2, R_3, \ldots, R_k$.

(2) Fill in the entries of this table as follows:
For each attribute A_i check if this attribute is one of the attributes of the scheme of the relation R_j. If attribute A_i is in the scheme of R_j, then in the entry (A_i, R_j) of the table write a_i. If attribute A_i *is not* one of the attributes in the scheme of relation R_j then in the entry (A_i,R_j) write b_{ij}.

(3) For each of the functional dependencies $X \rightarrow Y$ of F do the following *until* it is not possible to make any more changes to the table. When the table no longer changes continue with step 4.
Look for two or more rows that have the same value under the attribute or attributes that comprise X (the determinant of the FD under consideration). There are two possible outcomes to this search:

(3-a) If there are two or more rows with the same value under the attribute or attributes of the determinant X then make equal their entries under attribute Y (the right-hand side of the FD under consideration). When making equal two or more symbols under any column, if one of them is a_j, make all of them a_j. If they are b_{ij} and b_{kl}, choose one of these two values as the representative value and make the other values equal to it. Continue with step 3.

(3-b) If there are no two rows with the same value under the attribute or attributes of the determinant X continue with step 3.

(4) Check the rows of the table. If there is a row with its entries equal to $a_1 a_2 \ldots a_n$ then the decomposition is lossless. Otherwise, the decomposition is lossy.

Example 5.12[5]

Consider the relation r(X, Y, Z, W, Q), the set F {X → Z, Y → Z, Z → W, WQ → Z, ZQ → X} and the decomposition of r into relations R_1(X, W), R_2(X, Y), R_3(Y, Q), R_4(Z, W, Q), and R_5(X, Q). Using the Lossless-Join Algorithm determine if the decomposition is lossless or lossy.

Steps (1–2) Since the original relation has 5 attributes and the original relation has been decomposed into 5 relations, we need to create a table with 5 columns and 5 rows. The columns of the table are named X, Y, Z, W and Q respectively. The rows of the table are named R_1, R_2, R_3, R_4 and R_5 respectively. For explanation purposes we have renamed the attributes A_1, $A_2, \ldots, A_5$. The table is shown below.

	X(A_1)	Y(A_2)	Z(A_3)	W(A_4)	Q(A_5)
R_1					
R_2					
R_3					
R_4					
R_5					

Since X is one of the attributes of relation R_1 we write a_1 in the entry (R_1, A_1) or its equivalent (R_1, X). In other words, under column A_1 (or X) and row R_1 we write a_1 as seen in the row pointed to by the arrow (see below). Likewise, we write a_4 in the entry corresponding to (R_1, A_4) or its equivalent (R_1, W) because W is also an attribute of relation R_1. That is, under column A_4 (or W) and row R_1 we write a_4 as seen in the row pointed to by the arrow (see below). In the remaining entries of row R_1 we write the values b_{ij} where i is the column number and j is the row number. These entries (from left to right) are b_{12}, b_{13} and b_{15} respectively as seen in the row pointed to by the arrow in the following table:

	X(A_1)	Y(A_2)	Z(A_3)	W(A_4)	Q(A_5)
→ R_1	a_1	b_{12}	b_{13}	a_4	b_{15}
R_2					
R_3					
R_4					
R_5					

[5] A similar example appears in *Principles of Database and Knowledge-Base Systems* Vol 1, by J. D. Ullman, Computer Science Press, 1988.

Proceeding in this fashion we fill in the remaining entries in the table. After filling in all entries the table looks like this.

	X(A_1)	Y(A_2)	Z(A_3)	W(A_4)	Q(A_5)
R_1	a_1	b_{12}	b_{13}	a_4	b_{15}
R_2	a_1	a_2	b_{23}	b_{24}	b_{25}
R_3	b_{31}	a_2	b_{33}	b_{34}	a_5
R_4	b_{41}	b_{42}	a_3	a_4	a_5
R_5	a_1	b_{52}	b_{53}	b_{54}	a_5

Steps (3/3-a) 1st time

Considering $X \rightarrow Z$ or its equivalent $A_1 \rightarrow A_3$ we look for tuples that have the same value under column X (or A_1). In this case, rows R_1, R_2 and R_5 have the same value a_1. Therefore, we equate or make equal the values under attribute Z (or A_3). Remember that Z (or A_3) is the right-hand side of the functional dependency that we are considering. Notice that the corresponding entries for rows R_1, R_2 and R_5 under the Z column are b_{13}, b_{23} and b_{53} respectively. To equate these entries to the same value we need to choose one of them arbitrarily and make the other two entries the same. Choosing b_{13} as the representative value and changing the remaining two entries to this value, we have that the table looks like the one shown next. Notice that we have grayed the entries that were made equal to the value b_{13} of row R_1. Repeat step 3.

	X(A_1)	Y(A_2)	Z(A_3)	W(A_4)	Q(A_5)
R_1	a_1	b_{12}	b_{13}	a_4	b_{15}
R_2	a_1	a_2	b_{13}	b_{24}	b_{25}
R_3	b_{31}	a_2	b_{33}	b_{34}	a_5
R_4	b_{41}	b_{42}	a_3	a_4	a_5
R_5	a_1	b_{52}	b_{13}	b_{52}	a_5

Steps (3/3-a) 2nd time

Considering $Y \rightarrow Z$ or its equivalent $A_2 \rightarrow A_3$, we now look for rows that have the same value in the column Y (or A_2). In this case, rows R_2 and R_3 have the same value a_2. Therefore, we need to equate the corresponding entries under column Z (or A_3). Choosing b_{13} as the representative value we can change

the b_{33} entry to b_{13}. After this change the table looks like the one shown below. Notice that we have grayed the row whose entry changed. Repeat step 3.

	X(A_1)	Y(A_2)	Z(A_3)	W(A_4)	Q(A_5)
R_1	a_1	b_{12}	b_{13}	a_4	b_{15}
R_2	a_1	a_2	b_{13}	b_{24}	b_{25}
R_3	b_{31}	a_2	b_{13}	b_{34}	a_5
R_4	b_{41}	b_{42}	a_3	a_4	a_5
R_5	a_1	b_{52}	b_{13}	b_{52}	a_5

Steps (3/3-a) 3rd time

Considering $Z \rightarrow W$ or its equivalent $A_3 \rightarrow A_4$, we look for tuples that have identical values under column Z (or A_3). In this case rows R_1, R_2, R_3 and R_5 have the same value, b_{13}, under this column. Therefore, we need to make equal all entries under column W (or A_4). Since one of the values under column W (or A_4) is a_4 (for row R_1), we make all the b_{ij}'s entries equal to a_4. The resulting table is shown next. As before we have grayed all entries that were changed. Repeat step 3.

	X(A_1)	Y(A_2)	Z(A_3)	W(A_4)	Q(A_5)
R_1	a_1	b_{12}	a_3	a_4	b_{15}
R_2	a_1	a_2	a_3	a_4	b_{25}
R_3	b_{31}	a_2	a_3	a_4	a_5
R_4	b_{41}	b_{42}	a_3	a_4	a_5
R_5	a_1	b_{52}	a_3	a_4	a_5

Steps (3/3-a) 4th time

Considering $WQ \rightarrow Z$ or its equivalent $A_4A_5 \rightarrow A_3$, we now look for rows that have identical values under columns A_4 and A_5 simultaneously. Rows R_3, R_4 and R_5 have values of a_4 and a_5 under columns WQ (or A_4 and A_5) respectively. Therefore, we need to equate all the corresponding entries for these rows under column Z (or A_3). Since all the values under column Z (or A_3) are already equal no changes are necessary. Repeat step 3.

Steps (3/3-a) 5th time

Considering ZQ → X or its equivalent $A_3A_5 \rightarrow A_1$, we look for rows that have equal values under columns ZQ (or A_3A_5) simultaneously. Rows R_3, R_4 and R_5 have values equal to a_3 and a_5 under columns A_3 and A_5 respectively. Therefore, it is necessary to equate their corresponding entries under column X (or A_1). Since one of the entries is a_1 (for row R_5), we make all the remaining b_{ij}'s equal to a_1. The resulting table, after all the corresponding changes are made, looks like the one shown below. As in all cases before, we have grayed the entries that were affected by the changes. Repeat step 3.

	X(A_1)	Y(A_2)	Z(A_3)	W(A_4)	Q(A_5)
R_1	a_1	b_{12}	a_3	a_4	b_{15}
R_2	a_1	a_2	a_3	a_4	b_{25}
R_3	a_1	a_2	a_3	a_4	a_5
R_4	a_1	b_{42}	a_3	a_4	a_5
R_5	a_1	b_{52}	a_3	a_4	a_5

Steps (3/3-a) 6th time

There are no more FDs to consider and the table cannot undergo any more changes. Therefore, we are through with step 3 and move to step 4.

Step (4) 1st time

We now look for a row that has all a_i's. Since row R_3 has become $a_1 a_2 a_3 a_4 a_5$ (see below) the decomposition is lossless.

	X(A_1)	Y(A_2)	Z(A_3)	W(A_4)	Q(A_5)
R_1	a_1	b_{12}	a_3	a_4	b_{15}
R_2	a_1	a_2	a_3	a_4	b_{25}
R_3	a_1	a_2	a_3	a_4	a_5
R_4	a_1	b_{42}	a_3	a_4	a_5
R_5	a_1	b_{52}	a_3	a_4	a_5

Example 5.13

Consider the relation r(X, Y, Z) and its decomposition $R_1(X, Y)$ and $R_2(Y, Z)$. Assume that $X \rightarrow Y$ and $Z \rightarrow Y$. Use the Lossless-Join Algorithm to determine if this decomposition is lossless or lossy.

Steps (1–2) Since the original relation has 3 attributes and it has been decomposed into 2 relations we need to form a table with three columns and two rows. Notice again that for explanation purposes we have renamed the attributes $A_1, A_2, \ldots, A_5$. However, this step is not necessary.

	$X(A_1)$	$Y(A_2)$	$Z(A_3)$
R_1			
R_2			

The scheme of relation R_1 consists of attributes X and Y. Therefore under columns X (or A_1) and Y (or A_2) we write a_1 and a_2 respectively.

The scheme of relation R_2 consists of attributes Y and Z. Therefore under columns Y (or A_2) and Z (or A_3) we write a_2 and a_3 respectively.

	$X(A_1)$	$Y(A_2)$	$Z(A_3)$
R_1	a_1	a_2	b_{13}
R_2	b_{21}	a_2	a_3

Steps (3/3-b) 1st time Considering $X \rightarrow Y$ we look for rows that have the same value under attribute X. Since there are no two rows with identical value under attribute X, the table remains unchanged and we continue with step 3 again.

Steps (3/3-b) 2nd time Considering $Z \rightarrow Y$ we now look for rows with identical values under attribute Z. Since there are no two rows with identical value under this attribute, the table remains unchanged.

Step (3) 3rd time There are no more FDs to consider in F and therefore the table cannot undergo any more changes. We continue with step 4.

Step (4) 1st time Since there is no row in the table that has all a_i's in its entries the decomposition is lossy. That is, the original table cannot be recovered from the natural join of relations R_1 and R_2.

5.12 Preserving Functional Dependencies

As indicated in the previous section, for a relation r to be recoverable from its projections its decomposition must be lossless. In addition to this, the decomposition should satisfy another property known as the *dependency preservation*. What this property requires is that the decomposition satisfy all the FDs that are satisfied by the original relation. The reason this is desirable is that the set of functional dependencies that are satisfied by a relation define integrity constraints that the relation needs to meet. Any decomposition that does not preserve the dependencies of the original relation imposes an unnecessary burden on the RDBMS. If fact, any update to any of the relations of the decomposition would require a join of all these relations to check that the constraints are not violated. This is obviously a time-consuming operation that reduces efficiency of the system. The following example illustrates this.

Example 5.14

Consider a relation r(X, Y, Z) that satisfies the dependencies $XY \rightarrow Z$ and $Z \rightarrow X$. The decomposition of relation r(X, Y, Z) into $R_1(XY)$ and $R_2(XZ)$ is lossless but it does not preserve the dependencies. Consider the following instances of these relations.

R_1

Y	Z
y_1	z_1
y_1	z_2

R_2

Z	X
z_1	x_1
z_2	x_1

Notice that relation R_2 satisfies $Z \rightarrow X$ but that the join of these two relations does not satisfy the functional dependency $XY \rightarrow Z$.

R_1 Join R_2

X	Y	Z
x_1	y_1	z_1
x_1	y_1	z_2

5.12.1 PROJECTION OF A SET OF DEPENDENCIES ONTO A SET OF ATTRIBUTES

To formalize the concept of dependency preservation and to define an algorithm that allows us to test for dependency preservation some additional terminology is necessary. Assume that a relation r(R) has been decomposed into a series of relations ρ $(R_1, R_2, \ldots, R_k)$ and that F is a set of FDs satisfied by r. We define the *projection of F onto a set of attributes Z*, denoted by $\pi_{(Z)}F$, as follows:

$\pi_{(Z)}F$ $\{X \rightarrow Y \subset F$ /$XY \subset Z\}$ where the symbol "/" reads "such that".

It is important to observe that this definition does not require that $X \rightarrow Y$ be in F but in F (where F is closure of F). Notice also that both X and Y may be composite attributes whose union must be a subset of the attributes of Z. The FDs of $\pi_{(Z)}F$ are said to be satisfied by the attributes of Z.

To calculate the projection $\pi_{(Z)}F$ consider the proper subsets X of attributes of Z ($X \subset Z$ and $X \neq Z$) that appear as the determinant of a functional dependency or are part of the determinant of a functional dependency of F and do the following:

(1) Calculate X .

(2) For each set of attributes Y of X^{+} that satisfies simultaneously the following conditions:

a. $Y \subset Z$
b. $Y \subset X$ (with respect to F)
c. $Y \not\subset X$ (This requirement excludes the consideration of trivial dependencies. Trivial dependencies are true anyway due to the axiom of Transitivity)

include $X \rightarrow Y$ as one of the FDs of $\pi_{(Z)}F$. The set of FDs in $\pi_{(Z)}F$ are said to be satisfied by the attributes of Z.

Example 5.15
Given the relation r(X, Y, W, Z, Q) and the set F – { $X \rightarrow Z$, $Y \rightarrow Q$, $ZQ \rightarrow W$}, find the projection of F onto the set of attributes {X, Y, W}.

The only attributes of {X, Y, W} that appear as determinants of F are X and Y. The proper subsets of {X, Y, W} that need to be considered are {X}, {Y}, and {X, Y}.

Considering attribute X

Step (1) 1st time: Calculate X^{+}. Using the closure algorithm (see Section 4.6.2) we have that X {X, Z}.

Step (2) 2nd time: Considering attribute Z of X , we observe that $Z \not\subset$ {X, Y, W}. Since Z does not meet condition (a) of step 2 no FD is included in $\pi_{(Z)}F$.

Considering attribute Y

Step (1) 1st time: Calculate Y^{+}. Using the closure algorithm (see Section 4.6.2) we have that Y = {Y, Q}.

Step (2) 2nd time: Considering attribute Q of Y , we have that $Q \not\subset$ {X, Y, W}. Since Q does not meet condition (a) of step 2 no FD is included in $\pi_{(Z)}F$.

Considering attributes XY

Step (1) 1st time: Calculate {XY} . Using the closure algorithm (see Section 4.6.2) we have that {XY} {X, Y, Z, Q, W}.

Step (2) 2nd time Considering the attributes of $\{XY\} - \{X, Y, Z, Q, W\}$, the definition of closure and excluding the trivial functional dependencies we have that $XY \rightarrow W$, $XY \rightarrow Q$, and $XY \rightarrow Z$. Of all these FDs, only $XY \rightarrow W$ satisfies the conditions of step 2a through 2b, therefore this FD can be added to $\pi_{(Z)}F$. This FD of $\pi_{(Z)}$ F is the only FD that is satisfied by the attributes of $\{X, Y, W\}$.

5.12.2 TESTING PRESERVATION OF DEPENDENCIES

Given a relation r(R), a decomposition $\rho = (R_1, R_2, \ldots, R_k)$ of the relation and a set F of FDs satisfied by r(R), we say that *the decomposition ρ preserves the functional dependencies of r* if and only if the following conditions are satisfied simultaneously:

(1) $G = \bigcup_{1}^{K} \pi_{Ri}(F)$

(2) $G = F$

In other words, the decomposition ρ preserves a set of dependencies F if the union of all the dependencies in $\bigcup_{1}^{K} \pi_{Ri}(F)$ logically implies all the dependencies in F.

This definition also provides a procedure to test whether or not a decomposition of a given relation preserves a set F of functional dependencies. Just take the projections of F onto all the R_i's, union these sets and test if this set is equivalent to F. Calculating F , as we indicated before, is a very tedious and time-consuming task. Fortunately, there is a shorter algorithm that does not require the computation of F . However, before introducing this new algorithm it is necessary to define the following operation on a set of attributes with respect to a set of FDs.

An *R-operation on a set of attributes Z with respect to set of dependencies F* replaces attribute Z with the following set $Z \cup ((Z \cap R) \cap R)$. The purpose of this operation is to add to the set Z all attributes A such that $(Z \cap R) \rightarrow A \in \pi_R(F)$.

To verify if the sets F and $G = \bigcup_{1}^{K} \pi_{Ri}(F)$ are equivalent without having to calculate F , the algorithm considers each $X \rightarrow Y$ in F and determines if Y is in X by considering the effect of calculating the closure with respect to the projections of F onto the various R_i's. The algorithm is shown next.

The Test Preservation Algorithm[6]

The input to this algorithm is a decomposition $\rho = (R_1, R_2, \ldots, R_k)$ and a set F of functional dependencies. The output of the algorithm is a statement that indicates whether or not the decomposition preserves the dependencies.

(1) For each $X \rightarrow Y \in F$ initialize a set T of attributes with the attributes of X (the determinant of the FD under consideration). That is, set $T = X$ and continue with step 2.

(2) Repeat step 3 until the set T no longer changes. When T no longer changes continue with step 4.g

(3) For each relation R_i $(1 \leq i \leq k)$ of the input decomposition apply the corresponding R_i operation (on a set of attributes T with respect to set of dependencies F). That is, do the following:

$$T = T \cup ((T \cap R_i)^+ \cap R_i) \text{ and repeat step 3.}$$

(4) Test to see if Y (the right-hand side of the FD under consideration) is such that $Y \subset T$. There are two outcomes to this test. If the answer is negative, that is, if $Y \not\subset T$ stop the execution of the algorithm and report that the decomposition $\rho = (R_1, R_2, \ldots, R_k)$ does not preserve the functional dependencies. If the answer is affirmative, that is, if $Y \subset T$ then $X \rightarrow Y \in G^+$. If there are other FDs in F that need to be considered repeat step 1 with a functional dependency that has not been considered before. If there are no more FDs in F that can be considered continue with step 5.

(5) The two sets of FDs are equivalent and the algorithm reports that the decomposition preserves $\rho = (R_1, R_2, \ldots, R_k)$, the functional dependencies of the original relation.

Example 5.16
Determine if the decomposition $\rho = \{R_1(X, Y), R_2(Y, Z), R_3(Z, W)\}$ of the relation $r(X, Y, Z, W)$ preserves the dependencies of the set $F = \{X \rightarrow Y, Y \rightarrow Z, Z \rightarrow W, W \rightarrow X\}$.

For explanation purposes and to be somewhat methodical, we will consider the different FDs of the set F in the order in which they are listed inside F.

Step (1) 1st time (with respect to $X \rightarrow Y$)
Considering $X \rightarrow Y$, we initialize the set of attributes T to the determinant of the FD under consideration. That is, we set $T = \{X\}$.

[6] Adapted from *Principles of Database and Knowledge-Base Systems* Vol. 1, by J. D. Ullman, Computer Science Press, 1988.

Steps (2/3) 1st time (with respect to $X \rightarrow Y$)

Applying the R_1 operation $T \cup ((T \cap R_1) \quad \cap R_1)$ with respect to F we have that

$T \cap R_1 - \{X\} \cap \{X,Y\} - \{X\}$

$(T \cap R_1) \quad - \{X\} \quad - \{X, Y, Z, W\}$ (applying the closure algorithm of Section 4.6.2)

$(T \cap R_1) \quad \cap R_1 - \{X, Y, Z, W\} \cap \{X, Y\} - \{X, Y\}$

$T \cup ((T \cap R_1) \quad \cap R_1) - \{X\} \cup \{X, Y\} - \{X, Y\}$

$T - T \cup ((T \cap R_1) \quad \cap R_1) - \{X, Y\}$

$T = \{X, Y\}$ (This value of T is carried over the next iteration with R_2)

Step (3) 2nd time (with respect to $X \rightarrow Y$)

Applying the R_2 operation $T \cup ((T \cap R_2) \quad \cap R_2)$ with respect to F we have that

$T \cap R_2 \quad \{X, Y\} \cap \{Y, Z\} \quad \{Y\}$

$(T \cap R_2) \quad \{Y\} \quad \{Y, Z, W, X\}$ (applying the closure algorithm of Section 4.6.2)

$(T \cap R_2) \quad \cap R_2 \quad \{X, Y, Z, W\} \cap \{Y, Z\} \quad \{Y, Z\}$

$T \cup ((T \cap R_2) \quad \cap R_2) \quad \{X, Y\} \cup \{Y, Z\} \quad \{X, Y, Z\}$

$T \quad T \cup ((T \cap R_2) \quad \cap R_2) \quad \{X, Y, Z\}$

$T \quad \{X, Y, Z\}$ (This value of T is carried over the next iteration with R_3)

Step (3) 3rd time (with respect to $X \rightarrow Y$)

Applying the R_3 operation $T \cup ((T \cap R_3) \quad \cap R_3)$ with respect to F we have that

$T \cap R_3 - \{X, Y, Z\} \cap \{Z, W\} - \{Z\}$

$(T \cap R_3) \quad = \{Z\} \quad = \{Z, W, X, Y\}$ (applying the closure algorithm of Section 4.6.2)

$(T \cap R_3) \quad \cap R_3 = \{X, Y, Z, W\} \cap \{Z, W\} = \{Z, W\}$

$T \cup ((T \cap R_3) \quad \cap R_3) = \{X, Y, Z\} \cup \{Z, W\} = \{X, Y, Z, W\}$

$T = T \cup ((Z \cap R_3) \quad \cap R_3) = \{X, Y, Z, W\}$

$T = \{X, Y, Z, W\}$

At this point the algorithm calls for repeating the R_i's operation with this new T. However, T will not change. We have omitted these steps because they will produce similar results to the ones already obtained. We continue with step 4.

