Data Management

Databases and Data Analytics

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You can purchase a physical version of the book from Prospect Press.

Preface

The pedagogical advantages of this text

This is not your traditional database textbook. It differs in three fundamental ways.

First, it is deeper than most database books in its coverage of data modeling and SQL. The market seeks graduates who have these fundamental skills. Time and again, students who have completed my data management class have told me how these skills have been invaluable in their first and subsequent jobs. The book places great emphasis on the core skills of data management. Consequently, there is a better match between the skills you develop and those the market needs. This means you will find this text highly relevant.

Second, the treatments of data modeling and SQL are intertwined because my database teaching experience indicates that students more readily understand the purpose of data modeling when they grasp the long-term goal—querying a well-designed relational database. The double helix, upward, intertwined, spiraling of data modeling and SQL is a unique pedagogical feature. Classroom testing indicates it is a superior method of teaching compared to handling data modeling and SQL separately. You will quickly understand the reason for data modeling and appreciate why it is a valuable skill. Also, rapid exposure to SQL means you gain hands-on experience more quickly.

Third, the book is broader than most database books. Databases are one component of an expansive organizational memory. You need to develop a wide perspective of data management if you are to comprehend fully the organizational role of information systems.

This book is deeper where it matters—data modeling and SQL—and broader to give you a managerial outlook and an understanding of the latest technological advancements. Information is a key resource for modern organizations. It is a critical input to managerial tasks. Because managers need high-quality information to manage change in a turbulent, global environment, nearly every organizations has established systems for storing and retrieving data, the raw material of information. These storage and retrieval systems are an organization's memory. The organization relies on them, just as individuals rely on their personal memory, to be able to continue as a going concern.

Overview of the text

The central concern of information systems management is to design, build, and maintain information delivery systems. Information systems managers needs to discover their organization's information requirements, which includes the needs of its customers, so that it can design systems to serve these demands. It must merge a system's design and information technology to build applications that provide the organization and its customers with data in a timely manner, appropriate formats, and at convenient locations. Furthermore, it must manage applications so they evolve to meet changing needs, continue to operate under adverse conditions, and are protected from unauthorized access.

An information delivery system has two components: data and processes. This book concentrates on data, which is customarily thought of as a database. I deliberately set out to extend this horizon, however, by including all forms of organizational data stores because I believe you need to understand the role of data management that is aligned with current practice. In my view, data management is the design and maintenance of computer-based organizational memory. Thus, you will find chapters on XML and organizational intelligence technologies.

The decision to start the book with a managerial perspective arises from the observation that successful information systems practice is based on matching managerial needs, social system constraints, and technical opportunities in an ecologically sound way. I want you to appreciate the big picture before you become immersed in the intricacies of data modeling and SQL.

The second section of the book provides in-depth coverage of data modeling and SQL. Data modeling is the foundation of database quality. A solid grounding in data modeling principles and extensive practice are necessary for successful database design. In addition, this section exposes you to the full power of SQL.

I intend this book to be a long-term investment. There are useful reference sections for data modeling and SQL. The data modeling section details the standard structures and their relational mappings. The SQL section contains an extensive list of queries that serves as a basis for developing other SQL queries. The purpose of these sections is to facilitate pattern matching. For example, if you have an SQL query that is similar to a previous problem you can rapidly search the SQL reference section to find the closest match. You can then use the model answer as a guide to formulating the SQL query for the problem at hand. These reference sections are another unique teaching feature that will serve you well during the course and in your career.

The third section, Data Science & Advanced Data Management, has chapters on R, a statistics and graphics package, which provides the foundation necessary for the chapters on data visualization, text mining, cluster computing, and dashboards. These chapters provide you with the skills they need to work in topical areas such as data analytics. The advanced data management portion of this section covers spatial and temporal data, XML, and graph databases.

The fourth and final section examines the management of organizational data stores. It covers data structures and storage, data processing architectures, SQL and Java, and data integrity.

Benefits of studying this text

As a result of completing this text you will

- have a broad, managerial perspective of an organization's need for a memory;
- be able to design and create a relational database;
- be able to formulate complex SQL queries;

- be able to use R to create data visualizations, mine text data, write an R script for big data problems, and create dashboards;
- understand the purpose of XML and be able to design an XML schema, prepare an XML document, and write an XML stylesheet;
- be able to use Cypher to query a graph database
- have a sound understanding of database architectures and their managerial implications;
- be able to write a Java program to create a table from a CSV file and process a transaction.
- understand the fundamentals of data integrity.

My goal is to give you a data management text that is innovative, relevant, and lively. I trust that you will enjoy learning about managing data in today's organization.

Supplements

Accompanying this book are an instructor's manual and an extensive Web site [www.richardtwatson.com] that provides - over 80 SQL exercises for the ClassicModels database {https://www.richardtwatson.com/open/Reader/ClassicModels.html} [https://www.richardtwatson.com/open/Reader/ClassicModels.html] that gradually increase in difficulty and demonstrate useful business applications, such as a basket-of-goods analysis;
- slides in PowerPoint format; - all relational tables in the book as a set of insert statements; - code for examples in the book; - the answers to every second exercise; - answers to the skill builder exercises found in each chapter - additional exercises at the end of each chapter.

Acknowledgments

I thank my wife, Clare, and son, Ned, for help with prior editions of the book. I appreciate the efforts of Christopher Gauthier in converting the prior edition to Bookdown format.

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Melbourne, Australia

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Section 1 The Managerial Perspective

> *People only see what they are prepared to see.*
>
> Ralph Waldo Emerson, *Journals*, 1863

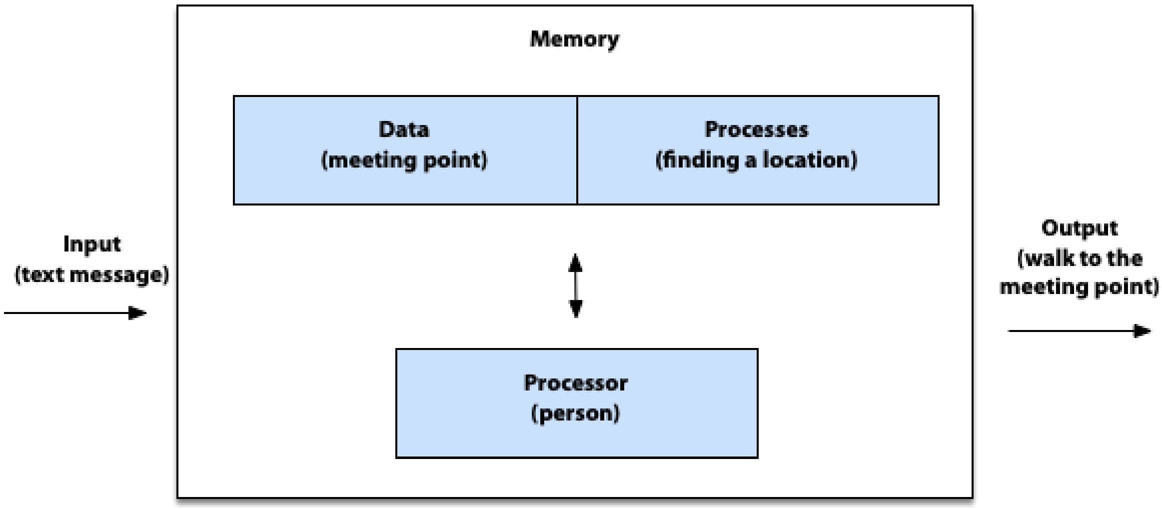
Organizations are accumulating vast volumes of data because of the ease with which data can be captured and distributed in digital format (e.g., smartphone cameras and tweets). The world's data are estimated to be doubling every 1–2 years, and large companies now routinely manage petabytes (10^{15} bytes) of data every day. Data management is a critical function for many organizations.

The first section of this book prepares you to see the role of data and information in an organization. The managerial perspective on data management concentrates on why enterprises design and maintain data management systems, or organizational memories. Chapter 1 examines this topic by detailing the components of organizational memory and then discussing some of its common problems. The intention is to make you aware of the scope of data management and its many facets. Chapter 2 discusses the relationship between information and organizational goals. Again, a very broad outlook is adopted in order to provide a sweeping perspective on the relationship of information to organizational success and change.

At this point, we want to give you some maps for understanding the territory you will explore. Since the terrain is possibly very new, these maps initially may be hard to read, and so you may need to consult them several times before you understand the landscape you are about to enter.

The first map is based on the Newell-Simon model[1] of the human information processing system, which shows that humans receive input, process it, and produce output. The processing is done by a processor, which is linked to a memory that stores both data and processes. The processor component retrieves both data and processes from memory.

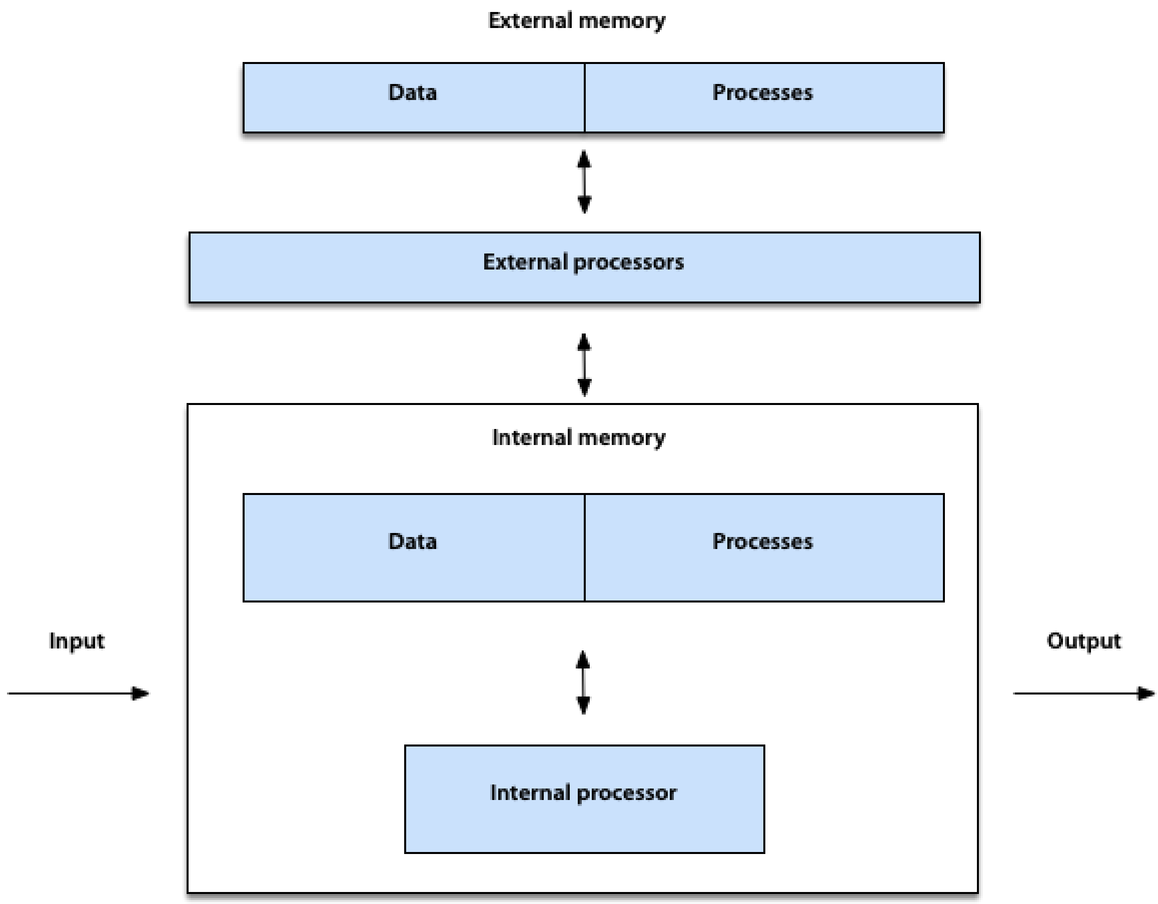
[1] Newell, A., & Simon, H. A. (1972). Human problem solving. Englewood Cliffs, NJ: Prentice-Hall.



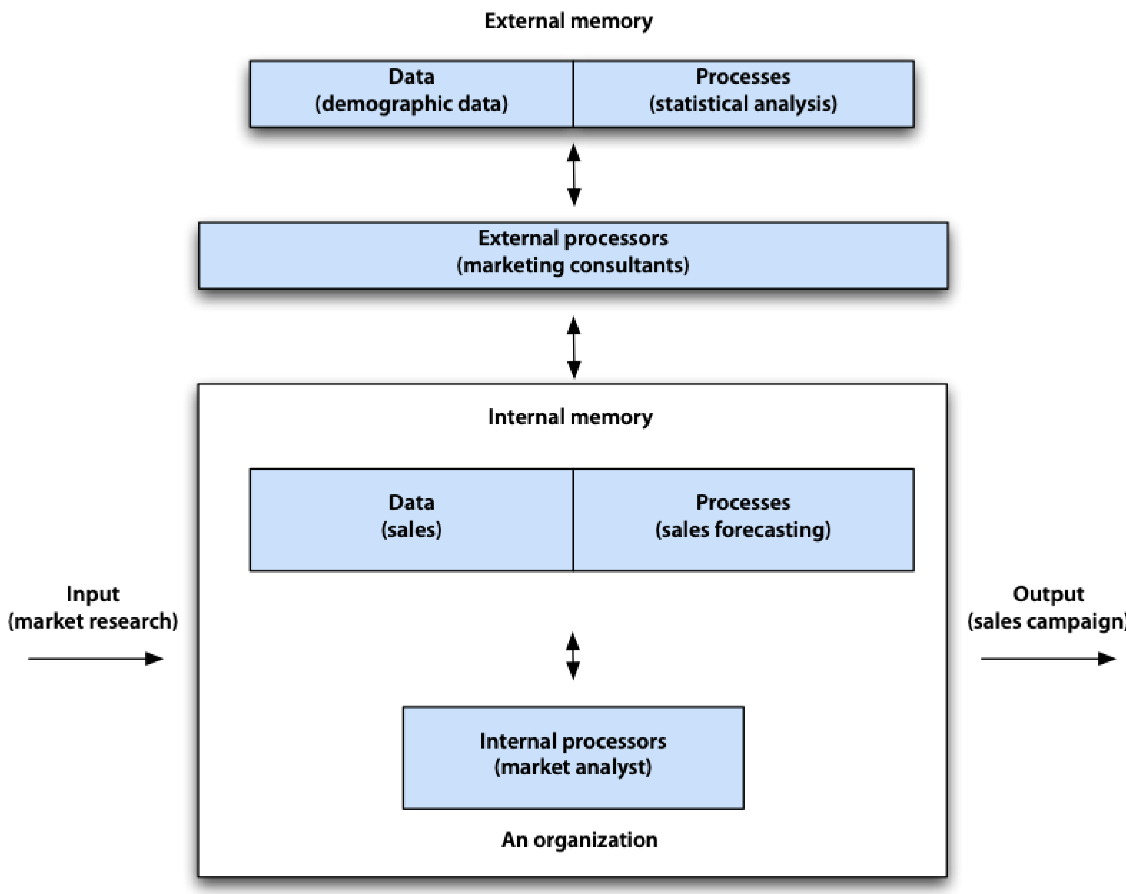
To understand this model, consider a person arriving on a flight who has agreed to meet a fellow traveler in the terminal. She receives a text message to meet her friend at B27. The message is input to her human information processing system. She retrieves the process for interpreting the message (i.e., decoding that B27 means terminal B and gate 27). The person then walks to the terminal and gate, the output. Sometimes these processes are so well ingrained in our memory that we never think about retrieving them. We just do them automatically.

Human information processing systems are easily overloaded. Our memory is limited, and our ability to process data is restricted; thus we use a variety of external tools to extend and augment our capacities. A contacts app is an instance of external data memory. A recipe, a description of the process for preparing food, is an example of external process memory. Smartphones are now the external processor of choice that we use to augment our limited processing capacity.

The original model of human information processing can be extended to include external memory, for storing data and processes, and external processors, for executing processes.



This model of augmented human information processing translates directly to an organizational setting. Organizations collect inputs from the environment: market research, customer tweets, and competitor actions. They process these data and produce outputs: sales campaigns, new products, price changes, and so on. The following figure gives an example of how an organization might process data. As a result of some market research (input), a marketing analyst (an internal processor) retrieves sales data (data) and does a sales forecast (process). The analyst also requests a marketing consultant (an external processor) to analyze (process) some demographic reports (data) before deciding to launch a new sales campaign (output).



An organization's memory comes in a variety of forms, as you will see in Chapter 1. This memory also can be divided into data and processes. The data part may contain information about customers. The process portion may store details of how to handle a customer order. Organizations use a variety of processors to handle data, including people and computers. Organizations also rely on external sources to extend their information processing capacity. For example, a business may use a specialist credit agency to check a customer's creditworthiness, or an engineering firm may use a cloud computing service for structural analysis of a bridge. Viewed this way, the augmented human information processing model becomes a pattern for an organizational information processing system.

This book focuses on the data side of organizational memory. While it is primarily concerned with data stored within the organization, there is also coverage of data in external memory. The process side of organizational memory is typically covered in a systems analysis and design or a business process management course.

1 Data

All the value of this company is in its people. If you burned down all our plants, and we just kept our people and our information files, we should soon be as strong as ever.

Thomas Watson, Jr., former chairman of IBM[1]

Learning objectives

Students completing this chapter will

- understand the key concepts of data management;
- recognize that there are many components of an organization's memory;
- understand the problems with existing data management systems;
- realize that successful data management requires an integrated understanding of organizational behavior and information technology.

Introduction

Imagine what would happen to a bank that forgot who owed it money or a digital newspaper that lost the account details of its subscribers. Both would soon be in serious difficulty, if not out of business. Organizations have data management systems to record the myriad of details necessary for transacting business and making informed decisions. Since the birth of agriculture, societies and organizations have recorded data. The system may be as simple as carving a notch in a stick to keep a tally, or as intricate as modern database technology. A memory system can be as personal as a to-do list or as public as Wikipedia.

The management of organizational data, generally known as data management, requires skills in designing, using, and managing the memory systems of modern organizations. It requires multiple perspectives. Data managers need to see the organization as a social system and to understand data management technology. The integration of these views, the socio-technical perspective, is a prerequisite for successful data management. Today's organizations are data-driven, and decisions are increasingly based on insights arising from data analytics.

Individuals also need to manage data. You undoubtedly are more familiar with individual memory management systems. They provide a convenient way of introducing some of the key concepts of data management.

[1] Quinn, J. B. (1994). Appraising intellectual assets. *The McKinsey Quarterly* (2), 90-96.

Individual data management

As humans, we are well aware of our limited capacity to remember many things. The brain, our internal memory, can get overloaded with too much detail, and its memory decays with time. We store a few things internally: our cell phone number, where we last parked our car, and faces of people we have met recently. We use external memory to keep track of those many things we would like to remember. External memory comes in a variety of forms.

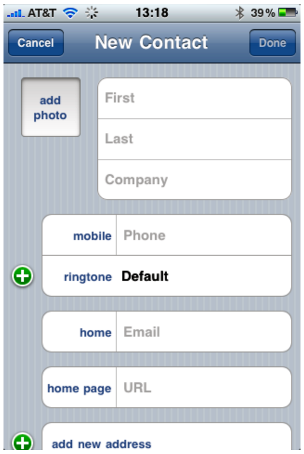
On our smartphones, we have calendars to remind us of meetings and project deadlines. We have a contact app to record the addresses and phone numbers of those we contact frequently. We use to-do lists to remind us of the things we must do today or this week. The interesting thing about these aides-mémoire is that each has a unique way of storing data and supporting its rapid retrieval.

Calendars come in many shapes and forms, but they are all based on the same organizing principle. A set amount of space is allocated for each day of the year, and the spaces are organized in date and time order, which supports rapid retrieval. Some calendars have added features to speed up access. For example, electronic calendars usually have a button to select today's data.

A calendar

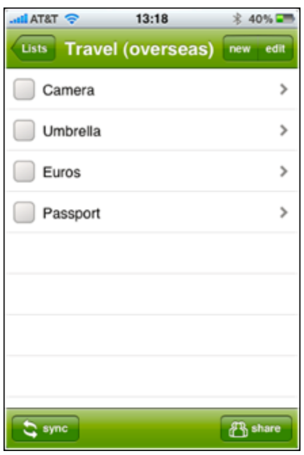
Address books also have a standard format. They typically contain predefined spaces for storing address details (e.g., name, company, phone, and email). Rapid access is supported by a search engine.

An address book



The structure of to-do lists tends to be fairly standard. They are often set up in list format with a small left-hand margin. The idea is to enter each item to be done on the right side of the screen. The left side is used to check or mark those tasks that have been completed. The beauty of the check method is that you can quickly scan the left side to identify incomplete tasks.

A to-do or reminder list



Many people use some form of the individual memory systems just described. They are typically included in the suite of standard applications for a smart phone.

These three examples of individual memory systems illustrate some features common to all data management systems:

- There is a storage medium. Data are stored electronically in each case.
- There is a structure for storing data. For instance, the address book has labeled spaces for entering pertinent data.
- The interface is organized for rapid data entry and retrieval. A calendar is stored in date and time sequence so that the data space for any appointment for a particular day can be found quickly.

- The selection of a data management system frequently requires a trade-off decision. In these examples, the trade-off is screen dimensions versus the amount of data that can be seen without scrolling. For example, you will notice the address book sample screen is truncated and will need to be scrolled to see full address details.

  ☒ *Skill builder*

  Smart phones have dramatically changed individual data management. We now have calendars, address books, to-do lists, and many more apps literally in our hands. What individual data are still difficult to manage? What might be the characteristics of an app for these data?

There are differences between internal and external memories. Our internal memory is small, fast, and convenient (our brain is always with us—well, most of the time). External memory is often slower to reference and not always as convenient. The two systems are interconnected. We rely on our internal memory to access external memory. Our internal memory and our brain's processing skills manage the use of external memories. For example, we depend on our internal memory to recall how to use our smartphone and its apps. Again, we see some trade-offs. Ideally, we would like to store everything in our fast and convenient internal memory, but its limited capacity means that we are forced to use external memory for many items.

Organizational data management

Organizations, like people, need to remember many things. If you look around any office, you will see examples of the apparatus of organizational memory: people, bookshelves, planning boards, and computers. The same principles found in individual memory systems apply to an organization's data management systems.

There is a storage medium. In the case of computers, the storage medium varies. Small files might be stored on a USB drive and large, archival files on a magnetic disk. The chapter *Data Structure and Storage* discusses electronic storage media in more detail.

A table is a common structure for storing data. For example, if we want to store details of customers, we can set up a table with each row containing individual details of a customer and each column containing data on a particular feature (e.g., customer code).

Storage devices are organized for rapid data entry and retrieval. Time is the manager's enemy: too many things to be done in too little time. Customers expect rapid responses to their questions and quick processing of their transactions. Rapid data access is a key goal of nearly all data management systems, but it always comes at a price. Fast access memories cost more, so there is nearly always a trade-off between access speed and cost.

As you will see, selecting *how* and *where* to store organizational data frequently involves a trade-off. Data managers need to know and understand what the compromises entail. They must know the key questions to ask when evaluating choices.

When we move from individual to organizational memory, some other factors come into play. To understand them, we need to review the different types of information systems. The automation of routine business transactions was the earliest application of information technology to business. A transaction processing system (TPS) handles common business tasks such as accounting, inventory, purchasing, and sales. The realization that the data collected by these systems could be sorted, summarized, and rearranged gave birth to the notion of a management information system (MIS). Furthermore, it was recognized that when internal data captured by a TPS is combined with appropriate external data, the raw material is available for a decision support system (DSS). Online analytical processing (OLAP), data mining (DM), business intelligence (BI), and machine learning (ML) are techniques analyzing data captured by business transactions and gathered from other sources (these systems are covered in detail in the chapter on *Organizational Intelligence*). The purpose of each of these systems is described in the following table and their interrelationship can be understood by examining the information systems cycle.

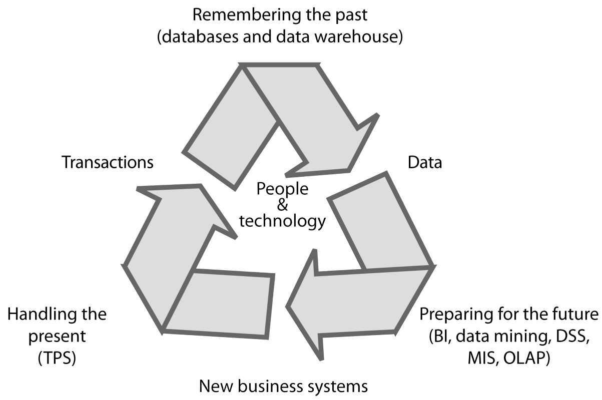
Types of information systems

	Type	System's purpose
TPS	Transaction processing system	Collect and store data from routine transactions
MIS	Management information system	Convert data from a TPS into information for planning, controlling, and managing an organization
DSS	Decision support system	Support managerial decision making by providing models for processing and analyzing data
BI	Business intelligence	Gather, store, and analyze data to improve decision making
OLAP	Online analytical processing	Provide a multidimensional view of data
DM	Data mining	Use of statistical analysis and artificial intelligence techniques to identify hidden relationships in data
ML	Machine learning	Using software to make decisions or recommendations traditionally made by humans.

The information systems cycle

The various systems and technologies found in an organization are linked in a cycle. The routine ongoing business of the organization is processed by TPSs, the systems that handle the present. Data collected by TPSs are stored in databases, a record of the past, the history of the organization and its interaction with those with whom it conducts business. These data are converted into information by analysts using a variety of software (e.g., a DSS). These technologies are used by the organization to prepare for the future (e.g., sales in Finland have expanded, so we will build a new service center in Helsinki). The business systems created to prepare for the future determine the transactions the company will process and the data that will be collected, and the process continues. The entire cycle is driven by people using technology (e.g., a customer booking a hotel room via a Web browser).

The information systems cycle



Decision making, or preparing for the future, is the central activity of modern organizations. Today's organizations are busy turning out goods, services, and decisions. Knowledge and information workers, over half of the U.S. labor force, produce the bulk of GDP. Many of these people are decision makers. Their success, and their organization's as well, depends on the quality of their decisions.

Industrial society is a producer of goods, and the hallmark of success is product quality. Japanese manufacturers convincingly demonstrated that focusing on product quality is the key to market leadership and profitability. The methods and the philosophy of quality gurus, such as W. Edwards Deming, have been internationally recognized and adopted by many providers of goods and services. We are now in the information age as is evidenced by the key consumer products of the times, such as smart phones, tablets, and wearables. These are all information appliances, and they are supported by a host of information services. For example, consider how Apple connects together its various devices and services through cloud-based systems. For example, a person can buy an electronic book from Apple's store to read with the iBooks app on an iPhone or iPad.

In the information society, which is based on innovation, knowledge, and services, the key determinant of success has shifted from product quality to decision quality. In the turbulent environment of global business, successful organizations are those able to quickly make high-quality decisions about what customers will buy, how much they will pay, and how to deliver a high-quality experience with a minimum of fuss. Companies are very dependent on information systems to create value for their customers.

Desirable attributes of data

Once we realize the critical importance of data to organizations, we can recognize some desirable attributes of data.

Desirable attributes of data

Shareable	Readily accessed by more than one person at a time
Transportable	Easily moved to a decision maker
Secure	Protected from destruction and unauthorized use
Accurate	Reliable, precise records
Timely	Current and up-to-date

Shareable	Readily accessed by more than one person at a time
Relevant	Appropriate to the decision

Shareable

Organizations contain many decision makers. There are many occasions when more than one person will require access to the same data at the same time. For example, in a large bank it would not be uncommon for two customer representatives simultaneously to want data on the latest rate for a three-year certificate of deposit. As data become more volatile, shareability becomes more of a problem. Consider a restaurant. The permanent menu is printed, today's special might be displayed on a blackboard, and the waiter tells you what is no longer available.

Transportable

Data should be transportable from their storage location to the decision maker. Technologies that transport data have a long history. Homing pigeons were used to relay messages by the Egyptians and Persians 3,000 years ago. The telephone revolutionized business and social life because it rapidly transmitted voice data. Computers have changed the nature of many aspects of business because they enable the transport of text, visuals, voice, and video.

