NINE

9 DATABASE DESIGN

In this chapter, you will learn:

- That successful database design must reflect the information system of which the database is a part
- That successful information systems are developed within a framework known as the Systems Development Life Cycle (SDLC)
- That within the information system, the most successful databases are subject to frequent evaluation and revision within a framework known as the Database Life Cycle (DBLC)
- How to conduct evaluation and revision within the SDLC and DBLC frameworks
- About database design strategies: top-down vs. bottom-up design and centralized vs. decentralized design

Preview

Databases are a part of a larger picture called an information system. Database designs that fail to recognize that the database is part of this larger whole are not likely to be successful. That is, database designers must recognize that the database is a critical means to an end rather than an end in itself. (Managers want the database to serve their management needs, but too many databases seem to require that managers alter their routines to fit the database requirements.)

Information systems don't just happen; they are the product of a carefully staged development process. Systems analysis is used to determine the need for an information system and to establish its limits. Within systems analysis, the actual information system is created through a process known as systems development.

The creation and evolution of information systems follows an iterative pattern called the Systems Development Life Cycle, a continuous process of creation, maintenance, enhancement, and replacement of the information system. A similar cycle applies to databases. The database is created, maintained, and enhanced. When even enhancement can no longer stretch the database's usefulness and the database can no longer perform its functions adequately, it might have to be replaced. The Database Life Cycle is carefully traced in this chapter and is shown in the context of the larger Systems Development Life Cycle.

At the end of the chapter, you are introduced to some classical approaches to database design: top-down vs. bottom-up and centralized vs. decentralized.

9.1 THE INFORMATION SYSTEM

Basically, a database is a carefully designed and constructed repository of facts. The database is a part of a larger whole known as an **information system**, which provides for data collection, storage, and retrieval. The information system also facilitates the transformation of data into information, and it allows for the management of both data and information. Thus, a complete information system is composed of people, hardware, software, the database(s), application programs, and procedures. **Systems analysis** is the process that establishes the need for and the extent of an information system. The process of creating an information system is known as **systems development**.

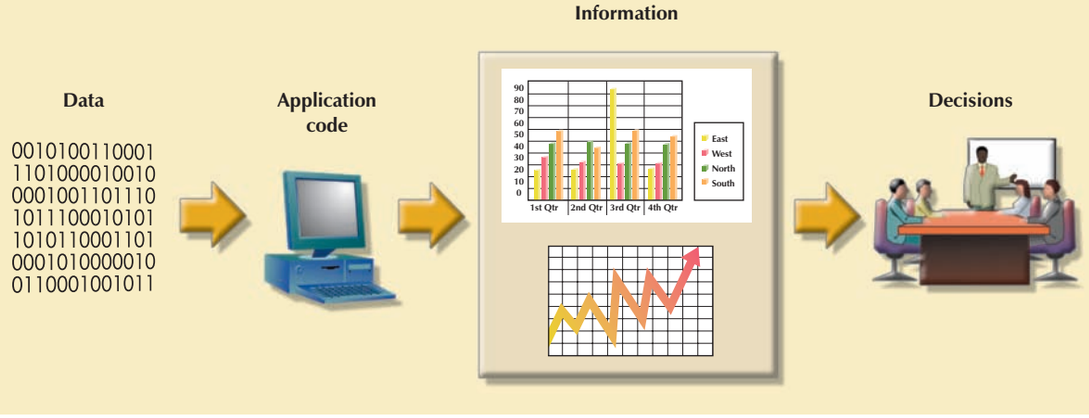
One key characteristic of current information systems is the strategic value of information in the age of global business. Therefore, information systems should always be aligned with the strategic business goals; the view of isolated and independent information systems is no longer valid. Current information systems should always be integrated with the company's enterprise-wide information systems architecture.

NOTE

This chapter is not meant to cover all aspects of systems analysis and development—those usually are covered in a separate course or book. However, this chapter should help you develop a better understanding of the issues associated with database design, implementation, and management that are affected by the information system in which the database is a critical component.

Within the framework of systems development, applications transform data into the information that forms the basis for decision making. Applications usually produce formal reports, tabulations, and graphic displays designed to produce insight into the information. Figure 9.1 illustrates that every application is composed of two parts: the data and the code (program instructions) by which the data are transformed into information. Data and code work together to represent real-world business functions and activities. At any given moment, physically stored data represent a snapshot of the business. But the picture is not complete without an understanding of the business activities that are represented by the code.

FIGURE 9.1 Generating information for decision making



The performance of an information system depends on a triad of factors:

- Database design and implementation.
- Application design and implementation.
- Administrative procedures.

This book emphasizes the database design and implementation segment of the triad—arguably the most important of the three. However, failure to address the other two segments will likely yield a poorly functioning information system. Creating a sound information system is hard work: systems analysis and development require much planning to ensure that all of the activities will interface with each other, that they will complement each other, and that they will be completed on time.

In a broad sense, the term **database development** describes the process of database design and implementation. The primary objective in database design is to create complete, normalized, nonredundant (to the extent possible), and fully integrated conceptual, logical, and physical database models. The implementation phase includes creating the database storage structure, loading data into the database, and providing for data management.

To make the procedures discussed in this chapter broadly applicable, the chapter focuses on the elements that are common to all information systems. Most of the processes and procedures described in this chapter do not depend on the size, type, or complexity of the database being implemented. However, the procedures that would be used to design a small database, such as one for a neighborhood shoe store, do not precisely scale up to the procedures that would be needed to design a database for a large corporation or even a segment of such a corporation. To use an analogy, building a small house requires a blueprint, just as building the Golden Gate Bridge does, but the bridge requires more complex and further-ranging planning, analysis, and design than the house.

The next sections will trace the overall Systems Development Life Cycle and the related Database Life Cycle. Once you are familiar with those processes and procedures, you will learn about various approaches to database design, such as top-down vs. bottom-up and centralized vs. decentralized design.

NOTE

The Systems Development Life Cycle (SDLC) is a general framework through which you can track and come to understand the activities required to develop and maintain information systems. Within that framework, there are several ways to complete various tasks specified in the SDLC. For example, this texts focus is on ER modeling and on relational database implementation issues, and that focus is maintained in this chapter. However, there are alternative methodologies, such as:

- Unified Modeling Language (UML) provides object-oriented tools to support the tasks associated with the development of information systems. UML is covered in **Appendix H, Unified Modeling Language (UML),** in the Student Online Companion.
- Rapid Application Development (RAD)[1] is an iterative software development methodology that uses prototypes, CASE tools, and flexible management to develop application systems. RAD started as an alternative to traditional structured development which had long deliverable times and unfulfilled requirements.
- Agile Software Development[2] is a framework for developing software applications that divides the work to be done in smaller subprojects to obtain valuable deliverables in shorter times and with better cohesion. This method emphasizes close communication among all users and continuous evaluation with the purpose of increasing customer satisfaction.

Although the development *methodologies* may change, the basic framework within which those methodologies are used does not change.

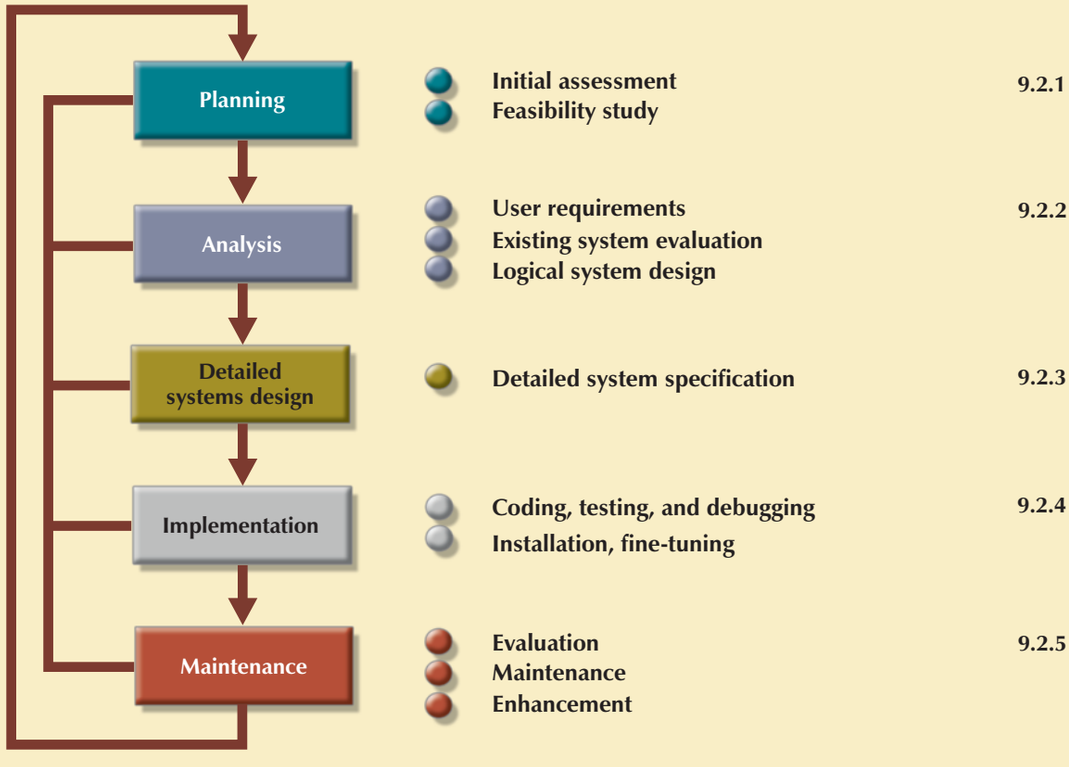
[1] See *Rapid Application Development*, James Martin, Prentice-Hall, Macmillan College Division, 1991.
[2] Further information about Agile Software Development can be found at *www.agilealliance.org*.

9.2 THE SYSTEMS DEVELOPMENT LIFE CYCLE (SDLC)

The **Systems Development Life Cycle** (**SDLC**) traces the history (life cycle) of an information system. Perhaps more important to the system designer, the SDLC provides the big picture within which the database design and application development can be mapped out and evaluated.

As illustrated in Figure 9.2, the traditional SDLC is divided into five phases: planning, analysis, detailed systems design, implementation, and maintenance. The SDLC is an iterative rather than a sequential process. For example, the details of the feasibility study might help refine the initial assessment, and the details discovered during the user requirements portion of the SDLC might help refine the feasibility study.

FIGURE 9.2 The Systems Development Life Cycle (SDLC)



Because the Database Life Cycle (DBLC) fits into and resembles the Systems Development Life Cycle (SDLC), a brief description of the SDLC is in order.

9.2.1 PLANNING

The SDLC planning phase yields a general overview of the company and its objectives. An initial assessment of the information flow-and-extent requirements must be made during this discovery portion of the SDLC. Such an assessment should answer some important questions:

- *Should the existing system be continued?* If the information generator does its job well, there is no point in modifying or replacing it. To quote an old saying, "If it ain't broke, don't fix it."
- *Should the existing system be modified?* If the initial assessment indicates deficiencies in the extent and flow of the information, minor (or even major) modifications might be in order. When considering modifications, the participants in the initial assessment must keep in mind the distinction between wants and needs.
- *Should the existing system be replaced?* The initial assessment might indicate that the current system's flaws are beyond fixing. Given the effort required to create a new system, a careful distinction between wants and needs is perhaps even more important in this case than it is in modifying the system.

Participants in the SDLC's initial assessment must begin to study and evaluate alternative solutions. If it is decided that a new system is necessary, the next question is whether it is feasible. The feasibility study must address the following:

- *The technical aspects of hardware and software requirements.* The decisions might not (yet) be vendor-specific, but they must address the nature of the hardware requirements (desktop computer, multiprocessor computer, mainframe, or supercomputer) and the software requirements (single- or multiuser operating systems, database type and software, programming languages to be used by the applications, and so on).
- *The system cost.* The admittedly mundane question, "Can we afford it?" is crucial. (And the answer to that question might force a careful review of the initial assessment.) It bears repeating that a million-dollar solution to a thousand-dollar problem is not defensible.
- *The operational cost.* Does the company possess the human, technical, and financial resources to keep the system operational? Do we count in the cost the management and end-user support needed to put in place the operational procedures to ensure the success of this system?

9.2.2 ANALYSIS

Problems defined during the planning phase are examined in greater detail during the analysis phase. A macroanalysis must be made of both individual needs and organizational needs, addressing questions such as:

- What are the requirements of the current system's end users?
- Do those requirements fit into the overall information requirements?

The analysis phase of the SDLC is, in effect, a thorough *audit* of user requirements.

The existing hardware and software systems are also studied during the analysis phase. The result of analysis should be a better understanding of the system's functional areas, actual and potential problems, and opportunities.

End users and the system designer(s) must work together to identify processes and to uncover potential problem areas. Such cooperation is vital to defining the appropriate performance objectives by which the new system can be judged.