Step (4) 1st time (with respect to $X \rightarrow Y$)

Since Y (the right-hand side of the FD under consideration) is such that $\{Y\} \subset T \quad \{X, Y, Z, W\}$, then $X \rightarrow Y \in G$.

Step (1) 1st time (with respect to $Y \rightarrow Z$)

Considering $Y \rightarrow Z$, we initialize the set of attributes T to the determinant of the FD under consideration. That is, we set $T \quad \{Y\}$.

Steps (2/3) 1st time (with respect to $Y \rightarrow Z$)

Applying the R_1 operation $T \cup ((T \cap R_1)^+ \cap R_1)$ with respect to F we have that

$T \cap R_1 = \{Y\} \cap \{X, Y\} = \{Y\}$

$(T \cap R_1)^+ = \{Y\}^+ = \{Y, Z, W, X\}$ (applying the closure algorithm of Section 4.6.2)

$(T \cap R_1)^+ \cap R_1 = \{Y, Z, W, X\} \cap \{X, Y\} = \{Y, X\}$

$T \cup ((T \cap R_1)^+ \cap R_1) = \{Y\} \cup \{X, Y\} = \{Y, X\}$

$T = T \cup ((T \cap R_1)^+ \cap R_1) = \{Y, X\}$

$T = \{Y, X\}$ (This value of T is carried over the next iteration with R_2)

Step (3) 2nd time (with respect to $Y \rightarrow Z$)

Applying the R_2 operation $T \cup ((T \cap R_2)^+ \cap R_2)$ with respect to F we have that

$T \cap R_2 = \{Y, X\} \cap \{Y, Z\} = \{Y\}$

$(T \cap R_2)^+ = \{Y\}^+ = \{Y, Z, W, X\}$ (applying the closure algorithm of Section 4.6.2)

$(T \cap R_2)^+ \cap R_2 = \{Y, Z, W, X\} \cap \{Y, Z\} = \{Y, Z\}$

$T \cup ((T \cap R_2)^+ \cap R_2) = \{Y, X\} \cup \{Y, Z\} = \{X, Y, Z\}$

$T = T \cup ((T \cap R_2)^+ \cap R_2) = \{X, Y, Z\}$

$T = \{X, Y, Z\}$ (This value of T is carried over the next iteration with R_3)

Step (3) 3rd time (with respect to $Y \rightarrow Z$)

Applying the R_3 operation $T \cup ((T \cap R_3)^+ \cap R_3)$ with respect to F we have that

$T \cap R_3 = \{X, Y, Z\} \cap \{Z, W\} = \{Z\}$

$(T \cap R_3)^+ = \{Z\}^+ = \{Z, W, X, Y\}$ (applying the closure algorithm of Section 4.6.2)

$(T \cap R_3)^+ \cap R_3 = \{Z, W, X, Y\} \cap \{Z, W\} = \{Z, W\}$

$T \cup ((T \cap R_3)^+ \cap R_3) = \{X, Y, Z\} \cup \{Z, W\} = \{X, Y, Z, W\}$

$T = T \cup ((T \cap R_3)^+ \cap R_3) = \{X, Y, Z, W\}$

$T = \{X, Y, Z, W\}$

At this point the algorithm calls for repeating the R_i's operation with this new T. However, T will not change. We have omitted these steps because they will produce similar results to the ones already obtained. We continue with step 4.

Step (4) 1st time (with respect to $Y \rightarrow Z$)

Since Z (the right-hand side of the FD under consideration) is such that $\{Z\} \subset T = \{X, Y, Z, W\}$, then $Y \rightarrow Z \in G^+$.

Step (1) 1st time (with respect to $Z \rightarrow W$)

Considering $Z \rightarrow W$, we initialize the set of attributes T to the determinant of the FD under consideration. That is, we set $T = \{Z\}$.

Steps (2/3) 1st time (with respect to $Z \rightarrow W$)

Applying the R_1 operation $T \cup ((T \cap R_1) \quad \cap R_1)$ with respect to F we have that

$T \cap R_1 - \{Z\} \cap \{X, Y\} \quad \varnothing$

$(T \cap R_1) \quad \varnothing \quad \varnothing$

$(T \cap R_1) \quad \cap R_1 \quad \varnothing$

$T \cup ((T \cap R_1) \quad \cap R_1) - \{Z\} \cup \varnothing \quad \{Z\}$

$T - T \cup ((T \cap R_1) \quad \cap R_1) - \{Z\}$

$T - \{Z\}$ (This value of T is carried over the next iteration with R_2)

Step (3) 2nd time (with respect to $Z \rightarrow W$)

Applying the R_2 operation $T \cup ((T \cap R_2) \quad \cap R_2)$ with respect to F we have that

$T \cap R_2 - \{Z\} \cap \{Y, Z\} - \{Z\}$

$(T \cap R_2) \quad - \{Z\} \quad - \{Z, W, X, Y\}$ (applying the closure algorithm of Section 4.6.2)

$(T \cap R_2) \quad \cap R_2 - \{Z, W, X, Y\} \cap \{Y, Z\} - \{Z, Y\}$

$T \cup ((T \cap R_2) \quad \cap R_2) - \{Z\} \cup \{Z, Y\} - \{Z, Y\}$

$T - T \cup ((T \cap R_2) \quad \cap R_2) - \{Z, Y\}$

$T - \{Z, Y\}$ (This value of T is carried over the next iteration with R_3)

Step (3) 3rd time (with respect to $Z \rightarrow W$)

Applying the R_3 operation $T \cup ((T \cap R_3) \quad \cap R_3)$ with respect to F we have that

$T \cap R_3 - \{Z, Y\} \cap \{Z, W\} - \{Z\}$

$(T \cap R_3) \quad - \{Z\} \quad - \{Z, W, X, Y\}$ (applying the closure algorithm of Section 4.6.2)

$(T \cap R_3) \quad \cap R_3 - \{Z, W, X, Y\} \cap \{Z, W\} - \{Z, W\}$

$T \cup ((T \cap R_3) \quad \cap R_3) - \{Z, Y\} \cup \{Z, W\} - \{Z, Y, W\}$

$T - T \cup ((T \cap R_3) \quad \cap R_3) - \{Z, Y, W\}$

$T - \{Z, Y, W\}$

At this point the algorithm calls for repeating the R_i's operation with this new T.

Step (3) 4th time (with respect to $Z \rightarrow W$)

Applying the R_1 operation $T \cup ((T \cap R_1) \quad \cap R_1)$ with respect to F we have that

$T \cap R_1 \quad \{Z, Y, W\} \cap \{X, Y\} \quad \{Y\}$

$(T \cap R_1) \quad \{Y\} \quad \{Y, Z, W, X\}$

$(T \cap R_1) \quad \cap R_1 \quad \{X, Y\}$

$T \cup ((T \cap R_1) \quad \cap R_1) \quad \{Z, Y, W\} \cup \{X, Y\} \quad \{Z, Y, W\}$

$T - T \cup ((T \cap R_1) \quad \cap R_1) - \{Z, Y, W\}$

$T - \{Z\}$ (This value of T is carried over the next iteration with R_2)

Step (4) 1st time (with respect to $Z \rightarrow W$)

Since W (the right-hand side of the FD under consideration) is such that $\{W\} \subset T \quad \{Z, Y, W\}$, then $Z \rightarrow W \subset G$.

Step (1) 1st time (with respect to $W \rightarrow X$)

Considering $W \rightarrow X$, we initialize the set of attributes T to the determinant of the FD under consideration. That is, we set $T - \{W\}$.

Steps (2/3) 1st time (with respect to $W \rightarrow X$)

Applying the R_1 operation $T \cup ((T \cap R_1) \quad \cap R_1)$ with respect to F we have that

$T \cap R_1 \quad \{W\} \cap \{X, Y\} \quad \varnothing$

$(T \cap R_1) \quad \varnothing \quad \varnothing$

$(T \cap R_1) \quad \cap R_1 \quad \varnothing$

$T \cup ((T \cap R_1) \quad \cap R_1) - \{W\} \cup \varnothing \quad \{W\}$

$T - T \cup ((T \cap R_1) \quad \cap R_1) - \{W\}$

$T - \{W\}$ (This value of T is carried over the next iteration with R_2)

Step (3) 2nd time (with respect to $W \rightarrow X$)

Applying the R_2 operation $T \cup ((T \cap R_2) \quad \cap R_2)$ with respect to F we have that

$T \cap R_2 \quad \{W\} \cap \{Y, Z\} \quad \varnothing$

$(T \cap R_2) \quad \varnothing \quad \varnothing$

$(T \cap R_2) \quad \cap R_2 - \{W\} \cap \varnothing \quad \varnothing$

$T \cup ((T \cap R_2) \quad \cap R_2) - \{W\} \cup \varnothing \quad \{W\}$

$T - T \cup ((T \cap R_2) \quad \cap R_2) - \{W\}$

$T - \{W\}$

Step (3) 3rd time (with respect to $W \rightarrow X$)

Applying the R_3 operation $T \cup ((T \cap R_3) \quad \cap R_3)$ with respect to F we have that

$T \cap R_3 \quad \{W\} \cap \{Z, W\} \quad \{W\}$

$(T \cap R_3) \quad \{W\} \quad \{W, X, Y, Z\}$ (applying the closure algorithm of Section 4.6.2)

$(T \cap R_3) \quad \cap R_3 \quad \{W, X, Y, Z\} \cap \{Z, W\} \quad \{Z, W\}$

$T \cup ((T \cap R_3) \quad \cap R_3) - \{W\} \cup \{Z, W\} - \{Z, W\}$

$T - T \cup ((T \cap R_3) \quad \cap R_3) - \{Z, W\}$

$T - \{Z, W\}$

Step (3) 4th time (with respect to $W \rightarrow X$)

Applying the R_1 operation $T \cup ((T \cap R_1) \quad \cap R_1)$ with respect to F we have that

$T \cap R_1 \quad \{Z, W\} \cap \{X, Y\} - \varnothing$

$(T \cap R_1) \quad \varnothing \quad \varnothing$

$(T \cap R_1) \quad \cap R_1 \quad \varnothing$

$T \cup ((T \cap R_1) \quad \cap R_1) \quad \{Z, W\} \cup \varnothing \quad \{Z, W\}$

$T - T \cup ((T \cap R_1) \quad \cap R_1) \quad \{Z, W\}$

$T - \{Z, W\}$ (This value of T is carried over the next iteration with R_2)

Step (3) 4th time (with respect to $W \rightarrow X$)

Applying the R_2 operation $T \cup ((T \cap R_2) \quad \cap R_2)$ with respect to F we have that

$T \cap R_2 - \{Z, W\} \cap \{Y, Z\} - \{Z\}$
$(T \cap R_2) \quad - \{Z\} \quad - \{Z, W, X, Y\}$
$(T \cap R_2) \quad \cap R_2 - \{Z, W, X, Y\} \cap \{Y, Z\} - \{Y, Z\}$
$T \cup ((T \cap R_2) \quad \cap R_2) - \{Z, W\} \cup \{Y, Z\} - \{Z, W, Y\}$
$T - T \cup ((T \cap R_2) \quad \cap R_2) - \{Z, W, Y\}$
$T - \{Z, W, Y\}$ (This value of T is carried over the next iteration with R_3)

Step (3) 5th time (with respect to $W \rightarrow X$)
Applying the R_3 operation $T \cup ((T \cap R_3) \quad \cap R_3)$ with respect to F we have that
$T \cap R_3 = \{Z, W, Y\} \cap \{Z, W\} = \{Z, W\}$
$(T \cap R_3) \quad = \{Z, W\} \quad = \{W, X, Y, Z\}$ (applying the closure algorithm of Section 4.6.2)
$(T \cap R_3) \quad \cap R_3 \quad \{W, X, Y, Z\} \cap \{Z, W\} \quad \{Z, W\}$
$T \cup ((T \cap R_3) \quad \cap R_3) \quad \{Z, W, Y\} \cup \{Z, W\} \quad \{Z, W, Y\}$
$T \quad T \cup ((T \cap R_3) \quad \cap R_3) \quad \{Z, W, Y\}$

Step (3) 4th time (with respect to $W \rightarrow X$)
Applying the R_1 operation $T \cup ((T \cap R_1) \quad \cap R_1)$ with respect to F we have that
$T \cap R_1 \quad \{Z, W, Y\} \cap \{X, Y\} \quad \{Y\}$
$(T \cap R_1) \quad \{Y\} \quad \{Y, Z, W, X\}$
$(T \cap R_1) \quad \cap R_1 \quad \{Y, Z, W, X\} \cap \{X, Y\} \quad \{X, Y\}$
$T \cup ((T \cap R_1) \quad \cap R_1) \quad \{Z, W, Y\} \cup \{X, Y\} \quad \{Z, W, Y, X\}$
$T \quad T \cup ((T \cap R_1) \quad \cap R_1) \quad \{Z, W, Y, X\}$
$T \quad \{Z, W, Y, X\}$ (This value of T is carried over the next iteration with R_2)

Step (3) 4th time (with respect to $W \rightarrow X$)
At this moment the algorithm calls for repeating step 3 with the R_i's; however, after executing these steps the set T no longer changes. We have omitted these steps here and continue with step 4.

Step (4) 1st time (with respect to $W \rightarrow X$)
Since X (the right-hand side of the FD under consideration) is such that $\{X\} \subset T \quad \{Z, W, Y, X\}$, then $W \rightarrow X \in G$.

Step (5) 1st time (with respect to $W \rightarrow X$)
Since all the FD of F are elements of G , the two sets are equivalent and the decomposition preserves the dependencies of F.

So far we have considered systematic procedures to test for the lossless-join and dependency preservation properties of a decomposition. However, the reader should be aware that the two properties do not imply each other. That is, it is possible to have a lossless decomposition that does not preserve the functional dependencies of the original relation and vice versa. Solved Problem 5.15 illustrates the use of an algorithm that allows us to find a 3NF lossless decomposition of a given relation that preserves the dependencies of the original relations. Likewise Solved Problem 5.16 shows an algorithm that provides us with a lossless BCNF decomposition of a given relation.

Solved Problems

5.1. In the EMPLOYEE table shown below, identify the table identifier, all repeating and nonrepeating attributes. Flatten the table and state if the resulting table is a relation. If not, how can you make it a relation?

EMPLOYEE

ID	Last-Name	Department	Dependent-Name	Dependent-DOB	Dependent-Sex	Dependent-ID
322135609	Cordani	CS	Mary Cindy John	01/12/60 04/24/65 07/12/68	F F M	800980432 953635262 992556631
423542641	Strange	VP	Fern Victoria	03/28/62 11/12/84	F F	790902462 800234979
536234809	VanKlaveren	Sales	Sadie	08/31/65	F	970073473
632390802	Miller	Sales	Sallie	09/21/45	F	890721289
980772345	Kroeger	MIS	Jonathan	08/15/85	M	943632552

The table identifier is the attribute ID. The nonrepeating attributes are: ID, Last-name and Department. The repeating attributes are: Dependent-Name, Dependent-Sex, and Dependent-ID.

To flatten the table we have to fill in all the entries of the table by copying the information of the corresponding nonrepeating attributes. The normalized table looks like this:

ID	Last-Name	Department	Dependent-Name	Dependent-DOB	Dependent-Sex	Dependent-ID
322135609 322135609 322135609	Cordani Cordani Cordani	CS CS CS	Mary Cindy John	01/12/60 04/24/65 07/12/68	F F M	800980432 953635262 992556631
423542641 423542641	Strange Strange	VP VP	Fern Victoria	03/28/62 11/12/84	F F	790902462 800234979
536234809	VanKlaveren	Sales	Sadie	08/31/65	F	970073473
632390802	Miller	Sales	Sallie	09/21/45	F	890721289
980772345	Kroeger	MIS	Jonathan	08/15/85	M	943632552

This "flat" table is not a relation because it does not have a primary key. Notice, for instance, that ID (the table identifier) no longer identifies any of the first three rows of this table. To transform this table into a relation we need to identify a suitable primary key for the relation. The composite key (ID, Dependent-ID) seems to be a suitable primary key.

5.2. Normalize the table of the previous example by creating two new relations. The table is reproduced below for the convenience of the reader.

ID	Last-Name	Department	Dependent-Name	Dependent-DOB	Dependent-Sex	Dependent-ID
322135609	Cordani	CS	Mary Cindy John	01/12/60 04/24/65 07/12/68	F F M	800980432 953635262 992556631
423542641	Strange	VP	Fern Victoria	03/28/62 11/12/84	F F	790902462 800234979
536234809	VanKlaveren	Sales	Sadie	08/31/65	F	970073473
632390802	Miller	Sales	Sallie	09/21/45	F	890721289
980772345	Kroeger	MIS	Jonathan	08/15/85	M	943632552

To normalize this table we need to create two new relations. The attributes of the first relation are the table identifier and all the nonrepeating attributes. The attributes of the second table are the table identifier and all the repeating attributes. The schemes of these two relations are shown below. Observe that the attribute ID (of Employee) has been renamed in the Dependent relation.

Employee (<u>ID</u>, Last-name, Department)

Dependent (<u>Emp-ID</u>, <u>Dependent-ID</u>, Dependent-Name, Dependent-Sex)

The corresponding instances of these two relations are shown next. Notice that duplicate rows have been deleted to comply with the definition of a relation. PKs are underlined.

Employee

Id	Last-Name	Department
322135609	Cordani	CS
423542640	Strange	VP
536234809	VanKlaveren	Sales
632390802	Miller	Sales
980772345	Kroeger	MIS

Dependent

Emp-Id	Dependent-Id	Dependent-Name	Dependent-DOB	Dependent-Sex
322135609	800980432	Mary	01/12/60	F
322135609	953635262	Cindy	04/24/65	F
322135609	992556631	John	07/12/68	M
423542641	790902462	Fern	03/28/62	F
423542641	800234979	Victoria	11/12/84	F
536234809	970073473	Sadie	08/31/65	F
632390802	890721289	Sallie	09/21/45	F
980772345	943632552	Jonathan	08/15/85	M

5.3. Consider the relational scheme of the relation SCHEDULE shown below. What is the highest normal form of this relation? What type of data anomalies does this relation have? Give an example of the type of data anomalies that this relation may experience.

SCHEDULE (Student-ID, Class_No, Student-Name, Student-Major, Class-Time, Building-Room, Instructor). Assume the following functional dependencies.

Student-ID → Student-Name
Student-ID → Student-Major
Class-No → Class-Time
Class-No → Building-Room
Class-No → Instructor

There are some partial dependencies on the key, for example, Class-No → Building-Room or Student-ID → Student-Major. Therefore, the highest form of the relation is in1NF.

Since the relation is in 1NF, there are insertion/deletion anomalies and update anomalies. For instance, if a student drops all his classes, the relation will experience deletion anomalies because information about the student number, name and major will also be lost. In addition, if the student is the last student in the class, information about the instructor will also disappear. Since there are deletion anomalies the relation will also experience insertion anomalies, for instance, information about Class-Time, Building-Room and Instructor cannot be inserted into the relation until there is a student enrolled in the class. Update anomalies occur if, for instance, a class is changed from one building to another. In this case, it is necessary to make sure that all tuples of the relation are changed or the database may end up in an inconsistent state.

5.4. Consider the relation scheme and FD shown below. What is the highest normal form of this relation? Transform this relation to its next higher form. Can the information of the given relation be recovered? What operation is necessary to recover it?

Programmer-Task (Programmer-ID, Programming-Package-ID, Programming-Package-Name, Total-Hours-Worked-on-Package).

Programming-Package-ID → Programming-Package-Name

The highest form of this relation is 1NF because there are partial dependencies on the composite key. Consider for example, Programming-Package-ID → Programming-Package-Name.

The next highest form of this relation is 2NF. To transform it we can use Fig. 5-3 as a guide. According to this figure, we need to create two new relations. The first relation has as its key the primary key of the given relation: Programmer-ID, Programming-Package-ID. The scheme of this first relation is:

Programmer-Activity (Programmer-ID, Programming-Package-ID, Total-Hours-Worked-on-Package)

The second relation has as its primary key the attribute Programming-Package-ID. The scheme of this relation is:

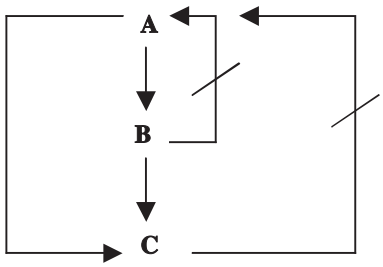
Package-Info (Programming-Package-ID, Programming-Package-Name)

The information of the original relation can be recovered by means of a join operation on the common attribute: Programming-Package-ID.

5.5. Show that the two definitions of 3NF given in Section 5.8 are equivalent.

The conditions given in Fig. 5-4 are the general conditions for transitivity dependencies. Any relation that satisfies these conditions has a transitive dependency and is not in 3NF. Assuming the A is the single key of the relation, we will have that attributes B and C cannot be keys since they do not functionally determine A. Attributes B and C are nonprime attributes. Notice that even if A → C is not explicitly stated in the diagram it can be determined by the transitivity axiom.

In Fig. 5-4 the only way to avoid having A → C is not having B → C. If we generalize this situation to any two nonprime attributes B and C, we can see that both definitions of 3NF are equivalent.



Conditions that define the transitive dependency of attribute C on attribute A.

5.6. Consider the relation scheme (Sales-Transaction-No, Item-No, Item-Price, Item-Quantity-Sold, Seller, Seller-District) and the FDs shown below. What is the key of this relation? Transform this relation to 3NF.