Today, transportability is more than just getting data to a decision maker's desk. It means getting product availability data to a salesperson in a client's office or advising a delivery driver, en route, of address details for an urgent parcel pickup. The general notion is that decision makers should have access to relevant data whenever and wherever required, although many organizations are still some way from fully achieving this goal.

Secure

In an information society, organizations value data as a resource. As you have already learned, data support day-to-day business transactions and decision making. Because the forgetful organization will soon be out of business, organizations are very vigilant in protecting their data. There are a number of actions that organizations take to protect data against loss, sabotage, and theft. A common approach is to duplicate data and store the copy, or copies, at other locations. This technique is popular for data stored in computer systems. Access to data is often restricted through the use of physical barriers (e.g., a vault) or electronic barriers (e.g., a password). Another approach, which is popular with firms that employ knowledge workers, is a noncompete contract. For example, some software companies legally restrain computer programmers from working for a competitor for two years after they leave, hoping to prevent the transfer of valuable data, in the form of the programmer's knowledge of software, to competitors.

Accurate

You probably recall friends who excel in exams because of their good memories. Similarly, organizations with an accurate memory will do better than their less precise competitors. Organizations need to remember many details precisely. For example, an airline needs accurate data to predict the demand for each of its flights. The quality of decision making will drop dramatically if managers use a data management system riddled with errors.

Polluted data threatens a firm's profitability. One study suggests that missing, wrong, and otherwise bad data cost U.S. firms billions of dollars annually. The consequences of bad data include improper billing, cost overruns, delivery delays, and product recalls. Because data accuracy is so critical, organizations need to be watchful when capturing data—the point at which data accuracy is most vulnerable.

Timely

The value of a collection of data is often determined by its age. You can fantasize about how rich you would be if you knew tomorrow's stock prices. Although decision makers are most interested in current data, the required currency of data can vary with the task. Operational managers often want real-time data. They want to tap the pulse of the production line so that they can react quickly to machine breakdowns or quality slippages. In contrast, strategic planners might be content with data that are months old because they are more concerned with detecting long-term trends.

Relevant

Organizations must maintain data that are relevant to transaction processing and decision making. In processing a credit card application, the most relevant data might be the customer's credit history, current employment status, and income level. Hair color would be irrelevant. When assessing the success of a new product line, a marketing manager probably wants an aggregate report of sales by marketing region. A voluminous report detailing every sale would be irrelevant. Data are relevant when they pertain directly to the decision and are aggregated appropriately.

Relevance is a key concern in designing a data management system. Clients have to decide what should be stored because it is pertinent now or could have future relevance. Of course, identifying data that might be relevant in the future is difficult, and there is a tendency to accumulate too much. Relevance is also an important consideration when extracting and processing data from a data management system. Provided the germane data are available, query languages can be used to aggregate data appropriately.

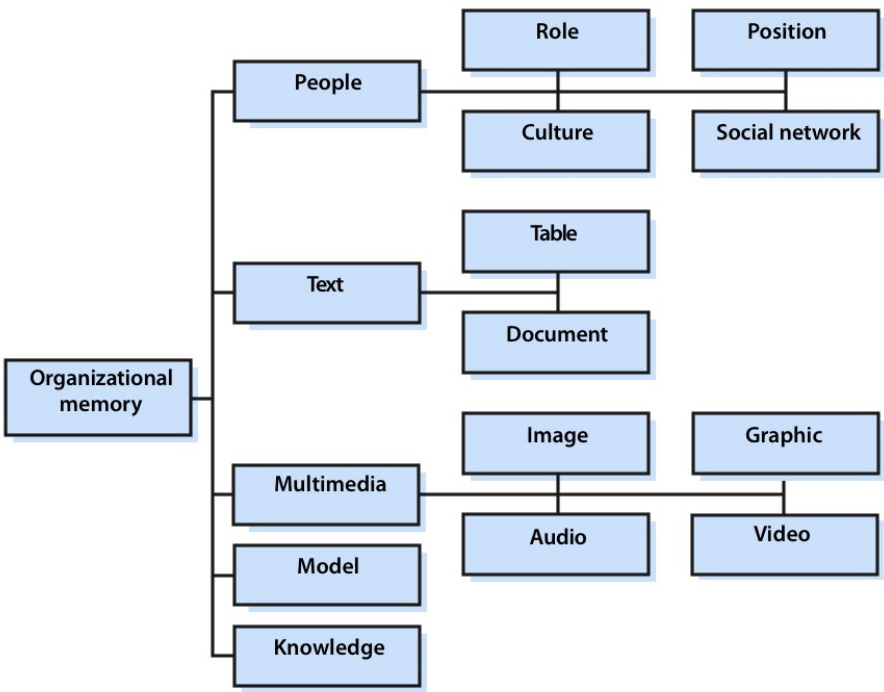
In the final years of the twentieth century, organizations started to share much of their data, both high and low volatility, via the Web. This move increased shareability, timeliness, and availability, and it has lowered the cost of distributing data.

In summary, a data management system for maintaining an organization's memory supports transaction processing, remembering the past, and decision making. Its contents must be shareable, secure, and accurate. Ideally, the clients of a data management system must be able to get timely and relevant data when and where required. A major challenge for data management professionals is to create data management systems that meet these criteria. Unfortunately, some existing systems fail in this regard, though we can understand some of the reasons why by reviewing the components of existing organizational memory systems.

Components of organizational memory

An organization's memory resides on various media in a variety of ways. It is in people's minds, standard operating procedures, roles, organizational culture, physical storage equipment, and electronic devices. It is scattered around the organization like pieces of a jigsaw puzzle designed by a berserk artist. The pieces don't fit together, they sometimes overlap, there are gaps, and there are no edge pieces to define the boundaries. Organizations struggle to design structures and use data management technology to link some of the pieces. To understand the complexity of this wicked puzzle, we need to examine some of the pieces. Data managers have a particular need to understand the different forms of organizational memory because their activities often influence a number of the components.

Components of organizational memory



People

People are the linchpin of an organization's memory. They recall prior decisions and business actions. They create, maintain, evolve, and use data management systems. They are the major component of an organization's memory because they know how to use many of the other components. People extract data from the various elements of organizational memory to provide as complete a picture of a situation as possible.

Each person in an organization has a role and a position in the hierarchy. Role and position are both devices for remembering how the organization functions and how to process data. By labeling people (e.g., Chief Information Officer) and placing their names on an organizational chart, the organization creates another form of organizational memory.

Organizational culture is the shared beliefs, values, attitudes, and norms that influence the behavior and expectations of each person in an organization. As a long-lived and stable memory system, culture establishes acceptable behavior and influences decision making.

People develop skills for doing their particular job—learning what to do, how to do it, and who can help them get things done. For example, they might discover someone in employee benefits who can handle personnel problems or a contact in a software company who can answer questions promptly. This social capital, which often take years to develop, is used to make things happen and to learn about the business environment. Despite its high value, social capital is rarely documented, at least not beyond an address book, and much is typically lost when a person leaves an organization.

Conversations are an important method for knowledge workers to create, modify, and share organizational memory and to build relationships and social capital. Discussions with customers are a key device for learning how to improve an organization's products and services and learning about competitors. The conversational company can detect change faster and react more rapidly. The telephone, instant message, e-mail, coffee machine, cocktail hour, and cafeteria are all devices for promoting conversation and creating social networks. Some firms deliberately create structures for supporting dialog to make the people component of organizational memory more effective.

Standard operating procedures exist for many organizational tasks. Processing a credit application, selecting a marketing trainee, and preparing a departmental budget are typical procedures that are clearly defined by many organizations. They are described on Web pages, computer programs, and job specifications. They are the way an organization remembers how to perform routine activities. This organizational capital is a critical resource.

Successful people learn how to use organizational memory. They learn what data are stored where, how to retrieve them, and how to put them together. In promoting a new product, a salesperson might send the prospect a package containing some brochures and an email of a product review in a trade journal, and supply the phone number and e-mail address of the firm's technical expert for that product. People's recall of how to use organizational memory is the core component of organizational memory. Academics call this metamemory; people in business call it *learning the ropes*. New employees spend a great deal of time building their metamemory so that they can use organizational memory effectively. Without this knowledge, organizational memory has little value.

Tables

A table is a common form of storing organizational data. The following table shows a price list in tabular form. Often, the first row defines the meaning of data in subsequent rows.

A price list

Product	Price
Pocket knife	4.50
Compass	10.00
Geopositioning system	100.00
Map measure	4.95

A table is a general form that describes a variety of other structures used to store data. Computer-based files are tables or can be transformed into tables; the same is true for general ledgers, worksheets, and spreadsheets. Accounting systems make frequent use of tables. As you will discover in the next section, the table is the central structure of the relational database model.

Data stored in tables typically have certain characteristics:

- Data in one column are of the same type. For example, each cell of the column headed "Price" contains a number. (Of course, the exception is the first row of each column, which contains the title of the column.)
- Data are limited by the width of the available space.

Rapid searching is one of the prime advantages of a table. For example, if the price list is sorted by product name, you can quickly find the price of any product.

Tables are a common form of storing organizational data because their structure is readily understood. People learn to read and build tables in the early years of their schooling. Also, a great deal of the data that organizations want to remember can be stored in tabular form.

Documents

A document—of which reports, manuals, brochures, and memos are examples—is a common medium for storing organizational data. Although documents may be subdivided into sections, chapters, paragraphs, and sentences, they lack the regularity and discipline of a table. Each row of a table has the same number of columns, but each paragraph of a document does not have the same number of sentences.

Most documents are now stored electronically. Because of the widespread use of word processing, text files are a common means of storing documents. Typically, such files are read sequentially like a book. Although there is support for limited searching of the text, such as finding the next occurrence of a specified text string, text files are usually processed linearly.

Hypertext, the familiar linking technology of the Web, supports nonlinear document processing. A hypertext document has built-in linkages between sections of text that permit the reader to jump quickly from one part to another, or to a different document. As a result, readers can find data they require more rapidly.

Although hypertext is certainly more reader-friendly than a flat, sequential text file, it takes time and expertise to establish the links between the various parts of the text and to other documents. Someone familiar with the topic has to decide what should be linked and then establish these links. While it takes the author more time to prepare a document this way, the payoff is the speed at which readers of the document can find what they want. A diligent author can save a great deal of time for many readers.

Multimedia

Many Web sites display multimedia objects, such as sound and video clips. Automotive company Web sites have video clips of cars, music outlets provide sound clips of new releases, and clothing companies have online catalogs displaying photos of their latest products. Maintaining a Web site, because of the many multimedia objects that some sites contain, has become a significant data management activity for some organizations. Consider the different types of data that a news outfit such as the Australian Broadcasting Corporation has to store to provide a timely, informative, and engaging Web site.

Images

Images are visual data: photographs and sketches. Image banks are maintained for several reasons. *First**, images are widely used for identification and security. Police departments keep fingerprints and mug shots. *Second*, images are used as evidence. Highly valuable items such as paintings and jewelry often are photographed for insurance records. *Third*, images are used for advertising and promotional campaigns, and organizations need to maintain records of material used in these ventures. Image archiving and retrieval are essential for online retailers. *Fourth*, some organizations specialize in selling images and maintain extensive libraries of clip art and photographs (e.g., Getty Images).

Graphics

Maps and engineering drawings are examples of electronically stored graphics. An organization might maintain a map of sales territories and customers. Manufacturers have extensive libraries of engineering drawings that define the products they produce. Graphics often contain a high level of detail. An engineering drawing will define the dimensions of all parts and may refer to other drawings for finer detail about any components.

A graphic differs from an image in that it contains explicitly embedded data. Consider the difference between an engineering plan for a widget and a photograph of the same item. An engineering plan shows dimensional data and may describe the composition of the various components. The embedded data are used to manufacture the widget. A photograph of a widget does not have embedded data and contains insufficient data to manufacture the product. An industrial spy will receive far more for an engineering plan than for a photograph of a widget.

A geographic information systems (GIS) is a specialized graphical storage system for geographic data. The underlying structure of a GIS is a map on which data are displayed. A power company can use a GIS to store and display data about its electricity grid and the location of transformers. Using a pointing device such as a mouse, an engineer can click on a transformer's location to display a window of data about the transformer (e.g., type, capacity, installation date, and repair history). GISs have found widespread use in governments and organizations that have geographically dispersed resources.

Audio

News organizations, such as National Public Radio (NPR) in the U.S., provide audio versions of their new stories for replay. Some firms conduct a great deal of their business by phone. In many cases, it is important to maintain a record of the conversation between the customer and the firm's representative. The Royal Hong Kong Jockey Club, which covers horse racing gambling in Hong Kong, records all conversations between its operators and customers. Phone calls are stored on a highly specialized voice recorder, which records the time of the call and other data necessary for rapid retrieval. In the case of a customer dispute, an operator can play back the original conversation.

Video

A video clip can give a potential customer additional detail that cannot be readily conveyed by text or a still image. Consequently, some auto companies use video and virtual reality to promote their cars. On a visit to Rivian's Web site, you can view video clips of the latest models in action.

Models

Organizations build mathematical models to describe their business. These models, usually placed in the broader category of DSS, are then used to analyze existing problems and forecast future business conditions. A mathematical model can often produce substantial benefits to the organization. Some of these models are now so detailed, they are a *digital twin* of a product or organization and support extensive exploration of possible product or business scenarios.

Machine learning can be used to create decision making models when an organization has a large set of data of prior decisions and their associated factors. The system *learns* by iteratively fitting a large number of mathematical equations to the data so that the model generated accurately predicts prior decisions.

Knowledge

Organizations build systems to capture the knowledge of their experienced decision makers and problem solvers. This expertise is typically represented as a set of rules, semantic nets, and frames in a knowledge base, another form of organizational memory.

Decisions

Decision making is the central activity of modern organizations. Very few organizations, however, have a formal system for recording decisions. Most keep the minutes of meetings, but these are often very brief and record only a meeting's outcome. Because they do not record details such as the objectives, criteria, assumptions, and alternatives that were considered prior to making a decision, there is no formal audit trail for decision making. As a result, most organizations rely on humans to remember the circumstances and details of prior decisions.

Specialized memories

Because of the particular nature of their business, some organizations maintain memories rarely found elsewhere. Perfume companies, for instance, maintain a library of scents, and paint manufacturers and dye makers catalog colors.

Components of organizational memory

Organizations are not limited to their own memory stores. There are firms whose business is to store data for resale to other organizations. Such businesses have existed for many years and are growing as the importance of data in a postindustrial society expands. U.S. lawyers can use document management services to access the laws and court decisions of all 50 American states and the U.S. federal government. Similar legal data services exist in many other nations. There is a range of other services that provide news, financial, business, scientific, and medical data.

Problems with data management systems

Successful management of data is a critical skill for nearly every organization. Yet few have gained complete mastery, and there are a variety of problems that typically afflict data management in most firms.

Problems with organizational data management systems

Problem	Examples
Redundancy	Same data are stored in different systems
Lack of data control	Data are poorly managed
Poor interface	Data are difficult to access
Delays	There are frequently delays following requests for reports
Lack of reality	Data management systems do not reflect the complexity of the real world
Lack of data integration	Data are dispersed across different systems

Redundancy

In many cases, data management systems have grown haphazardly. As a result, it is often the situation that the same data are stored in several different memories. The classic example is a customer's address, which might be stored in the sales reporting system, accounts receivable system, and a salesperson's address book. The danger is that when the customer changes address, the alteration is not recorded in all systems. Data redundancy causes additional work because the same item must be entered several times. Redundancy causes confusion when what is supposedly the same item has different values.

Lack of data control

Allied with the redundancy problem is poor data control. Although data are an important organizational resource, they frequently do not receive the same degree of management attention as other important organizational resources, such as people and money. Organizations have a personnel department to manage human resources and a treasury to handle cash. The IS department looks after data captured by the computer systems it operates, but there are many other data stores scattered around the organization. Data are stored everywhere in the organization (e.g., on tablets and the cloud), but there is a general lack of data management. This lack is particularly surprising, since many pundits claim that data are a key competitive resource.

Poor interface

Too frequently, the potential clients of data management systems are deterred by an unfriendly interface. The computer interface for accessing a data store is sometimes difficult to remember for the occasional inquirer. People become frustrated and give up because their queries are rejected and error messages are unintelligible.

Delays

Globalization and technology have accelerated the pace of business in recent years. Managers must make more decisions more rapidly. They cannot afford to wait for programmers to write special-purpose programs to retrieve data and format reports. They expect their questions to be answered rapidly, often within an hour and sometimes more quickly. Managers, or their support personnel, need query languages that provide rapid access to the data they need, in a format that they want.

Lack of reality

Organizational data stores must reflect the reality and complexity of the real world. Consider a typical bank customer who might have a personal checking account, mortgage account, credit card account, and some certificates of deposit. When a customer requests an overdraft extension, the bank officer needs full details of the customer's relationship with the bank to make an informed decision. If customer data are scattered across unrelated data stores, then these data are not easily found, and in some cases important data might be overlooked. The request for full customer details is reasonable and realistic, and the bank officer should expect to be able to enter a single query to obtain it. Unfortunately, this is not always the case, because data management systems do not always reflect reality.

In this example, the reality is that the personal checking, mortgage, and credit card accounts, and certificates of deposit all belong to one customer. If the bank's data management system does not record this relationship, then it does not mimic reality. This might make it impossible to retrieve a single customer's data with a single query.

A data management system must meet the decision making needs of managers, who must be able to request both routine and ad hoc reports. To do so effectively, a data management system must reflect the complexity of the real world. If it does not store required organizational data or record a real-world relationship between data elements, then some managerial queries might not be answerable quickly.

Lack of data integration

There is a general lack of data integration in most organizations. Not only are data dispersed in different forms of organizational memory (e.g., files and image stores). Many organizations maintain file systems that are not interconnected. Appropriate files in the accounting system might not be linked to the production system.

This lack of integration will be a continuing problem for most organizations for two important reasons. First, earlier computer systems might not have been integrated because of the limitations of available technology. Organizations created simple file systems to support a particular function. Many of these legacy systems are still in use. Second, integration is a long-term goal. As new systems are developed and old ones rewritten, organizations can evolve integrated systems. It is likely too costly and disruptive to try to solve the data integration problem in one or a few step.

Many data management problems can be solved with present technology. Data modeling and relational database technology, topics covered in Section 2, help overcome many of the current problems.

A brief history of data management systems

Data management is not a new organizational concern. It is an old problem that has become more significant, important, and critical because of the emergence of data as a critical resource for effective performance in the modern economy. Organizations have always needed to manage their data so that they could remember a wide variety of facts necessary to conduct their affairs. The recent history of computer-based data management systems is depicted in the following figure.

File systems were the earliest form of data management. Limited by the sequential nature of magnetic tape technology, it was very difficult to integrate data from different files. The advent of magnetic disk technology in the mid-1950s stimulated development of integrated file systems, and the hierarchical database management system (DBMS) emerged in the 1960s, followed some years later by the network DBMS. The spatial database, or geographic information system (GIS), appeared around 1970. Until the mid-1990s, the hierarchical DBMS, mainly in the form of IBM's DL/I product, was the predominant technology for managing data. It was replaced by the relational DBMS, a concept first discussed by Edgar Frank Codd in an academic paper in 1970 but not commercially available until the mid-1970s. In the late 1980s, the notion of an object-oriented DBMS, primed by the ideas of object-oriented programming, emerged as a solution to situations not handled well by the relational DBMS. Also around this time, the idea of modeling a database as a graph resulted in graph database technology. Towards the end of the 20th century, XML was developed for exchanging data between computers, and it can also be used as a data store as you will learn in section 3. More recently, distributed files system, such as Hadoop and Blockchain, have emerged as alternative models for data management. Other recent data management systems include NoSQL databases (Not Only SQL). While these are beyond the scope of an introductory data management text, if you decide to pursue a career in data management you should learn about their advantages and the applications to which they are well-suited. For example, graph databases are a good fit for the analysis of social networks.

This book concentrates on the relational model, currently the most widely used data management system. In 2022, the relational database market generated over USD50 billion in revenue.[2] As mentioned, Section 2 is devotedto the development of the necessary skills for designing and using a relational database.

Data, information, and knowledge

Often the terms data and information are used interchangeably, but they are distinctly different. Data are raw, unsummarized, and unanalyzed facts. Information is data that have been processed into a meaningful form.

A list of a supermarket's daily receipts is data, but it is not information, because it is too detailed to be very useful for decision making. A summary of the data that gives daily departmental totals is information, because the store manager can use the report to monitor store performance. The same report might be data for a regional manager, because it is too detailed for meaningful decision making at the regional level. Information for a regional manager might be a weekly report of sales by department for each supermarket.

Data are always data, but one person's information can be another person's data. Information that is meaningful to one person can be too detailed for another. A manager's notion of information can change quickly, however. When a problem is identified, a manager might request finer levels of detail to diagnose the problem's cause. Thus, what was previously data suddenly becomes information because it helps solve the problem. There is a need for information systems that let managers customize the processing of data so that they always get information. As their needs change, they need to be able to adjust the detail of the reports they receive.

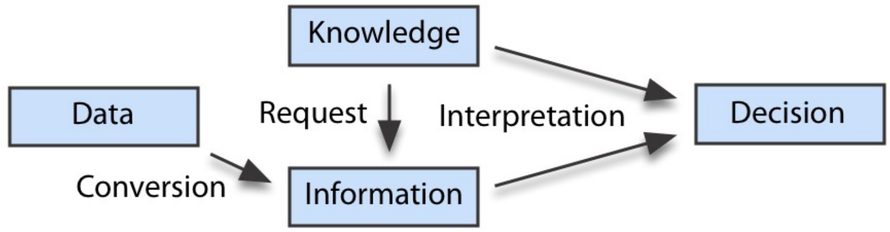
Knowledge is the capacity to use information. The education and experience that managers accumulate provide them with the expertise to make sense of the information they receive. Knowledge means that managers can interpret information and use it in decision making. In addition, knowledge is the capacity to recognize what information would be useful for making decisions. For example, a sales manager might know that requesting a report of profitability by product line is useful when they has to decide whether to employ a new product manager. Thus, when a new information system is delivered, managers need to be taught what information the system can deliver what that information means, and how it might be used.

The relationship between data, information, and knowledge is depicted in the following figure. A knowledgeable person requests information to support decision making. To fulfill the request, data are converted into information. Personal knowledge is then applied to interpret the requested information and reach a conclusion. Of course, the cycle can be repeated several times if more information is needed before a decision can be made. Notice how knowledge is essential for

[2] Abadi, D. et al., (2022). The Seattle report on database research. *Communications of the ACM*, 65(8), 72-79.

grasping what information to request and interpreting that information in terms of the required decision.

The relationship between data, information, and knowledge



The challenge

A major challenge facing organizations is to make effective use of the data currently stored in their diverse data management systems. This challenge exists because these various systems are not integrated and many potential clients not only lack the training to access the systems but often are unaware what data exist. Before data managers can begin to address this problem, however, they must understand how organizational memories are used. In particular, they need to understand the relationship between information and managerial decision making. Data management is not a new problem. It has existed since the early days of civilization and will be an enduring problem for organizations and societies.

Summary

Organizations must maintain a memory to process transactions and make decisions. Organizational data should be shareable, transportable, secure, and accurate, and provide timely, relevant information. The essential components are people (the most important), text, multimedia data, models, and knowledge. A wide variety of technologies can be used to manage data. External memories enlarge the range of data available to an organization. Data management systems often have some major shortcomings: redundancy, poor data control, poor interfaces, long lead times for query resolution, an inability to supply answers for questions posed by managers, and poor data integration. Data are raw facts; information is data processed into a meaningful form. Knowledge is the capacity to use information.

Key terms and concepts	
Data	Internal memory
Database management system (DBMS)	Knowledge
Data management	Machine learning (ML)
Data mining (DM)	Management information system (MIS)
Data security	Metamemory
Decision making	Online analytical processing (OLAP)
Decision quality	Organizational culture

Key terms and concepts	
Decision support system (DSS)	Organizational memory
Digital twin	Standard operating procedures
External memory	Tables
Geographic information system (GIS)	Transaction processing system (TPS)
Information	

References and additional readings

Davenport, T. H. (1998). Putting the enterprise into the enterprise system. *Harvard Business Review*, 76(4), 121–131.

Watson, R. T. (2020). *Capital, Systems and Objects: The Foundation and Future of Organizations*. Singapore: Springer

Exercises

1. What are the major differences between internal and external memory?
2. What is the difference between the things you remember and the things you record on your computer?
3. What features are common to most individual memory systems?
4. What do you think organizations did before computers were invented?
5. Discuss the memory systems you use. How do they improve your performance? What are the shortcomings of your existing systems? How could you improve them?
6. Describe the most "organized" person you know. Why is that person so organized? Why haven't you adopted some of the same methods? Why do you think people differ in the extent to which they are organized?
7. Think about the last time you enrolled in a class. What data do you think were recorded for this transaction?
8. What roles do people play in organizational memory?
9. What do you think is the most important attribute of organizational memory? Justify your answer.
10. What is the difference between transaction processing and decision making?
11. When are data relevant?
12. Give some examples of specialized memories.
13. How can you measure the quality of a decision?
14. What is organizational culture? Can you name some organizations that have a distinctive culture?

15. What is hypertext? How does it differ from linear text? Why might hypertext be useful in an organizational memory system?
16. What is imaging? What are the characteristics of applications well suited for imaging?
17. What is an external memory? Why do organizations use external memories instead of building internal memories?
18. What is the common name used to refer to systems that help organizations remember knowledge?
19. What is a DSS? What is its role in organizational memory?
20. What are the major shortcomings of many data management systems? Which do you think is the most significant shortcoming?
21. What is the relationship between data, information, and knowledge?
22. Estimate how much data Netflix requires to store its many movies.
23. Using the Web, find some stories about firms using data management systems. You might enter keywords such as "database" and "business analytics" and access the sites of publications such as Computerworld. Identify the purpose of each system. How does the system improve organizational productivity? What are the attributes of the technology that make it useful? Describe any trade-offs the organization might have made. Identify other organizations in which the same technology might be applied.
24. Make a list of the organizational memory systems identified in this chapter. Interview several people working in organizations. Ask them to indicate which organizational memory systems they use. Ask which system is most important and why. Write up your findings and your conclusion.

2 Information

Effective information management must begin by thinking about how people use information—not with how people use machines.

Davenport, T. H. (1994). Saving IT's soul: human-centered information management. *Harvard Business Review,* 72(2), 119-131.

Learning objectives

Students completing this chapter will

- understand the importance of information to society and organizations;
- be able to describe the various roles of information in organizational change;
- be able to distinguish between soft and hard information;
- know how managers use information;
- be able to describe the characteristics of common information delivery systems;
- distinguish the different types of knowledge.

Introduction

There are three characteristics of the first two decades of the twenty-first century: global warming, high-velocity global change, and the emerging power of information organizations.[1] The need to create a sustainable civilization, the globalization of business, and the rise of China as a major economic power are major forces contributing to mass change. Organizations are undergoing large-scale restructuring as they attempt to reposition themselves to survive the threats and exploit the opportunities presented by these changes.

This century, some very powerful and highly profitable information-based organizations have emerged. In 20212, Apple and Microsoft vied to be the world's largest company in terms of market value. Leveraging the iPhone and IOS, Apple has shown the power of information services to change an industry. Google has become a well-known global brand as it fulfills its mission "to organize the world's information and make it universally accessible and useful." Amazon is disrupting traditional retail. Facebook has digitized our social world, and Microsoft has dominated

[1] In late 2021, the four of five most valuable public companies were Apple, Microsoft, Amazon, and Alphabet (Google). Furthermore, these technology giants are concentrated on the west coast of the U.S. in either Silicon Valley or Seattle (source).

the office environment for decades. We gain further insights into the value of information by considering its role in civilization.

A historical perspective

Humans have been collecting data to manage their affairs for several thousand years. In 3000 BCE, Mesopotamians recorded inventory details in cuneiform, an early script. Today's society transmits Exabytes of data every day as billions of people and millions of organizations manage their affairs. The dominant issue facing each type of economy has changed over time, and the collection and use of data has changed to reflect these concerns, as shown in the following table.