Along with a study of user requirements and the existing systems, the analysis phase also includes the creation of a logical systems design. The logical design must specify the appropriate conceptual data model, inputs, processes, and expected output requirements.

When creating a logical design, the designer might use tools such as data flow diagrams (DFDs), hierarchical input process output (HIPO) diagrams, and entity relationship (ER) diagrams. The database design's data-modeling activities take place at this point to discover and describe all entities and their attributes and the relationships among the entities within the database.

Defining the logical system also yields functional descriptions of the system's components (modules) for each process within the database environment. All data transformations (processes) are described and documented using such systems analysis tools as DFDs. The conceptual data model is validated against those processes.

9.2.3 Detailed Systems Design

In the detailed systems design phase, the designer completes the design of the system's processes. The design includes all the necessary technical specifications for the screens, menus, reports, and other devices that might be used to help make the system a more efficient information generator. The steps are laid out for conversion from the old to the new system. Training principles and methodologies are also planned and must be submitted for management's approval.

NOTE

Because attention has been focused on the details of the systems design process, the book has not until this point explicitly recognized the fact that management approval is needed at all stages of the process. Such approval is needed because a GO decision requires funding. There are many GO/NO GO decision points along the way to a completed systems design!

9.2.4 Implementation

During the implementation phase, the hardware, DBMS software, and application programs are installed, and the database design is implemented. During the initial stages of the implementation phase, the system enters into a cycle of coding, testing, and debugging until it is ready to be delivered. The actual database is created, and the system is customized by the creation of tables and views, user authorizations, and so on.

The database contents might be loaded interactively or in batch mode, using a variety of methods and devices:

- Customized user programs.
- Database interface programs.
- Conversion programs that import the data from a different file structure, using batch programs, a database utility, or both.

The system is subjected to exhaustive testing until it is ready for use. Traditionally, the implementation and testing of a new system took 50 to 60 percent of the total development time. However, the advent of sophisticated application generators and debugging tools has substantially decreased coding and testing time. After testing is concluded, the final documentation is reviewed and printed and end users are trained. The system is in full operation at the end of this phase but will be continuously evaluated and fine-tuned.

9.2.5 MAINTENANCE

Almost as soon as the system is operational, end users begin to request changes in it. Those changes generate system maintenance activities, which can be grouped into three types:

- *Corrective maintenance* in response to systems errors.
- *Adaptive maintenance* due to changes in the business environment.
- *Perfective maintenance* to enhance the system.

Because every request for structural change requires retracing the SDLC steps, the system is, in a sense, always at some stage of the SDLC.

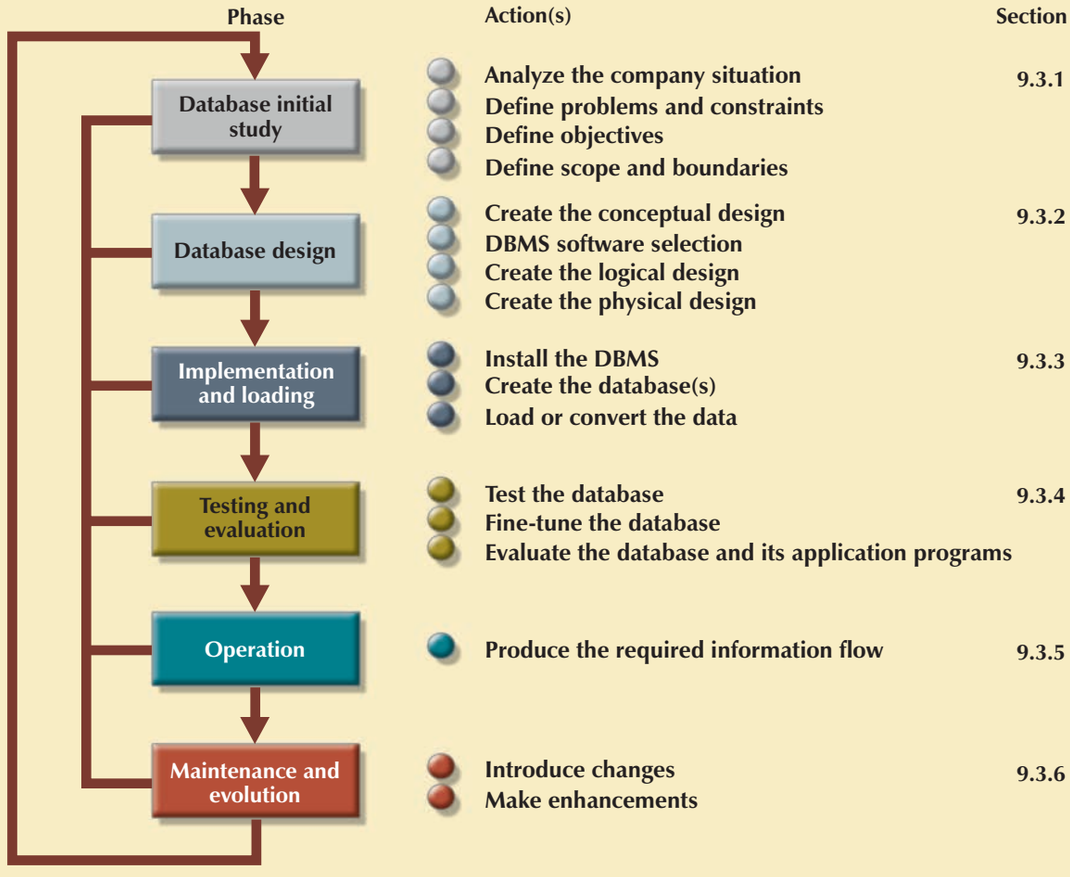
Each system has a predetermined operational life span. The actual operational life span of a system depends on its perceived utility. There are several reasons for reducing the operational life of certain systems. Rapid technological change is one reason, especially for systems based on processing speed and expandability. Another common reason is the cost of maintaining a system.

If the system's maintenance cost is high, its value becomes suspect. **Computer-aided systems engineering** (**CASE**) technology, such as System Architect or Visio Professional, helps make it possible to produce better systems within a reasonable amount of time and at a reasonable cost. In addition, CASE-produced applications are more structured, documented, and especially *standardized*, which tends to prolong the operational life of systems by making them easier and cheaper to update and maintain. For example, if you have used Microsoft's Visio Professional to develop your database design, you already know that Visio Professional tests the internal consistency of your ERDs when you create the relationships. Visio Professional implements the FKs according to the design's entity types (weak, strong) and the nature of the relationship (identifying, non-identifying) between those entities. When you see the result of the implementation, you immediately see whether the results are what you intended them to be. In addition, if there are circular arguments in the design, Visio Professional will make that clear. Therefore, you will be able to spot design problems before they become permanent.

9.3 THE DATABASE LIFE CYCLE (DBLC)

Within the larger information system, the database, too, is subject to a life cycle. The **Database Life Cycle** (**DBLC**) contains six phases, as shown in Figure 9.3: database initial study, database design, implementation and loading, testing and evaluation, operation, and maintenance and evolution.

FIGURE 9.3 The Database Life Cycle (DBLC)



9.3.1 The Database Initial Study

If a designer has been called in, chances are the current system has failed to perform functions deemed vital by the company. (You don't call the plumber unless the pipes leak.) So in addition to examining the current system's operation within the company, the designer must determine how and why the current system fails. That means spending a lot of time talking with (but mostly listening to) end users. Although database design is a technical business, it is also people-oriented. Database designers must be excellent communicators, and they must have finely tuned interpersonal skills.

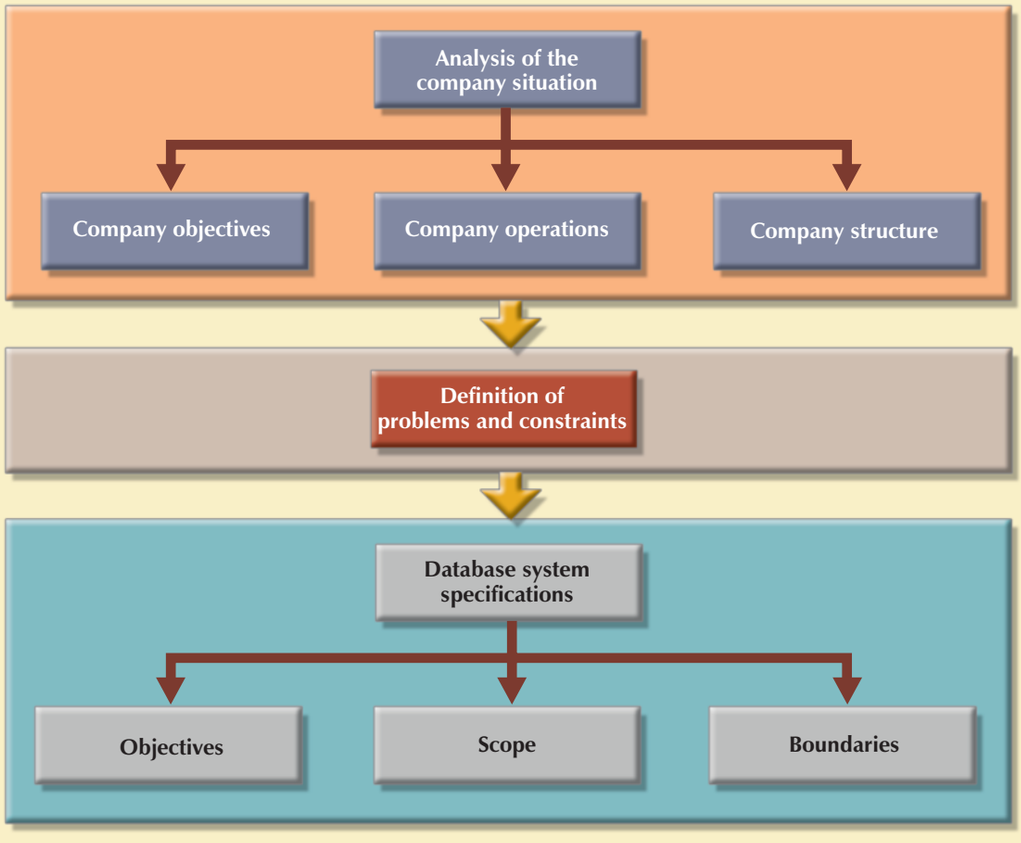
Depending on the complexity and scope of the database environment, the database designer might be a lone operator or part of a systems development team composed of a project leader, one or more senior systems analysts, and one or more junior systems analysts. The word *designer* is used generically here to cover a wide range of design team compositions.

The overall purpose of the database initial study is to:

- Analyze the company situation.
- Define problems and constraints.
- Define objectives.
- Define scope and boundaries.

Figure 9.4 depicts the interactive and iterative processes required to complete the first phase of the DBLC successfully. As you examine Figure 9.4, note that the database initial study phase leads to the development of the database system objectives. Using Figure 9.4 as a discussion template, let's examine each of its components in greater detail.

FIGURE 9.4 **A summary of activities in the database initial study**



Analyze the Company Situation

The *company situation* describes the general conditions in which a company operates, its organizational structure, and its mission. To analyze the company situation, the database designer must discover what the company's operational components are, how they function, and how they interact.

These issues must be resolved:

- *What is the organization's general operating environment, and what is its mission within that environment?* The design must satisfy the operational demands created by the organization's mission. For example, a mail-order business is likely to have operational requirements involving its database that are quite different from those of a manufacturing business.
- *What is the organization's structure?* Knowing who controls what and who reports to whom is quite useful when you are trying to define required information flows, specific report and query formats, and so on.

Define Problems and Constraints

The designer has both formal and informal sources of information. If the company has existed for any length of time, it already has some kind of system in place (either manual or computer-based). How does the existing system function? What input does the system require? What documents does the system generate? By whom and how is the system output used? Studying the paper trail can be very informative. In addition to the official version of the system's operation, there is also the more informal, real version; the designer must be shrewd enough to see how these differ.

The process of defining problems might initially appear to be unstructured. Company end users are often unable to describe precisely the larger scope of company operations or to identify the real problems encountered during company operations. Often the managerial view of a company's operation and its problems is different from that of the end users, who perform the actual routine work.

During the initial problem definition process, the designer is likely to collect very broad problem descriptions. For example, note these concerns expressed by the president of a fast-growing transnational manufacturing company:

Although the rapid growth is gratifying, members of the management team are concerned that such growth is beginning to undermine the ability to maintain a high customer service standard and, perhaps worse, to diminish manufacturing standards control.

The problem definition process quickly leads to a host of general problem descriptions. For example, the marketing manager comments:

I'm working with an antiquated filing system. We manufacture more than 1,700 specialty machine parts. When a regular customer calls in, we can't get a very quick inventory scan. If a new customer calls in, we can't do a current parts search by using a simple description, so we often do a machine setup for a part that we have in inventory. That's wasteful. And of course, some new customers get irritated when we can't give a quick response.

The production manager comments:

At best, it takes hours to generate the reports I need for scheduling purposes. I don't have hours for quick turnarounds. It's difficult to manage what I don't have information about.