Sales-Transaction-No, Item-No → Item-Quantity-Sold
Item-No → Item-Price
Sales-Transaction-No → Seller
Seller → Seller-District

The key of this relation is the composite attribute Sales-Transaction-No, Item-No. In fact, these two attributes determine all other attributes as indicated next.

a. Sales-Transaction-No, Item-No → *Sales-Transaction-No* (Reflexivity axiom)

b. Sales-Transaction-No, Item-No → *Item-No* (Reflexivity axiom)

c. Sales-Transaction-No, Item-No → *Item-Quantity-Sold* (given)

d. From Sales-Transaction-No, Item-No → Item-No (Reflexivity axiom) *and* Item-No → Item-Price (given) we have that Sales-Transaction-No, Item-No → *Item-Price* (Transitivity axiom)

e. From Sales-Transaction-No, Item-No → Sales-Transaction-No (Reflexivity axiom) *and* Sales Transaction-No → Seller (given) we have that Sales-Transaction-No, Item-No → *Seller* (Transitivity axiom)

f. From Sales-Transaction-No, Item-No → Seller (step e) and Seller → Seller-District we have that Sales-Transaction-No, Item-No → *Seller-District* (Transitivity axiom)

The highest form of this relation is 1NF because there are partial dependencies on the primary key.

To transform it into 2NF, we will use Fig. 5-3 as a guide. However, notice that we need to consider each of the partial dependencies separately. Therefore, instead of replacing the original relation with two, we need to replace it with three new relations. These relations are:

a. Item-Sold(Sales-Transaction-No, Item-No, Item-Quantity-Sold)

b. Item(Item-No, Item-Price)

c. Seller(Sales-Transaction-No, Seller, Region)

Relations (a) and (b) are in 3NF since the only nonprime attribute is fully dependent on the key. Relation (c) is not in 3NF because one of the nonprime attributes (Seller) functionally determines another nonprime attribute (Region). This relation can be transformed into 3NF by following the guidelines of Fig. 5-3. The new two relations are:

Seller-Transaction(Sales-Transaction-No, Seller)

Seller-Region(Seller, Region)

5.7. Transform into 2NF the relation of the Solved Problem 5.3. The relation and all its dependencies are reproduced below.

SCHEDULE (Student-ID, Class_No, Student-Name, Student-Major, Class-Time, Building-Room, Instructor).
Assume the additional functional dependencies also hold:

Student-ID → Student-Name
Student-ID → Student-Major
Class-No → Class-Time
Class-No → Building-Room
Class-No → Instructor

In all cases where we need to transform a relation into 2NF, we have been using Fig. 5-3 as a general guideline for the conversion. However, in this example, the solution is not as direct as in all previous cases. The reason for this is that the key is composite and each one of the prime attributes partially determines some other nonprime attributes. Therefore, instead of two relations we have to create at least three relations. These relations are:

STUDENT (Student-ID, Student-Name, Student-Major). Notice that all the attributes are dependent on the primary key Student-ID.

CLASS (Class-No, Class-Time, Building-Room, Instructor). Notice that all the attributes are dependent on the primary key Class-No.

Since the normalization process is reversible we should be able to recover the original relation, therefore, we need an extra relation to make this possible. In this case, we create a new relation STUDENT-CLASS (Student-ID, Class_No).

5.8. Consider the relation r(X, Y, Z, W) and a set F {Y ↔ W, XY → Z} where the symbol ↔ means that Y → W and W → Y simultaneously. What are the candidate keys of this relation? What is the highest normal form of this relation?

This relation has two candidate keys: XY and WX.

XY is a candidate key because XY determines all other attributes as shown below.

a. XY → *X* (Reflexivity axiom)
b. XY → *Y* (Reflexivity axiom)
c. XY → *Z* (given)
d. XY → Y and Y → W then XY → *W* (Transitivity Axiom)

WX is a candidate key because WX determines all other attributes as shown below.

a. WX → *W* (Reflexivity)

b. WX → *X* (Reflexivity)

c. We already know that XY → Z (given). We also know that W → Y (given). Using the Pseudotransitivity axiom, we have that XW → *Z*.

d. WX → W (step a) and W → Y (given) therefore WX → *Y* (Transitivity axiom)

The prime attributes are: X, Y and W. The only nonprime attribute is Z.

The relation is in 2NF because there are no partial dependencies of the nonprime attribute on the key. In both cases we have that Z is fully dependent on both keys.

The relation is in 3NF because there is only one nonprime attribute. Therefore, we cannot have one nonprime attribute determining another nonprime.

The relation is not in BCNF because the determinants of either W → Y or Y → W are not keys of the relation. Therefore, the highest form of this relation is 3NF.

5.9. Given the relation r(X, Y, W, Z, P, Q) and the set F { XY → W, XW → P, PQ → Z, XY → Q}, consider the decomposition R_1(Z, P, Q), R_2(X, Y, Z, P, Q). Is this decomposition lossless or lossy? Use the Lossless-Join algorithm.

Step (1) Construct a table with six columns (one column per attribute) and two rows (one row per relation of the decomposition). Name each column with the name of one attribute and each row with the name of a relation.

	X(A_1)	**Y(A_2)**	**Z(A_3)**	**W(A_4)**	**P(A_5)**	**Q(A_5)**
R_1						
R_2						

Step (2) Fill in the entries as follows:
The attributes of the scheme of R_1 are: Z (A_3), P(A_5), Q(A_6). Therefore, we place a_3, a_5 and a_6 under these columns respectively. The remaining entries of this row are filled with b_{11}, b_{12}, and b_{14} respectively.
The attributes of the scheme of R_2 are: X(A_1), Y(A_2), W(A_4), P(A_5), Q(A_6). Therefore, we place a_1, a_2, a_4, a_5 and a_6 under these columns respectively. The remaining entry of this row is filled with b_{23}.

	X(A_1)	**Y(A_2)**	**Z(A_3)**	**W(A_4)**	**P(A_5)**	**Q(A_5)**
R_1	b_{11}	b_{12}	a_3	b_{14}	a_5	a_6
R_2	a_1	a_2	b_{23}	a_4	a_5	a_6

Step (3) 1st time Considering XY → W we check if the two rows of the table have the same value under the columns that make up the determinant of the FD. Since the rows do not have identical values we repeat step 3 and consider another FD.

Step (3) 2nd time Considering $XW \rightarrow P$ we check if the two rows of the table have the same value under the columns that make up the determinant of the FD. Since the rows do not have identical values we repeat step 3 and consider another FD.

Step (3) 3rd time Considering $PQ \rightarrow Z$ we check if the two rows of the table have the same value under the columns that make up the determinant of the FD. Since the rows do have identical values under the attributes P and Q respectively, we make equal the entries of the two rows under attribute Z. Since one of the values is a_3, we make the other entry equal to this value.

	$X(A_1)$	$Y(A_2)$	$Z(A_3)$	$W(A_4)$	$P(A_5)$	$Q(A_5)$
R_1	b_{11}	b_{12}	a_3	b_{14}	a_5	a_6
R_2	a_1	a_2	a_3	a_4	a_5	a_6

Although the algorithm requires that we continue the table will not change. We have omitted these steps and continue with step 4.

Step (4) 1st time Since one of the rows has become all a_i's, the decomposition is lossless.

5.10. Given the relation r(X, Y, Z, W, Q) and the set F – {XY → WQ, Z → Q, W → Z, Q → X,}, find the FDs that are satisfied by relation R_1(X, Y, Z) of a decomposition (the other relations are not shown here) by projecting the set of dependencies F onto the attributes of the scheme of these relations.

To determine $\pi_{\{X,Y,Z\}}(F)$ consider the different proper subsets of the scheme (X, Y, Z) and calculate their closure. These subsets are: {X}, {Y}, {Z}, {X, Y}, {Y, Z}, {X, Z}.

For the single element subsets the closures are:

$$\{X\}^- - \{X\} \qquad \{Y\}^- - \{Y\} \qquad \{Z\}^+ - \{Z, Q, X\}$$

For the two-element subsets the closures are:

$$\{XY\}' - \{X, Y, W, Q, Z\} \qquad \{YZ\} - \{Y, Z, Q, X, W, Q\} \qquad \{XZ\}' - \{X, Z, Q\}$$

From each of the individual closures, we choose $X \rightarrow Y$ if Y is an element of {X} and the following conditions are met simultaneously: (a) $Y \subset \{X, Y, Z\}$, (b) $Y \in X'$ (with respect to F), (c) $Y \not\subset X$.

Closures $\{X\}'$ and {Y} only produce trivial dependencies which are not included in $\pi_{\{X,Y,Z\}}(F)$.

Therefore, from {Z} we select $Z \rightarrow X$. That is we add this FD to {X, Y, Z}(F). We also have $Z \rightarrow Q$ but attribute Q is not part of the scheme {X, Y, Z} as required by condition (a) indicated above.

Closure {XY} – {X, Y, W, Q, Z} produces $XY \rightarrow Z$

Closure {YZ} – {Y, Z, Q, X, W, Q} produces $YZ \rightarrow X$

Closure {XZ} – {X, Z, Q} produces only trivial dependencies

The elements of $\pi_{\{X,Y,Z\}}(F)$ are $\{XY \rightarrow Z, YZ \rightarrow X, Z \rightarrow X\}$

Eliminating redundant FDs we have that $\pi_{\{X,Y,Z\}}(F)$ $\{XY \rightarrow Z, Z \rightarrow X\}$

5.11. Consider the relation $r(X, Y, Z, W)$ and the decomposition $\rho = \{R_1(X, Y), R_2(Z, W)\}$. Is this relation dependency preserving with respect to $F = \{X \rightarrow Y, Z \rightarrow W\}$?

For explanation purposes and to be somewhat methodical, we will consider the different FDs of the set in the order in which they are listed in F.

Step (1) 1st time (with respect to $X \rightarrow Y$)
Initializing T to the determinant of the FD under consideration we have $T = \{X\}$.

Steps (2/3) 1st time (with respect to $X \rightarrow Y$)
Applying the R_1 operation $T = T \cup ((T \cap R_1)^+ \cap R_1)$ with respect to F we have that
$T \cap R_1 = \{X\} \cap \{X, Y\} = \{X\}$
$(T \cap R_1)^+ = \{X\}^+ = \{X, Y\}$ (applying the closure algorithm of Section 4.6.2)
$(T \cap R_1)^+ \cap R_1 = \{X, Y\} \cap \{X, Y\} = \{X, Y\}$
$T = T \cup ((T \cap R_1)^+ \cap R_1) = \{X\} \cup \{X, Y\} = \{X, Y\}$
$T = T \cup ((T \cap R_1)^+ \cap R_1) = \{X, Y\}$ (This is the value of X that is carried over the next iteration with R_2)

Step (3) 2nd time (with respect to $X \rightarrow Y$)
Applying the R_2 operation $T = T \cup ((T \cap R_2)^+ \cap R_2)$ with respect to F we have that
$T \cap R_2 = \{X, Y\} \cap \{Z, W\} = \varnothing$
$(T \cap R_2)^+ = \varnothing^+ = \varnothing$
$(T \cap R_2)^+ \cap R_2 = \varnothing \cap \{Z, W\} = \varnothing$
$T = T \cup ((T \cap R_2)^+ \cap R_2) = \{X, Y\} \cup \varnothing = \{X, Y\}$
$T = T \cup ((T \cap R_1)^+ \cap R_1) = \{X, Y\}$ (This is the value of X that is carried over the next iteration with R_1)

Step (3) 3rd time (with respect to $X \rightarrow Y$)
Applying the R_1 operation $T = T \cup ((T \cap R_1)^+ \cap R_1)$ with respect to F we have that
$T \cap R_1 = \{X, Y\} \cap \{X, Y\} = \{X, Y\}$
$(T \cap R_1)^+ = \{X, Y\} = \{X, Y\}$ (applying the closure algorithm of Section 4.6.2)
$(T \cap R_1)^+ \cap R_1 = \{X, Y\} \cap \{X, Y\} = \{X, Y\}$
$T = T \cup ((T \cap R_1)^+ \cap R_1) = \{X, Y\} \cup \{X, Y\} = \{X, Y\}$
$T = T \cup ((T \cap R_1)^+ \cap R_1) = \{X, Y\}$ (This is the value of X that is carried over the next iteration with R_2)
Since the set T will no longer change, we continue with step 4.

Step (4) 1st time (with respect to $X \rightarrow Y$)
Since Y (the right-hand side of the FD under consideration) is such that $\{Y\} \subseteq T = \{X, Y\}$ we have that $X \rightarrow Y \in G^+$ where $G = \bigcup_{i=1}^{K} \pi_{R_i}(F)$.

Steps (2/3) 1st time (with respect to $Z \rightarrow W$)
Applying the R_1 operation $T = T \cup ((T \cap R_1)^+ \cap R_1)$ with respect to F we have that
$T \cap R_1 = \{Z\} \cap \{X, Y\} = \varnothing$
$(T \cap R_1)^+ = \varnothing^+ = \varnothing$
$(T \cap R_1)^+ \cap R_1 = \varnothing \cap \{X, Y\} = \varnothing$
$T = T \cup ((T \cap R_1)^+ \cap R_1) = \{Z\} \cup \varnothing = \{Z\}$
$T = T \cup ((T \cap R_1)^+ \cap R_1) = \{Z\}$ (This is the value of X that is carried over the next iteration with R_2)

Step (3) 2nd time (with respect to $Z \rightarrow W$)

Applying the R_2 operation $T \cup ((T \cap R_2)' \cap R_2)$ with respect to F we have that

$T \cap R_2 = \{Z\} \cap \{Z, W\} = \{Z\}$

$(T \cap R_2)^+ = \{Z\}^- = \{Z, W\}$ (applying the closure algorithm of Section 4.6.2)

$(T \cap R_2)' \cap R_2 = \{Z, W\} \cap \{Z, W\} = \{Z, W\}$

$T \cup ((T \cap R_2)' \cap R_2) = \{Z\} \cup \{Z, W\} = \{Z, W\}$

$T = T \cup ((T \cap R_2)^+ \cap R_2) = \{Z, W\}$ (This is the value of X that is carried over the next iteration with R_1)

Step (3) 3rd time (with respect to $Z \rightarrow W$)

Applying the R_1 operation $T \cup ((T \cap R_1)' \cap R_1)$ with respect to F we have that

$T \cap R_1 = \{Z, W\} \cap \{X, Y\} = \varnothing$

$(T \cap R_1)' = \varnothing' = \varnothing$

$(T \cap R_1)' \cap R_1 = \varnothing \cap \{X, Y\} = \varnothing$

$T \cup ((T \cap R_1)' \cap R_1) = \{Z, W\} \cup \varnothing = \{Z, W\}$

$T = T \cup ((T \cap R_1)' \cap R_1) = \{Z, W\}$

Since the set T will no longer change, we continue with step 4.

Step (4) 1st time (with respect to $Z \rightarrow W$)

Since W (the right hand side of the FD under consideration) is such that $\{Y\} \subseteq T = \{Z, W\}$ we have that $Z \rightarrow W \in G'$ where $G = \bigcup_{i=1}^{K} \pi_{R_i}(F)$.

Step (5) 1st time

The previous results have shown that both $X \rightarrow Y$ and $Z \rightarrow W$ are elements of G, therefore, the decomposition $\rho = \{R_1(X, Y), R_2(Z, W)\}$ preserves the dependencies.

5.12. Show that every two-attribute relation is in BCNF. That is, if r(X, Y) then r(X, Y) is in BCNF.

Let us consider the following cases:

a. X is the sole key of the relation. In this case, the nontrivial dependency $X \rightarrow Y$ has X as a superkey since $X^+ = X$.

b. Y is the sole key of the relation. In this case, the nontrivial dependency $Y \rightarrow X$ has Y as a superkey since $Y^+ = Y$.

c. Both $X \rightarrow Y$ and $Y \rightarrow X$ hold simultaneously. Then whatever PK we consider for the relation we will have either X or Y as its determinant. Either one of the two possible cases has already been considered under (a) or (b).

5.13. Consider the relation r(A, B, C, D, E) and the set $F = \{AB \rightarrow CE, E \rightarrow AB, C \rightarrow D\}$. What is the highest normal form of this relation?

Since r is a relation by definition the relation is already in 1NF.

To determine the normal form of the given relation, we need to determine all possible keys of the relation. The two possible keys of this relation are AB and E. Let us see why this is so.

AB is a key

(1) $AB \rightarrow A$ (Reflexivity axiom)

(2) $AB \rightarrow B$ (Reflexivity axiom)

(3) From $AB \rightarrow CE$ (given) we have that $AB \rightarrow C$ (Projectivity axiom)

(4) From $AB \rightarrow CE$ (given) we have that $AB \rightarrow E$ (Projectivity axiom)

(5) From $AB \rightarrow C$ (step 3) and $C \rightarrow D$ (given) we have that $AB \rightarrow D$ (Transitivity axiom)

Since AB determines all attributes of the relation AB is a key.

E is a key
Since $E \rightarrow AB$ (given) and AB is a key then E is also a key because by application of the Transitivity axiom E can functionally determine all other attributes of the relation.

The prime attributes are: A, B, and E.

The nonprime attributes are: C and D.

The relation is in 2NF because there are no partial dependencies on any of the key.
The relation is not in 3NF because there is a transitivity dependency on the keys. Notice that $C \rightarrow D$ and both attributes are nonprime.

5.14. Given the relation r(A, B, C) and the FDs $A \rightarrow B$ and $B \rightarrow C$, we know that r is not in 3NF because there is a transitivity dependency on the key A. Would this relation be in 3NF if $C \rightarrow B$ is true for this relation?

The relation is not in 3NF even if this functional dependency is true. Refer to Fig. 5-4 and notice that $C \rightarrow B$ is not required.

5.15. The algorithm shown below takes as its input a relation r(R), a canonical set F_c of functional dependencies and a candidate key K of the relation. The output of the algorithm is a decomposition in third normal form of the relation ρ $(R_1, R_2, R_3, \ldots, R_n)$ that is lossless and preserves the dependencies.[7]

(1) Find all attributes of the scheme of the relation r that do not appear as part of the determinant or as part of the right-hand side of *any* dependency in F_c. If there are attributes that meet this condition form a set A with these attributes and do steps 1-a and 1-b, otherwise continue with step 2.

(1-a) Create a relation with the attributes of the set A. That is, create r(A)

(1-b) Remove all the attributes of the set A from the scheme of the relation r. That is, set R R {A}

(2) Look for a functional dependency $X \rightarrow Y$ in F_c such that all the attributes that remain in R appear in the dependency. If such a functional dependency is found then create the relation r(X, Y) and stop executing the algorithm. Otherwise continue with step 3.

(3) For every $X \rightarrow A$ in F_c (single attribute A since F_c is a canonical set) form a relation $R_i(X, A)$ where $X \rightarrow A$. When all FDs of F_c have been considered continue with step 4.

(4) Combine, if any, all relational schemes that have the same left-hand side. That is, combine $R_j(X, Z)$ where $X \rightarrow Z$ with $R_k(X, W)$ where $X \rightarrow W$ and form a relation $R_{jk}(X, ZW)$ where $X \rightarrow ZW$. Continue with step 5.

(5) If all the elements of the key K do not appear as part of the determinant associated with any of the relations formed in step 4, create a new relation whose attribute is the key K. Continue with step 6.

(6) The different relations $R_i(X, Y)$ form a 3NF lossless decomposition that preserves the dependencies.

[7] Adapted from *An Introduction to Database Systems* by B. C. Desai, West Publishing Company, 1990.

The following problem illustrates the use of this algorithm.

Given the relation r(X, Y, Z, W, Q) and the canonical set F_c {X → Y, XZ → W, YW → Q} find a 3NF decomposition using the algorithm of the previous problem.

Before applying the algorithm we need to find a candidate key for the given relation. In this case, that key is the composite attribute XZ. Let's see why this so.

XZ is a key.

(1) XZ → *X* (Reflexivity axiom)

(2) XZ → *Z* (Reflexivity axiom)

(3) From X → Y (given) and XZ → X (from 1) we have that XZ → *Y* (Transitivity axiom)

(4) XZ → *W* (given)

(5) From X → Y (given), XZ → W (given) and YW → Q we have that XXZ → Q (Pseudotransitivity axiom). The determinant of the latter FD can be written as XZ → *Q* because the union of attributes is commutative.

Since XZ functionally determines all other attributes XZ is a key of the relation. Applying the algorithm of Solved Problem 5.15 we have the following:

Step (1) There are no attributes in the scheme of r(X, Y, ZW, Q) that do not appear as part of a functional dependency of F_c. Continue with step 2.

Step (2) There is not a single functional dependency that has all the elements of the scheme of the given relation.

Step (3) Considering X → Y we form the relation R_1(X, Y)
Considering XZ → W we form the relation R_2(X, Z, W)
Considering YW → Q we form the relation R_3(Y, W, Q)

Step (4) There are no relations where their associated FDs have the same determinant. Continue with step 5.

Step (5) The attributes of the key (XZ) appear as part of the determinant of the functional dependency (XZ → Z) associated with the relation R_{XZW}(X, Z, W), therefore, there is no need to create another relation whose scheme is the candidate key XZ.

The decomposition ρ {R_1(X, Y), R_2(X, Z, W), R_3(Y, W, Q)} is lossless. To verify this we can apply the lossless-join algorithm of Section 5.11.1. The initial table corresponding to steps 1 and 2 is shown next.

	X(A_1)	Y(A_2)	Z(A_3)	W(A_4)	Q(A_5)
R_1	a_1	a_2	b_{13}	b_{14}	b_{15}
R_2	a_1	b_{22}	a_3	a_4	b_{25}
R_3	b_{31}	a_2	b_{33}	a_4	a_5

Considering the FD of the canonical set F_c $\{X \rightarrow Y, XZ \rightarrow W, YW \rightarrow Q\}$ and by successive application of step 3 the table looks like the one shown below.

	$X(A_1)$	$Y(A_2)$	$Z(A_3)$	$W(A_4)$	$Q(A_5)$
R_1	a_1	a_2	b_{13}	b_{14}	b_{15}
R_2	a_1	a_2	a_3	a_4	a_5
R_3	b_{31}	a_2	b_{33}	a_4	a_5

Since one of the rows (R_2) has all a_i's the decomposition is lossless. We leave as an exercise to the reader to prove that the decomposition preserves the dependencies.