Societal focus

Economy	Subsistence	Agricultural	Industrial	Service	Sustainable
Question	How to survive?	How to farm?	How to manage resources?	How to create customers?	How to reduce environmental impact?
Dominant issue	Survival				
		Production			
				Customer service	
					Sustainability
Key information systems	Gesturing Speech	Writing Calendar Money Measuring	Accounting ERP Project management	BPM CRM Analytics	Simulation Optimization Design

Agrarian society was concerned with productive farming, and an important issue was when to plant crops. Ancient Egypt, for example, based its calendar on the flooding of the Nile. The focus shifted during the industrial era to management of resources (e.g., raw materials, labor, logistics). Accounting, ERP, and project management became key information systems for managing resources. In the current service economy, the focus has shifted to customer creation. There is an oversupply of many consumer products (e.g., cars) and companies compete to identify services and product features that will attract customers. They are concerned with determining what types of customers to recruit and finding out what they want. As a result, we have seen the rise of business analytics and customer relationship management (CRM) to address this dominant issue. As well as creating customers, firms need to serve those already recruited. High quality service often requires frequent and reliable execution of multiple processes during manifold encounters with customers by a firm's many customer facing employees (e.g., a quick service restaurant, an airline, a hospital). Consequently, business process management (BPM) has grown in importance since the mid 1990s when there was a surge of interest in business process reengineering.

We are in transition to a new era, sustainability, where attention shifts to assessing environmental impact because, after several centuries of industrialization, atmospheric CO_2 levels have become alarmingly high. We are also exceeding the limits of the planet's resources as global population nears eight billion people. As a result, a new class of application is emerging, such as environmental management systems and UPS's telematics project.[2] These new systems will also include, for example, support for understanding environmental impact through simulation of energy consumption and production systems, optimization of energy systems, and design of low impact production and customer service systems. Notice that dominant issues don't disappear but rather aggregate in layers, so today's business will be concerned with survival, production, customer service, and sustainability. As a result, a firm's need for data never diminishes, and each new layer creates another set of data needs. The flood will not subside and for most firms the data flow will need to grow significantly to meet the new challenge of sustainability.

A constant across all of these economies is organizational memory, or in its larger form, social memory. Writing and paper manufacturing developed about the same time as agricultural societies. Limited writing systems appeared about 30,000 years ago. Full writing systems, which have evolved in the last 5,000 years, made possible the technological transfer that enabled humanity to move from hunting and gathering to farming. Writing enables the recording of knowledge, and information can accumulate from one generation to the next. Before writing, knowledge was confined by the limits of human memory.

There is a need for a technology that can store knowledge for extended periods and support the transport of written information. Storage medium has advanced from clay tablets (4000 BCE), papyrus (3500 BCE), and parchment (2000 BCE) to paper (100 CE). Written knowledge gained great impetus from Johannes Gutenberg, whose achievement was a printing system involving movable metal type, ink, paper, and press. In less than 50 years, printing technology diffused throughout most of Europe. In the last century, a range of new storage media appeared (e.g., photographic, magnetic, and optical).

Organizational memories emerged with the development of large organizations such as governments, armies, churches, and trading companies. The growth of organizations during the industrial revolution saw a massive increase in the number and size of organizational memories. This escalation continued throughout the twentieth century.

The Internet has demonstrated that we now live in a borderless world. There is a free flow of information, investment, and industry across borders. Customers ignore national boundaries to buy products and services. In the borderless information age, the old ways of creating wealth have been displaced by intelligence, marketing, global reach, and education. Excelling in the management of data, information, and knowledge has become a prerequisite for corporate and national wealth.

Wealth creation

The old	The new
Military power	Intelligence
Natural resources	Marketing
Population	Global reach
Industry	Education

[2]Watson, R. T., Boudreau, M.-C., Li, S., & Levis, J. (2010). Telematics at UPS: En route to Energy Informatics. MISQ Executive, 9(1), 1-11.

This brief history shows the increasing importance of information. Civilization was facilitated by the discovery of means for recording and disseminating information. In our current society, organizations are the predominant keepers and transmitters of information.

A brief history of information systems

Information systems has three significant eras. In the first era, information work was transported to the computer. For instance, a punched card deck was physically transported to a computer center, the information was processed, and the output physically returned to the worker as a printout.

Information systems eras

Era	Focus	Period	Technology	Networks
1	Take information work to the computer	1950s – mid-1970s	Batch	Few data networks
2	Take information work to the employee	Mid-1970s – mid-1990s	Host/terminal Client/server	Spread of private networks
3	Take information work to the customer and other stakeholders	Mid-1990s – present	Browser/server	Public networks (Internet)

In the second era, private networks were used to take information work to the employee. Initially, these were time-sharing and host/terminal systems. IS departments were concerned primarily with creating systems for use by an organization's employees when interacting with customers (e.g., a hotel reservation system used by call center employees) or for the employees of another business to transact with the organization (e.g., clerks in a hospital ordering supplies).

Era 3 starts with the appearance of the Web browser in the mid-1990s. The browser, which can be used on the public and global Internet, permits organizations to take information and information work to customers and other stakeholders. Now, the customer undertakes work previously done by the organization (e.g., making an airline reservation).

The scale and complexity of era 3 is at least an order of magnitude greater than that of era 2. Nearly every company has far more customers than employees. For example, UPS, with an annual investment of billions in information systems and over 500,000 employees, is one of the world's largest employers. However, there are over 11 million customers, over 20 times the number of employees, who are electronically connected to UPS.

Era 3 introduced direct electronic links between a firm and its stakeholders, such as investors and citizens. In the earlier eras, intermediaries often communicated with stakeholders on behalf of the firm (e.g., a press release to the news media). These messages could be filtered and edited, or sometimes possibly ignored, by intermediaries. Now, organizations can communicate directly with their stakeholders via the Web, e-mail, social media. Internet technologies offer firms a chance to rethink their goals vis-à-vis each stakeholder class and to use Internet technology to pursue these goals.

This brief history leads to the conclusion that the value IS creates is determined by whom an organization can reach, how it can reach them, and where and when it can reach them.

- Who. Who an organization can contact determines whom it can influence, inform, or transfer work to. For example, if a hotel can be contacted electronically by its customers, it can promote online reservations (transfer work to customers), and reduce its costs.
- How. How an organization reaches a stakeholder determines the potential success of the interaction. The higher the bandwidth of the connection, the richer the message (e.g., using video instead of text), the greater the amount of information that can be conveyed, and the more information work that can be transferred.
- Where. Value is created when customers get information directly related to their current location (e.g., a navigation system) and what local services they want to consume (e.g., the nearest Italian restaurant).
- When. When a firm delivers a service to a client can greatly determine its value. Stockbrokers, for instance, who can inform clients immediately of critical corporate news or stock market movements are likely to get more business.

Information characteristics

Three useful concepts for describing information are hardness, richness, and class. Information hardness is a subjective measure of the accuracy and reliability of an item of information. Information richness describes the concept that information can be rich or lean depending on the information delivery medium. Information class groups types of information by their key features.

Information hardness

In 1812, the Austrian mineralogist Friedrich Mohs proposed a scale of hardness, in order of increasing relative hardness, based on 10 common minerals. Each mineral can scratch those with the same or a lower number, but cannot scratch higher-numbered minerals.

A similar approach can be used to describe information. Market information, such as the current price of gold, is the hardest because it is measured extremely accurately. There is no ambiguity, and its measurement is highly reliable. In contrast, the softest information, which comes from unidentified sources, is rife with uncertainty.

An information hardness scale

Mineral	Scale	Data
Talc	1	Unidentified source—rumors, gossip, and hearsay
Gypsum	2	Identified non-expert source—opinions, feelings, and ideas

Mineral	Scale	Data
Calcite	3	Identified expert source—predictions, speculations, forecasts, and estimates
Fluorite	4	Unsworn testimony—explanations,justifications, assessments, and justifications, assessments, and interpretations
Apatite	5	Sworn testimony—explanations, justifications, assessments, and interpretations
Orthoclase	6	Budgets, formal plans
Quartz	7	News reports, non-financial data, industry statistics, and surveys
Topaz	8	Unaudited financial statements, and government statistics
Corundum	9	Audited financial statements
Diamond	10	Stock exchange and commodity market data

Audited financial statements are in the corundum zone. They are measured according to standard rules (known as "generally accepted accounting principles") that are promulgated by national accounting societies. External auditors monitor the application of these standards, although there is generally some leeway in their application and sometimes multiple standards for the same item. The use of different accounting principles can lead to different profit and loss statements. As a result, the information in audited financial statements has some degree of uncertainty.

There are degrees of hardness within accounting systems. The hardest data are counts, such as units sold or customers served. These are primary measures of organizational performance. Secondary measures, such as dollar sales and market share, are derived from counts. Managers vary in their preference for primary and secondary measures. Operational managers opt for counts for measuring productivity because they are uncontaminated by price changes and currency fluctuations. Senior managers, because their focus is on financial performance, select secondary measures.

The scratch test provides a convenient and reliable method of assessing the hardness of a mineral. Unfortunately, there is no scratch test for information. Managers must rely on their judgment to assess information hardness.

Although managers want hard information, there are many cases when it is not available from a single source. They compensate by seeking information from several different places. Relatively consistent information from multiple sources is reassuring.

Information richness

Information can be described as rich or lean. It is richest when delivered face-to-face. Conversation permits immediate feedback for verification of meaning. You can always stop the other speaker and ask, "What do you mean?" Face-to-face information delivery is rich because you see the speaker's body language, hear the tone of voice, and natural language is used. A numeric document is the leanest form of information. There is no opportunity for questions, no additional information from body movements and vocal tone. The information richness of some communication media is shown in the following table.

Information richness and communication media[3]

Richest				Leanest
Face-to-face	Telephone	Personal documents	Impersonal documents	Numeric documents

Managers seek rich information when they are trying to resolve equivocality or ambiguity, which means that managers cannot make sense of a situation because they arrive at multiple, conflicting interpretations of the information. An example of an equivocal situation is a class assignment where some of the instructions are missing and others are contradictory (of course, this example is an extremely rare event).

Equivocal situations cannot be resolved by collecting more information, because managers are uncertain about what questions to ask and often a clear answer is not possible. Managers reduce equivocality by sharing their interpretations of the available information and reaching a collective understanding of what the information means. By exchanging opinions and recalling their experiences, they try to make sense of an ambiguous situation.

Many of the situations that managers face each day involve a high degree of equivocality. Formal organizational memories, such as databases, are not much help, because the information they provide is lean. Many managers rely far more on talking with colleagues and using informal organizational memories such as social networks.

Data management is almost exclusively concerned with administering the formal information systems that deliver lean information. Although this is their proper role, data managers must realize that they can deliver only a portion of the data required by decision makers.

Information classes

Information can be grouped into four categories: content, form, behavior, and action. Until recently, most organizational information fell into the first class.

Information classes

Class	Description
Content	Quantity, location, and types of items
Form	Shape and composition of an object
Behavior	Simulation of a physical object
Action	Creation of action (e.g., industrial robots)

[3] *Daft, R. L., & Lengel, R. H. (1986). Organizational information requirements, media richness, and structural design.* Management Science*, 32(5), 554–571.

Content information records details about quantity, location, and types of items. It tends to be historical in nature and is traditionally the class of information collected and stored by organizations. The content information of a car would describe its model number, color, price, options, horsepower, and so forth. Hundreds of bytes of data may be required to record the full content information of a car. Typically, content data are captured by a TPS.

Form information describes the shape and composition of an object. For example, the form information of a car would define the dimensions and composition of every component in it. Millions of bytes of data are needed to store the form of a car. CAD/CAM systems are used to create and store form information.

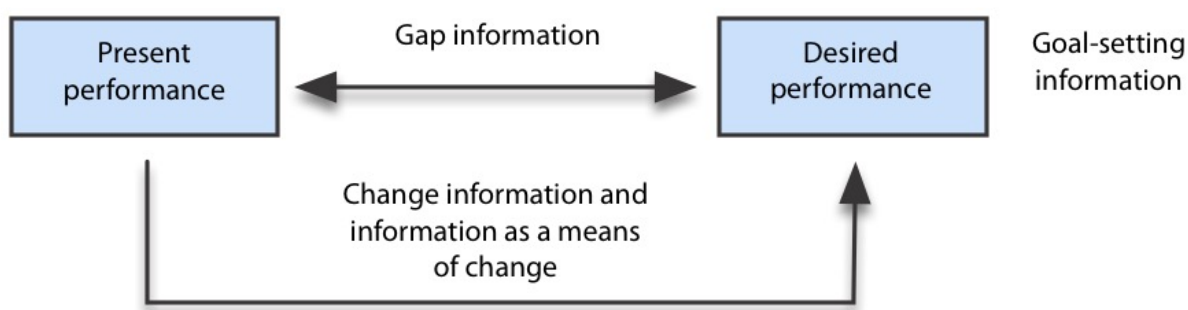
Behavior information is used to predict the responses of a physical object using simulation techniques. Such systems typically require a combination of input data and mathematical equations. Massive numbers of calculations per second are required to simulate behavior. For example, simulating the flight of a new aircraft design may require trillions of computations. Behavior information is often presented visually because the vast volume of data generated cannot be easily processed by humans in other formats.

Action information enables the instantaneous creation of sophisticated action. Industrial robots take action information and manufacture parts, weld car bodies, or transport items. Antilock brakes are an example of action information in use.

Information and organizational change

Organizations are goal-directed. They undergo continual change as they use their resources, people, technology, and financial assets to reach some future desired outcome. Goals are often clearly stated, such as to make a profit of USD 100 million, win a football championship, or decrease the government deficit by 25 percent in five years. Goals are often not easily achieved, however, and organizations continually seek information that supports goal attainment. The information they seek falls into three categories: goal setting, gap, and change.

Organizational information categories



The emergence of an information society also means that information provides dual possibilities for change. Information is used to plan change, and information is a medium for change.

Goal-setting information

Organizations set goals or levels of desired performance. Managers need information to establish goals that are challenging but realistic. A common approach is to take the previous goal and stretch it. For example, a company with a 15 percent return on investment (ROI) might set the new goal at 17 percent ROI. This technique is known as “anchoring and adjusting.” Prior performance is used as a basis for setting the new performance standards. The problem with anchoring and adjusting is that it promotes incremental improvement rather than radical change because internal information is used to set performance standards. Some organizations have turned to external information and are using benchmarking as a source of information for goal setting.

Planning

Planning is an important task for senior managers. To set the direction for the company, they need information about consumers’ potential demands and social, economic, technical, and political conditions. They use this information to determine the opportunities and threats facing the organization, thus permitting them to take advantage of opportunities and avoid threats.

Most of the information for long-term planning comes from sources external to the company. There are think tanks that analyze trends and publish reports on future conditions. Journal articles and books can be important sources of information about future events. There will also be a demand for some internal information to identify trends in costs and revenues. Major planning decisions, such as building a new plant, will be based on an analysis of internal data (use of existing capacity) and external data (projected customer demand).

Benchmarking

Benchmarking establishes goals based on best industry practices. It is founded on the Japanese concept of *dantotsu*, striving to be the best of the best. Benchmarking is externally directed. Information is sought on those companies, regardless of industry, that demonstrate outstanding performance in the areas to be benchmarked. Their methods are studied, documented, and used to set goals and redesign existing practices for superior performance.

Other forms of external information, such as demographic trends, economic forecasts, and competitors’ actions can be used in goal setting. External information is valuable because it can force an organization to go beyond incremental goal setting.

Organizations need information to identify feasible, motivating, and challenging goals. Once these goals have been established, they need information on the extent to which these goals have been attained.

Gap information

Because goals are meant to be challenging, there is often a gap between actual and desired performance. Organizations use a number of mechanisms to detect a gap and gain some idea of its size. Problem identification and scorekeeping are two principal methods of providing gap information.

Problem identification

Business conditions are continually changing because of competitors' actions, trends in consumer demand, and government actions. Often these changes are reflected in a gap between expectations and present performance. This gap is often called a problem.

To identify problems, managers use exception reports, which are generated when conditions vary from the established goal or standard. Once a potential problem has been identified, managers collect additional information to confirm that a problem really exists. Once management has been alerted, the information delivery system needs to shift into high gear. Managers will request rapid delivery of ad hoc reports from a variety of sources. The ideal organizational memory system can adapt smoothly to deliver appropriate information quickly.

Scorekeeping

Keeping track of the score provides gap information. Managers ask many questions: How many items did we make yesterday? What were the sales last week? Has our market share increased in the last year? They establish measurement systems to track variables that indicate whether organizational performance is on target. Keeping score is important; managers need to measure in order to manage. Also, measurement lets people know what is important. Once a manager starts to measure something, subordinates surmise that this variable must be important and pay more attention to the factors that influence it.

There are many aspects of the score that a manager can measure. The overwhelming variety of potentially available information is illustrated by the sales output information that a sales manager could track. Sales input information (e.g., number of service calls) can also be measured, and there is qualitative information to be considered. Because of time constraints, most managers are forced to limit their attention to 10 or fewer key variables singled out by the critical success factors (CSF) method.[4] Scorekeeping information is usually fairly stable.

Sales output tracking information

Category	Example
Orders	Number of current customers
	Average order size
	Batting average (orders to calls)
Sales volume	Dollar sales volume
	Unit sales volume
	By customer type
	By product category
	Translated to market share

[4] Rockart, J.F. (1982). The changing role of the information systems executive: a critical success factors perspective. *Sloan Management Review*, 24(1), 3–13.

Category	Example
	Quota achieved
Margins	Gross margin
	Net profit
	By customer type
	By product
Customers	Number of new accounts
	Number of lost accounts
	Percentage of accounts sold
	Number of accounts overdue
	Dollar value of receivables
	Collections of receivables

Change information

Accurate change information is very valuable because it enables managers to predict the outcome of various actions to close a gap with some certainty. Unfortunately, change information is usually not very precise, and there are many variables that can influence the effect of any planned change. Nevertheless, organizations spend a great deal of time collecting information to support problem solving and planning.

Problem solution

Once a concern has been identified, a manager seeks to find its cause. A decrease in sales could be the result of competitors introducing a new product, an economic downturn, an ineffective advertising campaign, or many other reasons. Data can be collected to test each of these possible causes. Additional data are usually required to support analysis of each alternative. For example, if the sales decrease has been caused by an economic recession, the manager might use a decision support system (DSS) to analyze the effect of a price decrease or a range of promotional activities.

Information as a means of change

The emergence of an information society means that information can be used as a means of changing an organization's performance. Corporations can create information-based products and services, adding information to products, and using information to enhance existing performance or gain a competitive advantage. Further insights into the use of information as a change agent are gained by examining marketing, customer service, and empowerment.

Marketing

Marketing is a key strategy for changing organizational performance by increasing sales. Information has become an important component in marketing. Airlines and retailers have established frequent flyer and buyer programs to encourage customer loyalty and gain more information about customers. These systems are heavily dependent on database technology because of the massive volume of data that must be stored. Indeed, without database technology, some marketing strategies could never be implemented.

Database technology offers the opportunity to change the very nature of communications with customers. Broadcast media have been the traditional approach to communication. Advertisements are aired on television, placed in magazines, or displayed on a Web site. Database technology can be used to address customers directly. No longer just a mailing list, today's database can be a memory of customer relationships, a record of every message and response between the firm and a customer. Some companies keep track of customers' preferences and customize advertisements to their needs. Leading online retailers now send customers only those emails for products for which they estimate there is a high probability of a purchase. For example, a customer with a history of streaming jazz music is sent an email promoting a jazz concert in their city.

The Web has significantly enhanced the value of database technology. Many firms now use a combination of a Web site and a DBMS to market products and service customers.

Customer Service

Many business leaders consider customer service as a critical goal for organizational success. Many of the developed economies are service driven. In the United States, services account for nearly 80 percent of the GNP and most of the new jobs. Many companies now compete for customers by offering superior customer service. Information is frequently a key to this improved service.

> ☒ *Skill builder*
>
> For many businesses, information is the key to high-quality customer service. Some firms use information, and thus customer service, as a key differentiating factor, while others might compete on price. Compare the electronics component of Web sites Amazon and Walmart. How do they use price and information to compete? What are the implications for data management if a firm uses information to compete?

Empowerment

Empowerment means giving employees greater freedom to make decisions. More precisely, it is sharing with frontline employees

- information about the organization's performance;
- rewards based on the organization's performance;
- knowledge and information that enable employees to understand and contribute to organizational performance;

- power to make decisions that influence organizational direction and performance.

Notice that information features prominently in the process. A critical component is giving employees access to the information they need to perform their tasks with a high degree of independence and discretion. Information is empowerment. By linking employees to organizational memory, data managers play a pivotal role in empowering people. Empowerment can contribute to organizational performance by increasing the quality of products and services. Together, empowerment and information are mechanisms of planned change.

Information and managerial work

Because managers frequently use data management systems in their normal activities as a source of information about change and as a means of implementing change, it is crucial for systems designers to understand how managers work. Failure to take account of managerial behavior can result in a system that is technically sound but rarely used because it does not fit the social system.

Studies over several decades reveal a very consistent pattern: Managerial work is very fragmented. Managers spend an average of 10 minutes on any task, and their day is organized into brief periods of concentrated attention to a variety of tasks. They work unrelentingly and are frequently interrupted by unexpected disturbances. Managers are action oriented and rely on intuition and judgment far more than contemplative analysis of information.

Managers strongly prefer oral communication. They spend a great deal of time conversing directly or by telephone. Managers use interpersonal communication to establish networks and build social capital, which they later use as a source of information and a way to influence outcomes. The continual flow of verbal information helps them make sense of events and lets them feel the organizational pulse.

Managers rarely use formal reporting systems. They do not spend a lot of time analyzing computer reports or querying databases but resort to formal reports to confirm impressions, should interpersonal communications suggest there is a problem. Even when managers are provided with a purpose-built, ultra-friendly executive information system, their behavior changes very little. They may access a few screens during the day, but oral communication is still their preferred method of data gathering and dissemination.

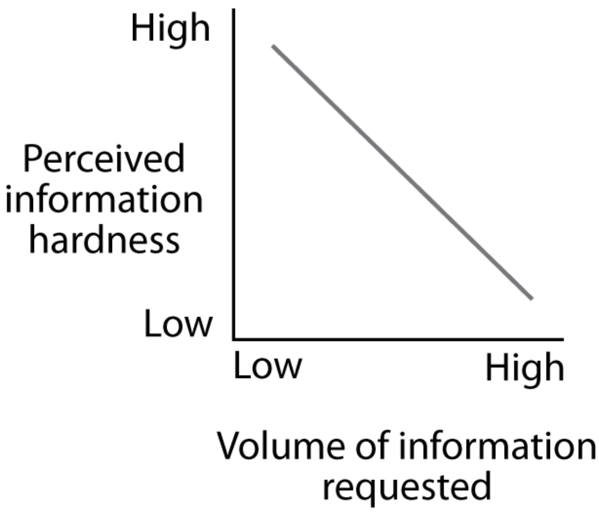
Managers' information requirements

Managers have certain requirements of the information they receive. These expectations should shape a data management system's content and how data are processed and presented.

Managers expect to receive information that is useful for their current task under existing business conditions. Unfortunately, managerial tasks can change rapidly. The interlinked, global, economic environment is highly turbulent. Since managers' expectations are not stable, the information delivery system must be sufficiently flexible to meet changing requirements.

Managers' demands for information vary with their perception of its hardness; they require only one source that scores 10 on the information hardness scale. The Nikkei Index at the close of today's market is the same whether you read it in the *Asian Wall Street Journal* or *The Western Australian* or hear it on CNN. As perceived hardness decreases, managers demand more information, hoping to resolve uncertainty and gain a more accurate assessment of the situation. When the reliability of a source is questionable, managers seek confirmation from other sources. If a number of different sources provide consistent information, a manager gains confidence in the information's accuracy.

Relationship of perceived information hardness to volume of information requested



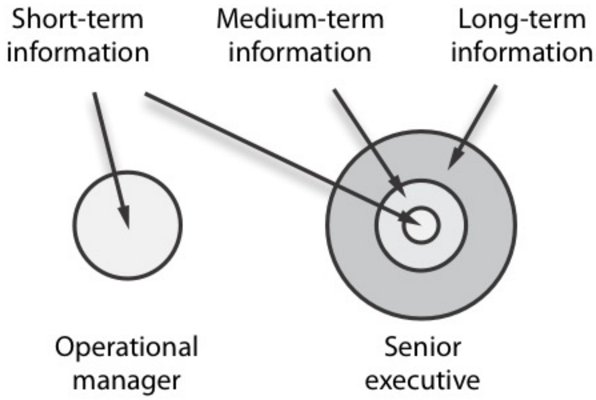
It is not unusual, therefore, to have a manager seek information from a database, a conversation with a subordinate, and a contact in another organization. If a manager gets essentially the same information from each source, they have the confirmation they sought. This means each data management system should be designed to minimize redundancy, but different components of organizational memory can supply overlapping information.

Managers' needs for information vary accordingly with responsibilities

Operational managers need detailed, short-term information to deal with well-defined problems in areas such as sales, service, and production. This information comes almost exclusively from internal sources that report recent performance in the manager's area. A sales manager may get weekly reports of sales by each direct report.

As managers move up the organizational hierarchy, their information needs both expand and contract. They become responsible for a wider range of activities and are charged with planning the future of the organization, which requires information from external sources on long-term economic, demographic, political, and social trends. Despite this long-term focus, top-level managers also monitor short-term, operational performance. In this instance, they need less detail and more summary and exception reports on a small number of key indicators. To avoid information overload as new layers of information needs are added, the level of detail on the old layers naturally must decline, as illustrated in the following figure.

Management level and information need



Information satisficing

Because managers face making many decisions in a short period, most do not have the time or resources to collect and interpret all the information they need to make the best decision. Consequently, they are often forced to satisfice. That is, they accept the first satisfactory decision they discover. They also satisfice in their information search, collecting only enough information to make a satisfactory decision.

Ultimately, information satisficing leads to lower-quality decision making. If, however, information systems can accelerate delivery and processing of the right information, then managers should be able to move beyond selecting the first satisfactory decision to selecting the best of several satisfactory decisions.

Information delivery systems

Most organizations have a variety of delivery systems to provide information to managers. Developed over many years, these systems are integrated, usually via a Web site, to give managers better access to information. There are two aspects to information delivery. First, there is a need for software that accesses an organizational memory, extracts the required data, and formats it for presentation. We can use the categories of organizational memories introduced in Chapter 1 to describe the software side of information delivery systems. The second aspect of delivery is the hardware that gets information from a computer to the manager.

Information delivery systems software

Organizational memory	Delivery systems
People	Conversation E-mail Meeting Report

Organizational memory	Delivery systems
	Groupware
Documents	Web browser
	E-mail attachment
Images	Image processing system (IPS)
Graphics	Computer aided design (CAD)
	Geographic information system (GIS)
Voice	Voice mail
	Voice recording system
Mathematical model	Decision support system (DSS)
Decisions	Conversation
	E-mail
	Meeting
	Report
	Groupware

Software is used to move data to and from organizational memory. There is usually tight coupling between software and the format of an organizational memory. For example, a relational database management system can access tables but not decision-support models. This tight coupling is particularly frustrating for managers who often want integrated information from several organizational memories. For example, a sales manager might expect a monthly report to include details of recent sales (from a relational database) to be combined with customer comments (from email messages to a customer service system). A quick glance at the preceding table shows that there are many different information delivery systems. We will discuss each of these briefly to illustrate the lack of integration of organizational memories.

Verbal exchange

Conversations, meetings, and oral reporting are commonly used methods of information delivery. Indeed, managers show a strong preference for verbal exchange as a method for gathering information. This is not surprising because we are accustomed to oral information. This is the way we learned for thousands of years as a preliterate culture. Only recently have we learned to make decisions using computer reports and visuals.

Voice mail

Voice mail is useful for people who do not want to be interrupted. It supports asynchronous communication; that is, the two parties to the conversation are not simultaneously connected. Voice-mail systems also can store many prerecorded messages that can be selectively replayed using a phone’s keypad. Organizations use this feature to support standard customer queries.

Electronic mail

Email is an important system of information delivery. It too supports asynchronous messaging, and it is less costly than voice mail for communication. Many documents are exchanged as attachments to email.