I don't get quick product request routing. Take machine setup. Right now I've got operators either waiting for the right stock or getting it themselves when a new part is scheduled for production. I can't afford to have an operator doing chores that a much lower-paid worker ought to be doing. There's just too much waiting around with the current scheduling. I'm losing too much time, and my schedules back up. Our overtime bill is ridiculous.

I sometimes produce parts that are already in inventory because we don't seem to be able to match what we've got in inventory with what we have scheduled. Shipping yells at me because I can't turn out the parts, and often they've got them in inventory one bay down. That's costing us big bucks sometimes.

New reports can take days or even weeks to get to my office. And I need a ton of reports to schedule personnel, downtime, training, etc. I can't get new reports that I need NOW. What I need is the ability to get quick updates on percent defectives, percent rework, the effectiveness of training, you name it. I need such reports by shift, by date, by any characteristic I can think of to help me manage scheduling, training, you name it.

A machine operator comments:

It takes a long time to set my stuff up. If I get my schedule banged up because John doesn't get the paperwork on time, I wind up looking for setup specs, startup material, bin assignments, and other stuff. Sometimes I spend two or three hours just setting up. Now you know why I can't meet schedules. I try to be productive, but I'm spending too much time getting ready to do my job.

After the initial declarations, the database designer must continue to probe carefully in order to generate additional information that will help define the problems within the larger framework of company operations. How does the problem of the marketing manager's customer fit within the broader set of marketing department activities? How does the solution to the customer's problem help meet the objectives of the marketing department and the rest of the company? How do the marketing department's activities relate to those of the other departments? That last question is especially important. Note that there are common threads in the problems described by the marketing and production department managers. If the inventory query process can be improved, both departments are likely to find simple solutions to at least some of the problems.

Finding precise answers is important, especially concerning the operational relationships among business units. If a proposed system will solve the marketing department's problems but exacerbate those of the production department, not much progress will have been made. Using an analogy, suppose your home water bill is too high. You have determined the problem: the faucets leak. The solution? You step outside and cut off the water supply to the house. Is that an adequate solution? Or would the replacement of faucet washers do a better job of solving the problem? You might find the leaky faucet scenario simplistic, yet almost any experienced database designer can find similar instances of so-called database problem solving (admittedly more complicated and less obvious).

Even the most complete and accurate problem definition does not always lead to the perfect solution. The real world usually intrudes to limit the design of even the most elegant database by imposing constraints. Such constraints include time, budget, personnel, and more. If you must have a solution within a month and within a $12,000 budget, a solution that takes two years to develop at a cost of $100,000 is not a solution. *The designer must learn to distinguish between what's perfect and what's possible.*

Define Objectives

A proposed database system must be designed to help solve at least the major problems identified during the problem discovery process. As the list of problems unfolds, several common sources are likely to be discovered. In the previous example, both the marketing manager and the production manager seem to be plagued by inventory inefficiencies. If the designer can create a database that sets the stage for more efficient parts management, both departments gain. The initial objective, therefore, might be to create an efficient inventory query and management system.

NOTE

When trying to develop solutions, the database designer must look for the *source* of the problems. There are many cases of database systems that failed to satisfy the end users because they were designed to treat the *symptoms* of the problems rather than their source.

Note that the initial study phase also yields proposed problem solutions. The designer's job is to make sure that the database system objectives, as seen by the designer, correspond to those envisioned by the end user(s). In any case, the database designer must begin to address the following questions:

- What is the proposed system's initial objective?
- Will the system interface with other existing or future systems in the company?
- Will the system share the data with other systems or users?

Define Scope and Boundaries

The designer must recognize the existence of two sets of limits: scope and boundaries. The system's **scope** defines the extent of the design according to operational requirements. Will the database design encompass the entire organization, one or more departments within the organization, or one or more functions of a single department? The designer must know the "size of the ballpark." Knowing the scope helps in defining the required data structures, the type and number of entities, the physical size of the database, and so on.

The proposed system is also subject to limits known as **boundaries**, which are external to the system. Has any designer ever been told, "We have all the time in the world" or "Use an unlimited budget and use as many people as needed to make the design come together"? Boundaries are also imposed by existing hardware and software. Ideally, the designer can choose the hardware and software that will best accomplish the system goals. In fact, software selection is an important aspect of the Systems Development Life Cycle. Unfortunately, in the real world, a system often must be designed around existing hardware. Thus, the scope and boundaries become the factors that force the design into a specific mold, and the designer's job is to design the best system possible within those constraints. (Note that problem definitions and the objectives sometimes must be reshaped to meet the system scope and boundaries.)

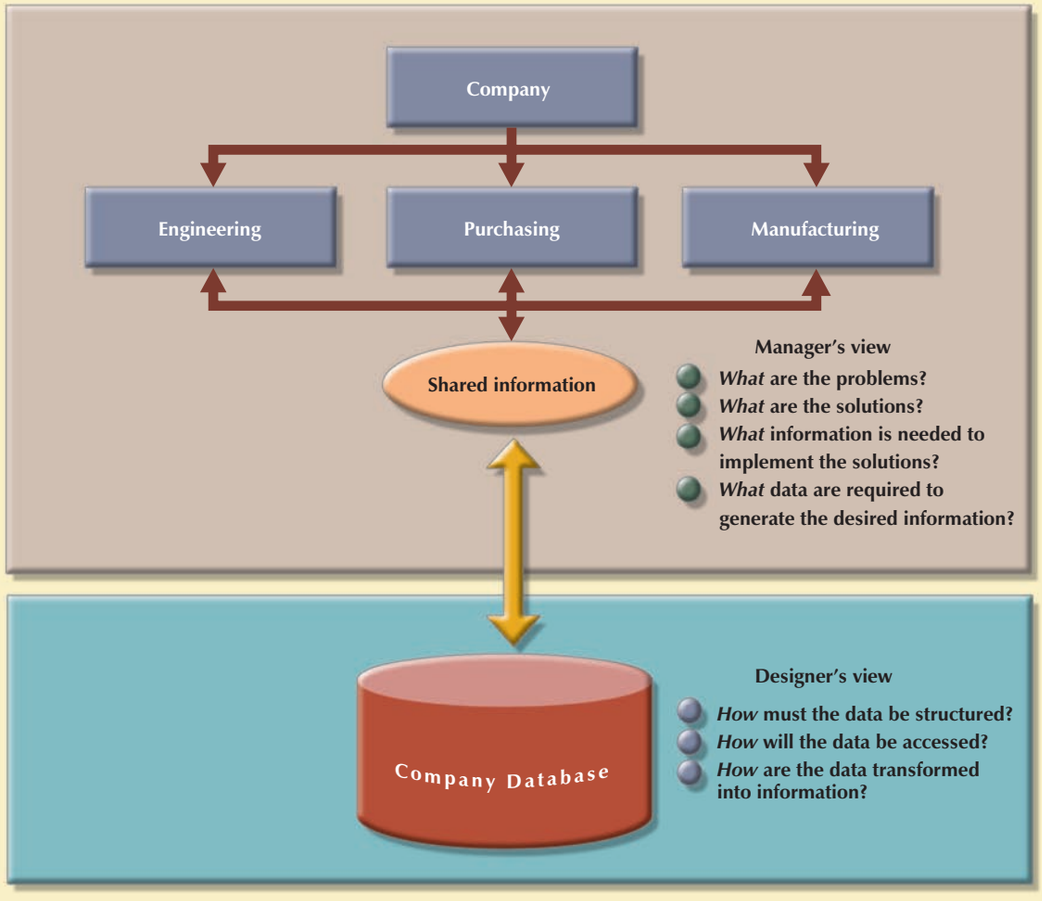
9.3.2 Database Design

The second phase focuses on the design of the database model that will support company operations and objectives. This is arguably the most critical DBLC phase: making sure that the final product meets user and system requirements. In the process of database design, you must concentrate on the data characteristics required to build the database model. At this point, there are two views of the data within the system: the business view of data as a source of information and the designer's view of the data structure, its access, and the activities required to transform the data into information. Figure 9.5 contrasts those views. Note that you can summarize the different views by looking at the terms *what* and *how*. Defining data is an integral part of the DBLC's second phase.

As you examine the procedures required to complete the design phase in the DBLC, remember these points:

- The process of database design is loosely related to the analysis and design of a larger system. The data component is only one element of a larger information system.
- The systems analysts or systems programmers are in charge of designing the other system components. Their activities create the procedures that will help transform the data within the database into useful information.
- The database design does not constitute a sequential process. Rather, it is an iterative process that provides continuous feedback designed to trace previous steps.

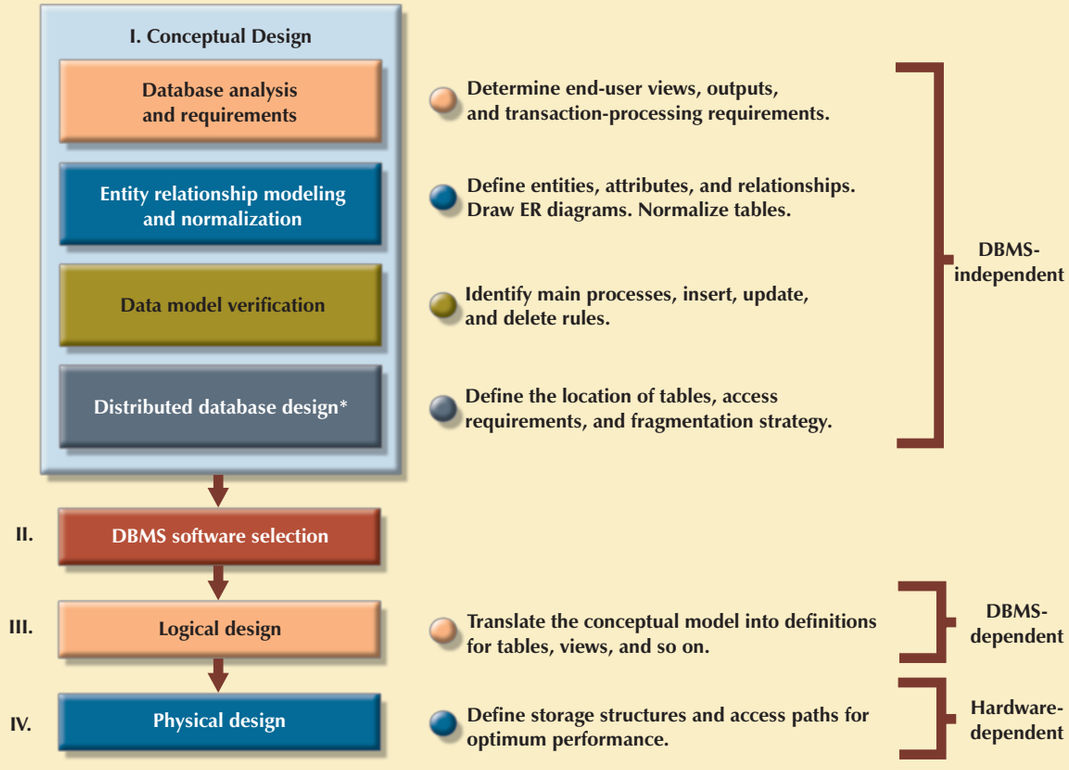
FIGURE 9.5 Two views of data: business manager and database designer



The database design process is depicted in Figure 9.6. Look at the procedure flow in the figure.

Now let's explore in detail each of the components in Figure 9.6. Knowing those details will help you successfully design and implement databases in a real-world setting.

FIGURE 9.6 Procedure flow in the database design



* See Chapter 12, Distributed Database Management Systems.

ONLINE CONTENT

In **Appendixes B** and **C** in the Student Online Companion, **The University Lab: Conceptual Design** and **The University Lab: Conceptual Design Verification, Logical Design, and Implementation,** respectively, you learn what happens during each of these stages in developing real databases.

I. Conceptual Design

In the **conceptual design** stage, data modeling is used to create an abstract database structure that represents real-world objects in the most realistic way possible. The conceptual model must embody a clear understanding of the business and its functional areas. At this level of abstraction, the type of hardware and/or database model to be used might not yet have been identified. Therefore, the design must be software- and hardware-independent so the system can be set up within any hardware and software platform chosen later.

Keep in mind the following **minimal data rule**:

All that is needed is there, and all that is there is needed.

In other words, make sure that all data needed are in the model and that all data in the model are needed. All data elements required by the database transactions must be defined in the model, and all data elements defined in the model must be used by at least one database transaction.

However, as you apply the minimal data rule, avoid an excessive short-term bias. Focus not only on the immediate data needs of the business, but also on the future data needs. Thus, the database design must leave room for future modifications and additions, ensuring that the business's investment in information resources will endure.