5.16. The algorithm shown below takes two inputs. The first input is a relation r(R). The second input is a nonredundant cover F' of the set F of functional dependencies that are satisfied by r(R). The output of the algorithm is a lossless BCNF decomposition ρ $(R_1, R_2, R_3, \ldots, R_n)$. The resulting decomposition may or may not satisfy all the FDs that are satisfied by the original relation. Notice that the algorithm only guarantees that the decomposition is lossless, not that it preserves the dependencies of the original relation. The reader should be aware that the *order* in which the FDs are selected in step 2 of the algorithm affects the resulting decomposition.

(1) Initialize a relation S_{in} to the given relation r(R). That is, S_{in} has the same scheme R of the relation r.
Initialize a set of relations S_{out} to the empty set, that is, set S_{out} $\{\}$.
Initialize an integer variable j to zero. That is, j 0.

(2) Look for a nontrivial $X \rightarrow Y$ in F' such that X is not a superkey of S_{in}. There are two outcomes to this search:

(2-a) If such a functional dependency is found do the following:
Increment j, that is, set $j - j + 1$
Create a relation $R_j(\underline{X}, Y)$ where X is the key of the relation. The relation R_j satisfies $X \rightarrow Y$.
Add the relation $R_j(\underline{X}, Y)$ to the set S_{out}. That is, set S_{out} S_{out} R_j.
Remove the right-hand side of $X \rightarrow Y$ from S_{in}. That is, set S_{in} S_{in} $\{Y\}$
Remove $X \rightarrow Y$ from the set F'.
If there are attributes left in S_{in} and there are FDs in F' then repeat step 2, otherwise do step 3.

(2-b) If no such functional dependency is found do step 3. Notice that this condition will occur when there are FDs $X \rightarrow Y$ in F' such that $XY \not\subseteq S_{in}$.

(3) If there are no FDs left in F' and there are no attributes left in S_{in}, the relations of S_{out} form a BCNF decomposition of the given relation r(R) that is both lossless and contains the same set of FDs of the original relations. If there are attributes left in S_{in} but there are no FDs left in F' or if there are no attributes left in S_{in} but there are FDs left in F' then the procedure produces a decomposition that is lossless but does not preserve all the FDs of the original relations. The final decomposition is $S_{out} \cup S_{in}$.

Consider the relation r(X, Y, W, Z, P, Q) and the nonredundant set F' of FDs {XY → W, XW → P, PQ → Z, XY → Q}.

Step (1) Initialize a relation S_{in} to the given relation r(R). S_{in} {X, Y, W, Z, P, Q}
Initialize a set of relations S_{out} to the empty set, that is, set S_{out} { }.
Initialize an integer variable j to zero. That is, j – 0.

Step (2/2-a) 1st time Consider the nontrivial FD: XY → W. Notice that this FD is not a superkey.
Increment j, that is, set j – 1
Create a relation R_1(<u>XY</u>, W) where XY is the key of the relation. The relation R_1 satisfies XY → W.
Add the relation R_1(<u>XY</u>, W) to S_{out}. S_{out} – $S_{out} \cup R_1$ – R_1(<u>XY</u>, W)
Remove the right-hand side of XY → W from S_{in}. That is, set S_{in} {X, Y, W, Z, P, Q} {W} { X, Y, Z, P, Q}
Remove XY → W from the set F'. That is, F' – {XW → P, PQ → Z, XY → Q}

Step (2/2-a) 2nd time Consider the nontrivial FD: XY → Q. Notice that this FD is not a superkey.
Increment j, that is, set j – 2
Create a relation R_2(<u>XY</u>, Q) where XY is the key of the relation. The relation R_2 satisfies XY → Q.
Add the relation R_2(<u>XY</u>, Q) to S_{out}. S_{out} – $S_{out} \cup R_2$ – {R_1(<u>XY</u>, W), R_2(<u>XY</u>, Q)}
Remove the right-hand side of XY → Q from S_{in}. That is, set S_{in} – {X, Y, Z, P, Q} {Q} – { X, Y, Z, P}
Remove XY → Q from the set F'. That is, F' {XW → P, PQ → Z}

Step (2/2-b) 1st time No FD can be considered because S_{in} – {X, Y, Z, P} and F' {XW → P, PQ → Z}. Notice that neither {XWP} ⊆ S_{in} {X, Y, Z, P} nor {PQZ} ⊆ S_{in} {X, Y Z, P}

Step (3) 1st time The resulting decomposition is S_{out} {R_1(<u>XY</u>, W), R_2(<u>XY</u>, Q), R_3(X, Z, W)}
The resulting decomposition does not preserve the dependencies of the original relation because the XW → P and PQ → Z are not associated with any relation R_i. However, the decomposition S_{out} is lossless. The final table of the application of the lossless-join algorithm after considering all the FDs of F' is shown below. Notice that at least one row is all a_i's.

	X(A_1)	Y(A_2)	W(A_3)	Z(A_4)	P(A_5)	Q(A_6)
R_1	a_1	a_2	a_3		a_5	
R_2	a_1	a_2	a_3	a_4	a_5	a_6
R_3	a_1	a_2	a_3	a_4	a_5	a_6

Supplementary Problems

5.17. Verify that if the FDs of Solved Problem 5.16 are considered in the following order: $PQ \rightarrow Z$, $XW \rightarrow P$, $XY \rightarrow Q$ and $XY \rightarrow W$, the resulting BCNF decomposition is lossless and preserves the dependencies.

5.18. Given the relation r(A, B, C, D, E, F, G, H, I, J, K, L) and the set F {$A \rightarrow B$, $A \rightarrow C$, $A \rightarrow D$, $AE \rightarrow G$, $B \rightarrow C$, $D \rightarrow C$, $E \rightarrow F$, $E \rightarrow H$, $H \rightarrow I$, $JKL \rightarrow E$, $JKL \rightarrow H$, $LHK \rightarrow J$, $LHK \rightarrow E$, $LAK \rightarrow J$, $LAK \rightarrow E$, $LKE \rightarrow J$} find a 3NF lossless and preserving dependency decomposition. Verify that the key is the composite set of attributes AKL. Assume that all attributes are single letters.

5.19. Consider the following relation REALTOR(Property-No, Date-Sold, License-No, Commission, Bonus). Assume also that the following dependencies hold in this database: Date-Sold → Bonus, and License-No → Commission. If we assume that attributes Property-No and License-No form a composite key, what is the highest normal form of this relation?

5.20. Consider the relation r(A, B, C, D, E, F) and the set F {$A \rightarrow B$, $C \rightarrow DF$, $AC \rightarrow E$, $D \rightarrow F$}. What is the key of the relation? What is the highest normal form of this relation? If it is not in 3NF find a decomposition that is lossless and dependency preserving.

5.21. Consider the relation r(A, B, C, D), the set F {$A \rightarrow B$, $C \rightarrow D$} and the decomposition R_1(AB) and R_2(CD). Is this decomposition lossless? Does it preserve the dependencies of the set F?

5.22. Given the relation r(A, B, C, D, E, F) and the set F {$A \rightarrow B$, $CD \rightarrow A$, $BC \rightarrow D$, $AE \rightarrow F$, $CE \rightarrow D$}, verify that the decomposition R_1(C, D, E), R_2(A, B), R_3(A, E, F) and R_4(A, C, E) is a BCNF lossless decomposition.

5.23. Consider the set of FDs {Employee → Department, Employee → Title, Employee → Pay-Scale, Title → Pay-Scale}, and find at least two different lossless decompositions for the given relation.

5.24. Consider the relation Supplier (Supplier-No, Part-No, Supplier-Name, Supplier-Control, Price) and assume that only the following FDs hold for this relation: Supplier-No → Supplier-Name, Supplier-No → Supplier-Control. What type of data anomalies does this relation have in its present form? Transform it to 3NF if not already in that form.

5.25. Find the highest normal form of the relation r(A, B, C, D) if the following FDs are satisfied by the relation F {AB → D, AC → BD, B → C}.

5.26. Consider the relation for release RECORD (Title, Performer, Style, Price, Label, Producer) and the dependencies shown below. Indicate what is the highest normal form of this relation. Indicate a possible 3NF decomposition of this relation.

Title → Label, Style Style → Price Performer → Producer

Answers to Supplementary Problems

5.17. S_{out} {R_1(P, Q, Z) satisfies PQ → Z, R_2(X, W, P) satisfies XW → P, R_3(X, Y, Q) satisfies XY → Q, R_4(X, Y, W) satisfies XY → W}.

5.18. The following FDs are redundant and do not appear as members of the canonical cover for the set F: {A → C, JLK → H, LKE → J, LKH → E, LAK → J}. The decomposition has the following relations: R_1(A, B, D) that satisfies A → BD, R_2(B, C) that satisfies B → C, R_3(D, C) that satisfies D → C, R_4(E, F, H) that satisfies E → FH, R_5(H, I) that satisfies H → I, R_6(J, L, K, E) that satisfies JLK → E, R_7(L, H, K, J) that satisfies LHK → J, R_8(L, A, K, J) that satisfies LAK → J, and R_9(A, E, G) that satisfies AE → G. There are no relations that contain attributes that do not appear as part of the determinant or the right-hand side of the FDs of F. The key appears as part of the determinant of a relation.

5.19. There is a partial dependency on the key. Consider the FD: License-No → Commission. Therefore, the highest normal form is 1NF.

5.20. The key of the relation is the composite attribute AC. As it stands this relation is only 1NF. A 3NF decomposition of this relation is R_1(A, C, E), R_2(C, D), R_3(D, F) and R_4(A, B). This decomposition is lossless and preserves the dependencies.

5.21. The decomposition preserves the functional dependencies but is not lossless.

5.22. Show that all relations are in BCNF and use the lossless-join algorithm to show that they are a lossless decomposition.

5.23. R_1(Employee, Department, Title) and R_2(Title, Pay-Scale). Two other decompositions are: R_1(Employee, Title) and R_2(Employee, Department, Pay-Scale) or R_1(Employee, Pay-Scale) and R_2(Employee, Department, Title).

5.24. This relation presents insertion anomalies, deletion anomalies and update anomalies. In this relation we cannot enter a Supplier-Control until that supplier supplies a part (insertion anomaly). Notice that this is necessary to preserve the integrity constraint of the key. If a supplier stops temporarily supplying a particular part, then the deletion of the last tuple containing that Supplier-No also deletes the Supplier-Control of the supplier (deletion anomaly). Finally, if the Supplier-Control of a particular supplier needs to be updated, we must look for every tuple that contains that supplier as part of the key. If a supplier supplies many parts and we fail to update all the corresponding tuples, the database may end up in an inconsistent state. We can transform this relation into a 2NF as follows:

Supplier(Supplier-No, Supplier-Name, Supplier-Control) and
Part(Part-No, Supplier-No, Price)

The relation is also in 3NF because there are no transitive dependencies. Notice each relation only has one nonprime attribute, therefore, there cannot be transitivity dependencies on the key.

5.25. The keys of this relation are: AB and AC. The prime attributes are: {A, B, C}. Attribute D is the sole nonprime attribute. Attribute D is not partially dependent on any key. Therefore, the relation is in 2NF. The relation is also in 3NF because there is only one nonprime attribute; therefore, a transitive dependency between two different nonprime attributes cannot exist. The relation is not in BCNF because $B \rightarrow C$ and B is not a superkey of the relation.

5.26. The key of the relation is the composite attribute Title, Performer. As it stands the relation is in 1NF because there is at least one partial dependency on the key. For example, Performer → Producer. A possible decomposition may be Record(Title, Performer), Genre(Title, Label, Style), Producer(Performer, Producer-Name), Cost(Style, Price).

CHAPTER 6

Basic Security Issues

6.1 The Need for Security

In any corporation data is the most valuable resource. Therefore, the database needs to be controlled, managed, protected and secured. In the context of RDBMS we will understand the term *security* to mean the protection of the database against unauthorized access or the intentional or unintentional disclosure, alteration or destruction of the database. In this chapter we consider some of the elementary aspects of data security. We recognize that security concerns are not limited to relational databases. Many of the issues discussed here apply to DBMS with other architectures, as all data must be kept accurate and secure. However, since this book concerns relational databases, in most cases we present a general introduction to the topic of security in relational databases. Also, some specific examples of handling security issues using SQL will be given.

The need for database security began in the early days of computing. In those days, the physical security of the entire computer system was the main concern for the large organizations that could afford the sizeable systems of that time. However, with the proliferation of personal computers, more organizations began relying on databases and logical security of the information itself became more critical. The need for security today is a result of a variety of factors, many mentioned in previous chapters, including:

- Multiple users trying to access and/or change databases at the same or different times.
- More data being kept in single location.
- Databases becoming accessible across communication lines and the existence of distributed databases.
- The advancement of the Internet.
- More specialized software available both to enter the system illegally to extract data and to analyze the information once it is obtained.

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Because it is important to centralize database security, the person primarily responsible for the security of the database is usually the Database Administrator (DBA). The DBA must consider a variety of potential threats to the system. Problems may arise from the general public as well as from people within the organization; therefore users must be authenticated and authorized. By *authentication*, we mean that the user has proven to the system that the user really is who he or she claims to be. Often this authentication process takes the form of verifying a password. *Authorization* then involves the specific privileges that the authenticated user has been granted. Authentication and authorization will be discussed in a later section.

Security breaks may be intentional or accidental, so inadvertent changes must be prevented as much as possible by the DBMS itself. Intentional security problems may be malicious or non-malicious, aimed at the computer system itself or at the data contained therein. Most of these issues will be explored in this chapter. The reader should consult other sources for more information. Many books specializing in database security are available, and DBMS documentation will provide specifics on your particular system.

6.2 Physical and Logical Security

Physical security usually means the security of the hardware associated with the system and the protection of the site where the computer resides. *Logical security* encompasses the security measures residing in the operating system and/or the DBMS designed to handle threats to the data, both to its accuracy and also to its confidentiality. One result of the growth of the Internet and the explosion in the number of communication lines is that people do not need to have physical access to the hardware to threaten the data. There is no longer a clear distinction between physical and logical security. This section will discuss some issues specifically relating to physical security of the database. Logical security is far more difficult to accomplish and will be examined throughout the rest of the chapter.

6.2.1 PHYSICAL SECURITY ISSUES

Usually physical security is not the job of the DBA. This job is the responsibility of the security officer in the organization. However, it is prudent for the DBA to make certain that reasonable measures are followed by the organization. In a single user system with the database residing on one personal computer, physical safeguards may entail only locking the workstation and securing the door of the room to limit access. A larger organization might use guards and alarm systems for the rooms that contain the server and other centralized computer equipment. Depending upon the particular organization and the sensitivity of the data, guards and other security measures might also be put into place for the entire building. Most office buildings in urban areas already employ such practices.

Physical threats are not always in the form of illegal entry. Natural events such as fire, floods, and earthquakes must also be considered. Computer equipment should never be kept in a basement area that might fill with water. Special fire extinguishers and smoke alarms are available and should certainly be utilized. Many organizations regularly store backup copies of databases in different cities to allow for fast recovery in the face of massive disasters. The DBA should consult with others in the organization to assess the particular risks and ensure that appropriate procedures are followed.

Example 6.1
A group of three doctors is investigating the physical security of their patient database. Their office is located on the sixth floor in a medical arts complex in a large city. The database is located on a single server and accessible by terminals in each room. What would you suggest they should do?

The doctors need to check to be sure that the building management follows appropriate security measures. If night guards patrol the building, probably secure locks and simple burglar alarms will suffice. If no night guards are available, the doctors could contract with an outside security company for protection. The room containing the server should be locked at all times to prevent patients and other unauthorized personnel from inadvertently entering during the day. The doctors also should consider keeping backup copies of the database at an alternate location that is not in the same building.

6.3 Design Issues

The DBA handles security issues and also all database design. Therefore, the smart DBA will follow a few guidelines to help build the most secure system from the beginning. These guidelines include:

(1) Keep it simple. The smaller and simpler the database design, the fewer ways there are for malicious users to sabotage and for authorized users accidentally to corrupt the data.

(2) Use an open design. All persons accessing the database should understand the schema of the database. (See Chapter 1 to refresh your memory on schemas.) If users thoroughly understand the design, they will be more able to access what they want when they want it with less possibility of error.

(3) Normalize the database. Chapter 5 described the anomalies that occur when the database is not normalized. Normalization takes place during the design phase. It is harder to impose normalization on the relations after the database has been in use.

(4) Always follow the principle of assuming privileges must be explicitly granted rather than excluded. If no privileges are assumed by any user, there is less likelihood that a user will be able to gain illegal access. The designer of the database should help decide which privileges are necessary for each group of users and only grant these privileges. It is safer to err on the side of caution and give the least privilege needed even if a higher level must be granted later rather than to give blanket rights that must be revoked. Section 6.6.6 provides examples of how to grant privileges using SQL.

(5) Create unique views for each user or group of users. Section 6.6.9 describes how to create and maintain views with SQL.

Example 6.2

The DBA of an insurance company is beginning to design a new customer database. What are three possible groups of user? What views should be created for these groups? Which groups would need to be granted rights of access or revision?

Three possible groups of users would be the billing department, the agents, and the customer service personnel. The billing department would need views containing all billing information. They should be able to access and change items such as current balance due and amount paid. The agents need to have a view with complete information on levels and types of coverage. They should be able to change the coverage as requested. Customer service personnel should be able to access both billing information and coverage so that they can answer questions over the telephone. However, they should not be given rights to revise the data.

6.4 Maintenance Issues

Once the database is designed, the DBA's job is not finished. Maintenance is necessary for the lifetime of the database. Most of the security issues regarding maintenance fall into three categories:

(1) Operating System Issues and Availability

(2) Confidentiality and Accountability

(3) Integrity

The following sections examine each of these areas. Once again, it is important to point out that these issues are similar for databases of any type of architecture. Whenever possible, problems and solutions specific to relational databases are discussed. Examples are provided using SQL.

6.5 Operating System Issues and Availability

Operating system security is not specific to the database and is usually handled by the system administrator (SYSAD) or the security officer rather than the DBA. However, as with physical security issues, the DBA should make certain that reasonable safeguards are being followed. The operating system should verify that users and application programs attempting to access the system are authorized and that they really are the particular user or application program that was authorized. There is some division of responsibility here. Accounts and passwords for the entire system are handled by the system administrator. Accounts and passwords for the database itself are handled by the DBA. These tasks will be explained in the next few sections.

Other tasks such as making sure the data are secure across communication lines and throughout a network are also the job of the general computer services department. The DBA should double check that appropriate security measures are being followed.

Availability usually entails being sure that the system is up and running during any period when it will be needed, often twenty-four hours a day, seven days a week. In today's terminology, system administrators are asked to provide "24/7" coverage. Of course, by Murphy's Law, the system will always go down at the most critical moment. The DBA should be prepared to get the system back up and running as soon as possible. It is critical to provide systematic backups and adequate recovery methods. Many RDBMS provide help in this process. Since this task is inextricably related to the operating system, it will not be addressed here.

6.6 Accountability

The task of maintaining the accountability of the database resides with the DBA. *Accountability* means that the system does not allow illegal entry; that is, all users are legal users and really are who they say they are (authentication). Accountability is related to both prevention and detection of illegal actions. There are several ways accountability is assured. First, regular audits of the system should be performed to identify security flaws. Second, the authentication and authorization of users must be continually monitored.

Accountability also relates to what levels of access and privileges users are granted (authorization). Once the users have been authenticated and authorized, they should have full rights to do everything they need to do for their particular jobs. In this section we will also consider the tasks of creating, dropping, and monitoring users, granting system and object privileges to users, and creating and updating views. Each RDBMS has its own methods of handling system availability. The explanation in this section will demonstrate how to accomplish these tasks using SQL in Oracle. Though the goals are the same, you will need to consult your RDBMS manual for specific ways to achieve these goals in other systems.

6.6.1 AUDITS

Auditing a database entails the monitoring and recording of certain actions by users. The record created by auditing resides in the *audit trail*. The most common actions that are audited are starting a session, shutting down a session, and connecting to the database using administrative privileges. Other types of auditing can track changes that are made to specific tables or views. The audit trail is kept in a secure place and is used in several ways. First, it can help answer the question, have the security controls in place prevented all unlawful entry to the system, or has unlawful entry occurred without being detected? Second, the audit trail can provide information about database usage for optimizing the system.

The process of auditing a database is not the same as auditing financial records. Specific methods, skills, and tools are necessary, which are beyond the scope of this book. Usually the particular RDBMS provides tools to aid in the auditing process. The most critical thing the organization must do is to construct an auditing strategy specific to that particular business or industry. The strategy is usually related to the organization's long-term database plan and the risks inherent in such a plan. The DBA should appreciate the necessity of a regular auditing strategy.

6.6.2 AUTHENTICATION AND AUTHORIZATION

Although the DBA is not personally responsible for the complete auditing of the database, he or she is responsible for monitoring its usage. In this section, we will address the topics of authentication and authorization of users.

6.6.2.1 Authentication

By *authentication*, we will refer to any mechanism that determines whether a user is who he or she claims to be. As stated before, authentication can be carried out at the operating system level or by the RDBMS. In either case, the SYSAD or the DBA creates for every user an individual account or username. In addition to these accounts, users are also assigned passwords. A *password* is a sequence of characters, numbers or a combination of both which is supposedly known only to the system and its legitimate user. Since the password is the first line of defense against unauthorized use by outsiders, it needs to be kept confidential by its legitimate user. It is highly recommended that users change their password frequently. It needs to be hard to guess, but easy for the user to remember. Several guidelines for choosing good passwords include:

- Passwords should be, at the very least, six characters long (some people suggest eight is better), and made up of a combination of letters, numbers and some other allowable keyboard symbols.
- Avoid words from a foreign language, geographical names, and common names such as nicknames or proper names.