Formal report

Formal reports have a long history in organizations. Before electronic communication, they were the main form of information delivery. They still have a role in organizations because they are an effective method of integrating information of varying hardness and from a variety of organizational memories. For example, a report can contain text, tables, graphics, and images.

Formal reports are often supplemented by a verbal presentation of the key points in the report. Such a presentation enhances the information delivered, because the audience has an opportunity to ask questions and get an immediate response.

Meetings

Because managers spend 30-80 percent of their time in meetings, these are a key source of information.

Groupware

Since meetings occupy so much managerial time and in many cases are poorly planned and managed, organizations are looking for improvements. Groupware is a general term applied to a range of software systems designed to improve some aspect of group work. It is excellent for tapping soft information and the informal side of organizational memory.

Image processing system

An image processing system (IPS) captures data using a scanner to digitize an image. Images in the form of letters, reports, illustrations, and graphics have always been an important type of organizational memory. An IPS permits these forms of information to be captured electronically and disseminated.

Computer-aided design

Computer-aided design (CAD) is used extensively to create graphics. For example, engineers use CAD in product design, and architects use it for building design. These plans are a part of organizational memory for designers and manufacturers.

Geographic information system

Many cities uses a geographic information system (GIS) to store graphical data about roads, utilities, and services. This information is another form of organizational memory.

Decision support system

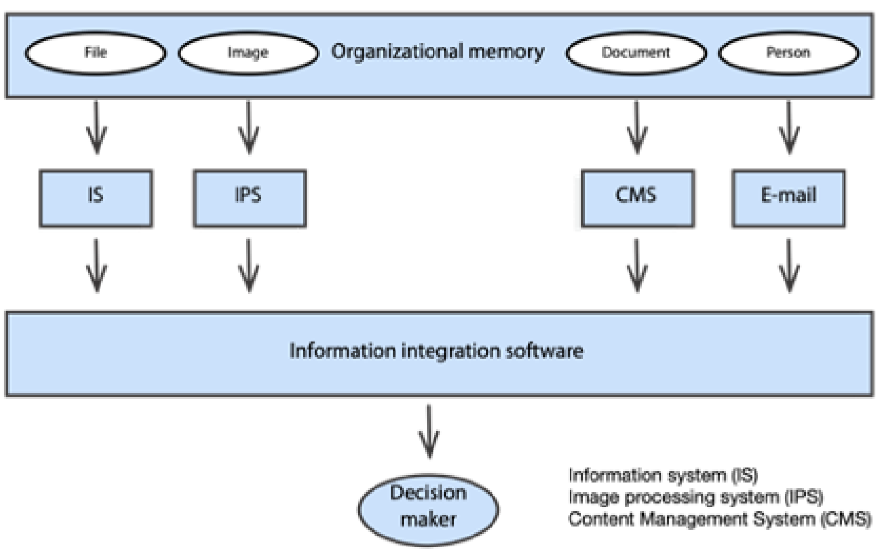
A DSS is frequently a computer-based mathematical model of a problem. DSS software permits the model and data to be retrieved and executed. Model parameters can be varied to investigate alternatives.

Information integration

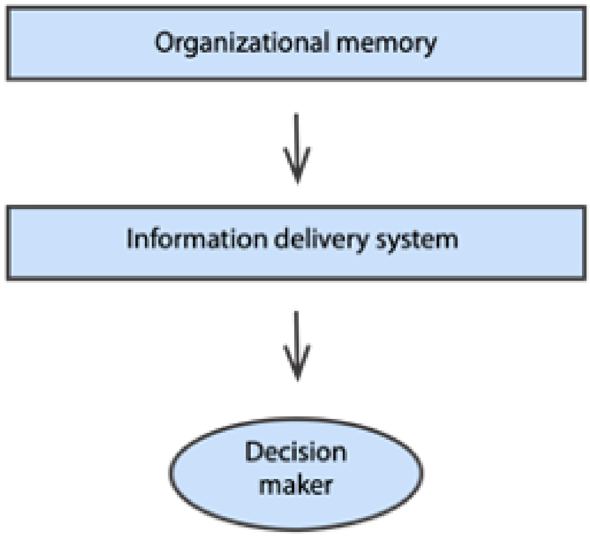
A fundamental problem for most organizations is that their memory is fragmented across a wide variety of formats and technologies. Sometimes, there is a one-to-one correspondence between an organizational memory for a particular functional area and the software delivery system. For example, sales information is delivered by the sales system and production information by the production system. This is not a very desirable situation because managers want all the information they need, regardless of its source or format, amalgamated into a single report.

A common solution is to develop software, such as a Web application, that integrates information from a variety of delivery systems. An important task of this app is to integrate and present information from multiple organizational memories. Recently, some organizations have created vast integrated data stores—data warehouses— that are organized repositories of organizational data.

Information integration - the present situation



The ideal organizational memory and information delivery system



Knowledge

The performance of many organizations is determined more by their cognitive capabilities and knowledge than their physical assets. A nation's wealth is increasingly a result of the knowledge and skills of its citizens (human capital), rather than its natural capital and industrial plants. Currently, about 85 percent of all jobs in America and 80 percent of those in Europe are knowledge-based.

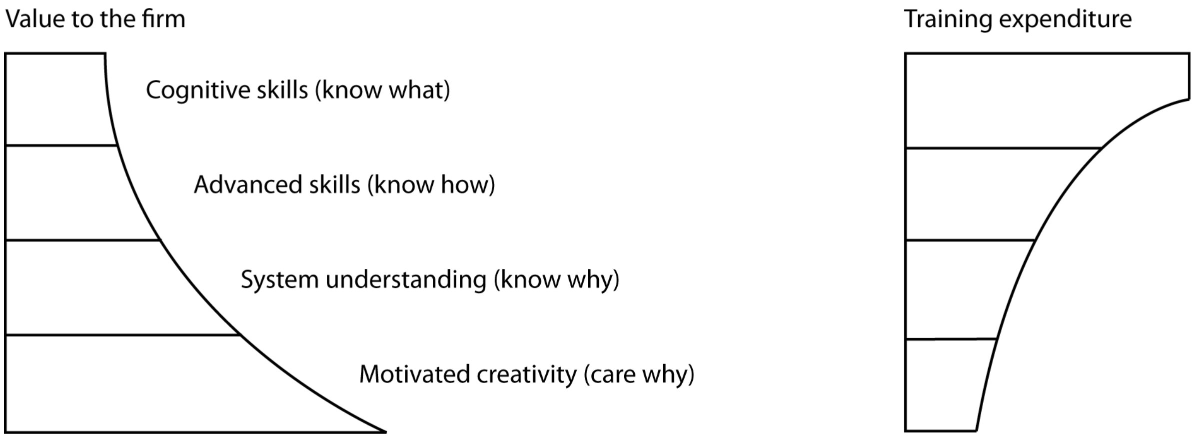
An organization's knowledge, in order of increasing importance, is

- cognitive knowledge (know what);
- advanced skills (know how);
- system understanding and trained intuition (know why);
- self-motivated creativity (care why).

This text illustrates the different types of knowledge. You will develop cognitive knowledge in Section 4, when you learn about data architectures and implementations. For example, knowing what storage devices can be used for archival data is cognitive knowledge. Section 2, data modeling and SQL, develops advanced skills because, upon completion of that section, you will know how to model data and write SQL queries. The first two chapters expand your understanding of the influence of organizational memory on organizational performance. You need to know why you should learn data management skills. Managers know when and why to apply technology, whereas technicians know what to apply and how to apply it. Finally, you are probably an IS major, and your coursework is inculcating the values and norms of the IS profession so that you care why problems are solved using information systems.

Organizations tend to spend more on developing cognitive skills than they do on fostering creativity. This is, unfortunately, the wrong priority. Returns are likely to be much greater when higher-level knowledge skills are developed. Well-managed organizations place more attention on creating know why and care why skills because they recognize that knowledge is a key competitive weapon. Furthermore, these firms have learned that knowledge grows, often very rapidly, when shared. Knowledge is like a communication network whose potential benefit grows exponentially as the nodes within the network grow arithmetically. When knowledge is shared within the organization, or with customers and suppliers, it multiplies as each person receiving knowledge imparts it to someone else in the organization or a business partner.

Skills values vs. training expenditures (Quinn et al., 1996)



There are two types of knowledge: explicit and tacit. Explicit knowledge is codified and transferable. This textbook is an example of explicit knowledge. Knowledge about how to design databases has been formalized and communicated with the intention of transferring it to you, the reader. Tacit knowledge is personal knowledge, experience, and judgment that is difficult to codify. It is more difficult to transfer tacit knowledge because it resides in people's minds. Usually, the transfer of tacit knowledge requires the sharing of experiences. In learning to model data, the subject of the next section, you will quickly learn how to represent an entity, because this knowledge is made explicit. However, you will find it much harder to model data, because this skill comes with practice. Ideally, you should develop several models under the guidance of an experienced modeler, such as your instructor, who can pass on their tacit knowledge.

Summary

Information has become a key foundation for organizational growth. The information society is founded on computer and communications technology. The accumulation of knowledge requires a capacity to encode and share information. Hard information is very exact. Soft information is extremely imprecise. Rich information exchange occurs in face-to-face conversation. Numeric reports are an example of lean information. Organizations use information to set goals, determine the gap between goals and achievements, determine actions to reach goals, and create new products and services to enhance organizational performance. Managers depend more on informal communication systems than on formal reporting systems. They expect to receive information that meets their current, ever changing needs. Operational managers need short-term information. Senior executives require mainly long-term information but still have a need for both short- and medium-term information. When managers face time constraints, they forced to collect only enough information to make a satisfactory decision. Organizational memory should be integrated to provide one interface to an organization's information stores.

Key terms and concepts	
Advanced skills (know how)	Information organization
Benchmarking	Information requirements
Change information	Information richness
Cognitive knowledge (know what)	Information satisficing
Empowerment	Information society
Explicit knowledge	Knowledge
Gap information	Managerial work
Global change	Organizational change
Goal-setting information	Phases of civilization
Information as a means of change	Self-motivated creativity (care why)
Information delivery systems	Social memory
Information hardness	System understanding (know why)
Information integration	Tacit knowledge

References and additional readings

Quinn, J. B., P. Anderson, and S. Finkelstein. 1996. Leveraging intellect. *Academy of Management Executive* 10 (3):7–27.

Exercises

1. From an information perspective, what is likely to be different about the customer service era compared to the sustainability era?
2. How does an information job differ from an industrial job?
3. Why was the development of paper and writing systems important?
4. What is the difference between soft and hard information?
5. What is the difference between rich and lean information exchange?
6. What are three major types of information connected with organizational change?
7. What is benchmarking? When might a business use benchmarking?
8. What is gap information?
9. Give some examples of how information is used as a means of change.
10. What sorts of information do senior managers want?
11. Describe the differences between the way managers handle hard and soft information.

12. What is information satisficing?
13. Describe an incident where you used information satisficing.
14. Give some examples of common information delivery systems.
15. What is a GIS? Who might use a GIS?
16. Why is information integration a problem?
17. How "hard" is an exam grade?
18. Could you develop a test for the hardness of a piece of information?
19. Is very soft information worth storing in formal organizational memory? If not, where might you draw the line?
20. If you had just failed your database exam, would you use rich or lean media to tell a parent or spouse about the result?
21. Interview a businessperson to determine his or her firm's critical success factors (CSFs). Remember, a CSF is something the firm must do right to be successful. Generally a firm has about seven CSFs. For the firm's top three CSFs, identify the information that will measure whether the CSF is being achieved.
22. If you were managing a quick service restaurant, what information would you want to track performance? Classify this information as short-, medium-, or long-term.
23. Interview a manager. Identify the information they use to manage the company. Classify this information as short-, medium-, or long-term information. Comment on your findings.
24. Why is organizational memory like a data warehouse? What needs to be done to make good use of a data warehouse?
25. What information are you collecting to help determine your career or find a job? What problems are you having collecting this information? Is the information mainly hard or soft?
26. What type of knowledge should you gain in a university class?
27. What type of knowledge is likely to make you most valuable?

Section 2 Data Modeling and SQL

> *It is a capital mistake to theorize before one has data.*
>
> Sir Arthur Conan Doyle, "A Scandal in Bohemia," *The Adventures of Sherlock Holmes*, 1891

The application backlog, a large number of requests for new information systems, has been a recurring problem in many organizations for decades. The demand for new information systems and the need to maintain existing systems have usually outstripped available information systems skills. The application backlog, unfortunately, is not a new problem. In the 1970s, Codd laid out a plan for improving programmer productivity and accelerating systems development by improving the management of data. Codd's relational model, designed to solve many of the shortcomings of earlier systems, has long been the most popular database model.

This section develops two key skills—data modeling and query formation—that are required to take advantage of the relational model. You will concentrate on the design and use of relational databases. This very abrupt change in focus is part of the plan to give you a dual understanding of data management. Section 1 is the managerial perspective, whereas this section covers technical skills development. Competent data managers are able to accommodate both views and apply whichever (or some blend of the two) is appropriate.

In Chapter 1, many forms of organizational memory were identified, and in this section we focus on files and their components. Thus, only the files branch of organizational memory is detailed in the following figure.

Organizational memory
|
Database
(collection of related files)
|
File
(table)
|
Record
(row)
|
Field
(column)
|
Character
(byte)
|
Bit

A collection of related files is a database. Describing the collection of files as related means that it has a common purpose (e.g., data about students). Sometimes files are also called tables, and there are synonyms for some other terms (the alternative names are shown in parentheses). Files contain records (or rows). Each record contains the data for one instance of an observation. For example, if the file stores data about students, each record will contain data about a single student. Records have fields (or columns) that store the fine detail of each instance (e.g., student's first name, last name, and date of birth). Fields are composed of characters (a, b, c,.., 1, 2, 3,..., %, $, #,..., A, B, etc.). A byte, a unit of storage sufficient to store a single letter (in English), consists of a string of eight contiguous bits or binary digits.

The data management hierarchy stimulates three database design questions:

- What collection of files should the database contain?
- How are these files related?
- What fields should each record in the file contain?

The first objective of this section is to describe data modeling, a technique for answering the three questions. Data modeling helps you to understand the structure and meaning of data, which is necessary before a database can be created. Once a database has been designed, built, and loaded with data, the aim is to deploy it to satisfy management's requests for information. Thus, the second objective is to teach you to query a relational database. The learning of modeling and querying will be intertwined, making it easier to grasp the intent of database design and to understand why data modeling is so critical to making a database an effective tool for managerial decision making.

Chapter 3 covers modeling a single entity and querying a single-table database. This is the simplest database that can be created. As you will soon discover, a data model is a graphical description of the components of a database. One of these components is an entity, some feature of the real world about which data must be stored. This section also introduces the notions of a data definition language (DDL), which is used to describe a database, and a data manipulation language (DML), which is used to maintain and query a database. Subsequent chapters in this section cover advanced data modeling concepts and querying capabilities.

3 The Single Entity

I want to be alone.

Attributed to Greta Garbo

Learning Objectives

Students completing this chapter will be able to

- model a single entity;
- define a single database;
- write queries for a single-table database.

The relational model

The relational model introduced by Codd in 1970 is the most popular technology for managing large collections of data. In this chapter, the major concepts of the relational model are introduced. Extensive coverage of the relational model is left until Chapter 8, by which time you will have sufficient practical experience to appreciate fully its usefulness, value, and elegance.

A relation, similar to the mathematical concept of a set, is a two-dimensional table arranged in rows and columns. This is a very familiar idea. You have been using tables for many years. A relational database is a collection of relations, where relation is a mathematical term for a table. One row of a table stores details of one observation, instance, or case of an item about which facts are retained—for example, one row for details of a particular student. All the rows in a table store data about the same type of item. Thus, a database might have one table for student data and another table for class data. Similarly, each column in the table contains the same type of data. For example, the first column might record a student's identification number. A key database design question is to decide what to store in each table. What should the rows and columns contain?

In a relational database, each row must be uniquely identified. There must be a primary key, such as student identifier, so that a particular row can be designated. The use of unique identifiers is very common. Telephone numbers and e-mail addresses are examples of unique identifiers. Selection of the primary key, or unique identifier, is another key issue of database design.

☒ Global legal entity identifier (LEI)

There is no global standard for identifying legal entities across markets and jurisdictions. The need for such a standard was amplified by Lehman Brothers collapse in 2008. Lehman had 209 registered subsidiaries, legal entities, in 21 countries, and it was party to more than 900,000 derivatives contracts upon its collapse. Key stakeholders, such as financial regulators and Lehman's creditors, were unable to assess their exposure. Furthermore, others were unable to assess the possible ripple on them of the effects of the collapse because of the transitive nature of many investments (i.e., A owes B, B owes C, and C owes D).

The adoption of a global legal entity identifier (LEI), should improve financial system regulation and corporate risk management. Regulators will find it easier to monitor and analyze threats to financial stability and risk managers will be more able evaluate their companies' risks.

The tables in a relational database are connected or related by means of the data in the tables. You will learn, in the next chapter, that this connection is through a pair of values—a primary key and a foreign key. Consider a table of airlines serving a city. When examining this table, you may not recognize the code of an airline, so you then go to another table to find the name of the airline. For example, if you inspect the next table, you find that AM is an international airline serving Atlanta.

International airlines serving Atlanta

Airline
AM
JL
KX
LM
MA
OS
RG
SN
SR
LH
LY

If you don't know which airline has the abbreviation AM, then you need to look at the table of airline codes to discover that AeroMexico, with code AM, serves Atlanta. The two tables are related by airline code. Later, you will discover which is the primary key and which is the foreign key.

A partial list of airline codes

Code	Airline
AA	American Airlines
AC	Air Canada
AD	Lone Star Airlines

Code	Airline
AE	Mandarin Airlines
AF	Air France
AG	Interprovincial Airlines
AI	Air India
AM	AeroMexico
AQ	Aloha Airlines

When designing the relational model, Codd provided commands for processing multiple records at a time. His intention was to increase the productivity of programmers by moving beyond the record-at-a-time processing that is found in most programming languages. Consequently, the relational model supports set processing (multiple records-at-a-time), which is most frequently implemented as Structured Query Language (SQL).[1]

The relational model separates the logical design of a database from its physical storage. This notion of data independence simplifies data modeling and database programming. In this section, we focus on logical database design, and now that you have had a brief introduction to the relational model, you are ready to learn data modeling.

Getting started

As with most construction projects, building a relational database must be preceded by a design phase. Data modeling, our design technique, is a method for creating a plan or blueprint of a database. The data model must accurately mirror real-world relationships if it is to support processing business transactions and managerial decision making.

Rather than getting bogged down with a *theory first, application later* approach to database design and use, we will start with application. We will get back to theory when you have some experience in data modeling and database querying. After all, you did not learn to talk by first studying sentence formation; you just started by learning and using simple words. We start with the simplest data model, a single entity, and the simplest database, a single table, as follows.

Share code	Share name	Share price	Share quantity	Share dividend	PE ratio
FC	Freedonia Copper	27.5	10,529	1.84	16
PT	Patagonian Tea	55.25	12,635	2.50	10
AR	Abyssinian Ruby	31.82	22,010	1.32	13
SLG	Sri Lankan Gold	50.37	32,868	2.68	16

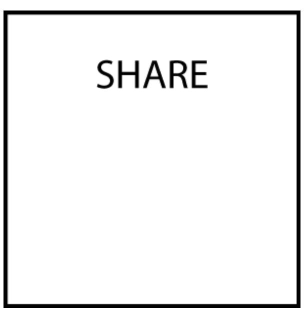
[1] Officially pronounced as “S-Q-L,” but often also pronounced as “sequel”.

Share code	Share name	Share price	Share quantity	Share dividend	PE ratio
ILZ	Indian Lead & Zinc	37.75	6,390	3.00	12
BE	Burmese Elephant	0.07	154,713	0.01	3
BS	Bolivian Sheep	12.75	231,678	1.78	11
NG	Nigerian Geese	35.00	12,323	1.68	10
CS	Canadian Sugar	52.78	4,716	2.50	15
ROF	Royal Ostrich Farms	33.75	1,234,923	3.00	6

Modeling a single-entity database

The simplest database contains information about one entity, which is some real-world thing. Some entities are physical—CUSTOMER, ORDER, and STUDENT; others are abstract or conceptual—WORK ASSIGNMENT, and AUTHORSHIP. We represent an entity by a rectangle: the following figure shows a representation of the entity SHARE. The name of the entity is shown in singular form in uppercase in the top part of the rectangle.

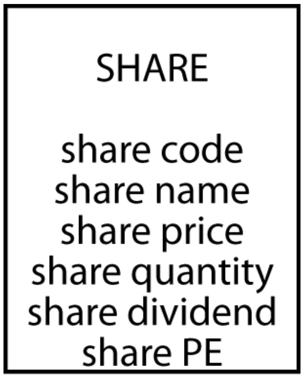
The entity SHARE



An entity has characteristics or attributes. An attribute is a discrete element of data; it is not usually broken down into smaller components. Attributes are describe the data we want to store. Some attributes of the entity SHARE are *share code*, *share name*, *share price*, *share quantity* (number owned), *share dividend*, and *PE ratio* (price-to-earnings ratio).[2] Attributes are shown below the entity's name. Notice that we refer to *share price*, rather than *price*, to avoid confusion if there should be another entity with an attribute called *price*. Attribute names must be carefully selected so that they are self-explanatory and unique. For example, *share dividend* is easily recognized as belonging to the entity SHARE.

The entity SHARE and its attributes

[2]Attributes are shown in italics.



An instance is a particular occurrence of an entity (e.g., facts about Freedonia Copper). To avoid confusion, each instance of an entity needs to be uniquely identified. Consider the case of customer billing. In most cases, a request to bill Smith $100 cannot be accurately processed because a firm might have more than one Smith in its customer file. If a firm has carefully controlled procedures for ensuring that each customer has a unique means of identification, then a request to bill customer number 1789 $100 can be accurately processed. An attribute or collection of attributes that uniquely identifies an instance of an entity is called an identifier. The identifier for the entity SHARE is *share code*, a unique identifier assigned by the stock exchange to a firm issuing shares.

There may be several attributes, or combinations of attributes, that are feasible identifiers for an instance of an entity. Attributes that are identifiers are prefixed by an asterisk. The following figure shows an example of a representation of an entity, its attributes, and identifier.

The entity SHARE, its attributes, and identifier

Briefly, entities are things in the environment about which we wish to store information. Attributes describe an entity. An entity must have a unique identifier.

The modeling language used in this text is designed to record the essential details of a data model. The number of modeling symbols to learn is small, and they preserve all the fundamental concepts of data modeling. Since data modeling often occurs in a variety of settings, the symbols used have been selected so that they can be quickly drawn using pencil-and-paper, whiteboard, or a general-purpose drawing program. This also means that models can be quickly revised as parts can be readily erased and redrawn.

The symbols are distinct and visual clutter is minimized because only the essential information is recorded. This also makes the language easy for clients to learn so they can read and amend models.

Models can be rapidly translated to a set of tables for a relational database. More importantly, since this text implements the fundamental notions of all data modeling languages, you can quickly convert to another data modeling dialect. Data modeling is a high-level skill, and the emphasis needs to be on learning to think like a data modeler rather than on learning a modeling language. This text's goal is to get you off to a fast start.

> ☒ *Skill builder*
>
> A ship has a name, registration code, gross tonnage, and a year of >construction. Ships are classified as cargo or passenger. Draw a data model >for a ship.

Creating a single-table database

The next stage is to translate the data model into a relational database. The translation rules are very direct:

- Each entity becomes a table.
- The entity name becomes the table name.
- Each attribute becomes a column.
- The identifier becomes the primary key.

The American National Standards Institute's (ANSI) recommended language for relational database definition and manipulation is SQL, which is both a data definition language (DDL) (to define a database), a data manipulation language (DML) (to query and maintain a database), and a data control language (DCL) (to control access). SQL is a common standard for describing and querying databases and is available with many commercial relational database products, including DB2, Oracle, and Microsoft SQL Server, and open source products such as MySQL and PostgreSQL.

In this book, MySQL is the relational database for teaching SQL. Because SQL is a standard, it does not matter which implementation of the relational model you use as the SQL language is common across both the proprietary and open variants.[3] SQL uses the CREATE[4] statement to define a table. It is not a particularly friendly command, and most products have friendlier interfaces for defining tables. However, it is important to learn the standard, because this is the command that SQL understands. Also, a table definition interface will generate a CREATE statement for execution by SQL. Your interface interactions ultimately translate into a standard SQL command.

It is common practice to abbreviate attribute names, as is done in the following example.

[3] Now would be a good time to install the MySQL Community server on your computer, unless your instructor has set up a class server.

[4] SQL keywords are shown in uppercase.

Defining a table

The CREATE command to establish a table called `share` is as follows:

```
CREATE TABLE share (
  shrcode CHAR(3),
  shrfirm VARCHAR(20) NOT NULL,
  shrprice DECIMAL(6,2),
  shrqty DECIMAL(8),
  shrdiv DECIMAL(5,2),
  shrpe DECIMAL(2),
  PRIMARY KEY (shrcode));
```

The first line of the command names the table; subsequent lines describe each of its columns. The first component is the name of the column (e.g., `shrcode`). The second component is the data type (e.g., CHAR), and its length is shown in parentheses. `shrfirm` is a variable-length character field of length 20, which means it can store up to 20 characters, including spaces. The column `shrdiv` stores a decimal number that can be as large as 999.99 because its total length is 5 digits and there are 2 digits to the right of the decimal point. Some examples of allowable data types are shown in the following table. The third component (e.g., NOT NULL), which is optional, indicates any instance that cannot have null values. A column might have a null value when it is either unknown or not applicable. In the case of the share table, we specify that `shrfirm` must be defined for each instance in the database.

The final line of the CREATE statement defines `shrcode` as the primary key, the unique identifier for SHARE When a primary key is defined, the relational database management system (RDBMS) will enforce the requirement that the primary key is unique and not null. Before any row is added to the table SHARE, the RDBMS will check that the value of `shrcode` is not null and that there does not already exist a duplicate value for `shrcode` in an existing row of `share`. If either of these constraints is violated, the RDBMS will not permit the new row to be inserted. This constraint, the entity integrity rule, ensures that every row has a unique, non-null primary key. Allowing the primary key to take a null value would mean there could be a row of `share` that is not uniquely identified. Note that an SQL statement is terminated by a semicolon, though this is not always enforced.

SQL statements can be written in any mix of valid upper and lowercase characters. To make it easier for you to learn the syntax, this book adopts the following conventions:

- SQL keywords are in uppercase.
- Table and column names are in lowercase.

There are more elaborate layout styles, but we will bypass those because it is more important at this stage to learn SQL. You should lay out your SQL statements so that they are easily read by you and others.

The following table shows some of the data types supported by most relational databases. Other implementations of the relational model may support some of these data types and additional ones. It is a good idea to review the available data types in your RDBMS before defining your first table.

Some allowable data types

Category	Data type	Description
Numeric	SMALLINT	A 15-bit signed binary value
	INTEGER	A 31-bit signed binary value
	FLOAT(p)	A scientific format number of p binary digits precision
	DECIMAL(p,q)	A packed decimal number of p digits total length; q decimal spaces to the right of the decimal point may be specified
String	CHAR(n)	A fixed-length string of n characters
	VARCHAR(n)	A variable-length string of up to n characters
	text	A variable-length string of up to 65,535 characters
Date/time	DATE	Date in the form yyyymmdd
	TIME	Time in the form hhmmss
	timesTAMP	A combination of date and time to the nearest microsecond
	time with time zone	Same as time, with the addition of an offset from universal time coordinated (UTC) of the specified time
	timestamp with time zone	Same as timestamp, with the addition of an offset from UTC of the specified time
Logical	Boolean	A set of truth values: TRUE, FALSE, or UNKNOWN

The CHAR and VARCHAR data types are similar but differ in the way character strings are stored and retrieved. Both can be up to 255 characters long. The length of a CHAR column is fixed to the declared length. When values are stored, they are right-padded with spaces to the specified length. When CHAR values are retrieved, trailing spaces are removed. VARCHAR columns store variable-length strings and use only as many characters as are needed to store the string. Values are not padded; instead, trailing spaces are removed. In this book, we use VARCHAR to define most character strings, unless they are short (less than five characters is a good rule-of-thumb).