Note in Figure 9.6 that conceptual design requires four steps, examined in the next sections:

1. Data analysis and requirements
2. Entity relationship modeling and normalization
3. Data model verification
4. Distributed database design

Data Analysis and Requirements The first step in conceptual design is to discover the characteristics of the data elements. An effective database is an information factory that produces key ingredients for successful decision making. Appropriate data element characteristics are those that can be transformed into appropriate information. Therefore, the designer's efforts are focused on:

- *Information needs*. What kind of information is needed—that is, what output (reports and queries) must be generated by the system, what information does the current system generate, and to what extent is that information adequate?
- *Information users*. Who will use the information? How is the information to be used? What are the various end-user data views?
- *Information sources*. Where is the information to be found? How is the information to be extracted once it is found?
- *Information constitution*. What data elements are needed to produce the information? What are the data attributes? What relationships exist among the data? What is the data volume? How frequently are the data used? What data transformations are to be used to generate the required information?

The designer obtains the answers to those questions from a variety of sources in order to compile the necessary information. Note these sources:

- *Developing and gathering end-user data views*. The database designer and the end user(s) interact to jointly develop a precise description of end-user data views. In turn, the end-user data views will be used to help identify the database's main data elements.
- *Directly observing the current system: existing and desired output*. The end user usually has an existing system in place, whether it's manual or computer-based. The designer reviews the existing system to identify the data and their characteristics. The designer examines the input forms and files (tables) to discover the data type and volume. If the end user already has an automated system in place, the designer carefully examines the current and desired reports to describe the data required to support the reports.
- *Interfacing with the systems design group*. As noted earlier in this chapter, the database design process is part of the Systems Development Life Cycle (SDLC). In some cases, the systems analyst in charge of designing the new system will also develop the conceptual database model. (This is usually true in a decentralized environment.) In other cases, the database design is considered part of the database administrator's job. The presence of a database administrator (DBA) usually implies the existence of a formal data-processing department. The DBA designs the database according to the specifications created by the systems analyst.

To develop an accurate data model, the designer must have a thorough understanding of the company's data types and their extent and uses. But data do not by themselves yield the required understanding of the total business. From a database point of view, the collection of data becomes meaningful only when business rules are defined. Remember

from Chapter 2, Data Models, that a *business rule* is a brief and precise description of a policy, procedure, or principle within a specific organization's environment. Business rules, derived from a detailed description of an organization's operations, help to create and enforce actions within that organization's environment. When business rules are written properly, they define entities, attributes, relationships, connectivities, cardinalities, and constraints.

To be effective, business rules must be easy to understand and they must be widely disseminated to ensure that every person in the organization shares a common interpretation of the rules. Using simple language, business rules describe the main and distinguishing characteristics of the data *as viewed by the company*. Examples of business rules are as follows:

- A customer may make many payments on account.
- Each payment on account is credited to only one customer.
- A customer may generate many invoices.
- Each invoice is generated by only one customer.

Given their critical role in database design, business rules must not be established casually. Poorly defined or inaccurate business rules lead to database designs and implementations that fail to meet the needs of the organization's end users.

Ideally, business rules are derived from a formal **description of operations**, which is a document that provides a precise, up-to-date, and thoroughly reviewed description of the activities that define an organization's operating environment. (To the database designer, the operating environment is both the data sources and the data users.) Naturally, an organization's operating environment is dependent on the organization's mission. For example, the operating environment of a university would be quite different from that of a steel manufacturer, an airline, or a nursing home. Yet no matter how different the organizations may be, the *data analysis and requirements* component of the database design process is enhanced when the data environment and data use are described accurately and precisely within a description of operations.

In a business environment, the main sources of information for the description of operations—and, therefore, of business rules—are company managers, policy makers, department managers, and written documentation such as company procedures, standards, and operations manuals. A faster and more direct source of business rules is direct interviews with end users. Unfortunately, because perceptions differ, the end user can be a less reliable source when it comes to specifying business rules. For example, a maintenance department mechanic might believe that any mechanic can initiate a maintenance procedure, when actually only mechanics with inspection authorization should perform such a task. Such a distinction might seem trivial, but it has major legal consequences. Although end users are crucial contributors to the development of business rules, it pays to verify end-user perceptions. Often interviews with several people who perform the same job yield very different perceptions of their job components. While such a discovery might point to "management problems," that general diagnosis does not help the database designer. Given the discovery of such problems, the database designer's job is to reconcile the differences and verify the results of the reconciliation to ensure that the business rules are appropriate and accurate.

Knowing the business rules enables the designer to understand fully how the business works and what role the data plays within company operations. Consequently, the designer must identify the company's business rules and analyze their impact on the nature, role, and scope of data.

Business rules yield several important benefits in the design of new systems:

- They help standardize the company's view of data.
- They constitute a communications tool between users and designers.
- They allow the designer to understand the nature, role, and scope of the data.
- They allow the designer to understand business processes.
- They allow the designer to develop appropriate relationship participation rules and foreign key constraints. (See Chapter 4, Entity Relationship (ER) Modeling.)

The last point is especially noteworthy: whether a given relationship is mandatory or optional is usually a function of the applicable business rule.

Entity Relationship Modeling and Normalization Before creating the ER model, the designer must communicate and enforce appropriate standards to be used in the documentation of the design. The standards include the use of diagrams and symbols, documentation writing style, layout, and any other conventions to be followed during documentation. Designers often overlook this very important requirement, especially when they are working as members of a design team. Failure to standardize documentation often means a failure to communicate later, and communications failures often lead to poor design work. In contrast, well-defined and enforced standards make design work easier and promise (but do not guarantee) a smooth integration of all system components.

Because the business rules usually define the nature of the relationship(s) among the entities, the designer must incorporate them into the conceptual model. The process of defining business rules and developing the conceptual model using ER diagrams can be described using the steps shown in Table 9.1.[3]

TABLE 9.1 Developing the Conceptual Model Using ER Diagrams

STEP	ACTIVITY
1	Identify, analyze, and refine the business rules.
2	Identify the main entities, using the results of Step 1.
3	Define the relationships among the entities, using the results of Steps 1 and 2.
4	Define the attributes, primary keys, and foreign keys for each of the entities.
5	Normalize the entities. (Remember that entities are implemented as tables in an RDBMS.)
6	Complete the initial ER diagram.
7	Have the main end users verify the model in Step 6 against the data, information, and processing requirements.
8	Modify the ER diagram, using the results of Step 7.

Some of the steps listed in Table 9.1 take place concurrently. And some, such as the normalization process, can generate a demand for additional entities and/or attributes, thereby causing the designer to revise the ER model. For example, while identifying two main entities, the designer might also identify the composite bridge entity that represents the many-to-many relationship between those two main entities.

To review, suppose you are creating a conceptual model for the JollyGood Movie Rental Corporation, whose end users want to track customers' movie rentals. The simple ER diagram presented in Figure 9.7 shows a composite entity that helps track customers and their video rentals. Business rules define the optional nature of the relationships between the entities VIDEO and CUSTOMER depicted in Figure 9.7. (For example, customers are not required to check out a video. A video need not be checked out in order to exist on the shelf. A customer may rent many videos, and a video may be rented by many customers.) In particular, note the composite RENTAL entity that connects the two main entities.

As you will likely discover, the initial ER model may be subjected to several revisions before it meets the system's requirements. Such a revision process is quite natural. Remember that the ER model is a communications tool as well as a design blueprint. Therefore, when you meet with the proposed system users, the initial ER model should give rise to questions such as, "Is this really what you meant?" For example, the ERD shown in Figure 9.7 is far from complete. Clearly, many more attributes must be defined and the dependencies must be checked before the design can be implemented. In addition, the design cannot yet support the typical video rental transactions environment. For example, each video is likely to have many copies available for rental purposes. However, if the VIDEO entity shown in Figure 9.7 is used to store the titles as well as the copies, the design triggers the data redundancies shown in Table 9.2.

[3] See "Linking Rules to Models," Alice Sandifer and Barbara von Halle, *Database Programming and Design*, 4(3), March 1991, pp. 13–16. Although the source seems dated, it remains the current standard. The technology has changed substantially, but the process has not.

FIGURE 9.7 A composite entity

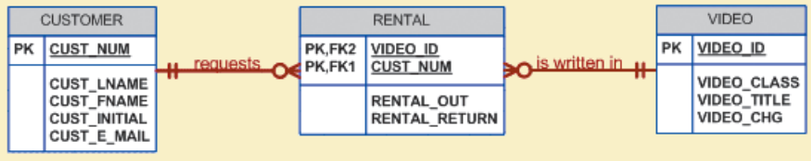


TABLE 9.2 Data Redundancies in the VIDEO Table

VIDEO_ID	VIDEO_TITLE	VIDEO_COPY	VIDEO_CHG	VIDEO_DAYS
SF-12345FT-1	Adventures on Planet III	1	$4.50	1
SF-12345FT-2	Adventures on Planet III	2	$4.50	1
SF-12345FT-3	Adventures on Planet III	3	$4.50	1
WE-5432GR-1	TipToe Canu and Tyler 2: A Journey	1	$2.99	2
WE-5432GR-2	TipToe Canu and Tyler 2: A Journey	2	$2.99	2

The initial ERD shown in Figure 9.7 must be modified to reflect the answer to the question, "Is more than one copy available for each title?" Also, payment transactions must be supported. (You will have an opportunity to modify this initial design in Problem 5 at the end of the chapter.)

From the preceding discussion, you might get the impression that ER modeling activities (entity/attribute definition, normalization, and verification) take place in a precise sequence. In fact, once you have completed the initial ER model, chances are you will move back and forth among the activities until you are satisfied that the ER model accurately represents a database design that is capable of meeting the required system demands. The activities often take place in parallel, and the process is iterative. Figure 9.8 summarizes the ER modeling process interactions. Figure 9.9 summarizes the array of design tools and information sources that the designer can use to produce the conceptual model.

All objects (entities, attributes, relations, views, and so on) are defined in a data dictionary, which is used in tandem with the normalization process to help eliminate data anomalies and redundancy problems. During this ER modeling process, the designer must:

- Define entities, attributes, primary keys, and foreign keys. (The foreign keys serve as the basis for the relationships among the entities.)
- Make decisions about adding new primary key attributes to satisfy end-user and/or processing requirements.
- Make decisions about the treatment of multivalued attributes.
- Make decisions about adding derived attributes to satisfy processing requirements.
- Make decisions about the placement of foreign keys in 1:1 relationships. (If necessary, review the supertype/subtype relationships in Chapter 6, Advanced Data Modeling.)
- Avoid unnecessary ternary relationships.
- Draw the corresponding ER diagram.
- Normalize the entities.
- Include all data element definitions in the data dictionary.
- Make decisions about standard naming conventions.

FIGURE 9.8 ER modeling is an iterative process based on many activities

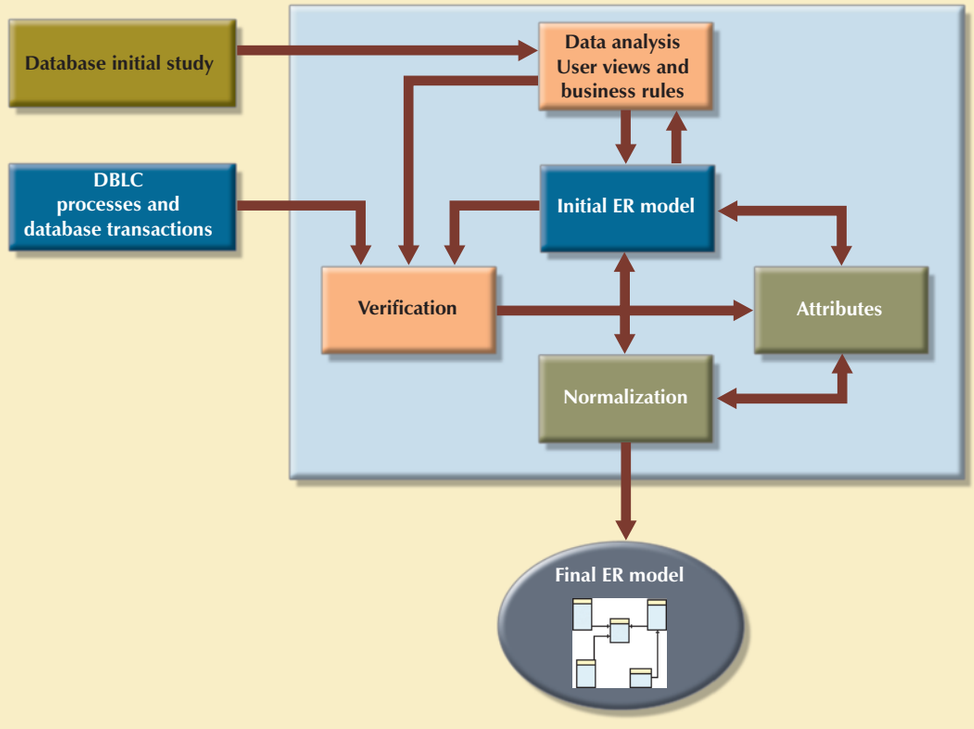
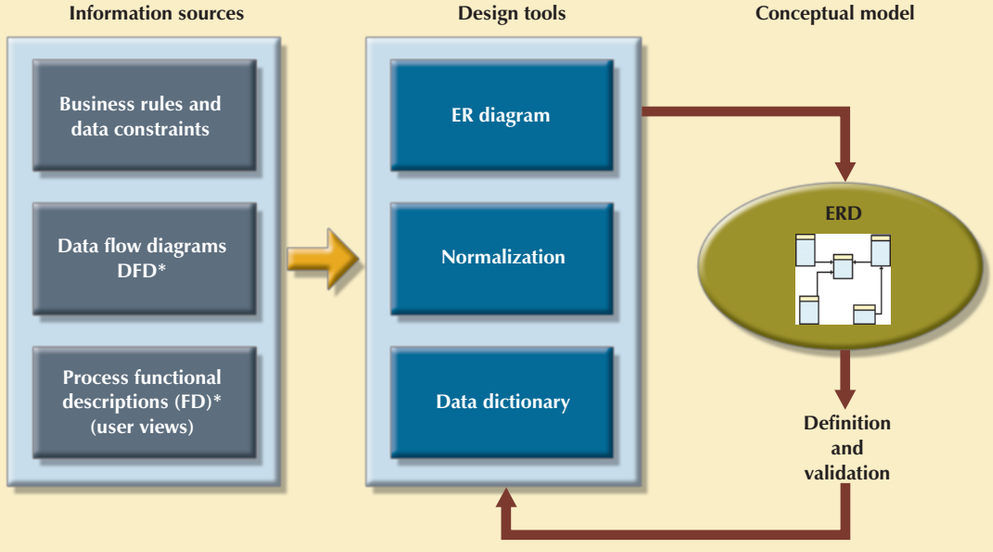