- Avoid choosing personal statistics such as social security number, phone number, license number, street address, etc.
- Consider concatenating two words together with a punctuation mark or digit in the middle. For example, dog6book, or bush sky.
- Consider thinking of a sentence and using the first letter of each word. For example, the sentence "Times New Roman is my favorite font" would result in the password tnrimff.

Example 6.3
Which of the following passwords should not be used and why?

a. 326High
b. cat
c. face9cow
d. Susie

a. 326High — No, sounds like a street address
b. cat — No, too short, and also a common word
c. face9cow — Yes, two unrelated words connected with a digit
d. Susie — No, a proper name

RDBMs store user names and passwords in an encrypted form in the data dictionary. To access the database, a user must run an application and connect to the database using his or her account or user name and the appropriate password. For example, for the exercises of this book, we have connected to the Personal Oracle 8 (PO8) database via the SQL Plus application using *scott* as the user name and *tiger* as the password respectively. To change a password in Oracle, a user can issue the following command.

```
ALTER USER user-name IDENTIFIED by new-password;
```

Example 6.4
Log into PO8 as scott/tiger and change the password to "tnrimff".

The corresponding instruction is as follows:

```
ALTER USER Scott IDENTIFIED BY tnrimff;
```

It should be obvious that after changing the password, the user will no longer be able to use his or her previous password. Users can change their passwords as many times as they want.

Another way to control security is through the use of profiles. A *profile* is a set of limits to system resources and passwords. A particular profile is given a name, and then assigned to users. Finally, the profile needs to be enabled. In this way, a large number of users can be monitored. System resources that can be limited are items such as CPU time, connect time, number of concurrent sessions, idle time, and memory space. Passwords can be controlled through aging, history,

and expiration dates. Accounts can be locked if a user fails to log into the system after a specified period of time. The general SQL syntax used by Oracle to create a profile is the following:

```
CREATE PROFILE profile_name LIMIT
     [parameter_1      max_value]
     [parameter_2      max_value]
               .....
     [parameter_n      max_value];
```

Some of the parameters that can be used for setting passwords in the `CREATE PROFILE` command are shown in Table 6-1. Many RDBMS systems also provide tools for password verification to force users to create good passwords. For instance, it can check to see if the new password is of minimum length, contains correct characters, and differs from the old by at least three or four letters.

Table 6-1. Password setting profile parameters.

Parameter	Description
FAILED_LOGIN_ATTEMPTS	Number of failed attempts to log in before account is locked
PASSWORD_LOCK_TIME	Number of days account will remain locked when password expires
PASSWORD_LIFE_TIME	Number of days the password is good before it expires
PASSWORD_GRACE_TIME	Number of days grace period for changing the password after the first login when it has expired
PASSWORD_REUSE_TIME	Number of days before password can be reused
PASSWORD_REUSE_MAX	Maximum number of times a password can be reused

Example 6.5

Create a profile called General that will allow the password to last thirty days with a three-day grace period. Allow only three failed login attempts before the account is locked. Do not allow a password to be used for two years, but it can be used an unlimited number of times.

```
CREATE PROFILE general LIMIT
     PASSWORD_LIFE_TIME        30
     PASSWORD_GRACE_TIME       3
     FAILED_LOGIN_ATTEMPTS     3
     PASSWORD_REUSE_MAX        UNLIMITED
     PASSWORD_REUSE_TIME       730;
```

Notice that there are no commas in the command and the parameters do not have to be listed in any particular order. Remember that all maximum values are listed in days. Any values can be granted as `UNLIMITED`, but that is not very wise. The values used in the profile should be part of the general database security strategy. Once the profile is created, it can be assigned to a user when an account is created, dropped, or altered later. The `CREATE` and `ALTER` commands will be demonstrated in the following sections.

6.6.2.2 Authorization

By *authorization* we will understand the *granting* of a *right* or *privilege* to a user that allows him or her to have access to the system or objects within the system. The basic types of privileges associated with any user are the system and object privileges. *System privileges* allow the user to gain access to the database. *Object privileges* allow the user to manipulate objects within the database. When a database user is *created*, the user is associated with a *schema* or a collection of objects in the database to which he or she has access. The system administrator or DBA determines and controls the access rights of a user through the user's *security domain*. The settings of this domain limit what the user can or cannot do in the database. In this sense, the security domain includes information about:

- Type of authentication for this user (through the operating system or the network services).
- The amount of system resources available to this user, including tablespaces (similar to directories in a Windows or DOS environment) and their default values.
- The database objects that the user can access and the operations that the user can perform on these objects.

Before a user can grant any system privileges to any other user he or she must have administrative privileges. Table 6-2 lists some of the basic system privileges.

Table 6-2. Partial list of system privileges.

THIS PRIVILEGE	ALLOWS THE USER TO
`CREATE SESSION`	connect to database
`CREATE TABLE`	create table in own schema and use commands such as `ALTER`, `DROP`, `TRUNCATE` on the tables
`SELECT [ANY TABLE]`	query tables in own schema. If `ANY` is granted user can access table in other schema
`CREATE SEQUENCE`	create sequence in own schema
`CREATE VIEW`	create view in own schema

The process of creating and granting rights and views to users will be discussed in the next section.

6.6.3 CREATING USERS

To create a user we can use the following simplified version of the CREATE USER command.

```
CREATE USER user-name IDENTIFIED BY user-password
DEFAULT TABLESPACE tablespace-name
TEMPORARY TABLESPACE temptablespace-name
QUOTA integer M on tablespace-name
QUOTA integer N on temptablespace-name
[PROFILE profile_name];
```

This command assigns to the user a default and a temporary tablespace. A *tablespace* is a logical storage unit similar to a directory in Windows or DOS. This command also establishes the amount of memory allocated to the user (his or her quota) in each of these tablespaces. A profile may or may not be assigned in the CREATE statement.

As indicated before, to create a user it is necessary to have administrative privileges. To be able to do this, it is necessary to log into PO8™ using SYSTEM as the user name and MANAGER as the password. This is a built-in account in Oracle with administrative privileges.[1]

Example 6.6
Create the user HAYLEY with password tbl42sho. Assign her the profile General from Example 6.5.

The command to create this user is shown below.

```
CREATE USER hayley IDENTIFIED BY tbl42sho
DEFAULT TABLESPACE user_data
TEMPORARY TABLESPACE temporary_data
QUOTA 5M on user_data QUOTA 1M on temporary_data
PROFILE general;
```

The tablespaces user_data and temporary_data come with the default database created for PO8™. We will use them in this section without further consideration since their explanation is beyond the scope of this book.

6.6.4 DROPPING USERS

After creating a user it may be necessary to remove him or her from the database. For instance, the user may resign or be fired. The instruction that allows us to do this is the following:

```
DROP USER user-name [CASCADE];
```

[1] In the following sections, unless otherwise indicated, we will assume that the reader has logged into the ORACLE database using this built-in account.

If the CASCADE option is used when dropping a user, not only the user but also all of the user's objects in his or her schema will be dropped too.

Example 6.7
Drop the user Hayley but leave all her objects in her schema.

```
DROP USER hayley;
```

6.6.5 MONITORING USERS

To display information about the user, there are several views (to be explained later in the chapter) that allow the database administrator to gather information about the database users. Views can be queried as any other ordinary table. Table 6-3 lists some of the views that provide information about users.

Table 6-3. Partial list of views that provide information about a user.

THIS VIEW	CAN BE USED TO OBTAIN INFORMATION ABOUT
ALL_USERS	all the users that have been created.
USER_USERS	the user currently logged-in
USER_TABLES	all the tables owned by the current user
USER_TS_QUOTAS	tablespace quotas for the current user
USER_OBJECTS	objects owned by the user

6.6.6 GRANTING SYSTEM PRIVILEGES TO USERS

Once a user has been created, the system administrator may grant the user a set of privileges. Table 6-4 lists some of the most common privileges assigned to a user.

Table 6-4. Partial list of common privileges granted to users.

THIS PRIVILEGE	ALLOWS THE USER TO
CREATE SESSION	connect to the database
CREATE TABLE	create tables in his/her schema
CREATE VIEW	create view in his/her schema
CREATE SEQUENCE	create sequence in his/her schema

The command to grant privileges to a user is the following:

```
GRANT priv-1 [,priv-2,...priv-n] TO USER user-name;
```

The first privilege that should be granted to a user is the one that allows the user to connect to the database. As indicated in Table 6-4, the name of this privilege is `CREATE SESSION`.

Example 6.8
Recreate the user hayley and grant her the `CREATE SESSION` privilege.

The corresponding command is

```
GRANT create session TO hayley;
```

If user hayley tries to log into the database, the login will succeed. However, if she tries to create a table, she will not be able to do it because she lacks the privileges to do so.

Example 6.9
Grant the necessary privileges to the user hayley to create tables and views.

The command that allows us to do this is as follows:

```
GRANT create table, create view TO hayley;
```

After this statement, the user hayley can connect to the database and create tables in it.

To avoid the tedious task of granting individual privileges to different users, database administrators create groups of related privileges and grant them to the users according to the privileges that the user needs. Each one of these groups of privileges that can be granted as a group is called by Oracle a *role*. For instance, there may be data entry operators with a set of particular privileges, and at the same time there may be a group of programmers with a different set of privileges. The database administrator can then create a role for the entry operators and a different role for the programmers. The DBA then assigns the privileges to each of these roles and grants them to the two groups of users. The command that allows us to create a role is shown below.

```
CREATE ROLE role-name;
```

To grant privileges to a role that has already been created, the DBA can use the `GRANT` command as shown below.

```
GRANT privilege-1 [, privilege...] TO role-name.
```

The following example illustrates this.

Example 6.10
Create a role that allows a user to create a session and create a table. At the same time create another role that allows a user to create a session and create a view but not a table. Call these roles `role_tables` and `role_views` respectively.

```
CREATE ROLE role_tables;
GRANT create session, create table to role_tables;
CREATE ROLE role_views;
GRANT create session, create view to role_views;
```

After these roles have been created, the DBA can assign them to any user using the grant command. Assuming there were users Bruce Rounder (roundeba) and Debbie Martinez (martinde) who needed to access the database and create tables but not views, the DBA could grant them these privileges using the following command:

```
GRANT role_tables to roundeba, martinde;
```

Once a privilege has been granted to a user or a role, it can also be taken away from the user or the role. The instructions that allows the DBA to take away a specific set of privileges from a user or a role are the following:

```
REVOKE priv-1 [,priv-2...priv-n ]
FROM [ user-1 [, user-2...,user-n]];
```

Command to revoke individual privileges from a user or users.

or

```
REVOKE priv-1 [,priv-2...priv-n ]
FROM [ role-1 [, role-2...,role-n]];
```

Command to revoke individual privileges from a role or roles.

Users who have been granted privileges can consult some of the individual views available for this purpose. Table 6-5 lists some of these views.

Table 6-5. Partial list of views that provide information about privileges granted or received.

THIS VIEW	ALLOWS THE USER TO
USER_SYS_PRIVS	check system privileges granted to the current user
USER_TAB_PRIVS_RECD	check grants on objects for which the user is the grantee
USER_ROLES_PRIVS	check roles granted to the user

6.6.7 GRANTING OBJECT PRIVILEGES TO USERS

So far we have considered system privileges; however, the DBA can also grant privileges on specific objects. This type of privilege is called an *object privilege*. Object privileges allow particular actions on the object. Table 6-6 lists several objects and their privileges.

Table 6-6. Partial list of object privileges for tables and views.

OBJECT PRIVILEGE	TABLE	VIEW
ALTER	✓	
DELETE	✓	✓
INSERT	✓	✓
REFERENCES	✓	
RENAME	✓	✓
SELECT	✓	✓
UPDATE	✓	✓

The command that allows us to grant privileges on a particular object to a user or role is the following:

```
GRANT obj-priv-1 [,obj-priv-2...,obj-priv-n]
ON object-1 [,object-2,...,object-n]
TO user-1[,user-2,...,user-n]
[WITH GRANT OPTION];
                                or
GRANT obj-priv-1 [,obj-priv-2...,obj-priv-n]
ON object-1 [,object-2,...,object-n]
TO role-1 [,role-2,...,role-n]
[WITH GRANT OPTION];
```

If the `WITH GRANT OPTION` option is used, the user or role to which the privileges are granted can then, in turn, grant these privileges to another user. Any user who owns an object can grant privileges to another user.

Example 6.11
Log in as scott and write the commands that allows scott to grant `SELECT` privileges to user hayley on the tables EMPLOYEE and DEPARTMENT.

```
GRANT select
ON employee
TO hayley;
GRANT select
ON department
TO hayley;
```

Users who have been granted privileges on objects owned by another user can always refer to these objects by preceding the name of the object with that of its owner and separating them with a period.

Owner-name.object-name

For example, had the user hayley logged on, she could access the table EMPLOYEE by preceding the table name with that of its owner scott. She could refer to this table as follows:

```
SELECT *
FROM scott.employee;
```

Notice the period separating the name of the owner of the object from the name of the object.

6.6.8 HIDING DATA THROUGH VIEWS

A mechanism that allows users to exclude data that other users should not see is that of a *view*. By this term, we will understand a *stored query* that, when executed, derives its data from other tables (the *base* or *underlying tables*). The view is a query literally stored in the data dictionary. The view does not contain data and it is not allocated any storage space either. When a user references a view, the RDBMS retrieves its definition from the dictionary and executes or "runs" the query.

Views provide a level of security because they allow us to hide data "behind" the query. That is, users who execute the query will only see the result of the query, not the tables or views from which the data is extracted. In this sense, views are a tailored presentation of the data contained in one or more tables or views. Notice that a view can be based on some other views providing an extra level of protection.

6.6.9 CREATING VIEWS

Since views may be derived from tables, there are many similarities between these two objects. From a practical point of view the user cannot easily differentiate views from tables. Users with the appropriate privileges can query views like any other table. In addition, users can, with some restrictions, update, insert and delete data from a view. Like any other database object, to create a view in his or her own schema, the user must have the system privilege `CREATE VIEW`.

The syntax of this command is shown below.

```
CREATE VIEW view-name [(alias-1, alias-2,...,alias-n)]
AS query
WITH [READ ONLY | WITH CHECK OPTION [CONSTRAINT
  constraint-name];
```

The aliases are names for the expressions SELECTed by the view's query. The number of aliases must match the number of expressions selected by the view. The WITH READ OPTION option prevents insertions, deletions or update of the underlying tables through the view. The WITH CHECK OPTION option specifies that inserts and updates performed through the view must result in rows that the view query can select.[2] The following examples illustrate this.

Example 6.12
Recall the C_PROGRAMMER table from Chapter 3.

C_PROGRAMMER

Employee_Id	Last_Name	First_Name	Project	Department
101123456	Venable	Mark	E-commerce	Sales Department
103705430	Cordani	John	Firewall	Information Technology
101936822	Serrano	Areant	E-commerce	Sales Department

Create a view that contains the following attributes of the C_PROGRAMMER table (the base table): last_name, first_name, project. Call the view E_commerce.

```
CREATE view E_commerce
AS SELECT last_name, first_name, project
FROM c_programmer
WHERE project = 'E-commerce'
WITH CHECK OPTION;
```

To display the contents of this view the user can issue the following command.

```
SELECT *
FROM e_commerce;
```

The result of this query is shown below.

```
LAST_NAME        FIRST_NAME       PROJECT
---------------- ---------------- ----------------
Venable          Mark             E-commerce
Serrano          Areant           E-commerce
```

[2] Actually, this option cannot make this guarantee if there is a subquery in the query of this view or any of the underlying views on which this view is based.

Example 6.13
Recall the EMPLOYEE and DEPARTMENT tables from Chapter 3.

EMPLOYEE

ID	NAME	DEPT	TITLE
100	Smith	Sales	Clerk
200	Jones	Marketing	Clerk
300	Martin	Accounting	Clerk
400	Bell	Accounting	Sr. Accountant

DEPARTMENT

ID	DEPT	LOCATION
100	Accounting	Miami
200	Marketing	New York
300	Sales	Miami

Create a view called `Clerks` that displays the name, the name of the department and the location for all employees who are Clerks. Name the headings `Employee`, `Department`, and `City`.

The query that allows us to display this information is the join of the EMPLOYEE and DEPARTMENT tables on the common attribute `Dept` in each table. The corresponding command is

```
CREATE VIEW Clerks (Employee,Department, City)
AS SELECT E. name, D.dept, D.location
FROM employee E, department D
WHERE E.dept = D.dept
AND E.title ='Clerk';
```

The output of the execution of this view is as follows:

```
SELECT *
FROM clerks;

EMPLOYEE        DEPARTMENT      CITY
--------------- --------------- ------------
Martin          Accounting      Miami
Jones           Marketing       New York
Smith           Sales           Miami
```

This example clearly illustrates the power of views to hide data. Notice that as far as the user is concerned there are no practical differences between this view and any other table. In fact, if we describe this view (see below), we will not have any idea that its base table is the join of two tables. Observe also how the aliases help to hide the data even more since there is no mention of the real name of the original columns.

```
DESC clerks;
Name                                    Null?    Type
----------------------------------- -------- -------------
EMPLOYEE                                         VARCHAR2(15)
DEPARTMENT                                       VARCHAR2(15)
CITY                                             VARCHAR2(12)
```

6.6.10 UPDATING VIEWS

As indicated before, a user can update a view if he or she has the appropriate privileges. The command to update a view is similar to that of updating a table (see Chapter 3, Section 3.2.3). However, in some instances, to preserve the integrity of the data it is necessary to ensure that any update performed through the view will not affect the data that the view is able to select. This type of update can be prevented by creating the view with the `WITH CHECK` option as we did in Example 6.11. The following example illustrates this.

Example 6.14
Update the query of Example 6.11 by changing the project from "E-commerce" to "E-business" for the programmer whose last name is "Venable".

The corresponding command is as follows:

```
UPDATE E_commerce
SET project ='E-business'
WHERE last_name = 'Venable';
```

Notice that if we try to execute this command we get an error. This error reads something like this:

```
SQL> UPDATE E_commerce
  2 SET project ='E-business'
  3 WHERE last_name = 'Venable';
UPDATE E_commerce
       *
ERROR at line 1:
ORA-DDD: view WITH CHECK OPTION where-clause violation
```

In this case, DDD stands for a manufacturer internal error. This error occurs because we are trying to change a row that is retrieved by the query. That is, if we update the corresponding row, the query can no longer retrieve it since it will change the region_id from 'E-commerce' to 'E-business'. If we were not using the option `WITH CHECK OPTION` we would have been able to update the view and its underlying table

6.7 Integrity

Integrity refers to the accuracy or correctness of the data in the database. There are a number of ways to maintain the integrity of the data. The RDBMS usually provides a number of tools to help in this process. However, in order to gain full benefit, it is important to understand these tools.

6.7.1 INTEGRITY CONSTRAINTS

A number of constraints should be used to maintain database integrity. These tools include entity constraints, referential integrity constraints, the use of primary keys and foreign keys, and a number of other constraints. The integrity of the database is of primary importance when designing such constraints. These constraints, which are directly related to database security, were explained in Chapter 2. One integrity issue not discussed previously is the concept of concurrency.

6.7.2 CONCURRENCY ISSUE — COMMIT AND ROLLBACK

When there are several users accessing and perhaps changing the data at the same time, it is important for the RDBMS to maintain integrity so that successive changes do not corrupt the data. SQL in Oracle provides a way to monitor these changes. To make permanent all changes made to a table through the use of an `INSERT`, `UPDATE` or `DELETE` operation, the user needs to commit these changes. The instruction that allows a user to record these changes permanently into the database is the `COMMIT` statement. The basic syntax of this statement is this:

```
COMMIT [WORK];
```

Notice that the keyword `WORK` is optional.

The reader should be aware that prior to the execution of a `COMMIT` command, all changes made to the rows of a table are stored in a *database buffer* or working storage in main memory. If for some reason the user quits the database *before* committing the changes, no data will be written to the database files and the changes will be lost. If the user making changes to a table is working in a multi-user environment and other users share this table, no changes made to the table will be accessible to the other users unless the person making the

changes issues a commit command. This happens because whenever a user modifies the rows of a table, he or she has exclusive access to these rows *until* the changes have been committed. By exclusive access of a row, we mean that no other users can view the current contents of the row that have been changed. The affected rows are said to be *locked*. At this time, any other user accessing the same table will not notice that the table has changed. When the user commits the changes, the modified rows are written to the database files; and the locks on all affected rows are released. Users whose transactions started *after* the data was committed can view the modified rows with their new content.

Assuming that the changes made to a table (insertions, updates or deletions) have not been committed, the user can cancel all the intermediates changes made to a table by issuing a `ROLLBACK` statement or by ending the session. These actions cause the RDBMS to ignore all changes made to any table or any other database object since the last commit or since the user began his or her interactive session.

Technically, a `ROLLBACK` statement is used to cancel or terminate the current transaction and return the table to its old values. A *transaction* is a *logical unit of work* that, in general, involves several database operations. *All operations of a transaction succeed or fail as a group*. In other words, if one operation fails then *all* operations fail. In this sense, the transactions are said to be *atomic*. In addition to this, transactions are said to be *durable*. What this implies is that once a transaction is `COMMIT`ted, the changes made to the tuples are guaranteed to be written to the database files even if there are system failures. A transaction begins with the first executable SQL statement after a `COMMIT`, a `ROLLBACK` or a connection to the database. A transaction ends after a `COMMIT`, a `ROLLBACK` or a disconnection from the database. Most databases issue an implicit commit statement after processing a DDL statement.

Sometimes it is desirable to go back to a particular point in time during an interactive session. For instance, we can imagine a user that has made several uncommitted changes to a table and realizes that the last few changes are incorrect or unnecessary. If at this moment the user issues a `ROLLBACK` statement, all changes made to the table will be ignored, including the changes that were correct, and the table would be restored to its original state. It would be nice if the user could go back to a prior state of the database buffer right before where he or she began making the incorrect changes. The SQL command that can be used to accomplish this is the `SAVEPOINT` command.