Data modeling with MySQL Workbench

MySQL Workbench is a professional quality, open source, cross-platform tool for data modeling and SQL querying. In this text, you will also learn some of the features of Workbench that support data modeling and using SQL. You will find it helpful to complete the tutorial on creating a data model prior to further reading, as we will assume you have such proficiency.

The entity share created with MySQL Workbench

You will notice some differences from the data model we have created previously. Workbench automatically generates the SQL code to create the table, so when modeling you establish the names you want for tables and columns. A gold key symbol is used to indicate the identifier, which becomes the primary key. An open diamond indicates that a column can be null, whereas a closed blue diamond indicate the column must have a value, as with `shrfirm` in this case.

When specifying columns in Workbench you must also indicate the datatype. We opt to turn off the display of a column's datatype[5] in a model to maintain focus on the entity.

A major advantage of using a tool such as Workbench is that it will automatically generate the CREATE statement code (Database > Forward Engineer ...) and execute the code to create the database. The Workbench tutorial will have shown you how to do this, and you should try this out for yourself by creating a database with the single `share` table.

Inserting rows into a table

The rows of a table store instances of an entity. A particular shareholding (e.g., Freedonia Copper) is an example of an instance of the entity `share`. The SQL statement INSERT is used to add rows to a table. Although most implementations of the relational model use an application for row insertion, if authorized, you might also use a RDBMS interface spreadsheet or import a structured text file, such as Comma Separated Value (CSV) file. The INSERT command is defined for completeness.

The following command adds one row to the table `share`:

[5] Preferences > Diagram > Show Column Types

```
INSERT INTO share
  (shrcode,shrfirm,shrprice,shrqty,shrdiv,shrpe)
  VALUES ('FC','Freedonia Copper',27.5,10529,1.84,16);
```

There is a one-to-one correspondence between a column name in the first set of parentheses and a value in the second set of parentheses. That is, `shrcode` has the value “FC”, `shrfirm` the value “Freedonia Copper”, and so on. Notice that the value of a column that stores a character string (e.g., `shrfirm`) is contained within straight quotes.

The list of field names can be omitted when values are inserted in all columns of the table in the same order as that specified in the CREATE statement, so the preceding expression could be written

```
INSERT INTO share
  VALUES ('FC','Freedonia Copper',27.5,10529,1.84,16);
```

The data for the `share` table will be used in subsequent examples. If you have ready access to a relational database, it is a good idea to now create a table and enter the data. Then you will be able to use these data to practice querying the table.

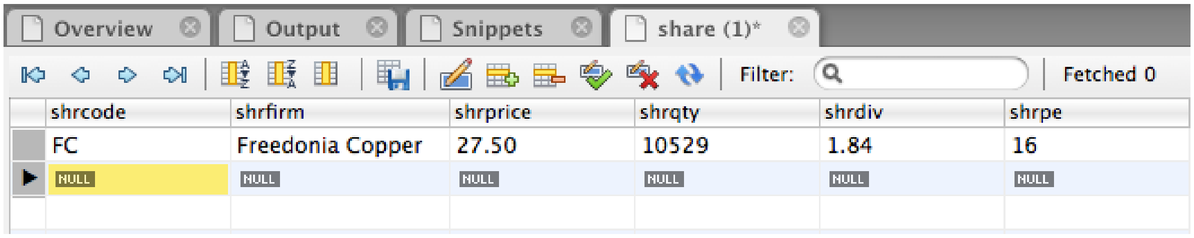
Data for share

*Code	Name	Price	Quantity	Dividend	PE
FC	Freedonia Copper	27.5	10,529	1.84	16
PT	Patagonian Tea	55.25	12,635	2.50	10
AR	Abyssinian Ruby	31.82	22,010	1.32	13
SLG	Sri Lankan Gold	50.37	32,868	2.68	16
ILZ	Indian Lead & Zinc	37.75	6,390	3.00	12
BE	Burmese Elephant	0.07	154,713	0.01	3
BS	Bolivian Sheep	12.75	231,678	1.78	11
NG	Nigerian Geese	35.00	12,323	1.68	10
CS	Canadian Sugar	52.78	4,716	2.50	15
ROF	Royal Ostrich Farms	33.75	1,234,923	3.00	6

Notice that `shrcode`,the primary key, is asterisked in the preceding table. This is a convention we will use, as in data modeling, to denote the primary key. In the relational model, an identifier becomes a primary key, a column that guarantees that each row of the table can be uniquely addressed.

MySQL Workbench offers a spreadsheet interface for entering data, as explained in the tutorial.

Inserting rows with MySQL Workbench



☒ *Skill builder*

Create a relational database for the ship entity you modeled previously. >Insert some rows.

Querying a single-table database

The objective of developing a database is to make it easier to use the stored data to solve problems. Typically, a manager raises a question (e.g., How many shares have a PE ratio greater than 12?). A question or request for information, usually called a query, is then translated into a specific data manipulation or query language. The most widely used query language for relational databases is SQL. After the query has been executed, the resulting data are displayed. In the case of a relational database, the answer to a query is always a table.

There is also a query language called relational algebra, which describes a set of operations on tables. Sometimes it is useful to think of queries in terms of these operations. Where appropriate, we will introduce the corresponding relational algebra operation.

Generally we use a four-phase format for describing queries:

1. A brief explanation of the query's purpose
2. The query in italics, prefixed by •, and some phrasing you might expect from a manager
3. The SQL version of the query
4. The results of the query.

Displaying an entire table

All the data in a table can be displayed using the SELECT statement. In SQL, the *all* part is indicated by an asterisk (*).

List all data in the share table.

```
SELECT * FROM share;
```

Table 3.6: 10 records

shrcode	shrfirm	shrprice	shrqty	shrdiv	shrpe
AR	Abyssinian Ruby	31.82	22010	1.32	13
BE	Burmese Elephant	0.07	154713	0.01	3
BS	Bolivian Sheep	12.75	231678	1.78	11
CS	Canadian Sugar	52.78	4716	2.50	15
FC	Freedonia Copper	27.50	10529	1.84	16
ILZ	Indian Lead & Zinc	37.75	6390	3.00	12
NG	Nigerian Geese	35.00	12323	1.68	10
PT	Patagonian Tea	55.25	12635	2.50	10
ROF	Royal Ostrich Farms	33.75	1234923	3.00	6
SLG	Sri Lankan Gold	50.37	32868	2.68	16

Project—choosing columns

The relational algebra operation project creates a new table from the columns of an existing table. Project takes a vertical slice through a table by selecting all the values in specified columns. The projection of `share` on columns `shrfirm` and `shrpe` produces a new table with 10 rows and 2 columns. The SQL syntax for the project operation simply lists the columns to be displayed.

Report a firm's name and price-earnings ratio.

```
SELECT shrfirm, shrpe FROM share;
```

Table 3.7: Displaying records 1 - 10

shrfirm	shrpe
Abyssinian Ruby	13
Burmese Elephant	3
Bolivian Sheep	11
Canadian Sugar	15
Freedonia Copper	16
Indian Lead & Zinc	12
Nigerian Geese	10
Patagonian Tea	10
Royal Ostrich Farms	6
Sri Lankan Gold	16

Restrict—choosing rows

The relational algebra operation restrict creates a new table from the rows of an existing table. The operation restricts the new table to those rows that satisfy a specified condition. Restrict takes all columns of an existing table but only those rows that meet the specified condition. The restriction of `share` to those rows where the PE ratio is less than 12 will give a new table with five rows and six columns.

Restrict is implemented in SQL using the WHERE clause to specify the condition on which rows are restricted.

Get all firms with a price-earnings ratio less than 12.

```
SELECT * FROM share WHERE shrpe < 12;
```

Table 3.8: 5 records

shrcode	shrfirm	shrprice	shrqty	shrdiv	shrpe
BE	Burmese Elephant	0.07	154713	0.01	3
BS	Bolivian Sheep	12.75	231678	1.78	11
NG	Nigerian Geese	35.00	12323	1.68	10
PT	Patagonian Tea	55.25	12635	2.50	10
ROF	Royal Ostrich Farms	33.75	1234923	3.00	6

In this example, we have a less than condition for the WHERE clause. All permissible comparison operators are listed below.

Operator	Meaning
=	Equal to
<	Less than
<=	Less than orequal to
>	Greater than
>=	Greater than or equal to
<>	Not equal to

In addition to the comparison operators, the BETWEEN construct is available.

The expression `a BETWEEN x AND y` is equivalent to `a >= x AND a <= y`.

Combining project and restrict—choosing rows and columns

SQL permits project and restrict to be combined. A single SQL SELECT statement can specify which columns to project and which rows to restrict.

List the name, price, quantity, and dividend of each firm where the share holding is at least 100,000.

```
SELECT shrfirm, shrprice, shrqty, shrdiv FROM share
  WHERE shrqty >= 100000;
```

Table 3.10: 3 records

shrfirm	shrprice	shrqty	shrdiv
Burmese Elephant	0.07	154713	0.01
Bolivian Sheep	12.75	231678	1.78
Royal Ostrich Farms	33.75	1234923	3.00

More about WHERE

The WHERE clause can contain several conditions linked by AND or OR. A clause containing AND means all specified conditions must be true for a row to be selected. In the case of OR, at least one of the conditions must be true for a row to be selected.

Find all firms where the PE is 12 or higher and the share holding is less than 10,000.

```
SELECT * FROM share
  WHERE shrpe >= 12 AND shrqty < 10000;
```

Table 3.11: 2 records

shrcode	shrfirm	shrprice	shrqty	shrdiv	shrpe
CS	Canadian Sugar	52.78	4716	2.5	15
ILZ	Indian Lead & Zinc	37.75	6390	3.0	12

The power of the primary key

The purpose the primary key is to guarantee that any row in a table can be uniquely addressed. In this example, we use `shrcode` to return a single row because `shrcode` is unique for each instance of `share`. The sought code (AR) must be specified in quotes because `shrcode` was defined as a character string when the table was created.

Report firms whose code is AR.

```
SELECT * FROM share WHERE shrcode = 'AR';
```

Table 3.12: 1 records

shrcode	shrfirm	shrprice	shrqty	shrdiv	shrpe
AR	Abyssinian Ruby	31.82	22010	1.32	13

A query based on a non-primary-key column cannot guarantee that a single row is accessed, as the following illustrates.

Report firms with a dividend of 2.50.

```
SELECT * FROM share WHERE shrdiv = 2.5;
```

Table 3.13: 2 records

shrcode	shrfirm	shrprice	shrqty	shrdiv	shrpe
CS	Canadian Sugar	52.78	4716	2.5	15
PT	Patagonian Tea	55.25	12635	2.5	10

☒ Mis-identification mess

Jieun Kim of Los Angeles and Jieun Kim of Chicagoland were mistakenly issued the same Social Security number when they emigrated to the US. They have the same name and were born on the same day in South Korea. As a result, their banking and savings accounts have been shut down and their credit cards blocked. They have suspected of engaging in identity theft

Source: https://apple.news/AhdshG6GLTq2S98knnma67A

The IN crowd

The keyword IN is used with a list to specify a set of values. IN is always paired with a column name. All rows for which a value in the specified column has a match in the list are selected. It is a simpler way of writing a series of OR statements.

Report data on firms with codes of FC, AR, or SLG.

```
SELECT * FROM share WHERE shrcode IN ('FC','AR','SLG');
```

The foregoing query could have also been written as

```
SELECT * FROM share
  WHERE shrcode = 'FC' or shrcode = 'AR' or shrcode = 'SLG';
```

Table 3.14: 3 records

shrcode	shrfirm	shrprice	shrqty	shrdiv	shrpe
AR	Abyssinian Ruby	31.82	22010	1.32	13
FC	Freedonia Copper	27.50	10529	1.84	16
SLG	Sri Lankan Gold	50.37	32868	2.68	16

The NOT IN crowd

A NOT IN list is used to report instances that do not match any of the values.

Report all firms other than those with the code CS or PT.

```
SELECT * FROM share WHERE shrcode NOT IN ('CS','PT');
```

is equivalent to

```
SELECT * FROM share WHERE shrcode <> 'CS' AND shrcode <> 'PT';
```

Table 3.15: 8 records

shrcode	shrfirm	shrprice	shrqty	shrdiv	shrpe
AR	Abyssinian Ruby	31.82	22010	1.32	13
BE	Burmese Elephant	0.07	154713	0.01	3
BS	Bolivian Sheep	12.75	231678	1.78	11
FC	Freedonia Copper	27.50	10529	1.84	16
ILZ	Indian Lead & Zinc	37.75	6390	3.00	12
NG	Nigerian Geese	35.00	12323	1.68	10
ROF	Royal Ostrich Farms	33.75	1234923	3.00	6
SLG	Sri Lankan Gold	50.37	32868	2.68	16

❎ *Skill Builder*

List those shares where the value of the holding exceeds one million.

Ordering columns

The order of reporting columns is identical to their order in the SQL command. For instance, compare the output of the following queries.

```
SELECT shrcode, shrfirm FROM share WHERE shrpe = 10;
```

Table 3.16: 2 records

shrcode	shrfirm
NG	Nigerian Geese
PT	Patagonian Tea

```
SELECT shrfirm, shrcode FROM share WHERE shrpe = 10;
```

Table 3.17: 2 records

shrfirm	shrcode
Nigerian Geese	NG
Patagonian Tea	PT

Ordering rows

People can generally process an ordered (e.g., sorted alphabetically) report faster than an unordered one. In SQL, the ORDER BY clause specifies the row order in a report. The default ordering sequence is ascending (A before B, 1 before 2). Descending is specified by adding DESC after the column name.

List all firms where PE is at least 10, and order the report in descending PE. Where PE ratios are identical, list firms in alphabetical order.

```
SELECT * FROM share WHERE shrpe >= 10
  ORDER BY shrpe DESC, shrfirm;
```

Table 3.18: 8 records

shrcode	shrfirm	shrprice	shrqty	shrdiv	shrpe
FC	Freedonia Copper	27.50	10529	1.84	16
SLG	Sri Lankan Gold	50.37	32868	2.68	16
CS	Canadian Sugar	52.78	4716	2.50	15
AR	Abyssinian Ruby	31.82	22010	1.32	13
ILZ	Indian Lead & Zinc	37.75	6390	3.00	12
BS	Bolivian Sheep	12.75	231678	1.78	11
NG	Nigerian Geese	35.00	12323	1.68	10
PT	Patagonian Tea	55.25	12635	2.50	10

Numeric versus character sorting

Numeric data in character fields (e.g., a product code) do not always sort the way you initially expect. The difference arises from the way data are stored:

- Numeric fields are right justified and have leading zeros.
- Character fields are left justified and have trailing spaces.

For example, the value 1066 stored as CHAR(4) would be stored as '1066' and the value 45 would be stored as '45'. If the column containing these data is sorted in ascending order, then '1066' precedes '45' because the leftmost character '1' is less than '4'. You can avoid this problem by always storing numeric values as numeric data types (e.g., integer or decimal) or preceding numeric values with zeros when they are stored as character data. Alternatively, start numbering at 1,000 so that all values are four digits, though the best solution is to store numeric data as numbers rather than characters.

Derived data

One of the important principles of database design is to avoid redundancy. One form of redundancy is including a column in a table when these data can be derived from other columns. For example, we do not need a column for yield because it can be calculated by dividing dividend by price and multiplying by 100 to obtain the yield as a percentage. This means that the query language does the calculation when the value is required.

Get firm name, price, quantity, and firm yield.

```
SELECT shrfirm, shrprice, shrqty,
shrdiv/shrprice*100 AS yield FROM share;
```

Table 3.19: Displaying records 1 - 10

shrfirm	shrprice	shrqty	yield
Abyssinian Ruby	31.82	22010	4.148334
Burmese Elephant	0.07	154713	14.285714
Bolivian Sheep	12.75	231678	13.960784
Canadian Sugar	52.78	4716	4.736643
Freedonia Copper	27.50	10529	6.690909
Indian Lead & Zinc	37.75	6390	7.947020
Nigerian Geese	35.00	12323	4.800000
Patagonian Tea	55.25	12635	4.524887
Royal Ostrich Farms	33.75	1234923	8.888889
Sri Lankan Gold	50.37	32868	5.320627

You can give the results of the calculation a column name. In this case, a good choice is `yield`. Note the use of AS to indicate the name of the column in which the results of the calculation are displayed.

In the preceding query, the keyword AS is introduced to specify an alias, or temporary name. The statement specifies that the result of the calculation is to be reported under the column heading `yield`. You can rename any column or specify a name for the results of an expression using an alias.

Aggregate functions

SQL has built-in functions to enhance its retrieval power and handle many common aggregation queries, such as computing the total value of a column. Four of these functions (AVG, SUM, MIN, and MAX) work very similarly. COUNT is a little different.

COUNT

COUNT computes the number of rows in a table. Use COUNT(*) to count all rows irrespective of their content (i.e., null or not null), and use COUNT(`columnname`) to count rows without a null value for `columnname`. Count can be used with a WHERE clause to specify a condition.

How many firms are there in the portfolio?

```
SELECT COUNT(shrcode) AS investments FROM share;
```

Table 3.20: 1 records

investments
10

How many firms have a holding greater than 50,000?

```
SELECT COUNT(shrfirm) AS bigholdings FROM share
  WHERE shrqty > 50000;
```

Table 3.21: 1 records

bigholdings
3

AVG—averaging

AVG computes the average of the values in a column of numeric data. Null values in the column are not included in the calculation.

Find the average dividend.

```
SELECT AVG(shrdiv) AS avgdiv FROM share;
```

Table 3.22: 1 records

avgdiv
2.031

What is the average yield for the portfolio?

```
SELECT AVG(shrdiv/shrprice*100) AS avgyield FROM share;
```

Table 3.23: 1 records

avgyield
7.530381

SUM, MIN, and MAX

SUM, MIN, and MAX differ in the statistic they calculate but are used similarly to AVG. As with AVG, null values in a column are not included in the calculation. SUM computes the sum of a column of values. MIN finds the smallest value in a column; MAX finds the largest.

Subqueries

Sometimes we need the answer to another query before we can write the query of ultimate interest. For example, to list all shares with a PE ratio greater than the portfolio average, you first must find the average PE ratio for the portfolio. You could do the query in two stages:

```
SELECT AVG(shrpe) FROM share;
```

and

```
SELECT shrfirm, shrpe FROM share WHERE shrpe > x;
```

where x is the value returned from the first query.

Unfortunately, the two-stage method introduces the possibility of errors. You might forget the value returned by the first query or enter it incorrectly. It also takes longer to get the results of the query. We can solve these problems by using parentheses to indicate the first query is nested within the second one. As a result, the value returned by the inner or nested subquery, the one in parentheses, is used in the outer query. In the following example, the nested query returns 11.20, which is then automatically substituted in the outer query.

Report all firms with a PE ratio greater than the average for the portfolio.

```
SELECT shrfirm, shrpe FROM share
  WHERE shrpe > (SELECT AVG(shrpe) FROM share);
```

Table 3.24: 5 records

shrfirm	shrpe
Abyssinian Ruby	13
Canadian Sugar	15
Freedonia Copper	16
Indian Lead & Zinc	12
Sri Lankan Gold	16

☒ The preceding query is often mistakenly written as SELECT shrfirm, shrpe from share WHERE shrpe > avg(shrpe); You need to use a subquery to find the average, so the computed value can be used in the outer query

☒ *Skill builder*

Find the name of the firm for which the value of the holding is greatest.

Regular expression—pattern matching

Regular expression is a concise and powerful method for searching for a specified pattern in a nominated column. Regular expression processing is supported by languages such as Java, R, and PHP. In this chapter, we introduce a few typical regular expressions and will continue developing your knowledge of this feature in the next chapter.

Search for a string

List all firms containing 'Ruby' in their name.

```
SELECT shrfirm FROM share WHERE shrfirm REGEXP 'Ruby';
```

Table 3.25: 1 records

shrfirm
Abyssinian Ruby

Search for alternative strings

In some situations you want to find columns that contain more than one string. In this case, we use the alternation symbol '|' to indicate the alternatives being sought. For example, a|b finds 'a' or 'b'.

List firms containing gold or zinc in their name, irrespective of case.

There can be variations on the spelling of zinc in a company name, such as Zinc and ZINC. To cater for all variations, convert a firm's name to lowercase with the built-in MySQL function LOWER().[6]

```
SELECT shrfirm FROM share
  WHERE LOWER(shrfirm) REGEXP 'gold|zinc';
```

Table 3.26: 2 records

shrfirm
Indian Lead & Zinc
Sri Lankan Gold

Search for a beginning string

If you are interested in finding a value in a column that starts with a particular character string, then use ^ to indicate this option.

List the firms whose name begins exactly with Sri.

```
SELECT shrfirm FROM share WHERE shrfirm REGEXP '^Sri';
```

Table 3.27: 1 records

shrfirm
Sri Lankan Gold

Search for an ending string

If you are interested in finding if a value in a column ends with a particular character string, then use $ to indicate this option.

List the firms whose name ends with any form of geese.

```
SELECT shrfirm FROM share
  WHERE LOWER(shrfirm) REGEXP 'geese$';
```

[6] For a full list of MySQL functions and operators, see https://dev.mysql.com/doc/refman/8.0/en/string-functions.html.

Table 3.28: 1 records

shrfirm
Nigerian Geese

☒ *Skill builder*

List the firms containing “ian” in their name.

DISTINCT—eliminating duplicate rows

The DISTINCT clause is used to eliminate duplicate rows. It can be used with column functions or before a column name. When used with a column function, it ignores duplicate values.

Report the different values of the PE ratio.

```
SELECT DISTINCT shrpe FROM share;
```

Table 3.29: 8 records

shrpe
13
3
11
15
16
12
10
6

Find the number of different PE ratios.

```
SELECT COUNT(DISTINCT shrpe) as 'Different PEs' FROM share;
```

Table 3.30: 1 records

Different PEs
8

When used before a column name, DISTINCT prevents the selection of duplicate rows. Notice a slightly different use of the keyword AS. In this case, because the alias includes a space, the entire alias is enclosed in straight quotes.

DELETE

Rows in a table can be deleted using the DELETE clause in an SQL statement. DELETE is typically used with a WHERE clause to specify the rows to be deleted. If there is no WHERE clause, all rows are deleted.

Erase the data for Burmese Elephant. All the shares have been sold.

```
DELETE FROM share WHERE shrfirm = 'Burmese Elephant';
```

In the preceding statement, `shrfirm` is used to indicate the row to be deleted.

UPDATE

Rows can be modified using SQL's UPDATE clause, which is used with a WHERE clause to specify the rows to be updated.

Change the share price of FC to 31.50.

```
UPDATE share SET shrprice = 31.50 WHERE shrcode = 'FC';
```

Increase the total number of shares for Nigerian Geese by 10% because of the recent bonus issue.

```
UPDATE share SET shrqty = shrqty*1.1
  WHERE shrfirm = 'Nigerian Geese';
```

Quotes

There are three types of quotes that you can typically use with SQL. Double and single quotes are equivalent and can be used interchangeably. Note that single and double quotes must be straight rather than curly, and the back quote is to the left of the 1 key.

Type of quote	Representation
Single	’
Double	“
Back	‘

The following SQL illustrates the use of three types of quotes to find a person with a last name of O'Hara and where the column names are `person first` and `person last`.

```
SELECT `person first` FROM person
  WHERE `person last` = "O'Hara";
```

Table 3.32: 1 records

person first
Sheila

Debriefing

Now that you have learned how to model a single entity, create a table, and specify queries, you are on the way to mastering the fundamental skills of database design, implementation, and use. Remember, planning occurs before action. A data model is a plan for a database. The action side of a database is inserting rows and running queries.

Summary

The relational database model is an effective means of representing real-world relationships. Data modeling is used to determine what data must be stored and how data are related. An entity is something in the environment. An entity has attributes, which describe it, and an identifier, which uniquely distinguishes an instance of an entity. Every entity must have a unique identifier. A relational database consists of tables with rows and columns. A data model is readily translated into a relational database. The SQL statement CREATE is used to define a table. Rows are added to a table using INSERT. In SQL, queries are written using the SELECT statement. Project (choosing columns) and restrict (choosing rows) are common table operations. The WHERE clause is used to specify row selection criteria. WHERE can be combined with IN and NOT IN, which specify values for a single column. The rows of a report are sorted using the ORDER BY clause. Arithmetic expressions can appear in SQL statements, and SQL has built-in functions for common arithmetic operations. A subquery is a query within a query. Regular expressions are used to find string patterns within character strings. Duplicate rows are eliminated with the DISTINCT clause. Rows can be erased using DELETE or modified with UPDATE.

Key terms and concepts

Alias	Instance
AS	MAX
Attribute	MIN
AVG	NOT IN
Column	ORDER BY
COUNT	Primary key
CREATE	Project
Data modeling	Relational database
Data type	Restrict
Database	Row
DELETE	SELECT

DISTINCT	SQL
Entity	Subquery
Entity integrity rule	SUM
Identifier	Table
IN	UPDATE
INSERT	WHERE

Exercises[7]

1. Draw data models for the following entities. In each case, make certain that you show the attributes and identifiers. Also, create a relational database and insert some rows for each of the models.
    a. Aircraft: An aircraft has a manufacturer, model number, call sign (e.g., N123D), payload, and a year of construction. Aircraft are classified as civilian or military.
    b. Car: A car has a manufacturer, range name, and style code (e.g., a Honda Accord DX, where Honda is the manufacturer, Accord is the range, and DX is the style). A car also has a vehicle identification code, registration code, and color.
    c. Restaurant: A restaurant has an address, seating capacity, phone number, and style of food (e.g., French, Russian, Chinese).
    d. Cow: A dairy cow has a name, date of birth, breed (e.g., Holstein), and a numbered plastic ear tag.
2. Do the following queries using SQL:
    a. List a share's name and its code.
    b. List full details for all shares with a price less than $1.
    c. List the names and prices of all shares with a price of at least $10.
    d. Create a report showing firm name, share price, share holding, and total value of shares held. (Value of shares held is price times quantity.)
    e. List the names of all shares with a yield exceeding 5 percent.
    f. Report the total dividend payment of Patagonian Tea. (The total dividend payment is dividend times quantity.)
    g. Find all shares where the price is less than 20 times the dividend.
    h. Find the share(s) with the minimum yield.
    i. Find the total value of all shares with a PE ratio > 10.
    j. Find the share(s) with the maximum total dividend payment.

[7] There are more than 80 SQL exercises for the ClassicModels database: https://www.richardtwatson.com/open/Reader/ClassicModels.html

k. Find the value of the holdings in Abyssinian Ruby and Sri Lankan Gold.

l. Find the yield of all firms except Bolivian Sheep and Canadian Sugar.

m. Find the total value of the portfolio.

n. List firm name and value in descending order of value.

o. List shares with a firm name containing “Gold.”

p. Find shares with a code starting with “B.”

3. Run the following queries and explain the differences in output. Write each query as a manager might state it.

   a. SELECT shrfirm FROM share WHERE shrfirm NOT REGEXP ‘s’;

   b. SELECT shrfirm FROM share WHERE shrfirm NOT REGEXP ‘S’;

   c. SELECT shrfirm FROM share WHERE shrfirm NOT REGEXP ‘s|S’;

   d. SELECT shrfirm FROM share WHERE shrfirm NOT REGEXP ‘^S’;

   e. SELECT shrfirm FROM share WHERE shrfirm NOT REGEXP ‘s$’;

4. A weekly newspaper, sold at supermarket checkouts, frequently reports stories of aliens visiting Earth and taking humans on short trips. Sometimes a captured human sees Elvis commanding the spaceship. To keep track of all these reports, the newspaper has created the following data model.

The paper has also supplied some data for the last few sightings and asked you to create the database, add details of these aliens, and answer the following queries:

a. What's the average number of heads of an alien?

a. Which alien has the most heads?

b. Are there any aliens with a double o in their names?

c. How many aliens are chartreuse?

d. Report details of all aliens sorted by smell and color.