FIGURE 9.9 Conceptual design tools and information sources



* Output generated by the systems analysis and design activities

The naming conventions requirement is important, yet it is frequently ignored at the designer's risk. Real database design is generally accomplished by teams. Therefore, it is important to ensure that the team members work in an environment in which naming standards are defined and enforced. Proper documentation is crucial to the successful completion of the design. Therefore, it is very useful to establish procedures that are, in effect, self-documenting.

Although some useful entity and attribute naming conventions were established in Chapter 4, they will be revisited in greater detail here. However, keep in mind that such conventions are sometimes subject to constraints imposed by the DBMS software. In an enterprise-wide database environment, the lowest common denominator rules. For example, Microsoft Access finds the attribute name LINE_ITEM_NUMBER to be perfectly acceptable. Many older DBMSs, however, are likely to truncate such long names when they are exported from one DBMS to another, thus making documentation more difficult. Therefore, table-exporting requirements might dictate the use of shorter names. (The same is true for data types. For example, many older DBMSs cannot handle OLE or memo formats.)

This book uses naming conventions that are likely to be acceptable across a reasonably broad range of DBMSs and will meet self-documentation requirements to the greatest extent possible. As the older DBMSs fade from the scene, the naming conventions will be more broadly applicable. You should try to adhere to the following conventions:

- Use descriptive entity and attribute names wherever possible. For example, in the University Computer Lab database, the USER entity contains data about the lab's users and the LOCATION entity is related to the location of the ITEMs that the lab director wants to track.
- Composite entities usually are assigned a name that describes the relationship they represent. For example, in the University Computer Lab database, an ITEM may be stored in many LOCATIONs and a LOCATION may have many ITEMs stored in it. Therefore, the composite (bridge) entity that links ITEM and LOCATION will be named STORAGE. Occasionally, the designer finds it necessary to show what entities are being linked by the composite entity. In such cases, the composite entity name may borrow segments of those entity names. For example, STU_CLASS may be the composite entity that links STUDENT and CLASS. However, that naming convention might make the next one more cumbersome, so it should be used sparingly. (A better choice would be the composite entity name ENROLL, to indicate that the STUDENT enrolls in a CLASS.)
- An attribute name should be descriptive, and it should contain a prefix that helps identify the table in which it is found. For the purposes here, the maximum prefix length will be five characters. For example, the VENDOR table might contain attributes such as VEND_ID and VEND_PHONE. Similarly, the ITEM table might contain attribute names such as ITEM_ID and ITEM_DESCRIPTION. The advantage of that naming convention is that it immediately identifies a table's foreign key(s). For example, if the EMPLOYEE table contains attributes such as EMP_ID, EMP_LNAME, and DEPT_CODE, it is immediately obvious that DEPT_CODE is the foreign key that probably links EMPLOYEE to DEPARTMENT. Naturally, the existence of relationships and table names that start with the same characters might dictate that you bend this naming convention occasionally, as you can see in the next bulleted item.
- If one table is named ORDER and its weak counterpart is named ORDER_ITEM, the prefix ORD will be used to indicate an attribute originating in the ORDER table. The ITEM prefix will identify an attribute originating in the ITEM table. Clearly, you cannot use ORD as a prefix to the attributes originating in the ORDER_ITEM table, so you should use a combination of characters, such as OI, as the prefix to the ORDER_ITEM attribute names. In spite of that limitation, it is generally possible to assign prefixes that identify an attribute's origin. (Keep in mind that some RDBMSs use a "reserved word" list. For example, ORDER might be interpreted as a reserved word in a SELECT statement. In that case, you should use a table name other than ORDER.)

As you can tell, it is not always possible to strictly adhere to the naming conventions. Sometimes the requirement to limit name lengths makes the attribute or entity names less descriptive. Also, with a large number of entities and attributes in a complex design, you might have to be somewhat inventive about using proper attribute name prefixes. But then those prefixes are less helpful in identifying the precise source of the attribute. Nevertheless, the consistent use of prefixes will reduce sourcing doubts significantly. For example, while the prefix CO does not obviously relate to the CHECK_OUT table, just as obvious is the fact that it does not originate in WITHDRAW, ITEM, or USER.

Adherence to the naming conventions just described serves database designers well. In fact, a common refrain from users seems to be this: "I didn't know why you made such a fuss over naming conventions, but now that I'm doing this stuff for real, I've become a true believer."

Data Model Verification The ER model must be verified against the proposed system processes in order to corroborate that the intended processes can be supported by the database model. Verification requires that the model be run through a series of tests against:

- End-user data views and their required transactions: SELECT, INSERT, UPDATE, and DELETE operations and queries and reports.
- Access paths and security.
- Business-imposed data requirements and constraints.

Revision of the original database design starts with a careful reevaluation of the entities, followed by a detailed examination of the attributes that describe those entities. This process serves several important purposes:

- The emergence of the attribute details might lead to a revision of the entities themselves. Perhaps some of the components first believed to be entities will, instead, turn out to be attributes within other entities. Or what was originally considered to be an attribute might turn out to contain a sufficient number of subcomponents to warrant the introduction of one or more new entities.
- The focus on attribute details can provide clues about the nature of relationships as they are defined by the primary and foreign keys. Improperly defined relationships lead to implementation problems first and to application development problems later.
- To satisfy processing and/or end-user requirements, it might be useful to create a new primary key to replace an existing primary key. For example, in the invoicing example illustrated in Figure 3.30 in Chapter 3, The Relational Database Model, a primary key composed of INV_NUMBER and LINE_NUMBER replaced the original primary key composed of INV_NUMBER and PROD_CODE. That change ensured that the items in the invoice would always appear in the same order as they were entered. To simplify queries and to increase processing speed, you may create a single-attribute primary key to replace an existing multiple-attribute primary key.
- Unless the entity details (the attributes and their characteristics) are precisely defined, it is difficult to evaluate the extent of the design's normalization. Knowledge of the normalization levels helps guard against undesirable redundancies.
- A careful review of the rough database design blueprint is likely to lead to revisions. Those revisions will help ensure that the design is capable of meeting end-user requirements.

Because real-world database design is generally done by teams, you should strive to organize the design's major components into modules. A **module** is an information system component that handles a specific function, such as inventory, orders, payroll, and so on. At the design level, a module is an ER segment that is an integrated part of the overall ER model. Creating and using modules accomplishes several important ends:

- The modules (and even the segments within them) can be delegated to design groups within teams, greatly speeding up the development work.
- The modules simplify the design work. The large number of entities within a complex design can be daunting. Each module contains a more manageable number of entities.
- The modules can be prototyped quickly. Implementation and applications programming trouble spots can be identified more readily. (Quick prototyping is also a great confidence builder.)
- Even if the entire system can't be brought online quickly, the implementation of one or more modules will demonstrate that progress is being made and that at least part of the system is ready to begin serving the end users.

As useful as modules are, they represent ER model fragments. Fragmentation creates a potential problem: the fragments might not include all of the ER model's components and might not, therefore, be able to support all of the required processes. To avoid that problem, the modules must be verified against the complete ER model. That verification process is detailed in Table 9.3.

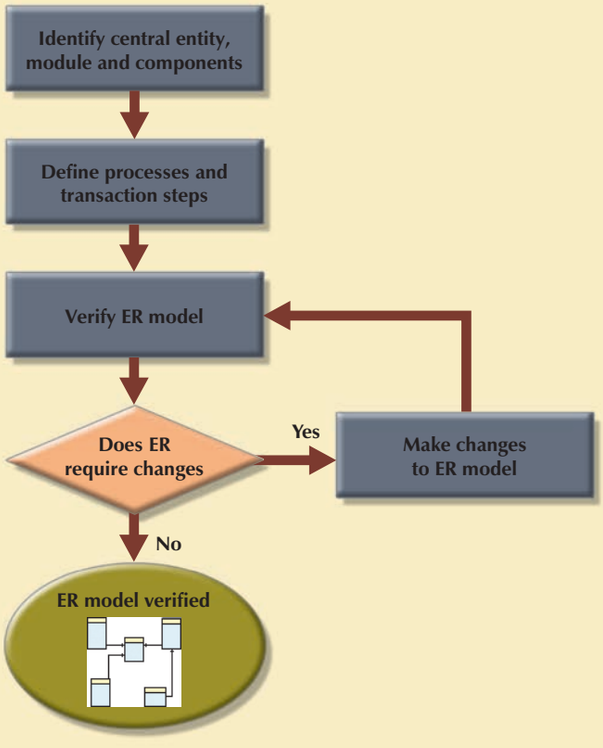
TABLE 9.3 The ER Model Verification Process

STEP	ACTIVITY
1	Identify the ER model's central entity.
2	Identify each module and its components.
3	Identify each module's transaction requirements: Internal: Updates/Inserts/Deletes/ Queries/Reports External: Module interfaces
4	Verify all processes against the ER model.
5	Make all necessary changes suggested in Step 4.
6	Repeat Steps 2–5 for all modules.

Keep in mind that the verification process requires the continuous verification of business transactions as well as system and user requirements. The verification sequence must be repeated for each of the system's modules. Figure 9.10 illustrates the iterative nature of the process.

The verification process starts with selecting the central (most important) entity. The central entity is defined in terms of its participation in most of the model's relationships, and it is the focus for most of the system's operations. In other words, to identify the central entity, the designer selects the entity involved in the greatest number of relationships. In the ER diagram, it is the entity that has more lines connected to it than any other.

FIGURE 9.10 Iterative ER model verification process



The next step is to identify the module or subsystem to which the central entity belongs and to define that module's boundaries and scope. The entity belongs to the module that uses it most frequently. Once each module is identified, the central entity is placed within the module's framework to let you focus your attention on the module's details.

Within the central entity/module framework, you must:

- *Ensure the module's cohesivity.* The term **cohesivity** describes the strength of the relationships found among the module's entities. A module must display *high cohesivity*—that is, the entities must be strongly related, and the module must be complete and self-sufficient.
- *Analyze each module's relationships with other modules to address module coupling.* **Module coupling** describes the extent to which modules are independent of one another. Modules must display *low coupling*, indicating that they are independent of other modules. Low coupling decreases unnecessary intermodule dependencies, thereby allowing the creation of a truly modular system and eliminating unnecessary relationships among entities.

Processes may be classified according to their:

- Frequency (daily, weekly, monthly, yearly, or exceptions).
- Operational type (INSERT or ADD, UPDATE or CHANGE, DELETE, queries and reports, batches, maintenance, and backups).

All identified processes must be verified against the ER model. If necessary, appropriate changes are implemented. The process verification is repeated for all of the model's modules. You can expect that additional entities and attributes will be incorporated into the conceptual model during its validation.

At this point, a conceptual model has been defined as hardware- and software-independent. Such independence ensures the system's portability across platforms. Portability can extend the database's life by making it possible to migrate to another DBMS and/or another hardware platform.

Distributed Database Design Portions of a database may reside in several physical locations. Processes that access the database may also vary from one location to another. For example, a retail process and a warehouse storage process are likely to be found in different physical locations. If the database process is to be distributed across the system, the designer must also develop the data distribution and allocation strategies for the database. The design complications introduced by distributed processes are examined in detail in Chapter 12, Distributed Database Systems.