A `SAVEPOINT` identifies a point in the transaction to which we can go back (roll back) provided that the transaction has not been committed. In this sense, we can think of a `SAVEPOINT` statement as a "bookmarker" within the database buffer. Savepoints allow us to undo only a part of the current transaction by allowing the user to go back to a particular point in time. The basic form of this statement is as follows:

```
SAVEPOINT savepoint-name;
```

where `savepoint_name` is a unique name within the transaction. Generally, savepoint names are single letters but they can be longer. Savepoints follow the same naming rules of any other object in the database. Savepoints are useful in

interactive programming because they give the user some degree of control over the execution of the program. To go back to a previous and uncommitted state of the database buffer it is necessary to issue the following command:

ROLLBACK `savepoint-name;`

Or

ROLLBACK TO SAVEPOINT `savepoint-name;`

Fig. 6-1 illustrates the combined use of the `SAVEPOINT` and `ROLLBACK` commands.

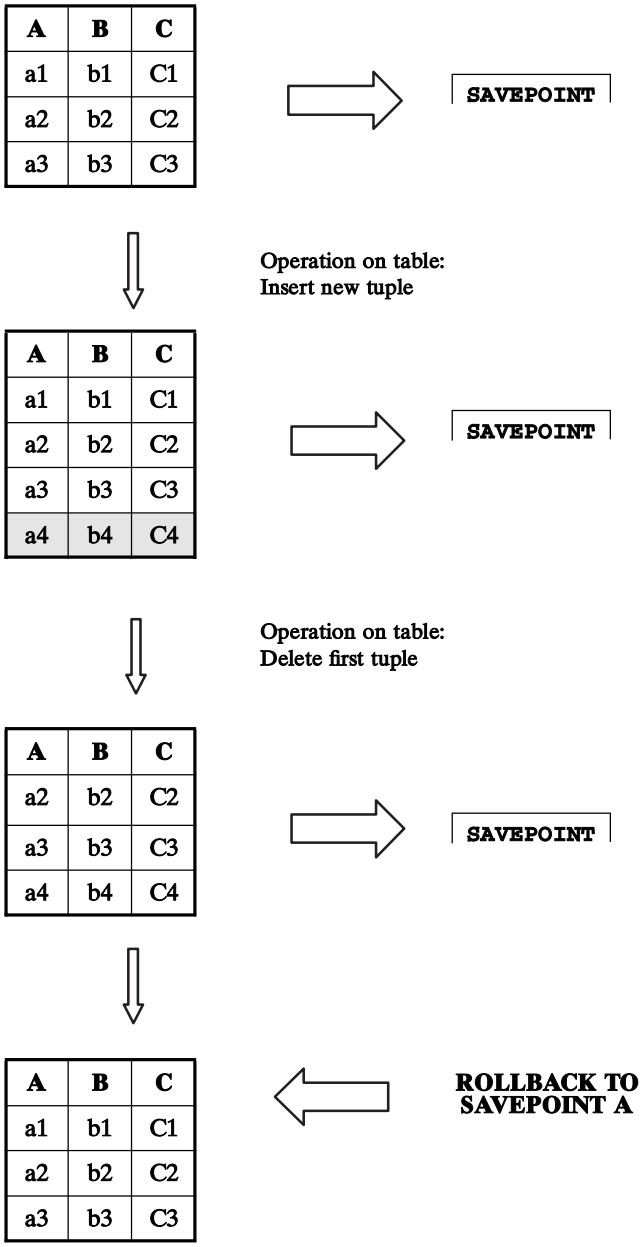

Fig. 6-1. `Savepoint` **and** `Rollback to savepoint.`

The sequence of actions depicted in Fig. 6-1 shows the effect of rolling back to a savepoint. In this case, we assume that the user begins his or her operation by issuing a savepoint A command. The user then inserts a new tuple and issues a savepoint B command. Processing continues and the user deletes the first tuple of the table and issues a savepoint C command. Finally, the user issues a rollback to savepoint A command. Notice that the effect of `ROLLBACK TO SAVEPOINT A` is to return the table to the state that it had when the user issued the savepoint A command. By rolling back to savepoint A, the user has ignored all changes made to the table after issuing the savepoint A command. Obviously, this example assumes that the user never issued a `COMMIT` statement between savepoint A and savepoint C. Had the user committed the data after savepoint C, it would have been impossible for the user to return to any of the previous savepoints A or B. It is important to keep in mind that, at the same time, the user cannot change his or her mind after returning to savepoint A. That is, he or she cannot return (roll forward) to any of the savepoints B or C. Notice that savepoint names must be unique within a given transaction. Whenever the user creates a savepoint with the same name of an earlier savepoint the earlier savepoint is erased. After the changes are committed, the user can reuse any of the previous savepoint names provided that they are unique within the transaction.

As we indicated before, when a user issues a `ROLLBACK` command without the `SAVEPOINT` clause, the net effect of this command is to end the transaction, erase all savepoints in the transaction, undo all changes in the transaction and release any locks.

Solved Problems

6.1. What are some reasons that the advancement of the Internet and distributed databases presented new problems for database security?

There are several potential problems that could arise. Distributed databases result in authorized people in several locations attempting to access the same data at the same time. Data flowing through communication lines may be intercepted or become corrupted. Internet access to databases allows an increased potentiality for non-authorized users to break into the database. All these security problems need to be addressed.

6.2. A woman runs a catering service operating out of her home using a single computer. She has asked for advice on the physical security of her customer database. What would you suggest?

Even though the woman uses her home computer, she should use reasonable measures to keep the database protected from inadvertent corruption by other family members. If she has children, she should consider purchasing a separate computer for their use and keeping

hers in a locked room. If this is impossible, and other family members will have access to the same computer, she should employ logical safeguards such as password protection to the database. As always, regular backups should be made and kept in fireproof containers. A simple customer database probably does not warrant special burglar alarms apart from what she would normally have for her other personal possessions.

6.3. A small college is designing a new student database. What steps should be taken and what items should be considered by the DBA?

First, the DBA should form a task force to examine the student entity to be represented by the system. The more categories of users that are included the more likely it is that a database will be designed to meet all users' needs. The task force should consider such questions as which attributes should be included? What is the simplest way to divide the attributes into relations? Once the relations are designed, the tables should be normalized at least to 3NF. Finally, the task force should determine which groups of users should be formed and what privileges and views these groups would require. Possible groups might include admissions officers, registrars, faculty, and departmental secretaries. Each of these groups need different privileges and views.

6.4. Which of the following passwords should not be used and why?

a. YK 334
b. mfmitm (for "My favorite movie is Tender Mercies")
c. Natalie1
d. Washington

a. YK 334 — No, sounds like auto license number, and no spaces allowed.
b. mfmitm (for "My favorite movie is Tender Mercies") — Yes, would be hard to guess.
c. Natalie1 — No, don't use proper names even with a digit.
d. Washington — No, proper name, and too long.

6.5. Write the command to change the password of the user Nakesha J. Sualki (sualkinj) from 6tv7box to 4cat2ball.

To change the password of this user we need to issue the following command:

```
ALTER USER sualkinj IDENTIFIED BY 4cat2ball;
```

6.6. Create the user my723acct with password kmd26pt. Use the `user_data` and `temporary_data` tablespaces provided by PO8 and provide to this user 10M of storage space in `user_data` and 5M of storage space in `temporary_data`.

The command to create this user using the tablespaces provided by PO8 is as follows:

```
CREATE USER my723acct IDENTIFIED BY kmd26pt
DEFAULT TABLESPACE user_data
TEMPORARY TABLESPACE temporary_data
QUOTA 10M on user_data QUOTA 5M on temporary_data;
```

6.7. Create the role role_tables_and_views.

The command to create this role is as follows:

```
CREATE ROLE role_tables_and_views;
```

6.8. Grant to the role of the previous question the privileges to connect to the database and the privileges to create tables and views.

The privilege to connect to the database is CREATE SESSION. The privileges to create tables and views are CREATE TABLE and CREATE VIEW respectively.

The command to grant these privileges to the given role is as follows:

```
GRANT create session, create table, create view
TO role_tables_and_views;
```

6.9. Grant the role of the previous question to the users sualkinj and my723acct. After granting the role to these two users, what they would be able to do?

```
GRANT role_tables_and_views TO sualkinj, my723acct;
```

Both users can connect to the database and are able to create tables and views.

6.10. The users sualkinj and my723acct do not have SELECT privileges on the tables INVENTORY and ITEM that were created by the user scott. Write the command that would allow scott to grant these users SELECT privileges on these two tables.

Scott would have to issue the following commands to allow these two users to do selections on the given tables.

```
GRANT select ON inventory TO sualkinj, my723acct;
```

and

```
GRANT select ON item TO sualkinj, my723acct;
```

6.11. User sualkinj has been transferred and no longer needs the privileges that were granted to her through the role role_tables_and_views. Make sure that she can no longer create tables and views or have access to the tables of the previous question. However, user sualkinj should still be able to connect to the database. Write the command to accomplish these tasks.

The commands shown below revoke the privileges mentioned above from the user sualkinj.

```
REVOKE select ON scott.inventory FROM sualkinj;
REVOKE select ON scott.item FROM sualkinj;
REVOKE create table, create view FROM sualkinj;
```

6.12. Assume that the user sualkinj finished all her tasks and has moved to another company. Since the objects that she created are no longer of any use, write the command that allows the DBA to remove this user and all her objects.

The corresponding command is shown below.

```
DROP USER sualkinj CASCADE;
```

Notice that to drop the user and his or her objects the CASCADE option is necessary.

6.13. Assume that the DBA suspects that a person currently logged-in may be an impostor impersonating the legal user dullbns. Is there any way to terminate the session of this person?

Yes, there is a way to end this user's session. However, before ending the session the DBA needs to obtain some information such as the *session id* and the *serial number* of the user session. The DBA can obtain this information from the V$SESSION view. A query to retrieve that information and its output are shown below.

```
SELECT sid,serial#,username FROM v$session;
      SID   SERIAL# USERNAME
--------- --------- ----------------------------
        1         1 dullbns
        2         3 scott
        .
        .
        9        11 SYSTEM
```

With this information, the DBA can kill the session by issuing the following command:

```
ALTER SYSTEM KILL SESSION '1,1';
```

6.14. The name of the Accounting department has changed to Bookkeeping. Change the name of the department in the EMPLOYEE table. Verify the result. Make sure that all changes can be discarded in case the user makes a mistake. If the operation is incorrect, how can the user undo the changes?

To change the name of the department it is necessary to update the appropriate rows in the EMPLOYEE table. However, before making any changes to this table let us define a savepoint. This way, we know that we can undo the changes.

```
SAVEPOINT before_update;
```

The current names of people in the Accounting department are shown here.

```
NAME            DEPT
--------------- ---------------
Martin          Accounting
Bell            Accounting
```

The SQL command to update the name of the department is shown below.

```
UPDATE employee
SET dept = 'Bookkeeping'
WHERE dept = 'Accounting';
```

We can verify that the changes are correct by issuing the following query.

```
SELECT name, dept
FROM employee
WHERE dept = 'Bookkeeping';
```

The output of this query is shown here.

```
NAME            DEPT
--------------- ---------------
Martin          Bookkeeping
Bell            Bookkeeping
```

If the update is incorrect the user can undo the changes by issuing the command:

```
ROLLBACK TO SAVEPOINT before_update;
```

6.15. As a user, how can I find out the default and temporary tablespaces to which I have been assigned?

The data dictionary view that allows any user to find out this information is the view USER_USERS. This view, in addition to the previous information, informs the user about his or her user id, and the time the account was created.

Supplementary Problems

6.16. A pharmaceutical company wants to examine the physical security of their research database. They have a large facility with multiple servers located in several different buildings within the complex. What would you suggest?

6.17. List the security guidelines that a conscientious database designer should follow.

6.18. Change the password of user Suzanne Vance (vancesk) from burg8two to big6bpw.

6.19. How do we delete a view?

6.20. Which of the following passwords should not be used and why?

a. Aristotle
b. tv9stove
c. 12345678
d. dribgib

6.21. Create the user thomasjp with password timbcns2. Use the tablespaces `user_data` and `temporary_data` provided by PO8. Assign to this user 12M of storage in `user_data` and 6M of storage in `temporary_data`.

6.22. Create the role `role_tables`.

6.23. Grant to the role of the previous question the privileges to connect to the database and the privileges to create tables only.

6.24. Grant the role of the previous question to the users all7clrks and jimzapsy.

6.25. Allow the users all7clrks and jimzapsy to have `SELECT` privileges on the WAREHOUSE and REGION tables created by scott.

6.26. Revoke all the privileges granted to all7clrks.

6.27. Remove user all7clrks and all his objects from the database.

6.28. Can a user that is currently connected to the database be dropped?

Answers to Supplementary Problems

6.16. Because of the sensitive nature of the data, this company should employ as much physical security as possible. They can place guards at the gates to the complex and within the lobby of each building. Motion detectors could be placed in each room that contains a server. Fire and flood protection should be implemented as much as possible. Probably, they should store copies of the data in secure locations off the premises.

6.17. LIST:

(1) Keep It Simple
(2) Use an open design.
(3) Normalize the database.
(4) Always follow the principle of assuming privileges must be explicitly granted rather than excluded.
(5) Create unique views for each user or group of users.

6.18.

```
ALTER user vancesk IDENTIFIED BY big6bpw;
```

6.19. Views like most of the database objects can be deleted using the DROP command. The syntax of this command is very similar to that of dropping a table. For instance, to drop the view clerks, we can issue the following command:

```
DROP VIEW clerks;
```

Notice that it does not make sense to use the CASCADE option because it is not possible to define integrity constraints on the view.

6.20.

a. Aristotle — No, don't use famous names
b. tv9stove — Yes, two unrelated words connected with a digit
c. 12345678 — No, don't use patterns of letters or digits
d. dribgib — No, this is "big bird" backwards, and would be too easy to guess

6.21.

```
CREATE USER thomasjp IDENTIFIED BY timbcns2
DEFAULT TABLESPACE user_data
TEMPORARY TABLESPACE temporary_data
QUOTA 12M on user_data QUOTA 6M on temporary_data;
```

6.22.

```
CREATE ROLE role_tables;
```

6.23.

```
GRANT create session, create table TO role_tables;
```

6.24.

```
GRANT role_tables TO all7clrks, jimzapsy;
```

6.25.

```
GRANT select ON s_warehouse TO all7clrks, jimzapsy;
```

and

```
GRANT select ON s_region TO all7clrks, jimzapsy;
```

6.26.

```
REVOKE create session FROM all7clrks;
REVOKE create table FROM all7clrks;
REVOKE select scott.warehouse FROM all7clrks;
REVOKE select scott.region FROM all7clrks;
```

6.27.

```
DROP USER all7clrks CASCADE;
```

6.28. No, a user that is currently logged in cannot be dropped. However, the DBA can kill his or her session and then drop the user.

CHAPTER 7

The Entity-Relationship Model

7.1 The Entity-Relationship Model

The modeling, design, and creation of a database is an iterative top-down process. There are several steps in the creation of a database. First, the designer must gather information about the organization in order to ascertain the specific requirements. This usually entails the use of interviews and a thorough examination of all the inputs and outputs of the system. Often software engineering tools, such as data flow diagrams and system flow charts, are used. The objective of this step is to determine both the work-flow and the information that is relevant to the organization. Building the Entity-Relationship (E-R) Model is the second step in the process. *The Entity-Relationship (E-R) Model* is a graphical representation of the database logic and includes a detailed description of all entities, relationships, and constraints. After the E-R Diagram has been successfully constructed, the designer creates the Table Instance Charts, one per entity, that contain information about the data types for the attributes of the entities and some sample data. Finally the individual tables are defined and created using a DBMS. The design steps are iterative because changes during a later step may entail revision of the E-R Diagram. Both E-R Diagrams and Table Instance Charts are explained in this chapter. It is important to remember that, as in any top-down approach, these tools should be constructed before beginning to implement the database.

As we explained in Chapter 1, a data model is a way of explaining the logical layout of the data and the relationships of various parts of the database to each other and to the whole. This entire book has focused on the relational database model, where all data are kept in tables or relations that are often connected in some way. By examining the relations alone, we have been able to see the logical

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layout. However, we have not yet demonstrated a clear method of illustrating the relationships of all the tables to each other. Just as the blueprints are the key to understanding and creating the design of a building, the E-R Diagram is the key to understanding and creating the design of the database.

The E-R Diagram is an attempt to conceptualize the database. The model helps to ensure that all the client's requirements are met and that these requirements do not conflict with one another. Functional dependencies are also identified. It is at this point that the normalization process explained in Chapter 5 takes place. While the database is still in a conceptual state and independent of any DBMS, it is easy to modify and refine all the individual pieces. Once the model is complete it can then be mapped to any specific type of database software. The model also helps to identify the potential levels of use and to define the views of the data that should be produced.

The E-R Model was described by P. P. Chen in 1976 in a paper "The Entity-Relationship Model: Toward a Unified View of Data."[1] It is now the most widely used model for the design of databases. Since there is not an accepted group of standards, different vendors and authors have developed their own conventions. In this book we will follow the E-R conventions used by the Oracle Corporation.

7.2 Entities and Attributes

The building blocks of the E-R Model are entities, attributes, and relationships. We have already defined entities and attributes in Chapter 1 and have consistently used these concepts throughout the book. Entities are the objects of significance for the organization about which information needs to be known. The characteristics that describe or qualify an entity are the attributes. In the E-R Diagram entities are represented by soft (rounded) boxes with unique names in capital letters. Attributes are the items of information about each entity. Attribute names are unique within the entity and are written in lower-case letters within the box.

Example 7.1

Identify two entities that might be important for a retail business. List at least three attributes for each entity. Then show what the entities and attributes would look like in an E-R Diagram.

Two entities of importance for a business might include employees and customers. Some of the information that may be relevant for employees may be ID number, last name, first name, and salary. Customers would have name, address, city, state, zip, and phone number. Fig. 7-1 shows the sample representation of these entities. Not all attributes are included for space purposes.

[1] Chen, P.O., "The Entity-Relationship Model: Toward a Unified View of Data," *ACM Transactions on Database Systems*, Vol.1, No.1. March 1976.

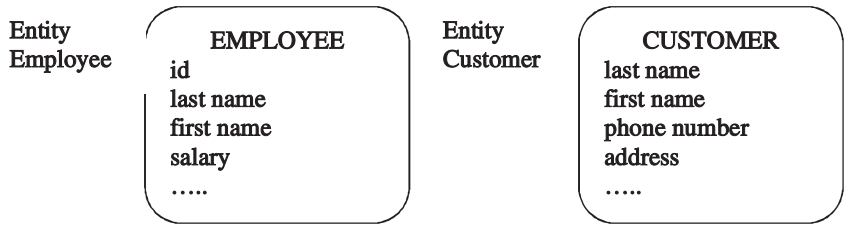


Fig. 7-1. Representation of two entities.

Each entity must have multiple occurrences. For example, the entity EMPLOYEE has one entry for each employee. Each instance has specific values for each attribute. Since entities have multiple occurrences, there must be a way to distinguish one instance from all the others that make up the entity. Therefore each entity must have a Unique Identifier (UID) that is an attribute or set of attributes that uniquely identifies each instance. Chapter 2 explained candidate keys and primary keys. The UID of the entity, which may be a single or composite attribute, is the primary key. If there seems to be no way to identify the entity in a unique way, it should be reevaluated as to whether or not it actually is an entity. The attributes which are the UID are marked in the E-R Diagram with #*. The asterisk (*) indicates the attribute is mandatory, that is, it may not be left blank for that instance. The pound sign or hash (#) indicates that the attribute is the UID, or part of the UID. Some attributes are mandatory even though they are not part of the UID, and they would be marked only with an asterisk. Optional attributes may be indicated with an o.

Example 7.2
Choose a UID for the entities EMPLOYEE and CUSTOMER in Example 7.1. Show the new representations.

The obvious UID for EMPLOYEE would be the *ID number*. The entity CUSTOMER could use *name* as UID. However, it is possible for two customers to have the same name and then the instance would no longer be unique. In some cases, it might be possible to use a combination of attributes, such as name and phone number. It is unlikely that two customers with the same name would have the same phone number. However, it is often easier and more beneficial to create a new attribute to be the UID. A new attribute can be added to the entity called ID number to assure that each instance of CUSTOMER will be unique. Notice that the UIDs are marked in Fig 7-2.

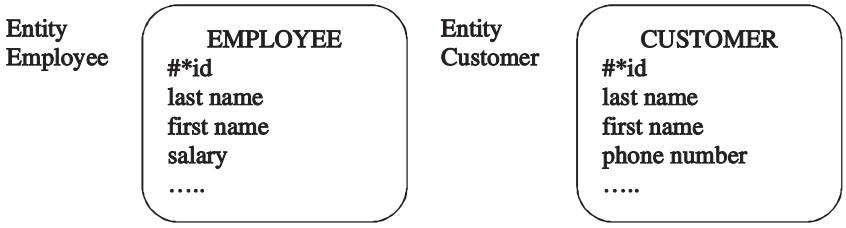


Fig. 7-2. Representation of an entity showing UID.

Remember that there is a difference between the entity and the instance of the entity. The entity is the general category of items, such as products or orders. The instance would be one particular example of the category, such as product #CN1234, a candlestick, which costs $5.14.

7.2.1 IDENTIFYING ENTITIES

Identifying the correct entities for the database is critical. Usually the first step of ascertaining requirements results in some kind of narrative explaining the system. In a narrative, entities are generally represented by nouns. The narrative should be examined closely for significant nouns. Identify synonyms within the list to avoid duplication. Look for meta-words, or words that might be categories rather than instances. Then list as many instances of the entity as you can think of to test that all have the same characteristics and are subject to the same rules. For example, a narrative about a furniture store may include items such as hide-a-bed, sofa, loveseat, or settee. The entity could be "couch" and each of these designations would be a type of couch. All the instances have attributes such as price, color, and type of covering. If entities are found, decide upon names. Establish what information must be kept about each entity. The attributes would be adjectives describing the entity. Decide which attribute or attributes can serve as the UID. Represent the entities that are identified, including the attributes, and mark the UID in the diagram.

Example 7.3

The gathering of specifications for a church database resulted in the explanation shown below. Choose the entities you might want to represent, the attributes for each entity, and model them in a diagram including the UID.