5. Eduardo, a bibliophile, has a collection of several hundred books. Being a little disorganized, he has his books scattered around his den. They are piled on the floor, some are in bookcases, and others sit on top of his desk. Because he has so many books, he finds it difficult to remember what he has, and sometimes he cannot find the book he wants. Eduardo has a simple personal computer file system that is fine for a single entity or file. He has decided that he would like to list each book by author(s)' name and type of book (e.g., literature, travel, reference). Draw a data model for this problem, create a single entity table, and write some SQL queries.
    a. How do you identify each instance of a book? (It might help to look at a few books.)
    b. How should Eduardo physically organize his books to permit fast retrieval of a particular one?
    c. Are there any shortcomings with the data model you have created?
6. What is an identifier? Why does a data model have an identifier?
7. What are entities?
8. What is the entity integrity rule?

4 The One-to-Many Relationship

Cow of many—well milked and badly fed.

Spanish proverb

Learning Objectives

Students completing this chapter will be able to

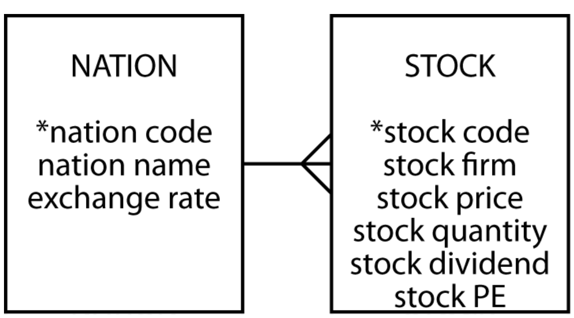
- model a one-to-many relationship between two entities;
- define a database with a one-to-many relationship;
- write queries for a database with a one-to-many relationship.

Relationships

Entities are not isolated; they are related to other entities. When we move beyond the single entity, we need to identify the relationships between entities to accurately represent the real world. Consider the case where a person's stocks are listed in different countries. We now need to introduce an entity called NATION. We now have two entities, STOCK and NATION. Consider the relationship between them. A NATION can have many listed stocks. A stock, in this case, is listed in only one nation. There is a 1:m (one-to-many) relationship between NATION and STOCK.

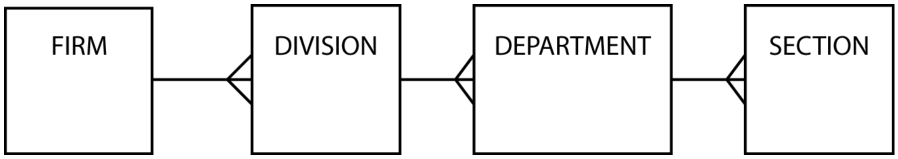
A 1:m relationship between two entities is depicted by a line connecting the two with a crow's foot at the many end of the relationship. The following figure shows the 1:m relationship between NATION and STOCK. This can be read as: "a nation can have many stocks, but a stock belongs to only one nation." The entity NATION is identified by *nation code* and has attributes *nation name* and *exchange rate*.

A 1:m relationship between NATION and STOCK



The 1:m relationship occurs frequently in business situations. Sometimes it occurs in a tree or hierarchical fashion. Consider a very hierarchical firm. It has many divisions, but a division belongs to only one firm. A division has many departments, but a department belongs to only one division. A department has many sections, but a section belongs to only one department.

A series of 1:m relationships



Why did we create an additional entity?

Another approach to adding data about listing nation and exchange rate is to add two attributes to STOCK: *nation name* and *exchange rate*. At first glance, this seems a very workable solution; however, this will introduce considerable redundancy, as the following table illustrates.

The table stock with additional columns

*stkcode	stkfirm	stkprice	stkqty	stkdiv	stkpe	natname	exchrate
FC	Freedonia Copper	27.5	10529	1.84	16	United Kingdom	1
PT	Patagonian Tea	55.25	12635	2.5	10	United Kingdom	1
AR	Abyssinian Ruby	31.82	22010	1.32	13	United Kingdom	1
SLG	Sri Lankan Gold	50.37	32868	2.68	16	United Kingdom	1
ILZ	Indian Lead & Zinc	37.75	6390	3	12	United Kingdom	1
BE	Burmese Elephant	0.07	154713	0.01	3	United Kingdom	1
BS	Bolivian Sheep	12.75	231678	1.78	11	United Kingdom	1
NG	Nigerian Geese	35	12323	1.68	10	United Kingdom	1
CS	Canadian Sugar	52.78	4716	2.5	15	United Kingdom	1
ROF	Royal Ostrich Farms	33.75	1234923	3	6	United Kingdom	1

*stkcode	stkfirm	stkprice	stkqty	stkdiv	stkpe	natname	exchrate
MG	Minnesota Gold	53.87	816122	1	25	USA	0.67
GP	Georgia Peach	2.35	387333	0.2	5	USA	0.67
NE	Narembeen Emu	12.34	45619	1	8	Australia	0.46
QD	Queensland Diamond	6.73	89251	0.5	7	Australia	0.46
IR	Indooroopilly Ruby	15.92	56147	0.5	20	Australia	0.46
BD	Bombay Duck	25.55	167382	1	12	India	0.0228

The exact same nation name and exchange rate pair occurs 10 times for stocks listed in the United Kingdom. This redundancy presents problems when we want to insert, delete, or update data. These problems, generally known as update anomalies, occur with these three basic operations.

Insert anomalies

We cannot insert a fact about a nation's exchange rate unless we first buy a stock that is listed in that nation. Consider the case where we want to keep a record of France's exchange rate and we have no French stocks. We cannot skirt this problem by putting in a null entry for stock details because stkcode, the primary key, would be null, and this is not allowed. If we have a separate table for facts about a nation, then we can easily add new nations without having to buy stocks. This is particularly useful when other parts of the organization, say International Trading, also need access to exchange rates for many nations.

Delete anomalies

If we delete data about a particular stock, we might also lose a fact about exchange rates. For example, if we delete details of Bombay Duck, we also erase the Indian exchange rate.

Update anomalies

Exchange rates are volatile. Most companies need to update them every day. What happens when the Australian exchange rate changes? Every row in stock with nation = 'Australia' will have to be updated. In a large portfolio, many rows will be changed. There is also the danger of someone forgetting to update all the instances of the nation and exchange rate pair. As a result, there could be two exchange rates for the one nation. If exchange rate is stored in a nation table, however, only one change is necessary, there is no redundancy, and there is no danger of inconsistent exchange rates.

Creating a database with a 1:m relationship

As before, each entity becomes a table in a relational database, the entity name becomes the table name, each attribute becomes a column, and each identifier becomes a primary key. The 1:m relationship is mapped by adding a column to the entity at the many end of the relationship. The additional column contains the identifier of the one end of the relationship.

Consider the relationship between the entities STOCK and NATION. The database has two tables: `stock` and `nation.` The table stock has an additional column, natcode, which contains the primary key of nation. If natcode is not stored in `stock`, then there is no way of knowing the identity of the nation where the `stock` is listed.

A relational database with tables nation and stock

nation		
*natcode	natname	exchrate
AUS	Australia	0.46
IND	India	0.0228
UK	United Kingdom	1
USA	United States	0.67

stock						
*stkcode	stkfirm	stkprice	stkqty	stkdiv	stkpe	*natcode*
FC	Freedonia Copper	27.5	10,529	1.84	16	UK
PT	Patagonian Tea	55.25	12,635	2.5	10	UK
AR	Abyssinian Ruby	31.82	22,010	1.32	13	UK
SLG	Sri Lankan Gold	50.37	32,868	2.68	16	UK
ILZ	Indian Lead & Zinc	37.75	6,390	3	12	UK
BE	Burmese Elephant	0.07	154,713	0.01	3	UK
BS	Bolivian Sheep	12.75	231,678	1.78	11	UK
NG	Nigerian Geese	35	12,323	1.68	10	UK
CS	Canadian Sugar	52.78	4,716	2.5	15	UK
ROF	Royal Ostrich Farms	33.75	1,234,923	3	6	UK
MG	Minnesota Gold	53.87	816,122	1	25	USA
GP	Georgia Peach	2.35	387,333	0.2	5	USA
NE	Narembeen Emu	12.34	45,619	1	8	AUS
QD	Queensland Diamond	6.73	89,251	0.5	7	AUS
IR	Indooroopilly Ruby	15.92	56,147	0.5	20	AUS
BD	Bombay Duck	25.55	167,382	1	12	IND

Notice that `natcode` appears in both the `stock` and `nation` tables. In `nation`, `natcode` is the primary key; it is unique for each instance of `nation`. In table `stock`, `natcode` is a foreign key because it is the primary key of `nation`, the one end of the 1:m relationship. The column `natcode` is a foreign key in `stock` because it is a primary key in `nation`. A matched primary key–foreign key pair is the method for recording the 1:m relationship between the two tables. This method of representing a relationship is illustrated using shading and arrows for the two USA stocks. In the `stock` table, `natcode` is italicized to indicate that it is a foreign key. This method, like asterisking a primary key, is a useful reminder.

Although the same name has been used for the primary key and the foreign key in this example, it is not mandatory. The two columns can have different names, and in some cases you are forced to use different names. When possible, we find it convenient to use identical column names to help us remember that the tables are related. To distinguish between columns with identical names, they must by qualified by prefixing the table name. In this case, use `nation.natcode` and `stock.natcode`. Thus, `nation.natcode` refers to the `natcode` column in the table `nation`.

Although a nation can have many stocks, it is not mandatory to have any. That is, in data modeling terminology, many can be zero, one, or more, but it is mandatory to have a value for `natcode` in `nation` for every value of `natcode` in `stock`. This requirement, known as the referential integrity constraint, helps maintain the accuracy of a database. Its application means that every foreign key in a table has an identical primary key in that same table or another table. In this example, it means that for every value of `natcode` in `stock`, there is a corresponding entry in `nation`. As a result, a primary key row must be created before its corresponding foreign key row. In other words, details for a `nation` must be added before any data about its listed stocks are entered.

Every foreign key must have a matching primary key (referential integrity rule), and every primary key must be non-null (entity integrity rule). A foreign key cannot be null when a relationship is mandatory, as in the case where a stock must belong to a nation. If a relationship is optional (a person can have a boss), then a foreign key can be null (i.e., a person is the head of the organization, and thus has no boss). The ideas of mandatory and optional will be discussed later in this book.

Why is the foreign key in the table at the "many" end of the relationship? Because each instance of `stock` is associated with exactly one instance of `nation`. The rule is that a `stock` must be listed in one, and only one, nation. Thus, the foreign key field is single-valued when it is at the "many" end of a relationship. The foreign key is not at the "one" end of the relationship because each instance of nation can be associated with more than one instance of `stock`, and this implies a multivalued foreign key. The relational model does not support multivalued fields.

Using SQL, the two tables are defined in a similar manner to the way we created a single table in Chapter 3. Here are the SQL statements:

```
CREATE TABLE nation (
  natcode CHAR(3),
  natname VARCHAR(20),
  exchrate DECIMAL(9,5),
  PRIMARY KEY(natcode));
```

```
CREATE TABLE stock (
  stkcode CHAR(3),
  stkfirm VARCHAR(20),
  stkprice DECIMAL(6,2),
```

```
  stkqty DECIMAL(8),
  stkdiv DECIMAL(5,2),
  stkpe DECIMAL(5),
  natcode CHAR(3),
  PRIMARY KEY(stkcode),
  CONSTRAINT fk_has_nation FOREIGN KEY(natcode)
  REFERENCES nation(natcode) ON DELETE RESTRICT);
```

Notice that the definition of `stock` includes an additional phrase to specify the foreign key and the referential integrity constraint. The CONSTRAINT clause defines the column or columns in the table being created that constitute the foreign key. A referential integrity constraint can be named, and in this case, the constraint's name is `fk_has_nation`. The foreign key is the column `natcode` in STOCK, and it references the primary key of `nation`, which is `natcode`.

The ON DELETE clause specifies what processing should occur if an attempt is made to delete a row in `nation` with a primary key that is a foreign key in `stock`. In this case, the ON DELETE clause specifies that it is not permissible (the meaning of RESTRICT) to delete a primary key row in `nation` while a corresponding foreign key in `stock` exists. In other words, the system will not execute the delete. You must first delete all corresponding rows in `stock` before attempting to delete the row containing the primary key. ON DELETE is the default clause for most RDBMSs, so we will dispense with specifying it for future foreign key constraints.

Observe that both the primary and foreign keys are defined as CHAR(3). The relational model requires that a primary key–foreign key pair have the same data type and are the same length.

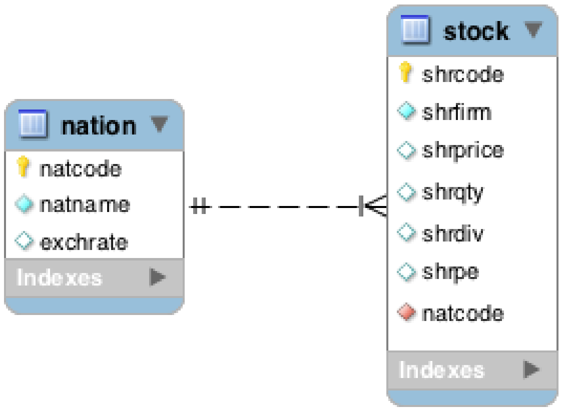
> ❎ *Skill builder*
>
> The university architect has asked you to develop a data model to record details of campus buildings. A building can have many rooms, but a room can be in only one building. Buildings have names, and rooms have a size and purpose (e.g., lecture, laboratory, seminar). Draw a data model for this situation and create the matching relational database.

MySQL Workbench

In Workbench, a 1:m relationship is represented in a similar manner to the method you have just learned. Also, note that the foreign key is shown in the entity at the many end with a red diamond. We omit the foreign key when data modeling because it can be inferred. You will observe some additional symbols on the line between the two entities, and these will be explained later, but take note of the crow's foot indicating the 1:m relationship between nation and stock. Because Workbench can generate automatically the SQL to create the tables,[1] we use lowercase table names and abbreviated column names.

Specifying a 1:m relationship in MySQL Workbench

[1]Database > Forward Engineer...



Querying a two-table database

A two-table database offers the opportunity to learn more SQL and another relational algebra operation: join.

Join

Join creates a new table from two existing tables by matching on a column common to both tables. Usually, the common column is a primary key–foreign key pair: The primary key of one table is matched with the foreign key of another table. Join is frequently used to get the data for a query into a single row. Consider the tables `nation` and `stock`. If we want to calculate the value—in British pounds—of a stock, we multiply stock price by stock quantity and then exchange rate. To find the appropriate exchange rate for a stock, get its `natcode` from stock and then find the exchange rate in the matching row in `nation`, the one with the same value for `natcode`. For example, to calculate the value of Georgia Peach, which has `natcode` = 'US', find the row in `nation` that also has `natcode` = 'US'. In this case, the stock's value is 2.35 * 387333 / 0.67 = £609,855.81.

Calculation of stock value is very easy once a join is used to get the three values in one row. The SQL command for joining the two tables is:

```
SELECT * FROM stock JOIN nation
    ON stock.natcode = nation.natcode;
```

Table 4.4: Displaying records 1 - 10

stkcode	stkfirm	stkprice	stkqty	stkdiv	stkpe	natcode	natcode	natname	exchrate
IR	Indooroopilly Ruby	15.92	56147	0.50	20	AUS	AUS	Australia	0.4600

stkcode	stkfirm	stkprice	stkqty	stkdiv	stkpe	natcode	natcode	natname	exchrate
NE	Narembeen Emu	12.34	45619	1.00	8	AUS	AUS	Australia	0.4600
QD	Queensland Diamond	6.73	89251	0.50	7	AUS	AUS	Australia	0.4600
BD	Bombay Duck	25.55	167382	1.00	12	IND	IND	India	0.0228
AR	Abyssinian Ruby	31.82	22010	1.32	13	UK	UK	United Kingdom	1.0000
BE	Burmese Elephant	0.07	154713	0.01	3	UK	UK	United Kingdom	1.0000
BS	Bolivian Sheep	12.75	231678	1.78	11	UK	UK	United Kingdom	1.0000
CS	Canadian Sugar	52.78	4716	2.50	15	UK	UK	United Kingdom	1.0000
FC	Freedonia Copper	27.50	10529	1.84	16	UK	UK	United Kingdom	1.0000
ILZ	Indian Lead & Zinc	37.75	6390	3.00	12	UK	UK	United Kingdom	1.0000

The join of stock and nation

The columns `stkprice` and `stkdiv` record values in the country's currency. Thus, the price of Bombay Duck is 25.55 Indian rupees. To find the value in U.K. pounds (GPB), multiply the price by 0.0228, because one rupee is worth 0.0228 GPB. The value of one share of Bombay Duck in U.S. dollars (USD) is 25.55 * 0.0228 / 0.67 because one USD is worth 0.67 GBP.

There are several things to notice about the SQL command and the result:

- To avoid confusion because `natcode` is a column name in both stock and nation, it needs to be qualified. If `natcode` is not qualified, the system will reject the query because it cannot distinguish between the two columns titled `natcode`.
- The new table has the `natcode` column replicated. Both are called `natcode`. The naming convention for the replicated column varies with the RDBMS. The columns, for example, should be labeled `stock.natcode` and `nation.natcode`.
- The SQL command specifies the names of the tables to be joined, the columns to be used for matching, and the condition for the match (equality in this case).
- The number of columns in the new table is the sum of the columns in the two tables.
- The stock value calculation is now easily specified in an SQL command because all the data are in one row.

Remember that during data modeling we created two entities, STOCK and NATION, and defined the relationship between them. We showed that if the data were stored in one table, there could be updating problems. Now, with a join, we have combined these data. So why separate the data only to put them back together later? There are two reasons. First, we want to avoid update anomalies. Second, as you will discover, we do not join the same tables every time.

Join comes in several flavors. The matching condition can be =, <>, <=, <, >=, and >. This generalized version is called a theta join. Generally, when people refer to a join, they mean an equijoin, when the matching condition is equality.

A join can be combined with other SQL commands.

Report the value of each stockholding in UK pounds. Sort the report by nation and firm.

```
SELECT natname, stkfirm, stkprice, stkqty, exchrate,
    stkprice*stkqty*exchrate as stkvalue
        FROM stock JOIN nation
            ON stock.natcode = nation.natcode
                ORDER BY natname, stkfirm;
```

Table 4.5: Displaying records 1 - 10

natname	stkfirm	stkprice	stkqty	exchrate	stkvalue
Australia	Indooroopilly Ruby	15.92	56147	0.4600	411175.71
Australia	Narembeen Emu	12.34	45619	0.4600	258951.69
Australia	Queensland Diamond	6.73	89251	0.4600	276303.25
India	Bombay Duck	25.55	167382	0.0228	97506.71
United Kingdom	Abyssinian Ruby	31.82	22010	1.0000	700358.20
United Kingdom	Bolivian Sheep	12.75	231678	1.0000	2953894.50
United Kingdom	Burmese Elephant	0.07	154713	1.0000	10829.91
United Kingdom	Canadian Sugar	52.78	4716	1.0000	248910.48
United Kingdom	Freedonia Copper	27.50	10529	1.0000	289547.50
United Kingdom	Indian Lead & Zinc	37.75	6390	1.0000	241222.50

Control break reporting

The purpose of a join is to collect the necessary data for a report. When two tables in a 1:m relationship are joined, the report will contain repetitive data. If you re-examine the report from the previous join, you will see that `nation` and `exchrate` are often repeated because the same values apply to many stocks. A more appropriate format is shown in the following figure, an example of a control break report.

Nation		Exchange rate			
	Firm		Price	Quantity	Value
Australia		0.46			
	Indooroopilly Ruby		15.92	56,147	411,175.71
	Narembeen Emu		12.34	45,619	258,951.69
	Queensland Diamond		6.73	89,251	276,303.25
India		0.0228			
	Bombay Duck		25.55	167,382	97,506.71
United Kingdom		0.0228			

Nation		Exchange rate			
	Abyssinian Ruby		31.82	22,010	700,358.20
	Bolivian Sheep		12.75	231,678	2,953,894.50
	Burmese Elephant		0.07	154,713	10,829.91
	Canadian Sugar		52.78	4,716	248,910.48
	Freedonia Copper		27.50	10,529	289,547.50
	Indian Lead & Zinc		37.75	6,390	241,222.50
	Nigerian Geese		35.00	12,323	431,305.00
	Patagonian Tea		55.25	12,635	698,083.75
	Royal Ostrich Farms		33.75	1,234,923	41,678,651.25
	Sri Lankan Gold		50.37	32,868	1,655,561.16
United States		0.0228			
	Georgia Peach		2.35	387,333	609,855.81
	Minnesota Gold		53.87	816,122	29,456,209.73

A control break report recognizes that the values in a particular column or columns seldom change. In this case, `natname` and `exchrate` are often the same from one row to the next, so it makes sense to report these data only when they change. The report is also easier to read. The column `natname` is known as a *control field*. Notice that there are four groups of data, because `natname` has four different values.

Many RDBMS packages have report-writing languages to facilitate creating a control break report. These languages typically support summary reporting for each group of rows having the same value for the control field(s). A table must usually be sorted on the control break field(s) before the report is created.

GROUP BY—reporting by groups

The GROUP BY clause is an elementary form of control break reporting. It permits grouping of rows that have the same value for a specified column or columns, and it produces one row for each different value of the grouping column(s).

Report by nation the total value of stockholdings.

```
SELECT natname, sum(stkprice*stkqty*exchrate) as stkvalue
    FROM stock JOIN nation ON stock.natcode = nation.natcode
        GROUP BY natname;
```

Table 4.7: 4 records

natname	stkvalue
Australia	946430.65
India	97506.71
United Kingdom	48908364.25
United States	30066065.54

SQL's built-in functions (COUNT, SUM, AVERAGE, MIN, and MAX) can be used with the GROUP BY clause. They are applied to a group of rows having the same value for a specified column. You can specify more than one function in a SELECT statement. For example, we can compute total value and number of different stocks and group by nation using:

Report the number of stocks and their total value by nation.

```
SELECT natname, COUNT(*), SUM(stkprice*stkqty*exchrate) AS stkvalue
    FROM stock JOIN nation
      ON stock.natcode = nation.natcode
    GROUP BY natname;
```

Table 4.8: 4 records

natname	COUNT(*)	stkvalue
Australia	3	946430.65
India	1	97506.71
United Kingdom	10	48908364.25
United States	2	30066065.54

You can group by more than one column name; however, all column names appearing in the SELECT clause must be associated with a built-in function or be in a GROUP BY clause.

List stocks by nation, and for each nation show the number of stocks for each PE ratio and the total value of those stock holdings in UK pounds.

```
SELECT natname,stkpe,COUNT(*),
    SUM(stkprice*stkqty*exchrate) AS stkvalue
        FROM stock JOIN nation ON stock.natcode = nation.natcode
            GROUP BY natname, stkpe;
```

Table 4.9: Displaying records 1 - 14

natname	stkpe	COUNT(*)	stkvalue
Australia	20	1	411175.71
Australia	8	1	258951.69
Australia	7	1	276303.25
India	12	1	97506.71
United Kingdom	13	1	700358.20
United Kingdom	3	1	10829.91
United Kingdom	11	1	2953894.50
United Kingdom	15	1	248910.48
United Kingdom	16	2	1945108.66
United Kingdom	12	1	241222.50
United Kingdom	10	2	1129388.75
United Kingdom	6	1	41678651.25

natname	stkpe	COUNT(*)	stkvalue
United States	5	1	609855.81
United States	25	1	29456209.73

In this example, stocks are grouped by both `natname` and `stkpe`. In most cases, there is only one stock for each pair of `natname` and `stkpe`; however, there are two situations (U.K. stocks with PEs of 10 and 16) where details of multiple stocks are grouped into one report line. Examining the values in the COUNT column helps you to identify these stocks.

HAVING—the WHERE clause of groups

The HAVING clause in a GROUP BY is like the WHERE clause in a SELECT. It restricts the number of groups reported, whereas WHERE restricts the number of rows reported. Used with built-in functions, HAVING is always preceded by GROUP BY and is always followed by a function (SUM, AVG, MAX, MIN, or COUNT).

Report the total value of stocks for nations with two or more listed stocks.

```sql
SELECT natname, SUM(stkprice*stkqty*exchrate) AS stkvalue
    FROM stock JOIN nation ON stock.natcode = nation.natcode
        GROUP BY natname
            HAVING COUNT(*) >= 2;
```

Table 4.10: 3 records

natname	stkvalue
Australia	946430.6
United Kingdom	48908364.2
United States	30066065.5

☒ *Skill builder*

Report by nation the total value of dividends.

Regular expression—pattern matching

Regular expression was introduced in the previous chapter, and we will now continue to learn some more of its features.

Search for a string not containing specified characters

The ^ (carat) is the symbol for NOT. It is used when we want to find a string not containing a character in one or more specified strings. For example, [^a-f] means any character not in the set containing a, b, c, d, e, or f.

List the names of nations with non-alphabetic characters in their names

```
SELECT natname FROM nation WHERE LOWER(natname) REGEXP '[^a-z]'
```

Table 4.11: 2 records

natname
United Kingdom
United States

Notice that the nations reported have a space in their name, which is a character not in the range a-z.

Search for string containing a repeated pattern or repetition

A pair of curly brackets is used to denote the repetition factor for a pattern. For example, {n} means repeat a specified pattern n times.

List the names of firms with a double lower case 'e'.

```
SELECT stkfirm FROM stock WHERE stkfirm REGEXP '[e]{2}';
```

Table 4.12: 5 records

stkfirm
Bolivian Sheep
Freedonia Copper
Narembeen Emu
Nigerian Geese
Queensland Diamond

Search combining alternation and repetition

Regular expressions becomes very powerful when you combine several of the basic capabilities into a single search expression.

List the names of firms with a double 's' or a double 'n'.

```
SELECT stkfirm FROM stock
  WHERE LOWER(stkfirm) REGEXP '[s]{2}|[n]{2}';
```

Table 4.13: 2 records

stkfirm
Abyssinian Ruby
Minnesota Gold

Search for multiple versions of a string

If you are interested in find a string containing several specified string, you can use the square brackets to indicate the sought strings. For example, [ea] means any character from the set containing e and a.

List the names of firms with names that include 'inia' or 'onia'.

```
SELECT stkfirm FROM stock
  WHERE LOWER(stkfirm) REGEXP '[io]nia';
```

Table 4.14: 3 records

stkfirm
Abyssinian Ruby
Freedonia Copper
Patagonian Tea

Search for a string in a particular position

Sometimes you might be interested in identifying a string with a character in a particular position.

Find firms with 't' as the third letter of their name.

```
SELECT stkfirm FROM stock
  WHERE LOWER(stkfirm) REGEXP '^(.){2}t';
```

Table 4.15: 1 records

stkfirm
Patagonian Tea

The regular expression has three elements:

- îndicates start searching at the beginning of the string;
- (.){2} specifies that anything is acceptable for the next two characters;
- t indicates what the next character, the third, must be.

Search for a string not containing any specified characters

There might be a need to find rows not containing specified characters anywhere in a givev coumn. You need to check every character in the string to ensure there are matches.

List the names of nations without s or S anywhere *in their names*

```
SELECT * FROM nation WHERE LOWER(natname) REGEXP '^[^s]*$'
```

Table 4.16: 2 records

natcode	natname	exchrate
IND	India	0.0228
UK	United Kingdom	1.0000

- ŝtart searching at the beginning of the string;
- $ end searching at the end of the string;
- * any character in a string;
- ŝ no lower case s (remember you have converted natname to all lowercase)

You have seen a few of the features of a very powerful tool. To learn more about regular expressions, see regexlib.com, which contains a library of regular expressions and a feature for finding expressions to solve specific problems. Check out the regular expression for checking whether a character string is a valid email address.

Subqueries

A subquery, or nested SELECT, is a SELECT nested within another SELECT. A subquery can be used to return a list of values subsequently searched with an IN clause.

Report the names of all Australian stocks.

```
SELECT stkfirm FROM stock
    WHERE natcode IN
        (SELECT natcode FROM nation
            WHERE natname = 'Australia');
```

Table 4.17: 3 records

stkfirm
Indooroopilly Ruby
Narembeen Emu
Queensland Diamond

Conceptually, the subquery is evaluated first. It returns a list of values for natcode ('AUS') so that the query then is the same as:

```
SELECT stkfirm FROM stock
    WHERE natcode IN ('AUS');
```

When discussing subqueries, sometimes a subquery is also called an inner query. The term outer query is applied to the SQL preceding the inner query. In this case, the outer and inner queries are:

Outer query	SELECT stkfirm FROM stock WHERE natcode IN
Inner query	(SELECT natcode FROM nation WHERE natname = 'Australia');

Note that in this case we do not have to qualify `natcode`. There is no identity crisis, because `natcode` in the inner query is implicitly qualified as `nation.natcode` and `natcode` in the outer query is understood to be `stock.natcode`.