II. DBMS Software Selection

The selection of DBMS software is critical to the information system's smooth operation. Consequently, the advantages and disadvantages of the proposed DBMS software should be carefully studied. To avoid false expectations, the end user must be made aware of the limitations of both the DBMS and the database.

Although the factors affecting the purchasing decision vary from company to company, some of the most common are:

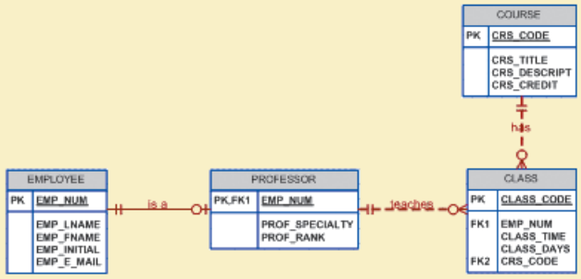
- *Cost*. This includes the original purchase price, along with maintenance, operational, license, installation, training, and conversion costs.
- *DBMS features and tools*. Some database software includes a variety of tools that facilitate the application development task. For example, the availability of query by example (QBE), screen painters, report generators, application generators, data dictionaries, and so on, helps to create a more pleasant work environment for both the end user and the application programmer. Database administrator facilities, query facilities, ease of use, performance, security, concurrency control, transaction processing, and third-party support also influence DBMS software selection.
- *Underlying model*. This can be hierarchical, network, relational, object/relational, or object-oriented.
- *Portability*. A DBMS can be portable across platforms, systems, and languages.
- *DBMS hardware requirements*. Items to consider include processor(s), RAM, disk space, and so on.

III. Logical Design

Logical design translates the conceptual design into the internal model for a selected database management system (DBMS) such as DB2, SQL Server, MySQL, Oracle, and Access. Therefore, the logical design is software-dependent.

Logical design requires that all objects in the model be mapped to the specific constructs used by the selected database software. For example, the logical design for a relational DBMS includes the specifications for the tables, indexes, views, transactions, access authorizations, and so on. In the following discussion, a small portion of the simple conceptual model shown in Figure 9.11 is converted into a logical design based on the relational model.

FIGURE 9.11 **A simple conceptual model**



The translation of the conceptual model in Figure 9.11 requires the definition of the attribute domains, design of the required tables, and appropriate access restriction formats. For example, the domain definitions for the CLASS_CODE, CLASS_DAYS, and CLASS_TIME attributes displayed in the CLASS entity in Figure 9.11 are written this way:

CLASS_CODE	is a valid class code. Type: numeric Range: low value = 1000 high value = 9999 Display format: 9999 Length: 4
CLASS_DAYS	is a valid day code. Type: character Display format: XXX Valid entries: MWF, TTh, M, T, W, Th, F, S Length: 3
CLASS_TIME	is a valid time. Type: character Display format: 99:99 (24-hour clock) Display range: 06:00 to 22:00 Length: 5

The logical design's tables must correspond to the entities (EMPLOYEE, PROFESSOR, COURSE, and CLASS) shown in the conceptual design of Figure 9.11, and the table columns must correspond to the attributes specified in the conceptual design. For example, the initial table layout for the COURSE table might look like Table 9.4.

TABLE 9.4 Sample Layout for the COURSE Table

CRS_CODE	CRS_TITLE	CRS_DESCRIPT	CRS_CREDIT
CIS-4567	Database Systems Design	Design and implementation of database systems; includes conceptual design, logical design, implementation, and management; prerequisites: CIS 2040, CIS 2345, CIS 3680, and upper-division standing	4
QM-3456	Statistics II	Statistical applications; course requires use of statistical software (MINITAB and SAS) to interpret data; prerequisites: MATH 2345 and QM 2233	3

The right to use the database is also specified during the logical design phase. Who will be allowed to use the tables, and what portion(s) of the table(s) will be available to which users? Within a relational framework, the answers to those questions require the definition of appropriate access rights and views.

The logical design translates the software-independent conceptual model into a software-dependent model by defining the appropriate domain definitions, the required tables, and the necessary access restrictions. The stage is now set to define the physical requirements that allow the system to function within the selected hardware environment.

IV. Physical Design

Physical design is the process of selecting the data storage and data access characteristics of the database. The storage characteristics are a function of the types of devices supported by the hardware, the type of data access methods supported by the system, and the DBMS. Physical design affects not only the location of the data in the storage device(s), but also the performance of the system.

Physical design is a very technical job, more typical of the client/server and mainframe world than of the PC world. Yet even in the more complex midrange and mainframe environments, modern database software has assumed much of the burden of the physical portion of the design and its implementation.

ONLINE CONTENT

Physical design is particularly important in the older hierarchical and network models described in **Appendixes K** and **L, The Hierarchical Database Model** and **The Network Database Model,** respectively, in the Student Online Companion. Relational databases are more insulated from physical details than the older hierarchical and network models.

In spite of the fact that relational models tend to hide the complexities of the computer's physical characteristics, the performance of relational databases is affected by physical characteristics. For example, performance can be affected by the characteristics of the storage media, such as seek time, sector and block (page) size, buffer pool size, and the number of disk platters and read/write heads. In addition, factors such as the creation of an index can have a considerable effect on the relational database's performance, that is, data access speed and efficiency.

Even the type of data request must be analyzed carefully to determine the optimum access method for meeting the application requirements, establishing the data volume to be stored, and estimating the performance. Some DBMSs automatically reserve the space required to store the database definition and the user's data in permanent storage devices. This ensures that the data are stored in sequentially adjacent locations, thereby reducing data access time and

increasing system performance. (Database performance tuning is covered in detail in Chapter 11, Database Performance Tuning and Query Optimization.)

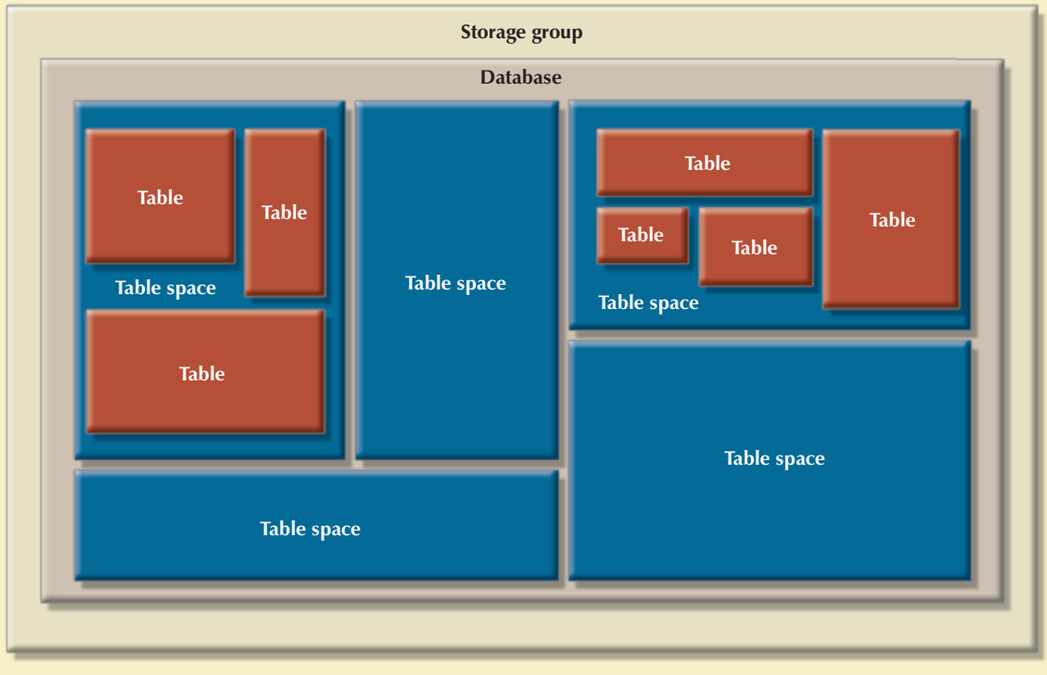
Physical design becomes more complex when data are distributed at different locations because the performance is affected by the communication media's throughput. Given such complexities, it is not surprising that designers favor database software that hides as many of the physical-level activities as possible.

The preceding sections have separated the discussions of logical and physical design activities. In fact, logical and physical design can be carried out in parallel, on a table-by-table (or file-by-file) basis. Logical and physical design can also be carried out in parallel when the designer is working with hierarchical and network models. Such parallel activities require the designer to have a thorough understanding of the software and hardware in order to take full advantage of both software and hardware characteristics.

9.3.3 Implementation and Loading

In most modern relational DBMSs, such as IBM DB2, Microsoft SQL Server, and Oracle, a new database implementation requires the creation of special storage-related constructs to house the end-user tables. The constructs usually include the storage group, the table space, and the tables. See Figure 9.12. Note that a table space may contain more than one table.

FIGURE 9.12 **Physical organization of a DB2 database environment**



For example, the implementation of the logical design in IBM's DB2 would require that you:

1. *Create the database storage group.* This step (done by the system administrator or SYSADM) is mandatory for such mainframe databases as DB2. Other DBMS software may create equivalent storage groups automatically when a database is created. (See Step 2.) Consult your DBMS documentation to see if you must create a storage group and, if so, what the command syntax must be.

2. Create the database within the storage group (also done by the SYSADM).
3. Assign the rights to use the database to a database administrator (DBADM).
4. Create the table space(s) within the database (usually done by a DBADM).
5. Create the table(s) within the table space(s) (also usually done by a DBADM). A generic SQL table creation might look like this:

```
CREATE TABLE COURSE (
CRS_CODE        CHAR(10) NOT NULL,
CRS_TITLE       CHAR(C15) NOT NULL,
CRS_DESCRIPT    CHARC(8) NOT NULL
CRS_CREDIT NUMBER,
PRIMARY KEY (CRS_CODE));
CREATE TABLE CLASS (
CLASS_CODE      CHAR(4) NOT NULL,
CLASS_DAYS      CHAR(3) NOT NULL,
CLASS_TIME      CHAR(14) NOT NULL,
CLASS_DAY       CHAR(3) NOT NULL,
CRS_CODE        CHAR(10) NOT NULL,
PRIMARY KEY (CLASS_CODE),
FOREIGN KEY (CRS_CODE) REFERENCES COURSE;
```

   (Note that the COURSE table is created first because it is referenced by the CLASS table.)
6. Assign access rights to the table spaces and to the tables within specified table spaces (another DBADM duty). Access rights may be limited to views rather than to whole tables. The creation of views is not required for database access in the relational environment, but views are desirable from a security standpoint.

   Access rights to a table named PROFESSOR may be granted to a person whose identification code is PROB by typing:

```
GRANT USE OF TABLE PROFESSOR
TO PROB;
```

   A view named PROF may be substituted for the PROFESSOR table:

```
CREATE VIEW PROF
SELEC           TEMP_LNAME
FROM            EMPLOYEE
WHERE           PROFESSOR.EMP_NUM = EMPLOYEE.EMP_NUM;
```

After the database has been created, the data must be loaded into the database tables. If the data are currently stored in a format different from that required by the new DBMS, the data must be converted prior to being loaded.

NOTE

The following summary of database implementation activities assumes the use of a sophisticated DBMS. All current generation DBMSs offer the features discussed next.

During the implementation and loading phase, you also must address performance, security, backup and recovery, integrity, and company standards. They will be discussed next.

Performance

Database performance is one of the most important factors in certain database implementations. Chapter 11 covers the subject in greater detail. However, not all DBMSs have performance-monitoring and fine-tuning tools embedded in their software, thus making it difficult to evaluate performance.

Performance evaluation is also rendered more difficult because there is no standard measurement for database performance. Performance varies according to the hardware and software environment used. Naturally, the database's size also affects database performance: a search of 10 tuples will be faster than a search of 100,000 tuples.

Important factors in database performance also include system and database configuration parameters, such as data placement, access path definition, the use of indexes, and buffer size.

Security

Data stored in the company database must be protected from access by unauthorized users. (It does not take much imagination to predict the likely results when students have access to a student database or when employees have access to payroll data!) Consequently, you must provide for (at least) the following:

- *Physical security* allows only authorized personnel physical access to specific areas. Depending on the type of database implementation, however, establishing physical security might not always be practical. For example, a university student research database is not a likely candidate for physical security. The existence of large multiserver PC networks often makes physical security impractical.
- *Password security* allows the assignment of access rights to specific authorized users. Password security is usually enforced at logon time at the operating system level.
- *Access rights* can be established through the use of database software. The assignment of access rights may restrict operations (CREATE, UPDATE, DELETE, and so on) on predetermined objects such as databases, tables, views, queries, and reports.
- *Audit trails* are usually provided by the DBMS to check for access violations. Although the audit trail is an after-the-fact device, its mere existence can discourage unauthorized use.
- *Data encryption* can be used to render data useless to unauthorized users who might have violated some of the database security layers.
- *Diskless workstations* allow end users to access the database without being able to download the information from their workstations.

For a more detailed discussion of security issues, please refer to Chapter 15, Database Administration and Security.