"The Third Presbyterian Church needs to keep track of its members. The members need to receive the newsletter regularly. There are several committees within the church, and each person may serve on only one committee. The Finance Committee wants to record the amount of money that individual members give to the church and report the total to them at the end of the year. The church needs to purchase supplies such as paper and bulletin covers. The secretary, a member of the staff, deals with several different office supply companies."

The nouns that might be identified in this narrative would include MEMBER, VENDOR, and COMMITTEE. Each entity needs a number of attributes that were described in the narrative. Diagrams are shown in Fig. 7-3.

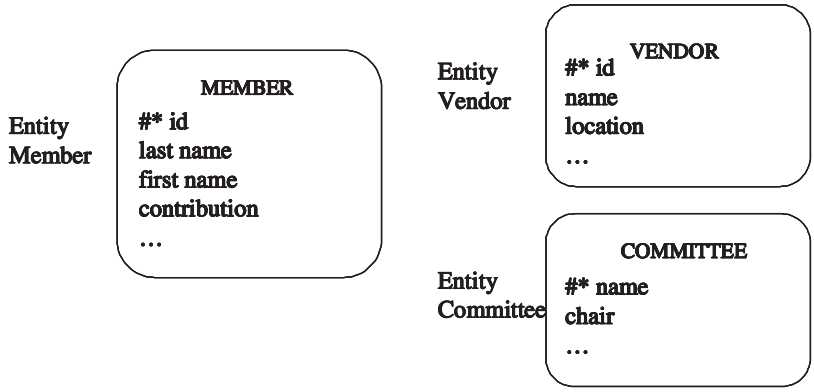


Fig. 7-3. Entities for Third Presbyterian Church.

Not all the necessary attributes are listed in Fig. 7-3 for space purposes. However, each entity has been assigned a UID. The attribute *name* can be used for the entity COMMITTEE because it is safe to assume that the church would not establish two committees with the same name. Both the other entities use ID number as UID. Notice that this diagram has no way to show the committee or committees on which each member serves. The entity MEMBER is related in some way to the entity COMMITTEE. The next section will explore representing such relationships in an E-R Diagram.

7.3 RELATIONSHIPS

Once the entities have been established along with their attributes, it is time to examine relationships. A *relationship* is a two-directional association or connection between two entities. If entities are the nouns of the database, relationships are the transitive verbs. For example, the customer *orders* a product, the member *serves* on a committee.

Begin by designing sentences connecting the entities that might be related. It is important to write out the sentences as clearly as possible. If you end up with a compound sentence, containing a comma or more than one verb, chances are there are two or more entities or relationships involved. If the sentence contains words relating to time, such as first, next, or after, they may be examples of constraints that must be represented in the model. Other types of sentences also reflect relationships. One form is "there are ... X in Y" which can be reworded using a transitive verb. The two sentences represent the two directions of the relationship. For example, "there are passengers on the flight" could be rewritten to reflect the relationship "a flight has passengers." If both flights and passengers are entities then a relationship between those entities has been identified. If the sentence contains an adverb, this often corresponds to an attribute of a relationship.

Once you have identified the entities and attributes, and have written sentences about them to identify relationships, it is time to examine all the

relationships of a particular entity to be sure they are relevant and unique. Remember that a relationship is between two *entities*, and the relationship often goes in both directions. It is important to name the relationships so they can be read in more than one direction. For example, "The product is part of the inventory." and "The inventory is composed of products." Fig. 7-4 shows a list of relationship names that might be helpful in this step. This list was created by Richard Barker.[2]

Useful Pairs of Relationship Names

about	subject of	owned by	owner of*
applicable to	context for*	part of	composed of
at	location of	part of	detailed by
based on	basis for	party to	for
based on	under	party to	holder of
bought in from	supplier of	placed on	responsible for
bound by	for	precluded by	precluded by
change authority for	on	represented by	representation of
classification for	of	responsible for	responsibility of
covered by	for	responsible for	of
defined by	part definition of	run by	carrier for
description of	for	source of	based on

Note: where the above are marked with an asterisk*, one should only use these as a last resort. For example, "owned by" should only be used as a relationship name when the relationship means legal ownership.

Some of the above names imply the role of a person or organization.

Fig. 7-4. Useful pairs of relationship names.

Each direction of the relationship must have the following:

- a *name*, usually in lower-case letters
- an *optionality*, which is either "mandatory" (continuous line) and is read "must be" or "optional" (dashed line) and is read "may be"
- a *degree* or *cardinality* which is "one or more" indicated by a crowsfoot or "one and only one" indicated by the absence of the crowsfoot

The name is positioned in the diagram close to the entity or noun of the sentence. The optionality is the line connecting the two entity boxes and the degree is indicated at the point where the line meets each box. Fig. 7-5 shows a sample relationship. That relationship can be read left to right as "Each MEMBER *may be* serving on *one or more* COMMITTEES." or right to left as "Each COMMITTEE *may be* made up of *one or more* MEMBERS."

[2] Barker, Richard, *CASE*METHOD*[SM] *Entity Relationship Modelling*, Addison-Wesley, 1989.

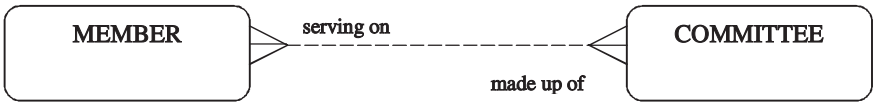
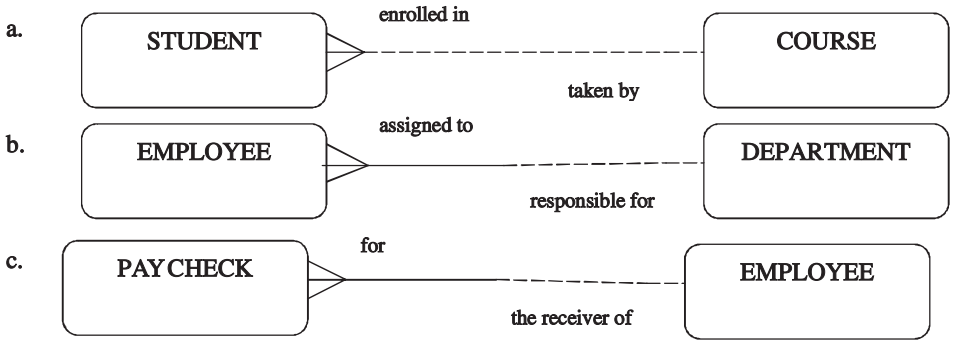


Fig. 7-5. Member-Committee relationship.

It is helpful to follow a few conventions to make a complex diagram easier to read. If one entity has degree of *one or more*, that entity should be on the left or on the top of the chart. Some authors say that "crows fly east or crows fly south." Following this convention, entities that are more volatile, whose instances change frequently, will end up being placed near the left top of the diagram. Entities that are less volatile will end up being placed nearer the bottom.

Example 7.4

Indicate how you would read each of the following relationships. Notice in the chart that the crowsfeet are on the left in each case.



a. L to R: Each STUDENT *may be* enrolled in *one and only one* COURSE.
R to L: Each COURSE *may be* taken by *one or more* STUDENTS.

b. L to R: Each EMPLOYEE *must be* assigned to *one and only one* DEPARTMENT.
R to L: Each DEPARTMENT *may be* responsible for *one or more* EMPLOYEES.

c. L to R: Each PAYCHECK *must be* for *one and only one* EMPLOYEE.
R to L: Each EMPLOYEE *may be* the receiver of *one or more* PAYCHECKS.

In some cases, it is possible for an entity to have a relationship with itself. Although rare, this kind of recursive relationship is possible. It would be indicated in a diagram by a circular line with both ends connected to the box and words defining the relationship at each end. For example, if each employee has a supervisor, the supervisor is also an employee.

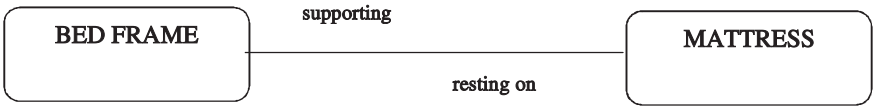
Once you have named the relationship and determined its cardinality and optionality, re-examine the model by reading aloud the relationships between the pairs. Do they make sense, especially for this particular organization? Often the relationships can be verified at this point before more time is invested.

There are three types of relationships: one-to-one, many-to-one, and many-to-many. They will be considered in the next two sections.

7.4 One-to-One Relationships

The *one-to-one relationship* has the cardinality or degree of *one and only one* in both directions. These relationships are denoted by *1 to 1* or *1:1*. 1:1 relationships are rare, especially 1:1 relationships that are mandatory in both directions. If you find a 1:1 relationship, examine the two entities closely, as they may actually be the same entity.

Example 7.5
A relationship exists that can be written two ways: "The bed frame *must* be supporting *one and only one* mattress." "The mattress *must* be resting on *one and only one* bed frame." Diagram this 1:1 relationship. Can the entities be expressed as only one entity?

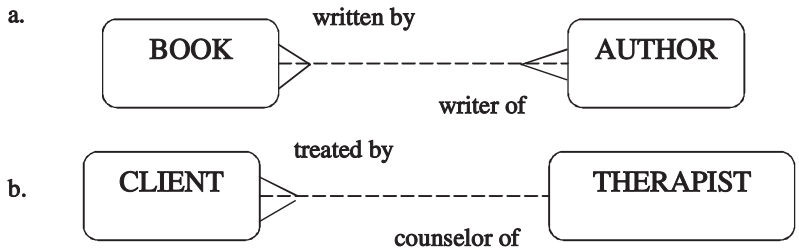


The diagram is shown as a 1:1 relationship that is mandatory in both directions. Since each bed frame supports only one mattress, you should consider the possibility that the two entities are really only one entity BED. The needs of the particular database will suggest whether they should be combined into one.

7.5 Many-to-One and Many-to-Many Relationships

The *many-to-one relationship* has a cardinality in one direction of *one or more* and in the other direction of *one and only one*. This relationship is usually denoted as M:1 or M to 1. It should be obvious to the reader that the relationship could also be expressed as *one-to-many*. However, since the convention in the E-R Diagram is to have the *one or more* cardinality on the left, it is usually expressed as M:1. All the samples in Example 7.4 are M:1 relationships. The *many-to-many relationship* is one where there is a degree of *one or more* in both directions. This relationship can be denoted as M:M (M to M) or M:N (M to N). Because the actual number of each degree is usually not the same, we will use the M:N notation. Fig. 7-5 shows an example of M:N relationship. Members can serve on *one or more* committee, and committees are made up of *one or more* members. Both M:1 and M:N relationships are very common. They are usually optional in both directions, but can be mandatory in one direction. It is unusual to find M:1 or M:N relationships that are mandatory in both directions.

Example 7.6
Examine the diagrams and identify the kinds of relationships illustrated.



a. Because a book can be written by one or more authors, and an author can write one or more books, this is an M:N relationship.
b. Because a client may be treated by one and only one therapist, and a therapist may be counselor of one or more clients, this is an M:1 relationship.

7.6 Normalizing the Model

Once the initial E-R Diagram has been formed, it must be normalized. The steps listed in Chapter 5 must be followed to put the model into 1NF, 2NF, 3NF or BCNF. We cannot overemphasize the importance of normalizing the model before the database is implemented using a DBMS. It is much harder to change the structure of the database after data has been entered into the tables.

Example 7.7
Refer to the PROJECT table in Fig. 5-2. That table could have been initially modeled as shown in Fig. 7-6. Is the entity in 1NF? If not, how can it be normalized?

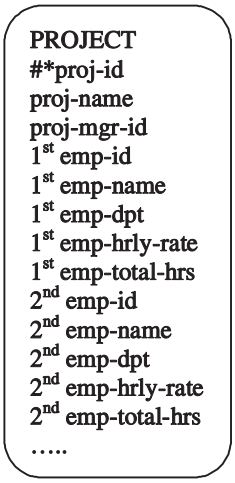


Fig. 7-6. PROJECT entity.

The objective of putting an entity into 1NF is to remove its repeating groups and ensure that all entries of the resulting table have at most a single value. It is clear in Fig. 7-6 that there are repeating values for each employee working on the project. Therefore, it is NOT in 1NF. Two entities are represented, PROJECT-EMPLOYEE and PROJECT. The first attempt at normalization from Chapter 5 Example 5.2 would result in the E-R Diagram in Fig. 7-7.

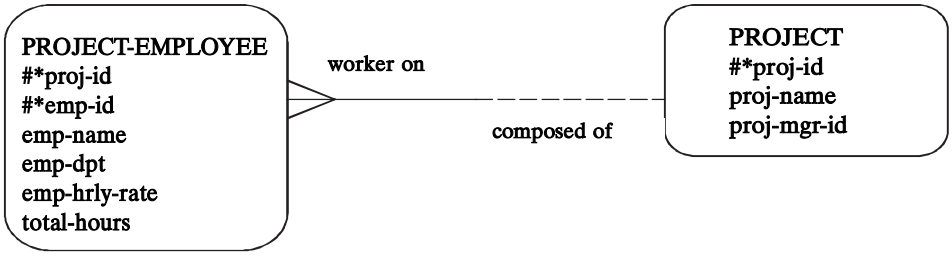


Fig. 7-7. PROJECT-EMPLOYEE and PROJECT entities.

Example 7.8
Put the model from Fig. 7-7 into 2NF.

Changing to 2NF assures that no nonprime attribute is partially dependent on any key. In this case, the only attribute that fully depends on the composite key (Proj-id,Emp-id) is Total-Hours. There would now be two entities, PROJECT-EMPLOYEE and HOURS-ASSIGNED, as shown in Fig. 7-8.

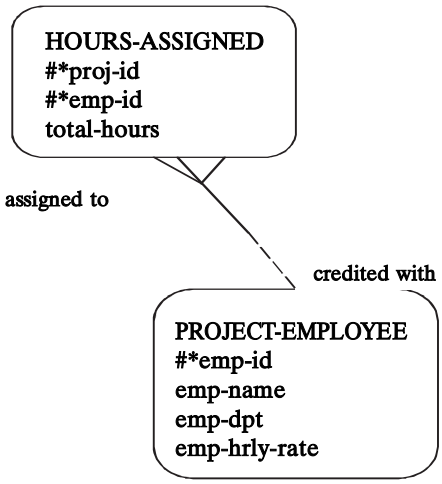


Fig. 7-8. HOURS-ASSIGNED and PROJECT-EMPLOYEE entities.

In the same way, an entity model can usually be changed into 3NF and BCNF using the normalization processes illustrated in Chapter 5. Performing these changes assures that the E-R Model and, therefore, the database, will be normalized from the beginning of its design.

7.7 Table Instance Charts

When you begin to implement a database in a particular DBMS, you must first create the tables. The CREATE TABLE command in SQL was demonstrated in Chapter 3. A sample CREATE TABLE command is shown in Fig. 7-9.

```
CREATE TABLE Flex_Card
(Student_Name        VARCHAR2(25),
 Card_Number         VARCHAR2(15) CONSTRAINT
                      calling_card_card_number_PK PRIMARY KEY,
 Starting_Value      NUMBER(4,2),
 Value_Left          NUMBER(4,2),
 Pin_Number          CHAR(12) CONSTRAINT
                     calling_card_pin_number_U UNIQUE);
```

Fig. 7-9. CREATE TABLE command in SQL.

It is clear that in order to write the CREATE TABLE command, you must already have defined the data types, primary and foreign keys, and all other constraints that will be used. Before beginning this step, it is helpful to organize all the information that has been generated during the design of the E-R Model. The *Table Instance Chart* (TIC), used by the Oracle Corporation, describes in a detailed manner each entity, its attributes and the relationship(s) in which the entity may participate, whether the relationship of the entity is to itself or to some other entities. Sometimes the TIC includes sample data to help the user understand the chart. The format of a TIC is shown in Fig. 7-10, and the conventions used as entries in the TIC are shown in Fig. 7-11.

Column Name						
Key Type						
Nulls/Unique						
FK Ref. table						
FK Ref. Columns						
Data Type						
Maximum Length						
Sample Data						

Fig. 7-10. Format of TIC.

SYMBOL	MEANING
PK	Primary Key
FK	Foreign Key
FK1, FK2	Two FKs within the same table
FK1, FK2	Two columns within the same composite FK
NN	NOT NULL column (required for mandatory attributes)
U	UNIQUE column
U1, U1	Two columns that are UNIQUE in combination

Fig. 7-11. Convention symbols for TIC.

The steps used to create the TIC are:

(1) Create a TIC for each entity of the E-R Diagram. Each chart will have the same name as the entity it represents.

(2) Create one column in the chart for each attribute of the entity. Mark mandatory attributes as NN. If the UID contains a single attribute, record the key type as PK and mark it as NN and U. If the UID is composite, record PK in each column and mark them NN and U.

(3) If the UID includes relationships, add the FK column for each relationship and label it PK and FK. Add FK columns to the right of all columns even if the FK is part of the PK. Use suffixes to distinguish FKs that appear within the same table.

(4) For M:1 relationships, take the PK at the *one* end and put it in the table at the *many* end as a FK.

(5) For mandatory 1:1 relationships, place the unique FK in the table at the mandatory end and label it NN. If the 1:1 relationship is optional in both directions, place the FK in the table at either end of the relationship.

(6) For an M:1 recursive relationship, add a FK column to the table. This FK column refers to values of the PK column of the same table.

Example 7.9

Create a TIC for the E-R Diagram from Figs 7-7 and 7-8. They can be combined into one diagram as shown in Fig. 7-12.

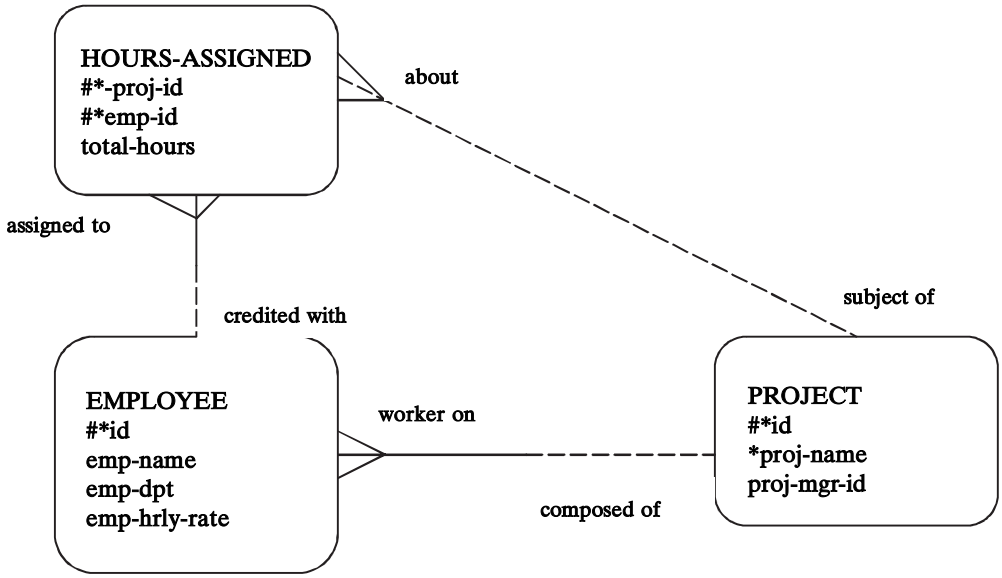


Fig. 7-12. E-R Diagram for HOURS/EMPLOYEE/PROJECT.

Because there are three entities in the diagram, there will be three TICs. EMPLOYEE will have four columns and the other two will both have three. We will build these charts one at a time.

a. We will start with EMPLOYEE. The table has columns for each attribute. The PK is ID, so it is marked both NN and U. There are no other mandatory attributes. Determine the data type and size of each attribute. The attribute ID is the FK at the *one* end of a M:1 relationship, so it will be put into the HOURS-ASSIGNED table. However, EMPLOYEE is at the *many* end of a relationship with PROJECT, so the proj-id from PROJECT is a FK for this entity. This attribute may not be NULL.

Column Name	id	emp-name	emp-dpt	emp-hrly-rate	proj-id
Key Type	PK				FK
Nulls/Unique	NN, U				NN
FK Ref. Table					PROJECT
FK Ref. Columns					proj-id
Data Type	Character	Character	Character	NUMBER	
Maximum Length	9	25	10	4,2	
Sample Data	123456789	Tom Jones	Sales	10.55	

b. The next TIC will be PROJECT. The table has columns for each attribute. The PK is ID, so it is marked both NN and U. There is one other mandatory attribute, proj-name, so it is marked NN. Determine the data type and size of each attribute. The attribute ID is the FK at the *one* end of a M:1 relationship, so it will be put into the HOURS-ASSIGNED table.

Column Name	id	proj- name	proj-mgr-id
Key Type	PK		
Nulls/Unique	NN, U	NN	
FK Ref. Table			
FK Ref. Columns			
Data Type	Character	Character	Character
Maximum Length	7	25	9
Sample Data	BRDG109	Second St. Bridge	987654321

c. The last TIC we will build will be HOURS-ASSIGNED. The table has columns for each attribute. The PK is composite, using both emp-id and proj-id. They are both marked NN and U. There are no other mandatory attributes. Determine the data type and size of each attribute. The attributes proj-id and emp-id are both the keys at the *many* end of a M:1 relationship, so a column is listed for each. They are marked NN and U.

Column Name	proj-id	emp-id	total-hours	PROJECT proj-id	EMPLOYEE emp-id
Key Type	PK	PK		FK	FK
Nulls/Unique	NN, U	NN, U		NN, U	NN, U
FK Ref. Table				PROJECT	EMPLOYEE
FK Ref. Columns				proj-id	emp-id
Data Type	Character	Character	NUMBER		
Maximum Length	6	9	4,1		
Sample Data	BRDG109	123456789	102.5		

Table Instance Charts can be invaluable in preparing the model for full implementation in a DBMS. Remember, proper design will always save time in implementation.