This query also can be run as a join by writing:

```
SELECT stkfirm FROM stock JOIN nation
    ON stock.natcode = nation.natcode
    AND natname = 'Australia';
```

Correlated subquery

In a correlated subquery, the subquery cannot be evaluated independently of the outer query. It depends on the outer query for the values it needs to resolve the inner query. The subquery is evaluated for each value passed to it by the outer query. An example illustrates when you might use a correlated subquery and how it operates.

Find those stocks where the quantity is greater than the average for that country.

An approach to this query is to examine the rows of stock one a time, and each time compare the quantity of stock to the average for that country. This means that for each row, the subquery must receive the outer query's country code so it can compute the average for that country.

```
SELECT natname, stkfirm, stkqty FROM stock JOIN nation
    ON stock.natcode = nation.natcode
    WHERE stkqty >
        (SELECT avg(stkqty) FROM stock
            WHERE stock.natcode = nation.natcode);
```

Table 4.19: 4 records

natname	stkfirm	stkqty
Australia	Queensland Diamond	89251
United Kingdom	Bolivian Sheep	231678
United Kingdom	Royal Ostrich Farms	1234923
United States	Minnesota Gold	816122

Conceptually, think of this query as stepping through the join of `stock` and `nation` one row at a time and executing the subquery each time. The first row has `natcode` = 'AUS' so the subquery becomes

```
SELECT AVG(stkqty) FROM stock
    WHERE stock.natcode = 'AUS';
```

Since the average stock quantity for Australian stocks is 63,672.33, the first row in the join, Narembeen Emu, is not reported. Neither is the second row reported, but the third is.

The term correlated subquery is used because the inner query's execution depends on receiving a value for a variable (`nation.natcode` in this instance) from the outer query. Thus, the inner query of the correlated subquery cannot be evaluated once and for all. It must be evaluated repeatedly—once for each value of the variable received from the outer query. In this respect, a correlated subquery is different from a subquery, where the inner query needs to be evaluated only once. The requirement to compare each row of a table against a function (e.g., average or count) for some rows of a column is usually a clue that you need to write a correlated subquery.

> ☒ *Skill builder*
>
> Why are no Indian stocks reported in the correlated subquery example? How would you change the query to report an Indian stock? Report only the three stocks with the largest quantities (i.e., do the query without using ORDER BY).

Views—virtual tables

You might have noticed that in these examples we repeated the join and stock value calculation for each query. Ideally, we should do this once, store the result, and be able to use it with other queries. We can do so if we create a view, a virtual table. A view does not physically exist as stored data; it is an imaginary table constructed from existing tables as required. You can treat a view as if it were a table and write SQL to query it.

A view contains selected columns from one or more tables. The selected columns can be renamed and rearranged. New columns based on arithmetic expressions can be created. GROUP BY can also be used when creating a view. Remember, a view contains no actual data. It is a virtual table.

This SQL command does the join, calculates stock value, and saves the result as a view:

```
CREATE VIEW stkvalue
    (nation, firm, price, qty, exchrate, value)
    AS SELECT natname, stkfirm, stkprice, stkqty, exchrate,
        stkprice*stkqty*exchrate
            FROM stock JOIN nation
            ON stock.natcode = nation.natcode;
```

There are several things to notice about creating a view:

- The six names enclosed in parentheses are the column names for the view.
- There is a one-to-one correspondence between the names in parentheses and the names or expressions in the SELECT clause. Thus the view column named `value` contains the result of the arithmetic expression `stkprice * stkqty * exchrate`.

A view can be used in a query, such as:

Find stocks with a value greater than £100,000.

```
SELECT nation, firm, value FROM stkvalue WHERE value > 100000;
```

Table 4.20: Displaying records 1 - 10

nation	firm	value
Australia	Indooroopilly Ruby	411175.7
Australia	Narembeen Emu	258951.7
Australia	Queensland Diamond	276303.2
United Kingdom	Abyssinian Ruby	700358.2
United Kingdom	Bolivian Sheep	2953894.5
United Kingdom	Canadian Sugar	248910.5
United Kingdom	Freedonia Copper	289547.5
United Kingdom	Indian Lead & Zinc	241222.5
United Kingdom	Nigerian Geese	431305.0
United Kingdom	Patagonian Tea	698083.8

There are two main reasons for creating a view. *First*, as we have seen, query writing can be simplified. If you find that you are frequently writing the same section of code for a variety of queries, then isolate the common section and put it in a view. This means that you will usually create a view when a fact, such as stock value, is derived from other facts in the table.

The *second* reason is to restrict access to certain columns or rows. For example, the person who updates `stock` could be given a view that excludes `stkqty`. In this case, changes in stock prices could be updated without revealing confidential information, such as the value of the stock portfolio.

> ☒ *Skill builder*
>
> How could you use a view to solve the following query that was used when discussing the correlated subquery?
>
> *Find those stocks where the quantity is greater than the average for that country.*

Summary

Entities are related to other entities by relationships. The 1:m (one-to-many) relationship occurs frequently in data models. An additional entity is required to represent a 1:m relationship to avoid update anomalies. In a relational database, a 1:m relationship is represented by an additional column, the foreign key, in the table at the many end of the relationship. The referential integrity constraint insists that a foreign key must always exist as a primary key in a table. A foreign key constraint is specified in a CREATE statement.

Join creates a new table from two existing tables by matching on a column common to both tables. Often the common column is a primary key–foreign key combination. A theta-join can have matching conditions of =, <>, <=, <, >=, and >. An equijoin describes the situation where the matching condition is equality. The GROUP BY clause is used to create an elementary control break report. The HAVING clause of GROUP BY is like the WHERE clause of SELECT. A subquery, which has a SELECT statement within another SELECT statement, causes two SELECT statements to be executed—one for the inner query and one for the outer query. A correlated subquery is executed as many times as there are rows selected by the outer query. A view is a virtual table that is created when required. Views can simplify report writing and restrict access to specified columns or rows.

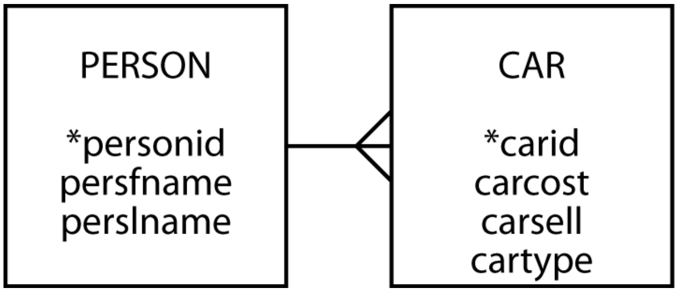
Key terms and concepts

Constraint	JOIN
Control break reporting	One-to-many (1:m) relationship
Correlated subquery	Referential integrity
Delete anomalies	Relationship
Equijoin	Theta-join
Foreign key	Update anomalies
GROUP BY	Views
HAVING	Virtual table
Insert anomalies	

Exercises

1. Draw data models for the following situations. In each case, make certain that you show the attributes and feasible identifiers:
   a. A farmer can have many cows, but a cow belongs to only one farmer.
   b. A university has many students, and a student can attend at most one university.
   c. An aircraft can have many passengers, but a passenger can be on only one flight at a time.
   d. A nation can have many states and a state many cities.
   e. An art researcher has asked you to design a database to record details of artists and the museums in which their paintings are displayed. For each painting, the researcher wants to know the size of the canvas, year painted, title, and style. The nationality, date of birth, and death of each artist must be recorded. For each museum, record details of its location and specialty, if it has one.
2. Report all values in British pounds:
   a. Report the value of stocks listed in Australia.
   b. Report the dividend payment of all stocks.
   c. Report the total dividend payment by nation.
   d. Create a view containing nation, firm, price, quantity, exchange rate, value, and yield.
   e. Report the average yield by nation.
   f. Report the minimum and maximum yield for each nation.
   g. Report the nations where the average yield of stocks exceeds the average yield of all stocks.
3. How would you change the queries in exercise 4-2 if you were required to report the values in American dollars, Australian dollars, or Indian rupees?
4. What is a foreign key and what role does it serve?
5. What is the referential integrity constraint? Why should it be enforced?
6. Kisha, against the advice of her friends, is simultaneously studying data management and Shakespearean drama. She thought the two subjects would be an interesting contrast. However, the classes are very demanding and often enter her midsummer dreams. Last night, she dreamed that William Shakespeare wanted her to draw a data model. He explained, before she woke up in a cold sweat, that a play had many characters but the same character never appeared in more than one play. "Methinks," he said, "the same name may have appeareth more than the once, but 'twas always a person of a different ilk." He then, she hazily recollects, went on to spout about the quality of data dropping like the gentle rain. Draw a data model to keep old Bill quiet and help Kisha get some sleep.

7. An orchestra has four broad classes of instruments (strings, woodwinds, brass, and percussion). Each class contains musicians who play different instruments. For example, the strings section of a full symphony orchestra contains 2 harps, 16 to 18 first violins, 14 to 16 second violins, 12 violas, 10 cellos, and 8 double basses. A city has asked you to develop a database to store details of the musicians in its three orchestras. All the musicians are specialists and play only one instrument for one orchestra.



8. Answer the following queries based on the following database for a car dealer:
    a. What is the personid of Sheila O'Hara?
    b. List sales personnel sorted by last name and within last name, first name.
    c. List details of the sales made by Bruce Bush.
    d. List details of all sales showing the gross profit (selling price minus cost price).
    e. Report the number of cars sold of each type.
    f. What is the average selling price of cars sold by Sue Lim?
    g. Report details of all sales where the gross profit is less than the average.
    h. What was the maximum selling price of any car?
    i. What is the total gross profit?
    j. Report the gross profit made by each salesperson who sold at least three cars.
    k. Create a view containing all the details in the car table and the gross profit
9. Find stocks where the third or fourth letter in their name is an 'm'.
10. An electricity supply company needs a database to record details of solar panels installed on its customers' homes so it can estimate how much solar energy will be generated based on the forecast level of solar radiation for each house's location. A solar panel has an area, measured in square meters, and an efficiency expressed as a percentage (e.g., 22% efficiency means that 22% of the incident solar energy is converted into electrical energy). Create a data model. How will you identify each customer and each panel?

5 The Many-to-Many Relationship

Fearful concatenation of circumstances.

Daniel Webster

Learning objectives

Students completing this chapter will be able to

- model a many-to-many relationship between two entities;
- define a database with a many-to-many relationship;
- write queries for a database with a many-to-many relationship.

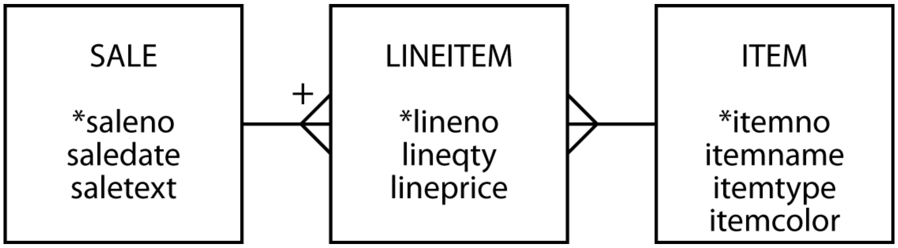
The many-to-many relationship

Consider the case when items are sold. We can immediately identify two entities: SALE and ITEM. A sale can contain many items, and an item can appear in many sales. We are not saying the same item can be sold many times, but the particular type of item (e.g., a compass) can be sold many times; thus we have a many-to-many (m:m) relationship between SALE and ITEM. When we have an m:m relationship, we create a third entity to link the entities through two 1:m relationships. Usually, it is fairly easy to name this third entity. In this case, this third entity, typically known as an associative entity, is called LINE ITEM. A typical old style sales form (see following) lists the items purchased by a customer. Each of the lines appearing on the order form is generally known in retailing as a line item, which links an item and a sale.

The Expeditioner Sale of Goods					
Sale#			Date:		
Item#		Description	Quantity	Unit price	Total
1					
2					
3					
4					
5					
6					
Grand total					

The representation of this m:m relationship is shown. We say many-to-many because there are two relationships—an ITEM is related to many SALEs, and a SALE is related to many ITEMs. This data model can also be read as: "a sale has many line items, but a line item refers to only one sale. Similarly, an item can appear as many line items, but a line item references only one item."

An m:m relationship between SALE and ITEM



The entity SALE is identified by *saleno* and has the attributes *saledate* and *saletext* (a brief comment on the customer—soft information). LINEITEM is partially identified by *lineno* and has attributes *lineqty* (the number of units sold) and *lineprice* (the unit selling price for this sale). ITEM is identified by *itemno* and has attributes *itemname*, *itemtype* (e.g., clothing, equipment, navigation aids, furniture, and so on), and *itemcolor*.

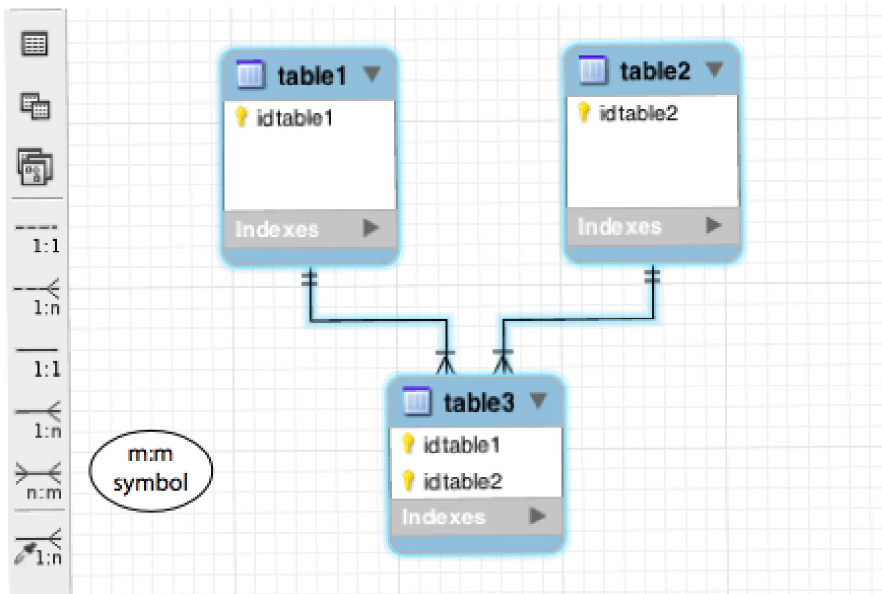
If you look carefully at the m:m relationship figure, you will notice that there is a plus sign (+) above the crow's foot at the "many" end of the 1:m relationship between SALE and LINEITEM. This plus sign provides information about the identifier of LINEITEM. As you know, every entity must have a unique identifier. A sales order is a series of rows or lines, and *lineno* is unique only within a particular order. If we just use *lineno* as the identifier, we cannot guarantee that every instance of LINEITEM is unique. If we use *saleno* and *lineno* together, however, we have a unique identifier for every instance of LINEITEM. Identifier *saleno* is unique for every sale, and *lineno* is unique within any sale. The plus indicates that LINEITEM's unique identifier is the concatenation of *saleno* and *lineno*. The order of concatenation does not matter.

LINEITEM is termed a weak entity because it relies on another entity for its existence and identification.

MySQL Workbench

Workbench automatically creates an associative entity for an m:m relationship and populates it with a composite primary key based on concatenating the primary keys of the two entities forming the m:m relationship. *First*, draw the two tables and enter their respective primary keys and columns. *Second*, select the m:m symbol and connect the two tables through clicking on one and dragging to the second and releasing. You can then modify the associative entity as required, such as changing its primary key. The capability to automatically create an associative entity for an m:m relationship is a very useful Workbench feature.

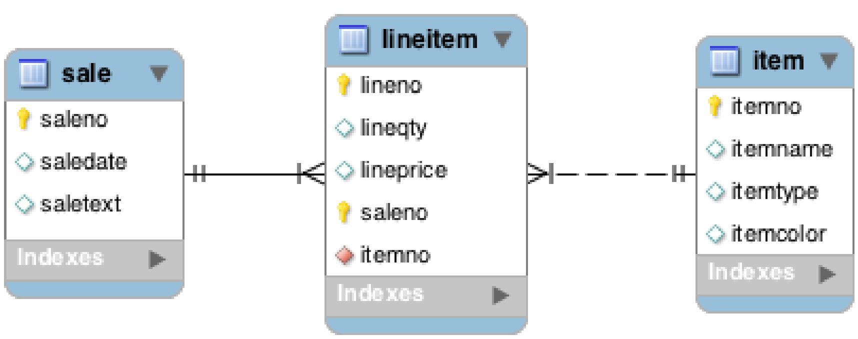
An m:m relationship with Workbench



Workbench distinguishes between two types of relationships. An identifying relationship, shown by a solid line, is used when the entity at the many end of the relationship is a weak entity and needs the identifier of the one end of the relationship to uniquely identify an instance of the relationship, as in LINEITEM. An identifying relationship corresponds to the + sign associated with a crow's foot. The other type of relationship, shown by a dashed line, is known as a *non-identifying* relationship. The mapping between the type of relationship and the representation (i.e., dashed or solid line) is arbitrary and thus not always easily recalled. We think that using a + on the crow's foot is a better way of denoting weak entities.

When the relationship between SALE and ITEM is drawn in Workbench, as shown in the following figure, there are two things to notice. *First*, the table, lineitem, maps the associative entity generated for the m:m relationship. *Second*, lineitem has an identifying relationship with sale and a non-identifying relationship with item.

An m:m relationship between SALE and ITEM in MySQL Workbench



Why did we create a third entity?

When we have an m:m relationship, we create an associative entity to store data about the relationship. In this case, we have to store data about the items sold. We cannot store the data with SALE because a sale can have many items, and an instance of an entity stores only single-value facts. Similarly, we cannot store data with ITEM because an item can appear in many sales. Since we cannot store data in SALE or ITEM, we must create another entity to store data about the m:m relationship.

You might find it useful to think of the m:m relationship as two 1:m relationships. An item can appear on many line item listings, and a line item entry refers to only one item. A sale has many line items, and each line item entry refers to only one sale.

> Social Security number is notunique!
>
> Two girls named Sarah Lee Ferguson were born on May 3, 1959. The U.S. government considered them one and the same and issued both the same Social Security number (SSN), a nine-digit identifier of U.S. residents. Now Sarah Lee Ferguson Boles and Sarah Lee Ferguson Johnson share the same SSN.[1]
>
> Mrs. Boles became aware of her SSN twin in 1987 when the Internal Revenue Service claimed there was a discrepancy in her reported income Because SSN is used as an identifier in IRS systems. Mrs. Boles encountered other incidents of mistaken identity. Some of Mrs. Johnson's purchases appeared on Mrs. Boles' credit reports.
>
> In late 1989, the Social Security Administration notified Mrs. Boles that her original number was given to her in error and she had to provide evidence of her age, identity, and citizenship to get a new number. When Mrs. Boles got her new SSN, it is likely she had to also get a new driver's license and establish a new credit history.

Creating a relational database with an m:m relationship

As before, each entity becomes a table in a relational database, the entity name becomes the table name, each attribute becomes a column, and each identifier becomes a primary key. Remember, a 1:m relationship is mapped by adding a column to the entity of the many end of the relationship. The new column contains the identifier of the one end of the relationship.

Conversion of the foregoing data model results in the three tables following. Note the one-to-one correspondence between attributes and columns for sale and item. Observe the lineitem has two additional columns, saleno and itemno. Both of these columns are foreign keys in lineitem (remember the use of italics to signify foreign keys). Two foreign keys are required to record the two 1:m relationships. Notice in lineitem that saleno is both part of the primary key and a foreign key.

Tables sale, lineitem, and item

[1] "Two women share a name, birthday, and S.S. number!" Athens Daily News, January 29 1990, 7A. Also, see https://www.computerworld.com/article/3004659/a-tale-of-two-women-same-birthday-same-social-security-number-same-big-data-mess.html

*saleno	saledate	saletext
1	2020-01-15	Scruffy Australian—called himself Bruce.
2	2020-01-15	Man. Rather fond of hats.
3	2020-01-15	Woman. Planning to row Atlantic—lengthwise!
4	2020-01-15	Man. Trip to New York—thinks NY is a jungle!
5	2020-01-16	Expedition leader for African safari.

*lineno	lineqty	lineprice	**saleno*	*itemno*
1	1	4.50	1	2
1	1	25.00	2	6
2	1	20.00	2	16
3	1	25.00	2	19
4	1	2.25	2	2
1	1	500.00	3	4
2	1	2.25	3	2
1	1	500.00	4	4
2	1	65.00	4	9
3	1	60.00	4	13
4	1	75.00	4	14
5	1	10.00	4	3
6	1	2.25	4	2
1	50	36.00	5	10
2	50	40.50	5	11
3	8	153.00	5	12
4	1	60.00	5	13
5	1	0.00	5	2

*itemno	itemname	itemtype	itemcolor
1	Pocket knife—Nile	E	Brown
2	Pocket knife—Avon	E	Brown
3	Compass	N	—
4	Geopositioning system	N	—
5	Map measure	N	—
6	Hat—Polar Explorer	C	Red
7	Hat—Polar Explorer	C	White
8	Boots—snake proof	C	Green
9	Boots—snake proof	C	Black
10	Safari chair	F	Khaki
11	Hammock	F	Khaki
12	Tent—8 person	F	Khaki
13	Tent—2 person	F	Khaki
14	Safari cooking kit	E	—
15	Pith helmet	C	Khaki

*itemno	itemname	itemtype	itemcolor
16	Pith helmet	C	White
17	Map case	N	Brown
18	Sextant	N	—
19	Stetson	C	Black
20	Stetson	C	Brown

The SQL commands to create the three tables are as follows:

```
CREATE TABLE sale (
    saleno      INTEGER,
    saledate        DATE NOT NULL,
    saletext        VARCHAR(50),
      PRIMARY KEY(saleno));
```

```
CREATE TABLE item (
    itemno      INTEGER,
    itemname        VARCHAR(30) NOT NULL,
    itemtype        CHAR(1) NOT NULL,
    itemcolor       VARCHAR(10),
        PRIMARY KEY(itemno));
```

```
CREATE TABLE lineitem (
    lineno      INTEGER,
    lineqty     INTEGER NOT NULL,
    lineprice       DECIMAL(7,2) NOT NULL,
    saleno      INTEGER,
    itemno      INTEGER,
        PRIMARY KEY(lineno,saleno),
        CONSTRAINT fk_has_sale FOREIGN KEY(saleno)
            REFERENCES sale(saleno),
        CONSTRAINT fk_has_item FOREIGN KEY(itemno)
            REFERENCES item(itemno));
```

Although the `sale` and `item` tables are created in a similar fashion to previous examples, there are two things to note about the definition of `lineitem`. *First,* the primary key is a composite of `lineno` and `saleno`, because together they uniquely identify an instance of `lineitem`. *Second*, there are two foreign keys, because `lineno` is at the "many" end of two 1: m relationships.

> ❎ *Skill builder*
>
> A hamburger shop makes several types of hamburgers, and the same type of ingredient can be used with several types of hamburgers. This does not literally mean the same piece of lettuce is used many times, but lettuce is used with several types of hamburgers. Draw the data model for this situation. What is a good name for the associative entity?

Querying an m:m relationship

A three-table join

The join operation can be easily extended from two tables to three or more merely by specifying the tables to be joined and the matching conditions. For example:

```
SELECT * FROM sale JOIN lineitem
    ON sale.saleno = lineitem.saleno
    JOIN item
    ON item.itemno = lineitem.itemno;
```

There are two matching conditions: one for `sale` and `lineitem` (`sale.saleno = lineitem.saleno`) and one for the item and `lineitem` tables (`item.itemno = lineitem.itemno`). The table `lineitem` is the link between `sale` and `item` and must be referenced in both matching conditions.

You can tailor the join to be more precise and report some columns rather than all.

List the name, quantity, price, and value of items sold on January 16, 2011.

```
SELECT itemname, lineqty, lineprice, lineqty*lineprice AS total
    FROM sale, lineitem, item
        WHERE lineitem.saleno = sale.saleno
        AND item.itemno = lineitem.itemno
        AND saledate = '2011-01-16';
```

Table 5.4: 5 records

itemname	lineqty	lineprice	total
Safari chair	50	36.0	1800
Hammock	50	40.5	2025
Tent - 8 person	8	153.0	1224
Tent - 2 person	1	60.0	60
Pocket knife - Avon	1	0.0	0

EXISTS—does a value exist

EXISTS is used in a WHERE clause to test whether a table contains at least one row satisfying a specified condition. It returns the value true if and only if some row satisfies the condition; otherwise it returns false. EXISTS represents the existential quantifier of formal logic. The best way to get a feel for EXISTS is to examine a query.

Report all clothing items (type "C") for which a sale is recorded.

```
SELECT itemname, itemcolor FROM item
    WHERE itemtype = 'C'
    AND EXISTS (SELECT * FROM lineitem
        WHERE lineitem.itemno = item.itemno);
```

Table 5.5: 4 records

itemname	itemcolor
Hat - Polar explorer	Red
Boots - snake proof	Black
Pith helmet	White
Stetson	Black

Conceptually, we can think of this query as evaluating the subquery for each row of item. The first item with itemtype = 'C', Hat—Polar Explorer (red), in item has itemno = 6. Thus, the query becomes

```
SELECT itemname, itemcolor FROM item
    WHERE itemtype = 'C'
    AND EXISTS (SELECT * FROM lineitem
        WHERE lineitem.itemno = 6);
```

Because there is at least one row in `lineitem` with `itemno` = 6, the subquery returns *true*. The item has been sold and should be reported. The second clothing item, Hat—Polar Explorer (white), in `item` has `itemno` = 7. There are no rows in `lineitem` with `itemno` = 7, so the subquery returns *false*. That item has not been sold and should not be reported.

You can also think of the query as, "Select clothing items for which a sale exists." Remember, for EXISTS to return *true*, there needs to be only one row for which the condition is *true*.

NOT EXISTS—select a value if it does not exist

NOT EXISTS is the negative of EXISTS. It is used in a WHERE clause to test whether all rows in a table fail to satisfy a specified condition. It returns the value *true* if there are no rows satisfying the condition; otherwise it returns *false*.

Report all clothing items that have not been sold.

```
SELECT itemname, itemcolor FROM item
    WHERE itemtype = 'C'
    AND NOT EXISTS
        (SELECT * FROM lineitem
            WHERE item.itemno = lineitem.itemno);
```

Table 5.6: 4 records

itemname	itemcolor
Hat - Polar explorer	White
Boots - snake proof	Green
Pith helmet	Khaki
Stetson	Brown

You can also think of the query as, “Select clothing items for which no sales exist.” Also remember, for NOT EXISTS to return *true*, no rows should satisfy the condition.

> ☒ *Skill builder*
>
> Report all red items that have not been sold. Write the query twice, once using EXISTS and once without EXISTS.

Divide (and be conquered)

In addition to the existential quantifier that you have already encountered, formal logic has a universal quantifier known as forall that is necessary for queries such as

Find the items that have appeared in all sales.

If a universal quantifier were supported by SQL, this query could be phrased as, “Select item names where *forall* sales there *exists* a `lineitem` row recording that this item was sold.” A quick inspection of the first set of tables shows that one item satisfies this condition (`itemno` = 2).