Backup and Recovery

Timely data availability is crucial for almost every database. Unfortunately, the database can be subject to data loss through unintended data deletion, power outages, and so on. Data backup and recovery (restore) procedures create a safety valve, allowing the database administrator to ensure the availability of consistent data. Typically, database vendors encourage the use of fault-tolerant components such as uninterruptible power supply (UPS) units, RAID storage devices, clustered servers, and data replication technologies to ensure the continuous operation of the database in case of a hardware failure. Even with these components, backup and restore functions constitute a very important component of daily database operations. Some DBMSs provide functions that allow the database administrator to schedule automatic database backups to permanent storage devices such as disks, DVDs, and tapes. Database backups can be performed at different levels:

- A **full backup** of the database, or *dump* of the entire database. In this case, all database objects are backed up in their entirety.

- A **differential backup** of the database, in which only the last modifications to the database (when compared with a previous full backup copy) are copied. In this case, only the objects that have been updated since the last full backup are backed up.
- A **transaction log backup**, which backs up only the transaction log operations that are not reflected in a previous backup copy of the database. In this case, only the transaction log is backed up; no other database objects are backed up. (For a complete explanation of the use of the transaction log see Chapter 10, Transaction Management and Concurrency Control.)

The database backup is stored in a secure place, usually in a different building from the database itself, and is protected against dangers such as fire, theft, flood, and other potential calamities. The main purpose of the backup is to guarantee database restoration following system (hardware/software) failures.

Failures that plague databases and systems are generally induced by software, hardware, programming exemptions, transactions, or external factors. Table 9.5 briefly summarizes the most common sources of database failure.

TABLE 9.5 Common Sources of Database Failure

SOURCE	DESCRIPTION	EXAMPLE
Software	Software-induced failures may be traceable to the operating system, the DBMS software, application programs, or viruses.	The SQL.Slammer worm affected many unpatched MS SQL Server systems in 2003 causing damages valued in millions of dollars.
Hardware	Hardware-induced failures may include memory chip errors, disk crashes, bad disk sectors, and "disk full" errors.	A bad memory module or a multiple hard disk failure in a database system can bring a database system to an abrupt stop.
Programming exemptions	Application programs or end users may roll back transactions when certain conditions are defined. Programming exemptions can also be caused by malicious or improperly tested code that can be exploited by hackers.	Hackers constantly searching for exploits in unprotected Web database systems.
Transactions	The system detects deadlocks and aborts one of the transactions. (See Chapter 10.)	Deadlock occurs when executing multiple simultaneous transactions.
External factors	Backups are especially important when a system suffers complete destruction due to fire, earthquake, flood, or other natural disaster.	The 2005 Katrina hurricane in New Orleans caused data losses in the millions of dollars.

Depending on the type and extent of the failure, the recovery process ranges from a minor short-term inconvenience to a major long-term rebuild. Regardless of the extent of the required recovery process, recovery is not possible without a usable backup.

The database recovery process generally follows a predictable scenario. First, the type and extent of the required recovery are determined. If the entire database needs to be recovered to a consistent state, the recovery uses the most recent backup copy of the database in a known consistent state. The backup copy is then rolled forward to restore all subsequent transactions by using the transaction log information. If the database needs to be recovered but the committed portion of the database is still usable, the recovery process uses the transaction log to "undo" all of the transactions that were not committed.

Integrity

Data integrity is enforced by the DBMS through the proper use of primary and foreign key rules. In addition, data integrity is also the result of properly implemented data management policies. Such policies are part of a comprehensive data administration framework. For a more detailed study of this topic, see The DBA's Managerial Role section in Chapter 15.

Company Standards

Database standards may be partially defined by specific company requirements. The database administrator must implement and enforce such standards.

9.3.4 Testing and Evaluation

Once the data have been loaded into the database, the DBA tests and fine-tunes the database for performance, integrity, concurrent access, and security constraints. The testing and evaluation phase occurs in parallel with applications programming.

Programmers use database tools to *prototype* the applications during coding of the programs. Tools such as report generators, screen painters, and menu generators are especially useful to the applications programmers during the prototyping phase.

If the database implementation fails to meet some of the system's evaluation criteria, several options may be considered to enhance the system:

- For performance-related issues, the designer must consider fine-tuning specific system and DBMS configuration parameters. The best sources of information are the hardware and software technical reference manuals.
- Modify the physical design. (For example, the proper use of indexes tends to be particularly effective in facilitating pointer movements, thus enhancing performance.)
- Modify the logical design.
- Upgrade or change the DBMS software and/or the hardware platform.

9.3.5 Operation

Once the database has passed the evaluation stage, it is considered to be operational. At that point, the database, its management, its users, and its application programs constitute a complete information system.

The beginning of the operational phase invariably starts the process of system evolution. As soon as all of the targeted end users have entered the operations phase, problems that could not have been foreseen during the testing phase begin to surface. Some of the problems are serious enough to warrant emergency "patchwork," while others are merely minor annoyances. For example, if the database design is implemented to interface with the Web, the sheer volume of transactions might cause even a well-designed system to bog down. In that case, the designers have to identify the source(s) of the bottleneck(s) and produce alternative solutions. Those solutions may include using load-balancing software to distribute the transactions among multiple computers, increasing the available cache for the DBMS, and so on. In any case, the demand for change is the designer's constant concern, which leads to phase 6, maintenance and evolution.

9.3.6 Maintenance and Evolution

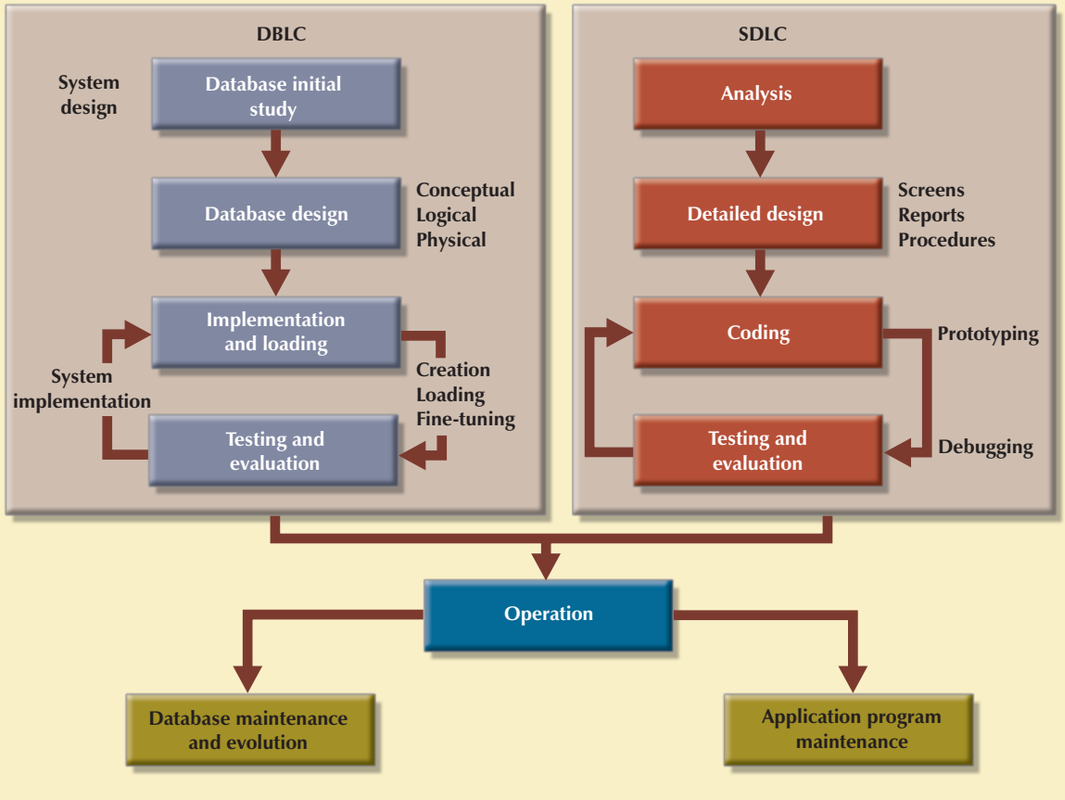
The database administrator must be prepared to perform routine maintenance activities within the database. Some of the required periodic maintenance activities include:

- Preventive maintenance (backup).
- Corrective maintenance (recovery).
- Adaptive maintenance (enhancing performance, adding entities and attributes, and so on).
- Assignment of access permissions and their maintenance for new and old users.
- Generation of database access statistics to improve the efficiency and usefulness of system audits and to monitor system performance.
- Periodic security audits based on the system-generated statistics.
- Periodic (monthly, quarterly, or yearly) system-usage summaries for internal billing or budgeting purposes.

The likelihood of new information requirements and the demand for additional reports and new query formats require application changes and possible minor changes in the database components and contents. Those changes can be easily implemented only when the database design is flexible and when all documentation is updated and online. Eventually, even the best-designed database environment will no longer be capable of incorporating such evolutionary changes; then the whole DBLC process begins anew.

You should not be surprised to discover that many of the activities described in the Database Life Cycle (DBLC) remind you of those in the Systems Development Life Cycle (SDLC). After all, the SDLC represents the framework within which the DBLC activities take place. A summary of the parallel activities that take place within the SDLC and the DBLC is shown in Figure 9.13.

FIGURE 9.13 Parallel activities in the DBLC and the SDLC



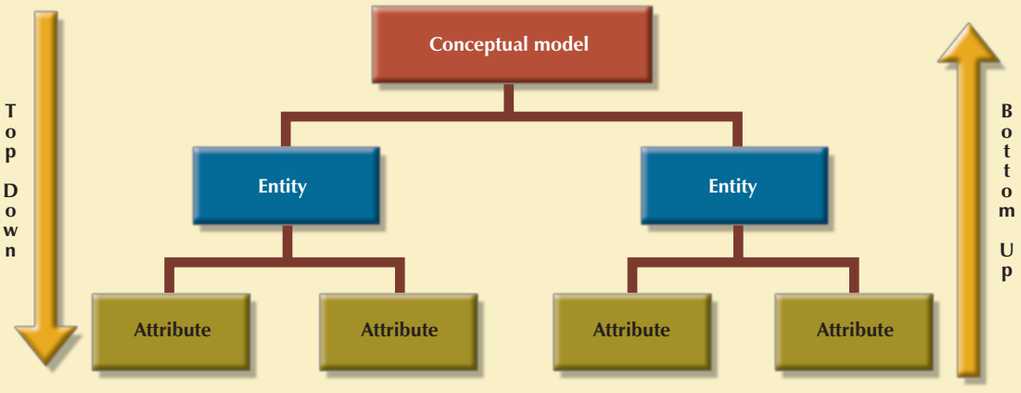
9.4 DATABASE DESIGN STRATEGIES

There are two classical approaches to database design:

- **Top-down design** starts by identifying the data sets, and then defines the data elements for each of those sets. This process involves the identification of different entity types and the definition of each entity's attributes.
- **Bottom-up design** first identifies the data elements (items), and then groups them together in data sets. In other words, it first defines attributes, and then groups them to form entities.

The two approaches are illustrated in Figure 9.14. The selection of a primary emphasis on top-down or bottom-up procedures often depends on the scope of the problem or on personal preferences. Although the two methodologies are complementary rather than mutually exclusive, a primary emphasis on a bottom-up approach may be more productive for small databases with few entities, attributes, relations, and transactions. For situations in which the number, variety, and complexity of entities, relations, and transactions is overwhelming, a primarily top-down approach may be more easily managed. Most companies have standards for systems development and database design already in place.

FIGURE 9.14 Top-down vs. bottom-up design sequencing



NOTE

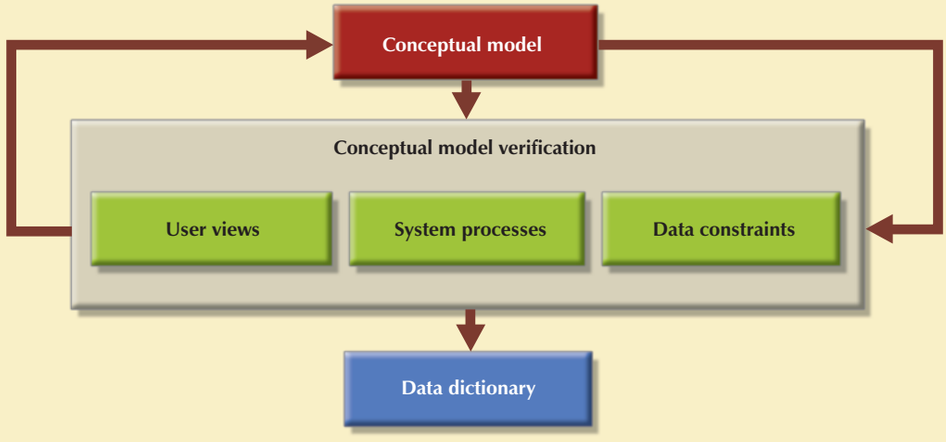
Even when a primarily top-down approach is selected, the normalization process that revises existing table structures is (inevitably) a bottom-up technique. ER models constitute a top-down process even when the selection of attributes and entities can be described as bottom-up. Because both the ER model and normalization techniques form the basis for most designs, the top-down vs. bottom-up debate may be based on a theoretical distinction rather than an actual difference.