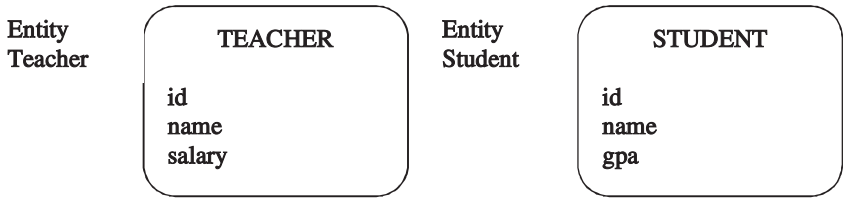
Solved Problems

7.1. List the steps necessary in the design of a database.

(1) Gather data and ascertain requirements.
(2) Build the E-R Diagram.
(3) Construct the table instance charts.
(4) Define the individual tables.
(5) Implement using a DBMS.

7.2. Identify two entities that might be important for a school. List at least three attributes for each entity. Then show what the entities and attributes would look like in an E-R Diagram.

Two entities of importance for a school might include teachers and students. Teachers would have ID numbers, names, and salaries. Students would have ID numbers, names, and grade point averages.

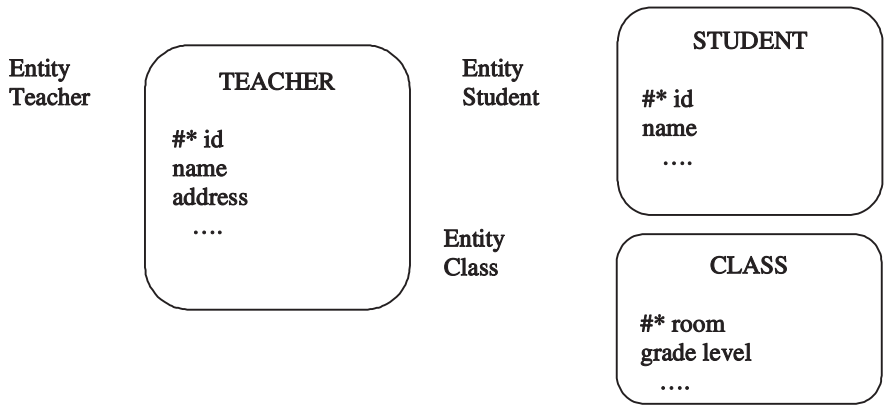


7.3. List the steps necessary to identify the entities from the specifications.

(1) Examine specifications closely for a noun that might be of significance.
(2) Give it a name. Be sure to name both directions. (Ask how ENTITY A is related to ENTITY B and how ENTITY B is related to ENTITY A.)
(3) Determine the relationship optionality. (Ask, is the relationship mandatory or optional?)
(4) Establish what information must be kept about this entity.
(5) Decide which attribute or attributes can serve as the UID.
(6) Represent the entities including the attributes and mark the UID in the diagram.
(7) Repeat for all other significant nouns in the requirements documentation.

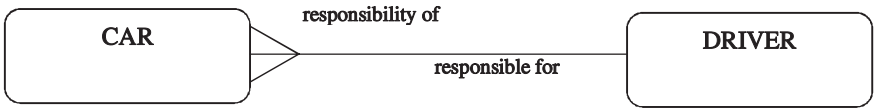
7.4. The gathering of specifications for a school database resulted in the explanation shown below. Choose the entities you might want to represent, the attributes for each entity, and model them in a diagram including the UID.

"The Beverly Elementary School needs a database. The school has a number of students in each class, one class in each room, and two classes for each grade. Each teacher teaches only one class."



The two most obvious entities are STUDENT and TEACHER. However, it is also clear that both STUDENT and TEACHER entities need to know their class. The class information should not be positioned in two separate places. Therefore a separate entity CLASS is created. No relationships are indicated in this diagram.

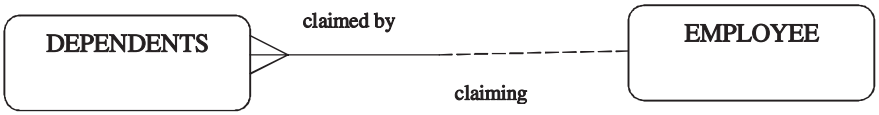
7.5. Indicate how you would read the following relationship. Identify the type of relationship.



L to R: Each CAR *must be* responsibility of *one and only one* DRIVER.
R to L: Each DRIVER *must be* responsible for *one or more* CARS.

This is a M:1 relationship, mandatory in both directions.

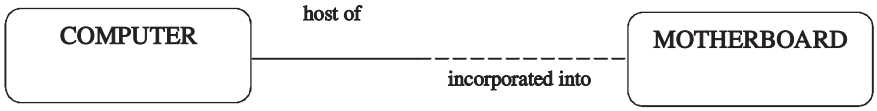
7.6. Indicate how you would read the following relationship. Identify the type of relationship.



L to R: Each DEPENDENT *must be* claimed by *one and only one* EMPLOYEE.
R to L: Each EMPLOYEE *may be* claiming *one or more* DEPENDENTS

This is an M:1 relationship mandatory in only one direction.

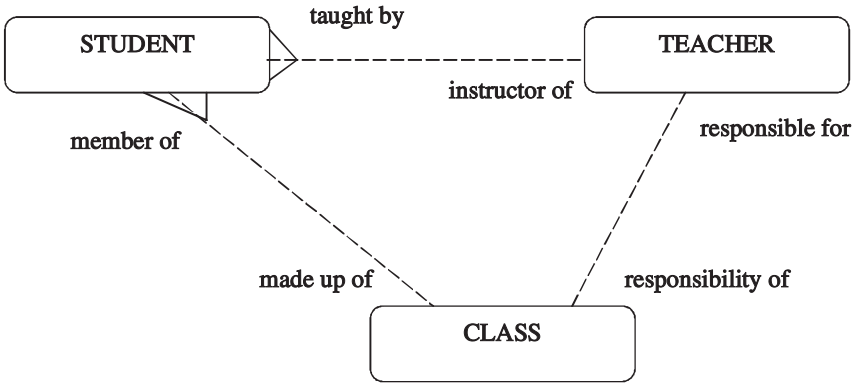
7.7. Diagram this relationship. What kind of relationship is it? "The COMPUTER *must be* the host of *one and only* one MOTHERBOARD." "The MOTHERBOARD *may be* incorporated into *one and only one* COMPUTER."



This is a 1:1 relationship that is mandatory in one direction only.

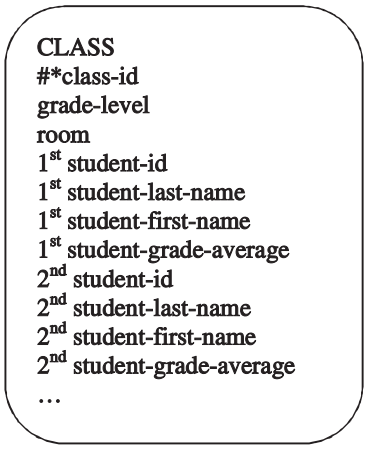
7.8. Create an E-R Diagram showing these relationships. Indicate what kind of relationships they are.

a. The STUDENT may be taught by one and only one TEACHER.
The TEACHER may be instructor of one or more STUDENTS.
b. The TEACHER may be responsible for one and only one CLASS.
The CLASS may be the responsibility of one and only one TEACHER.
c. The CLASS may be made up of one or more STUDENTS.
The STUDENT may be a member of one and only one CLASS.

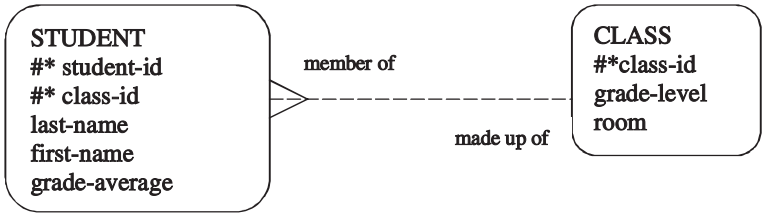


The E-R Diagram depicts these relationships. There are three entities, and each relationship is bi-directional between exactly two entities. Relationships between the TEACHER and CLASS are 1:1 and the others are M:1. Notice in the diagram that the crowsfeet always go east and/or south.

7.9. Look at the CLASS entity and determine if it is in 1NF. If not, how would you normalize it?

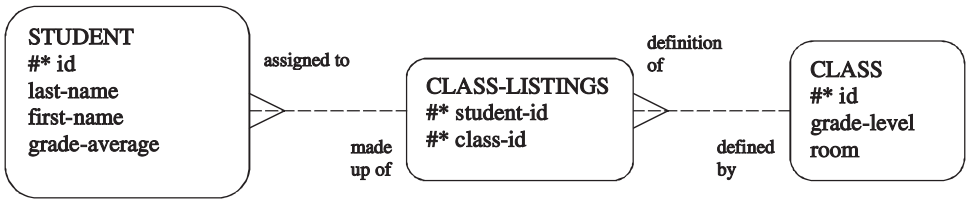


The entity CLASS is not in 1NF because there are repeating values for each instance of class-id. Therefore it should be split into two entities, CLASS and STUDENT. The E-R Diagram is shown below.



7.10. Look at the E-R Diagram of the previous problem. Are both CLASS and STUDENT in 2NF? Why or why not? If not, normalize the entities.

The entity CLASS is in 2NF, but the entity STUDENT is not. The attributes last-name, first-name, and grade-average do not depend upon the class-id. Therefore, a separate entity should be created called CLASS-LISTING as shown below. Often you need such a connecting table in order to be sure that the entity model is in 2NF.



7.11. Build the Table Instance Chart for the E-R Diagram in the previous example.

There are three entities, so there are three tables.

a. We will start with STUDENT. The table has columns for each attribute. The PK is ID, so it is marked both NN and U. There are no other mandatory attributes. Determine the data type and size of each attribute. The attribute ID is the FK at the *many* end of a M:1 relationship, so it has its own column.

Column Name	id	last-name	first-name	grade average	CLASS-LISTINGS student-id
Key Type	PK				FK
Nulls/Unique	NN, U				NN, U
FK Ref. Table					CLASS-LISTINGS
FK Ref. Columns					student-id
Data Type	Character	Character	Character	NUMBER	
Maximum Length	9	15	15	4,2	
Sample Data	123456789	Simpson	Marj	3.98	

b. The next table is CLASS-LISTINGS. The table has columns for each attribute. The PK is a composite of student-id and class-id, so they are both marked NN and U. There are no other mandatory attributes. Determine the data type and size of each attribute. The attribute class-ID is the FK at the *many* end of a M:1 relationship, so it has its own column. The attribute student-ID is at the *one* end of a M:1 relationship, so it was placed in the STUDENT table.

Column Name	student-id	class-id	CLASS class-id
Key Type	PK		FK
Nulls/Unique	NN, U		NN,U
FK Ref. Table			CLASS
FK Ref. Columns			id
Data Type	Character	Character	
Maximum Length	7	9	
Sample Data	GR4RM102	123456789	

c. The last table is CLASS. The table has columns for each attribute. The PK is ID, so it is marked both NN and U. There are no other mandatory attributes. Determine the data type and size of each attribute. The attribute ID is the FK at the *one* end of a M:1 relationship, so it was put into the CLASS-LISTINGS table.

Column Name	student-id	grade-level	room
Key Type	PK		
Nulls/Unique	NN, U		
FK Ref. Table			
FK Ref. Columns			
Data Type	Character	NUMBER	Character
Maximum Length	7	2	3
Sample Data	GR4RM102	4	102

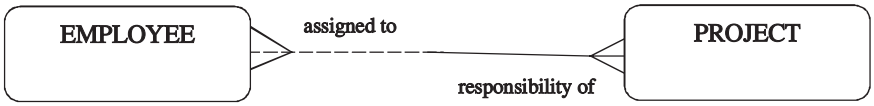
Supplementary Problems

7.12. Identify two entities that might be important for a theater. List at least three attributes for each entity. Then show what the entities and attributes would look like in an E-R Diagram.

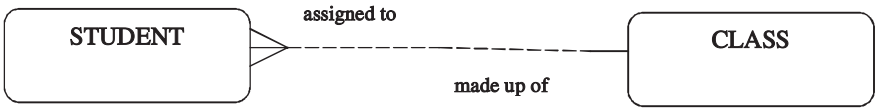
7.13. The gathering of specifications for a software company database resulted in the explanation shown below. Choose the entities you might want to represent, the attributes for each entity, and model them in a diagram including the UID.

"The WeSatisfy Software company has employees that work on different projects. Each employee may work on more than one project. For each project the database needs to record the total amount of time spent to help in the billing process. The company has a number of customers that purchase the software."

7.14. Indicate how you would read the following relationship. Identify what kind of relationship it is.



7.15. Indicate how you would read the following relationship. Identify what kind of relationship it is.



7.16. Diagram this relationship. What kind of relationship is it? "Each MAN *must be* married to *one and only one* WOMAN." "Each WOMAN *must be* married to *one and only one* MAN." What kind of relationship is it?

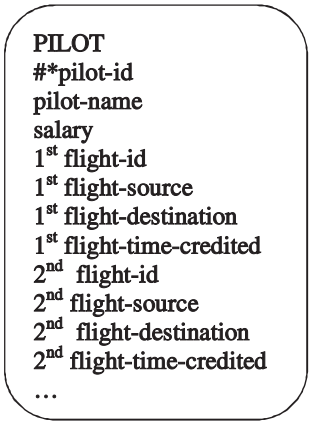
7.17. Create an E-R Diagram showing these relationships. Indicate what kind of relationships they are.

a. Each FLIGHT may be carrier for one or more PASSENGERS.
Each PASSENGER may be traveler on one or more FLIGHTS.

b. Each FLIGHT may be responsibility of one and only one PILOT.
Each PILOT may be responsible for one or more FLIGHTS.

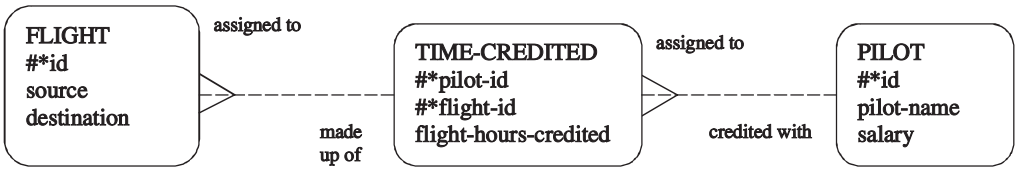
c. Each PASSENGER may be responsibility of one or more PILOTS.
Each PILOT may be responsible for one or more PASSENGERS.

7.18. Look at the PILOT entity and determine if it is in 1NF. If not, how would you normalize it?



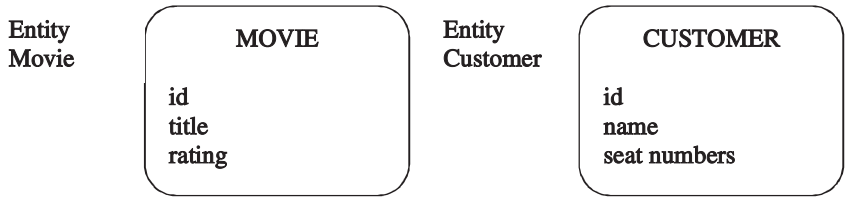
7.19. Look at the answer to the previous question. Determine if the PILOT entity is in 2NF. If not, redraw the E-R Diagram correctly.

7.20. Build the Table Instance Chart for this E-R Diagram.

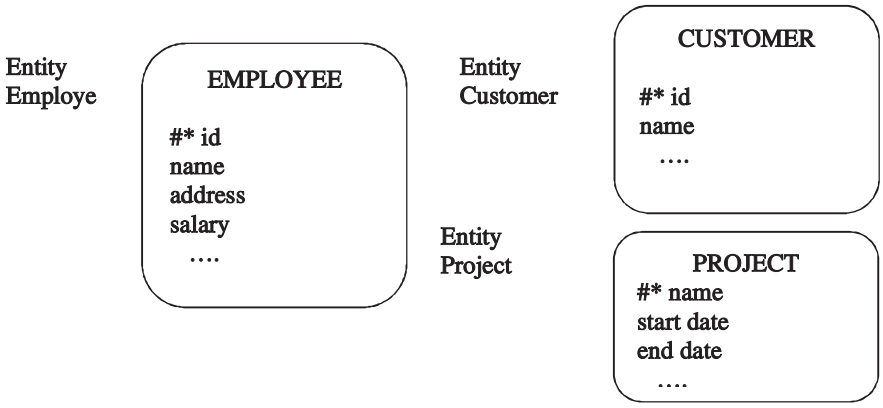


Answers to Supplementary Problems

7.12. Two entities of importance for a theater might include movies and customers. Movies would have ID numbers, titles, and rating. Customers would have ID numbers, names, and seat numbers.



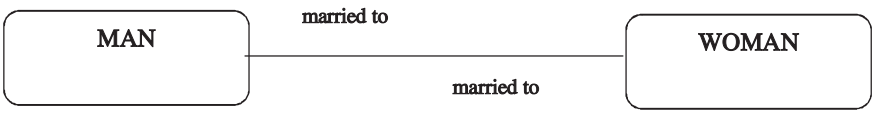
7.13. The entities are EMPLOYEE, CUSTOMER, and PROJECT. No relationships are indicated in this diagram.



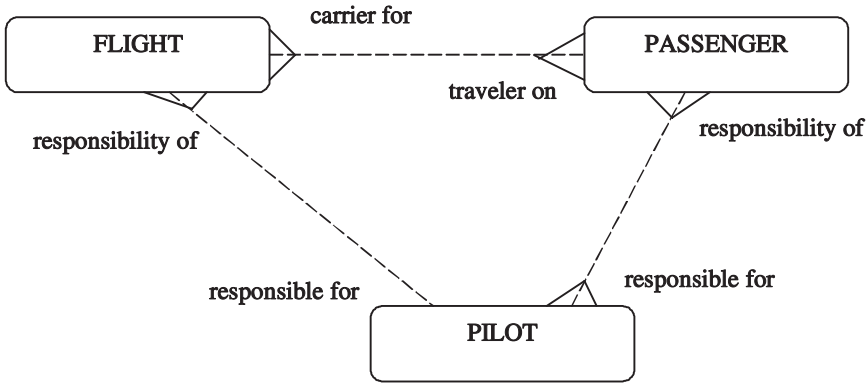
7.14. L to R: Each EMPLOYEE *may be* assigned to *one or more* PROJECTS.
R to L: Each PROJECT *must be* responsibility of *one or more* EMPLOYEES.
This is an M:N relationship mandatory in only one direction.

7.15. L to R: Each STUDENT *may* be assigned to *one and only one* CLASS.
R to L: Each CLASS *may be* made up of *one or more* STUDENTS.
This is an M:1 relationship optional in both directions.

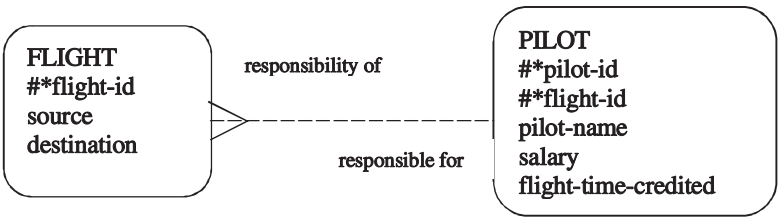
7.16. This is a 1:1 relationship mandatory in both directions.



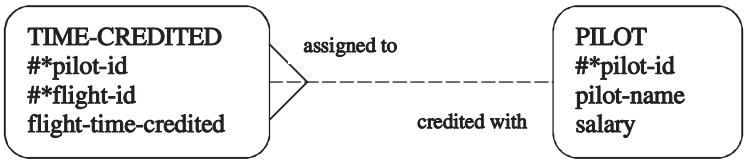
7.17. The relationship between the FLIGHT and PILOT is M:1. The other relationships are M:N.



7.18. To put the PILOT entity into 1NF, it must be split into two entities, PILOT and FLIGHT, as shown below. The repeating elements have been eliminated.



7.19. The PILOT entity in the answer to the previous question is not in 2NF because, although the composite key is (flight-id, pilot-id), the flight-time-credited is dependent only on the flight-id, not on the pilot-id. Therefore it should be split into two entities, PILOT and TIME-CREDITED.



7.20. There are three entities, so there are three tables.

a. We will start with FLIGHT. The table has columns for each attribute. The PK is ID, so it is marked both NN and U. There are no other mandatory attributes. Determine the data type and size of each attribute. The attribute ID is the FK at the *many* end of a M:1 relationship, so it has its own column.

Column Name	id	source	destination	TIME-CREDITED flight-id
Key Type	PK			FK
Nulls/Unique	NN, U			NN,U
FK Ref. Table				TIME-CREDITED
FK Ref. Columns				student-id
Data Type	Character	Character	Character	
Maximum Length	4	15	15	
Sample Data	2987	Atlanta	Dallas	

b. The next table is TIME-CREDITED. The table has columns for each attribute. The PK is a composite of pilot-id and flight-id, so they are both marked NN and U. There are no other mandatory attributes. Determine the data type and size of each attribute. The attribute pilot-ID is the FK at the *many* end of a M:1 relationship, so it has its own column. The attribute flight-ID is at the *one* end of a M:1 relationship, so it was placed in the FLIGHT table.

Column Name	pilot-id	flight-id	flight-hours-credited	PILOT pilot-id
Key Type	PK			FK
Nulls/Unique	NN, U			NN, U
FK Ref. Table				PILOT
FK Ref. Columns				id
Data Type	Character	Character	NUMBER	
Maximum Length	9	4	4,1	
Sample Data	123456789	2987	6.5	

c. The last table is PILOT. The table has columns for each attribute. The PK is ID, so it is marked both NN and U. There are no other mandatory attributes. Determine the data type and size of each attribute. The attribute ID is the FK at the *one* end of a M:1 relationship, so it was put into the TIME-CREDITED table.

Column Name	id	name	salary
Key Type	PK		
Nulls/Unique	NN, U		
FK Ref. Table			
FK Ref. Columns			
Data Type	Character	Character	NUMBER
Maximum Length	7	15	5,2
Sample Data	GR4RM102	Thompson	1200.00

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