9.5 CENTRALIZED VS. DECENTRALIZED DESIGN

The two general approaches (bottom-up and top-down) to database design can be influenced by factors such as the scope and size of the system, the company's management style, and the company's structure (centralized or decentralized). Depending on such factors, the database design may be based on two very different design philosophies: centralized and decentralized.

Centralized design is productive when the data component is composed of a relatively small number of objects and procedures. The design can be carried out and represented in a fairly simple database. Centralized design is typical of relatively simple and/or small databases and can be successfully done by a single person (database administrator) or by a small, informal design team. The company operations and the scope of the problem are sufficiently limited to allow even a single designer to define the problem(s), create the conceptual design, verify the conceptual design with the user views, define system processes and data constraints to ensure the efficacy of the design, and ensure that the design will comply with all the requirements. (Although centralized design is typical for small companies, do not make the mistake of assuming that centralized design is limited to small companies. Even large companies can operate within a relatively simple database environment.) Figure 9.15 summarizes the centralized design option. Note that a single conceptual design is completed and then validated in the centralized design approach.

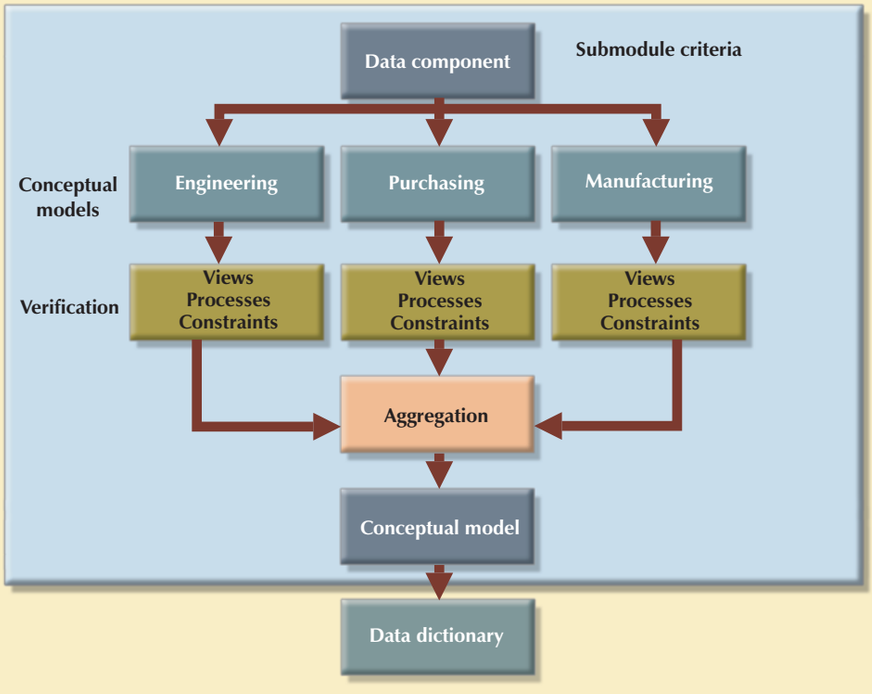
FIGURE 9.15 Centralized design



Decentralized design might be used when the data component of the system has a considerable number of entities and complex relations on which very complex operations are performed. Decentralized design is also likely to be employed when the problem itself is spread across several operational sites and each element is a subset of the entire data set. See Figure 9.16.

In large and complex projects, the database design typically cannot be done by only one person. Instead, a carefully selected team of database designers is employed to tackle a complex database project. Within the decentralized design framework, the database design task is divided into several modules. Once the design criteria have been established, the lead designer assigns design subsets or modules to design groups within the team.

FIGURE 9.16 Decentralized design

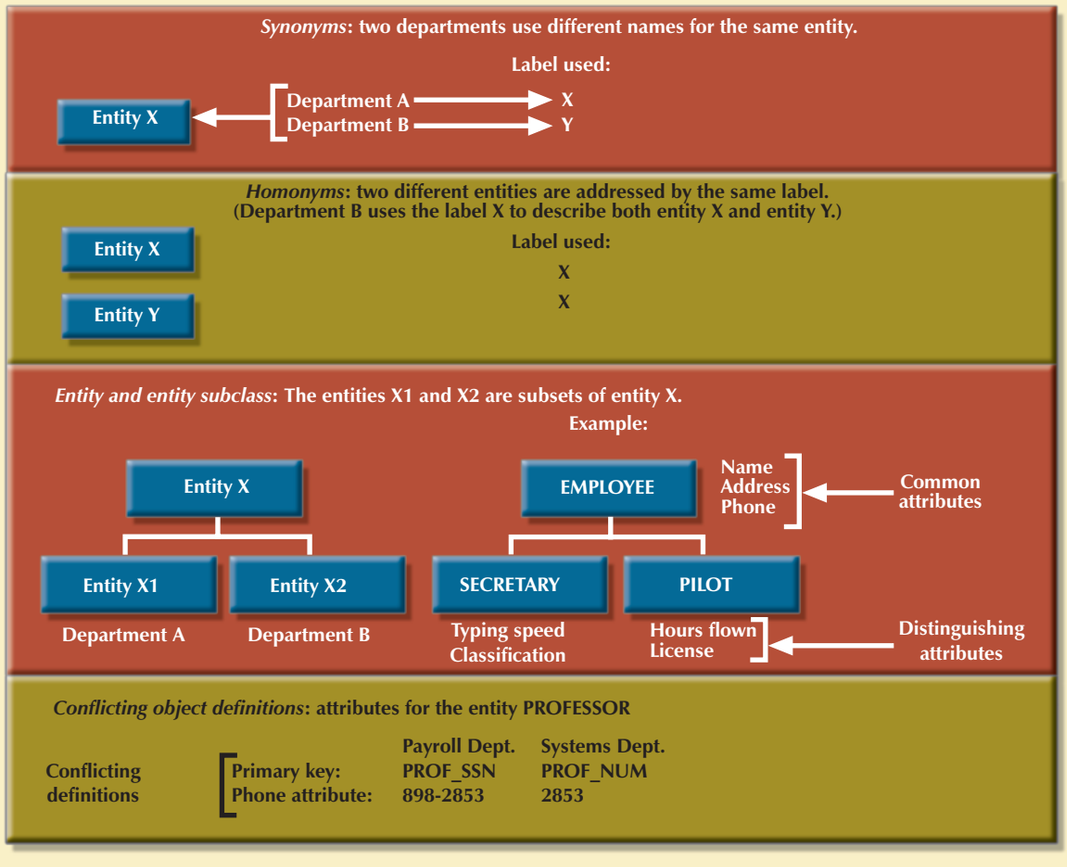


Because each design group focuses on modeling a subset of the system, the definition of boundaries and the interrelation among data subsets must be very precise. Each design group creates a conceptual data model corresponding to the subset being modeled. Each conceptual model is then verified individually against the user views, processes, and constraints for each of the modules. After the verification process has been completed, all modules are integrated into one conceptual model. Because the data dictionary describes the characteristics of all objects within the conceptual data model, it plays a vital role in the integration process. Naturally, after the subsets have been aggregated into a larger conceptual model, the lead designer must verify that the combined conceptual model is still able to support all of the required transactions.

Keep in mind that the aggregation process requires the designer to create a single model in which various aggregation problems must be addressed. See Figure 9.17.

- *Synonyms and homonyms*. Various departments might know the same object by different names (synonyms), or they might use the same name to address different objects (homonyms). The object can be an entity, an attribute, or a relationship.
- *Entity and entity subtypes*. An entity subtype might be viewed as a separate entity by one or more departments. The designer must integrate such subtypes into a higher-level entity.
- *Conflicting object definitions*. Attributes can be recorded as different types (character, numeric), or different domains can be defined for the same attribute. Constraint definitions, too, can vary. The designer must remove such conflicts from the model.

FIGURE 9.17 Summary of aggregation problems



SUMMARY

- An information system is designed to facilitate the transformation of data into information and to manage both data and information. Thus, the database is a very important part of the information system. Systems analysis is the process that establishes the need for and the extent of an information system. Systems development is the process of creating an information system.
- The Systems Development Life Cycle (SDLC) traces the history (life cycle) of an application within the information system. The SDLC can be divided into five phases: planning, analysis, detailed systems design, implementation, and maintenance. The SDLC is an iterative rather than a sequential process.
- The Database Life Cycle (DBLC) describes the history of the database within the information system. The DBLC is composed of six phases: database initial study, database design, implementation and loading, testing and evaluation, operation, and maintenance and evolution. Like the SDLC, the DBLC is iterative rather than sequential.
- The database design and implementation process moves through a series of well-defined stages: database initial study, database design, implementation and loading, testing and evaluation, operation, and maintenance and evolution.
- The conceptual portion of the design may be subject to several variations based on two basic design philosophies: bottom-up vs. top-down and centralized vs. decentralized.

KEY TERMS

bottom-up design, 402
boundaries, 383
centralized design, 403
cohesivity, 394
computer-aided systems engineering (CASE), 378
conceptual design, 385
database development, 374
Database Life Cycle (DBLC), 378
decentralized design, 404
description of operations, 387
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Systems Development Life Cycle (SDLC), 373
top-down design, 402
transaction log backup, 400

ONLINE CONTENT

Answers to selected Review Questions and Problems for this chapter are contained in the Student Online Companion for this book.

REVIEW QUESTIONS

1. What is an information system? What is its purpose?
2. How do systems analysis and systems development fit into a discussion about information systems?
3. What does the acronym SDLC mean, and what does an SDLC portray?
4. What does the acronym DBLC mean, and what does a DBLC portray?
5. Discuss the distinction between centralized and decentralized conceptual database design.

6. What is the minimal data rule in conceptual design? Why is it important?
7. Discuss the distinction between top-down and bottom-up approaches in database design.
8. What are business rules? Why are they important to a database designer?
9. What is the data dictionary's function in database design?
10. What steps are required in the development of an ER diagram? (*Hint*: See Table 9.1.)
11. List and briefly explain the activities involved in the verification of an ER model.
12. What factors are important in a DBMS software selection?
13. What three levels of backup may be used in database recovery management? Briefly describe what each of those three backup levels does.

PROBLEMS

1. The ABC Car Service & Repair Centers are owned by the SILENT car dealer; ABC services and repairs only SILENT cars. Three ABC Car Service & Repair Centers provide service and repair for the entire state.

   Each of the three centers is independently managed and operated by a shop manager, a receptionist, and at least eight mechanics. Each center maintains a fully stocked parts inventory.

   Each center also maintains a manual file system in which each car's maintenance history is kept: repairs made, parts used, costs, service dates, owner, and so on. Files are also kept to track inventory, purchasing, billing, employees' hours, and payroll.

   You have been contacted by the manager of one of the centers to design and implement a computerized database system. Given the preceding information, do the following:

   a. Indicate the most appropriate sequence of activities by labeling each of the following steps in the correct order. (For example, if you think that "Load the database." is the appropriate first step, label it "1.")

      _____ Normalize the conceptual model.
      _____ Obtain a general description of company operations.
      _____ Load the database.
      _____ Create a description of each system process.
      _____ Test the system.
      _____ Draw a data flow diagram and system flowcharts.
      _____ Create a conceptual model using ER diagrams.
      _____ Create the application programs.
      _____ Interview the mechanics.
      _____ Create the file (table) structures.
      _____ Interview the shop manager.

   b. Describe the various modules that you believe the system should include.
   c. How will a data dictionary help you develop the system? Give examples.
   d. What general (system) recommendations might you make to the shop manager? (For example, if the system will be integrated, what modules will be integrated? What benefits would be derived from such an integrated system? Include several general recommendations.)
   e. What is the best approach to conceptual database design? Why?
   f. Name and describe at least four reports the system should have. Explain their use. Who will use those reports?

2. Suppose you have been asked to create an information system for a manufacturing plant that produces nuts and bolts of many shapes, sizes, and functions. What questions would you ask, and how would the answers to those questions affect the database design?
   a. What do you envision the SDLC to be?
   b. What do you envision the DBLC to be?
3. Suppose you perform the same functions noted in Problem 2 for a larger warehousing operation. How are the two sets of procedures similar? How and why are they different?
4. Using the same procedures and concepts employed in Problem 1, how would you create an information system for the Tiny College example in Chapter 4?
5. Write the proper sequence of activities in the design of a video rental database. (The initial ERD was shown in Figure 9.7.) The design must support all rental activities, customer payment tracking, and employee work schedules, as well as track which employees checked out the videos to the customers. After you finish writing the design activity sequence, complete the ERD to ensure that the database design can be successfully implemented. (Make sure that the design is normalized properly and that it can support the required transactions.)