While SQL does not directly support the universal quantifier, formal logic shows that *forall* can be expressed using EXISTS. The query becomes, “Find items such that there does not exist a sale in which this item does not appear.” The equivalent SQL expression is

```
SELECT itemno, itemname FROM item
    WHERE NOT EXISTS
        (SELECT * FROM sale
            WHERE NOT EXISTS
                (SELECT * FROM lineitem
                    WHERE lineitem.itemno = item.itemno
                    AND lineitem.saleno = sale.saleno));
```

Table 5.7: 1 records

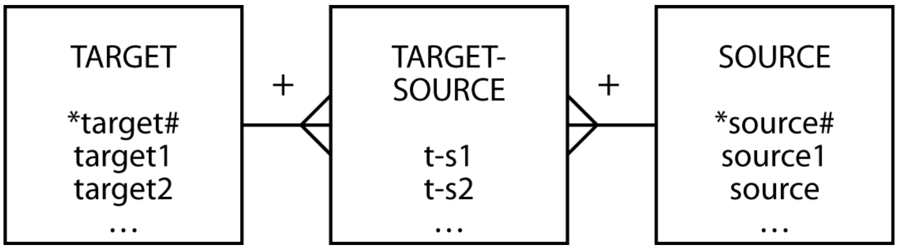
itemno	itemname
2	Pocket knife - Avon

If you are interested in learning the inner workings of the preceding SQL for divide, see the additional material for Chapter 5 on the book’s Web site.

Relational algebra (Chapter 9) has the divide operation, which makes divide queries easy to write. Be careful: Not all queries containing the word *all* are divides. With experience, you will learn to recognize and conquer divide.

To save the tedium of formulating this query from scratch, we have developed a template for dealing with these sorts of queries. Divide queries typically occur with m:m relationships.

A template for divide



An appropriate generic query and template SQL command are

Find the target1 that have appeared in all sources.

```
SELECT target1 FROM target
 WHERE NOT EXISTS
    (SELECT * FROM source
        WHERE NOT EXISTS
            (SELECT * FROM target-source
                WHERE
                  target-source.target# = target.target#
                AND
                  target-source.source# = source.source#));
```

☒ *Skill builder*

Find the brown items that have appeared in all sales.

Beyond the great divide

Divide proves troublesome to most people because of the double negative—we just don't think that way. If divide sends your neurons into knots, then try the following approach.

The query "Find the items that have appeared in all sales" can be rephrased as "Find the items for which the number of sales that include this item is equal to the total number of sales." This is an easier query to write than "Find items such that there does not exist a sale in which this item does not appear."

The rephrased query has two parts. *First*, determine the total number of sales. Here we mean distinct sales (i.e., the number of rows with a distinct value for saleno). The SQL is

```
SELECT COUNT (DISTINCT saleno) FROM sale;
```

Second, group the items sold by `itemno` and `itemname` and use a HAVING clause with COUNT to calculate the number of sales in which the item has occurred. Forcing the count in the HAVING clause to equal the result of the first query, which becomes an inner query, results in a list of items appearing in all sales.

```
SELECT item.itemno, item.itemname
    FROM item JOIN lineitem
        ON item.itemno = lineitem.itemno
            GROUP BY item.itemno, item.itemname
                HAVING COUNT(DISTINCT saleno)
                    = (SELECT COUNT(DISTINCT saleno) FROM sale);
```

Set operations

Set operators are useful for combining the values derived from two or more SQL queries. The UNION operation is equivalent to *or*, and INTERSECT is equivalent to *and*.

List items that were sold on January 16, 2011, or are brown.

Resolution of this query requires two tables: one to report items sold on January 16, 2011, and one to report the brown items. UNION (i.e., or) then combines the results of the tables, including *any* rows in both tables and excluding duplicate rows.

```
SELECT itemname FROM item JOIN lineitem
    ON item.itemno = lineitem.itemno
    JOIN sale
    ON lineitem.saleno = sale.saleno
    WHERE saledate = '2011-01-16'
UNION
    SELECT itemname FROM item WHERE itemcolor = 'Brown';
```

Table 5.8: 8 records

itemname
Safari chair
Hammock
Tent - 8 person
Tent - 2 person
Pocket knife - Avon
Pocket knife - Nile
Map case
Stetson

List items that were sold on January 16, 2011, and are brown.

This query uses the same two tables as the previous query. In this case, INTERSECT (i.e., and) then combines the results of the tables including only rows in both tables and excluding duplicates.[2]

```
SELECT itemname FROM item JOIN lineitem
    ON item.itemno = lineitem.itemno
    JOIN sale
    ON lineitem.saleno = sale.saleno
    WHERE saledate = '2011-01-16'
INTERSECT
    SELECT itemname FROM item WHERE itemcolor = 'Brown';
```

> ❎ *Skill builder*
>
> List the items that contain the words “Hat”, “Helmet”, or “Stetson” in their names

Summary

There can be a many-to-many (m:m) relationship between entities, which is represented by creating an associative entity and two 1:m relationships. An associative entity stores data about an m:m relationship. The join operation can be extended from two tables to three or more tables. EXISTS tests whether a table has at least one row that meets a specified condition. NOT EXISTS tests whether all rows in a table do not satisfy a specified condition. Both EXISTS and NOT EXISTS can return *true* or *false*. The relational operation divide, also known as *forall*, can be translated into a double negative. It is represented in SQL by a query containing two NOT EXISTS statements. Set operations enable the results of queries to be combined.

Key terms and concepts

Associative entity	Many-to-many (m:m) relationship
Divide	NOT EXISTS
Existential quantifier	UNION
EXISTS	Universal quantifier
INTERSECT	

Exercises

1. Draw data models for the following situations. In each case, think about the names you give each entity:

    a. Farmers can own cows or share cows with other farmers.

[2] MySQL does not support INTERSECT. Use another AND in the WHERE statement.

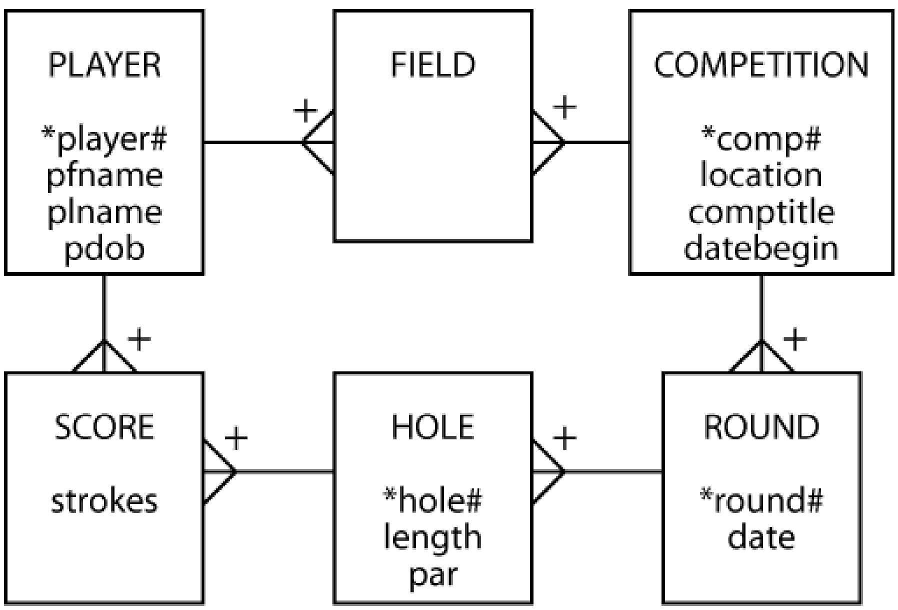
b. A track and field meet can have many competitors, and a competitor can participate in more than one event.

c. A patient can have many physicians, and a physician can have many patients.

d. A student can attend more than one class, and the same class can have many students.

e. *The Marathoner*, a monthly magazine, regularly reports the performance of professional marathon runners. It has asked you to design a database to record the details of all major marathons (e.g., Boston, London, and Paris). Professional marathon runners compete in several races each year. A race may have thousands of competitors, but only about 200 or so are professional runners, the ones *The Marathoner* tracks. For each race, the magazine reports a runner's time and finishing position and some personal details such as name, gender, and age.

2. The data model shown was designed by a golf statistician. Write SQL statements to create the corresponding relational database.



3. Write the following SQL queries for the database described in this chapter:

   a. List the names of items for which the quantity sold is greater than one for any sale.

   b. Compute the total value of sales for each item by date.

   c. Report all items of type "F" that have been sold.

   d. List all items of type "F" that have not been sold.

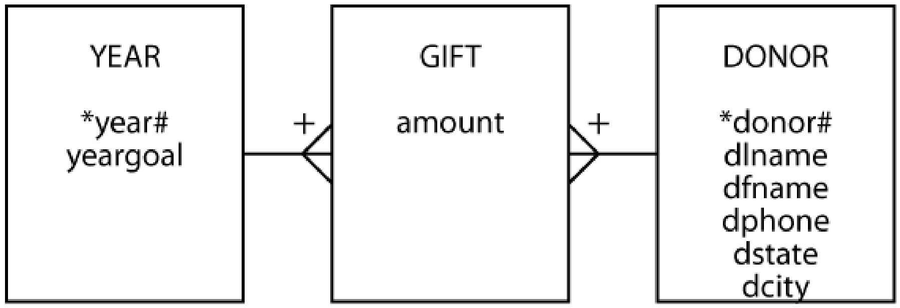
   e. Compute the total value of each sale.

4. Why do you have to create a third entity when you have an m:m relationship?

5. What does a plus sign near a relationship arc mean?

6. How does EXISTS differ from other clauses in an SQL statement?

7. Answer the following queries based on the described relational database.



   a. List the phone numbers of donors Hays and Jefts.
   b. How many donors are there in the donor table?
   c. How many people made donations in 1999?
   d. What is the name of the person who made the largest donation in 1999?
   e. What was the total amount donated in 2000?
   f. List the donors who have made a donation every year.
   g. List the donors whose average donation is more than twice the average donation of all donors.
   h. List the total amount given by each person across all years; sort the report by the donor's name.
   i. Report the total donations in 2001 by state.
   j. In which years did the total donated exceed the goal for the year?

8. The following table records data found on the side of a breakfast cereal carton. Use these data as a guide to develop a data model to record nutrition facts for a meal. In this case, a meal is a cup of cereal and 1/2 cup of skim milk.

Nutrition facts Serving size 1 cup (30g) Servings per container about 17		
Amount per serving	Cereal	with 1/2 cup of skim milk
Calories	110	150
Calories from Fat	10	10
		% Daily Value |
Total Fat 1g	1%	2%
Saturated Fat 0g	0%	0%
Polyunsaturated Fat 0g		
Monounsaturated Fat 0g		
Cholesterol 0mg	0%	1%
Sodium 220mg	9%	12%
Potassium 105 mg	3%	9%

Nutrition facts Serving size 1 cup (30g) Servings per container about 17		
Total Carbohydrate 24g	8%	10%
Dietary Fiber 3g	13%	13%
Sugars 4g		
Other Carbohydrate 17g		
Protein 3g		
Vitamin A	10%	15%
Vitamin C	10%	10%
Calcium	2%	15%
Iron	45%	45%
Vitamin D	10%	25%
Thiamin	50%	50%
Riboflavin	50%	50%
Niacin	50%	50%
Vitamin B12	50%	60%
Phosphorus	10%	20%
Magnesium	8%	10%
Zinc	50%	50%
Copper	4%	4%

6 One-to-One and Recursive Relationships

Self-reflection is the school of wisdom.

Baltasar Gracián, *The Art of Worldly Wisdom*, 1647

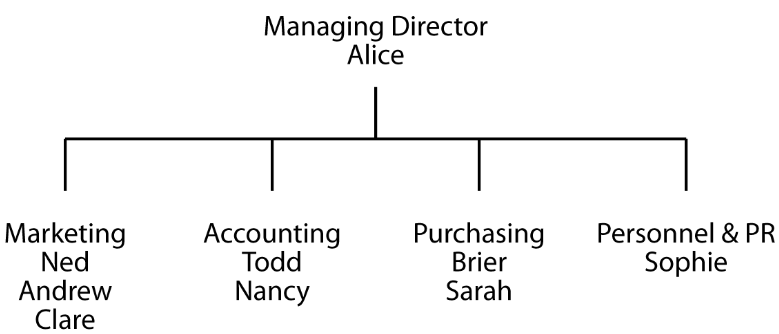
Learning objectives

Students completing this chapter will be able to

- model one-to-one and recursive relationships;
- define a database with one-to-one and recursive relationships;
- write queries for a database with one-to-one and recursive relationships.

An organizational chart, as shown in the following diagram, can be modeled with several relationships.

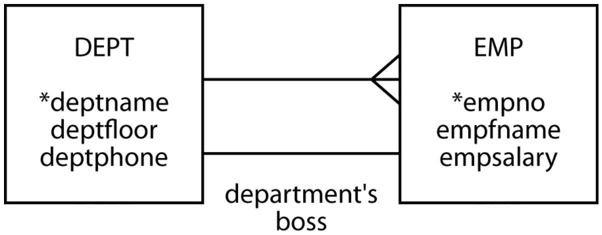
An organizational chart



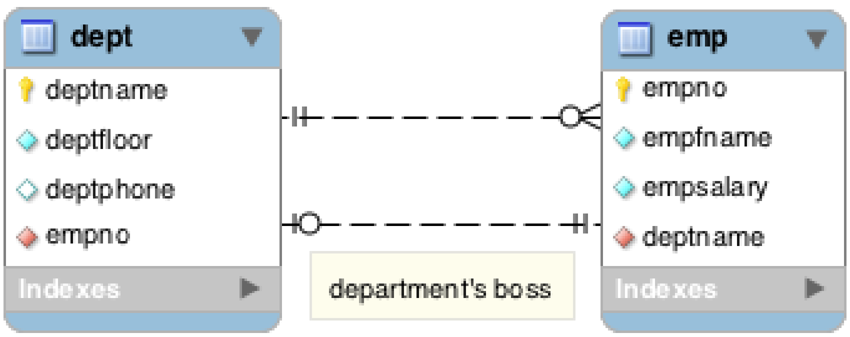
Modeling a one-to-one relationship

Initially, the organization chart appears to record two relationships. *First*, a department has one or more employees, and an employee belongs to one department. *Second*, a department has one boss, and a person is boss of only one department. That is, boss is a 1:1 relationship between DEPT and EMP. The data model for this situation is shown.

A data model illustrating a 1:m and 1:1 relationship



MySQL Workbench version of a 1:m and 1:1 relationship

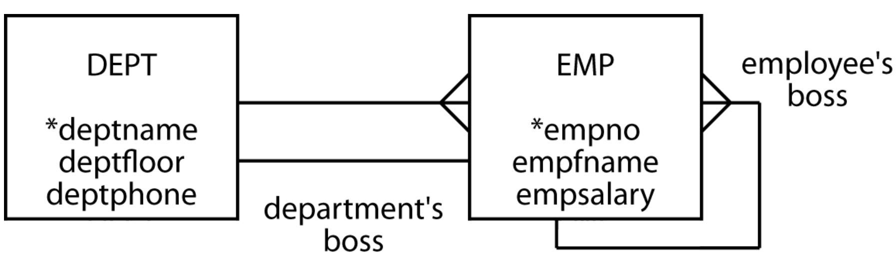


As a general rule, the 1:1 relationship is labeled to avoid confusion because the meaning of such a relationship cannot always be inferred. This label is called a relationship descriptor. The 1:m relationship between DEPT and EMP is not labeled because its meaning is readily understood by reading the model. Use a relationship descriptor when there is more than one relationship between entities or when the meaning of the relationship is not readily inferred from the model.

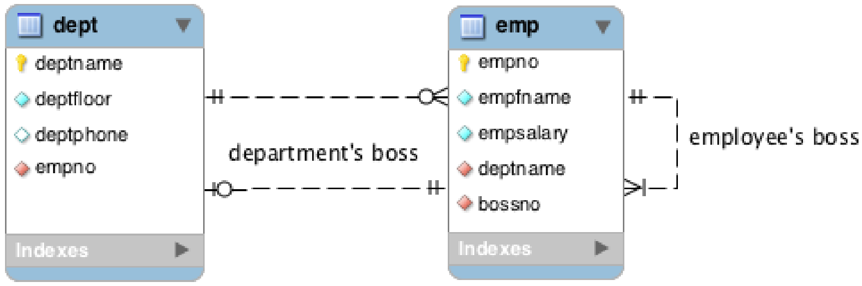
If we think about this problem, we realize there is more to boss than just a department. People also have a boss. Thus, Alice is the boss of all the other employees. In this case, we are mainly interested in who directly bosses someone else. So, Alice is the direct boss of Ned, Todd, Brier, and Sophie. We need to record the person-boss relationship as well as the department-boss relationship.

The person-boss relationship is a recursive 1:m relationship because it is a relationship between employees—an employee has one boss and a boss can have many employees. The data model is shown in the following figure.

A data model illustrating a recursive 1:m relationship



MySQL Workbench version of a recursive 1:m relationship



It is a good idea to label the recursive relationship, because its meaning is often not obvious from the data model.

Mapping a one-to-one relationship

Since mapping a 1:1 relationship follows the same rules as for any other data model, the major consideration is where to place the foreign key(s). There are three alternatives:

1. Put the foreign key in dept.

   Doing so means that every instance of dept will record the empno of the employee who is boss. Because it is mandatory that all departments, in this case have a boss, the foreign key will always be non-null.
2. Put the foreign key in emp.

   Choosing this alternative means that every instance of emp should record deptname of the department this employee bosses. Since many employees are not bosses, the value of the foreign key column will generally be null.
3. Put a foreign key in both dept and emp.

   The consequence of putting a foreign key in both tables in the 1:1 relationship is the combination of points 1 and 2.

The best approach is to put the foreign key in dept, because it is mandatory for each department to have a boss, and the foreign key will always be non-null.

Mapping a recursive one-to-many relationship

A recursive 1:m relationship is mapped like a standard 1:m relationship. An additional column, for the foreign key, is created for the entity at the “many” end of the relationship. Of course, in this case the “one” and “many” ends are the same entity, so an additional column is added to `emp`. This column contains the key `empno` of the “one” end of the relationship. Since `empno` is already used as a column name, a different name needs to be selected. In this case, it makes sense to call the foreign key column `bossno` because it stores the boss’s employee number.

The mapping of the data model is shown in the following table. Note that `deptname` becomes a column in `emp`, the "many" end of the 1:m relationship, and `empno` becomes a foreign key in `dept`, an end of the 1:1 relationship.

The tables dept and emp

*deptname	deptfloor	deptphone	*empno*
Management	5	2001	1
Marketing	1	2002	2
Accounting	4	2003	5
Purchasing	4	2004	7
Personnel & PR	1	2005	9

*empno	empfname	empsalary	deptname	bossno
1	*Alice*	75000	*Management*	
2	*Ned*	45000	*Marketing*	1
3	*Andrew*	25000	*Marketing*	2
4	*Clare*	22000	*Marketing*	2
5	*Todd*	38000	*Accounting*	1
6	*Nancy*	22000	*Accounting*	5
7	*Brier*	43000	*Purchasing*	1
8	*Sarah*	56000	*Purchasing*	7
9	*Sophie*	35000	*Personnel & PR*	1

If you examine `emp`, you will see that the boss of the employee with `empno` = 2 (Ned) has `bossno` = 1. You can then look up the row in `emp` with `empno` = 1 to find that Ned's boss is Alice. This "double lookup" is frequently used when manually interrogating a table that represents a recursive relationship. Soon you will discover how this is handled with SQL.

Here is the SQL to create the two tables:

```
CREATE TABLE dept (
    deptname        VARCHAR(15),
    deptfloor       SMALLINT NOT NULL,
    deptphone       SMALLINT NOT NULL,
    empno           SMALLINT NOT NULL,
    PRIMARY KEY(deptname));
```

```
CREATE TABLE emp (
    empno           SMALLINT,
    empfname        VARCHAR(10),
    empsalary       DECIMAL(7,0),
    deptname        VARCHAR(15),
    bossno          SMALLINT,
    PRIMARY KEY(empno),
```

```
    CONSTRAINT fk_belong_dept FOREIGN KEY(deptname)
        REFERENCES dept(deptname),
    CONSTRAINT fk_has_boss FOREIGN KEY(bossno)
        REFERENCES emp(empno));
```

You will notice that there is no foreign key definition for `empno` in `dept` (the 1:1 department's boss relationship). Why? Observe that `deptname` is a foreign key in `emp`. If we make `empno` a foreign key in `dept`, then we have a *deadly embrace*. A new department cannot be added to the `dept` table until there is a boss for that department (i.e., there is a person in the `emp` table with the `empno` of the boss); however, the other constraint states that an employee cannot be added to the `emp` table unless there is a department to which that person is assigned. If we have both foreign key constraints, we cannot add a new department until we have added a boss, and we cannot add a boss until we have added a department for that person. Nothing, under these circumstances, can happen if both foreign key constraints are in place. Thus, only one of them is specified.

In the case of the recursive employee relationship, we can create a constraint to ensure that `bossno` exists for each employee, except of course the person, Alice, who is top of the pyramid. This form of constraint is known as a self-referential foreign key. However, we must make certain that the first person inserted into `emp` is Alice. The following statements illustrate that we must always insert a person's boss before we insert the person.

```
INSERT INTO emp (empno, empfname, empsalary, deptname)
  VALUES (1,'Alice',75000,'Management');
INSERT INTO emp VALUES (2,'Ned',45000,'Marketing',1);
INSERT INTO emp VALUES (3,'Andrew',25000,'Marketing',2);
INSERT INTO emp VALUES (4,'Clare',22000,'Marketing',2);
INSERT INTO emp VALUES (5,'Todd',38000,'Accounting',1);
INSERT INTO emp VALUES (6,'Nancy',22000,'Accounting',5);
INSERT INTO emp VALUES (7,'Brier',43000,'Purchasing',1);
INSERT INTO emp VALUES (8,'Sarah',56000,'Purchasing',7);
INSERT INTO emp VALUES (9,'Sophie',35000,'Personnel',1);
```

In more complex modeling situations, such as when there are multiple relationships between a pair of entities, use of a FOREIGN KEY clause may result in a deadlock. Always consider the consequences of using a FOREIGN KEY clause before applying it.

> ❎ *Skill builder*
>
> A consulting company has assigned each of its employees to a specialist group (e.g., database management). Each specialist group has a team leader. When employees join the company, they are assigned a mentor for the first year. One person might mentor several employees, but an employee has at most one mentor.

Querying a one-to-one relationship

Querying a 1:1 relationship presents no special difficulties but does allow us to see additional SQL features.

List the salary of each department's boss.

```
SELECT empfname, deptname, empsalary FROM emp
    WHERE empno IN (SELECT empno FROM dept);
```

or

```
SELECT empfname, dept.deptname, empsalary
    FROM emp JOIN dept
        ON dept.empno = emp.empno;
```

Table 6.3: 5 records

empfname	deptname	empsalary
Todd	Accounting	38000
Alice	Management	75000
Ned	Marketing	45000
Sophie	Personnel	35000
Brier	Purchasing	43000

Querying a recursive 1:m relationship

Querying a recursive relationship is puzzling until you realize that you can join a table to itself by creating two copies of the table. In SQL, you use the WITH clause, also known as the *common table expression (CTE)* to create a temporary copy, a table alias. First, use WITH to define two aliases, `wrk` and `boss` for `emp`. Table aliases are required so that SQL can distinguish which copy of the table is referenced. To demonstrate:

Find the salary of Nancy's boss.

First, use WITH to define two aliases, `wrk` and `boss` for `emp`.

```
WITH
wrk AS (SELECT * FROM emp),
boss AS (SELECT * FROM emp)
SELECT wrk.empfname, wrk.empsalary,
     boss.empfname, boss.empsalary
    FROM wrk JOIN boss
        ON wrk.bossno = boss.empno
        WHERE wrk.empfname = 'Nancy';
```

Many queries are solved by getting all the data you need to answer the request in one row. In this case, the query is easy to answer once the data for Nancy and her boss are in the same row. Thus, think of this query as joining two copies of the table `emp` to get the worker and her boss's data in one row. Notice that there is a qualifier (`wrk` and `boss`) for each copy of the table to distinguish between them. It helps to use a qualifier that makes sense. In this case, the `wrk` and `boss` qualifiers can be thought of as referring to the worker and boss tables, respectively. You can understand how the query works by examining the following table illustrating the result of the self-join.

wrk					boss				
empno	empfname	empsalary	deptname	bossno	empno	empfname	empsalary	deptname	bossno
2	Ned	45000	Marketing	1	1	Alice	75000	Management	
3	Andrew	25000	Marketing	2	2	Ned	45000	Marketing	1
4	Clare	22000	Marketing	2	2	Ned	45000	Marketing	1
5	Todd	38000	Accounting	1	1	Alice	75000	Management	
6	Nancy	22000	Accounting	5	5	Todd	38000	Accounting	1
7	Brier	43000	Purchasing	1	1	Alice	75000	Management	
8	Sarah	56000	Purchasing	7	7	Brier	43000	Purchasing	1
9	Sophie	35000	Personnel & PR	1	1	Alice	75000	Management	

The result of the SQL query is now quite clear once we apply the WHERE clause (see the highlighted row in the preceding table):

```
WITH
wrk AS (SELECT * FROM emp),
boss AS (SELECT * FROM emp)
SELECT wrk.empfname, wrk.empsalary,
       boss.empfname, boss.empsalary
    FROM wrk JOIN boss
        ON wrk.bossno = boss.empno
        WHERE wrk.empfname = 'Nancy';
```

Table 6.5: 1 records

empfname	empsalary	empfname	empsalary
Nancy	22000	Todd	38000

Find the names of employees who earn more than their boss.

This would be very easy if the employee and boss data were in the same row. We could simply compare the salaries of the two people. To get the data in the same row, we repeat the self-join with a different WHERE condition. The result is as follows:

```
WITH
wrk AS (SELECT * FROM emp),
boss AS (SELECT * FROM emp)
SELECT wrk.empfname FROM wrk JOIN boss
        ON wrk.bossno = boss.empno
        WHERE wrk.empsalary > boss.empsalary;
```

Table 6.6: 1 records

empfname
Sarah

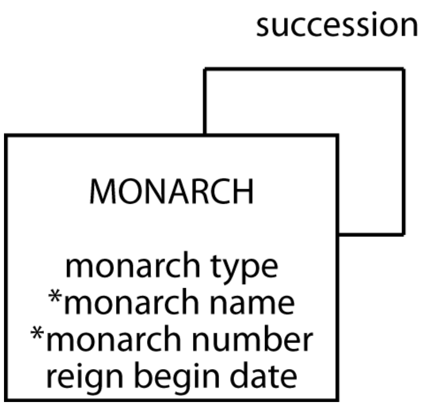
☒ *Skill builder*

Find the name of Sophie's boss.

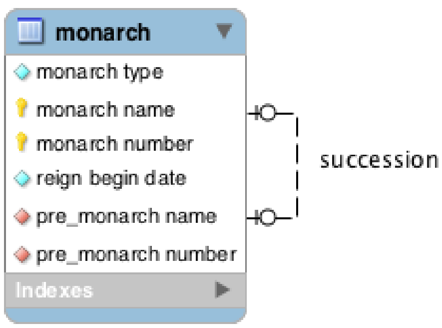
Modeling a recursive one-to-one relationship

The British monarchy can be represented by a simple one-entity model. A monarch has one direct successor and one direct predecessor. The sequencing of monarchs can be modeled by a recursive 1:1 relationship, shown in the following figure.

A data model illustrating a recursive 1:1 relationship



MySQL Workbench version of a recursive 1:1 relationship



Mapping a recursive one-to-one relationship

The recursive 1:1 relationship is mapped by adding a foreign key to `monarch`. You can add a foreign key to represent either the successor or predecessor relationship. In this case, for no particular reason, the preceding relationship is selected. Because each instance of a monarch is identified by a composite key, two columns are added to `monarch` for the foreign key. Data for recent monarchs are shown in the following table.

The table monarch

montype	*monname	*monnum	rgnbeg	*premonname*	*premonnum*
King	William	IV	1830/6/26		
Queen	Victoria	I	1837/6/20	William	IV
King	Edward	VII	1901/1/22	Victoria	I
King	George	V	1910/5/6	Edward	VII
King	Edward	VIII	1936/1/20	George	V
King	George	VI	1936/12/11	Edward	VIII
Queen	Elizabeth	II	1952/02/06	George	VI
King	Charles	III	2022/09/08	Elizabeth	II

The SQL statements to create the table are very straightforward.

```
CREATE TABLE monarch (
    montype       CHAR(5) NOT NULL,
    monname       VARCHAR(15),
    monnum          VARCHAR(5),
    rgnbeg          DATE,
    premonname  VARCHAR(15),
    premonnum       VARCHAR(5),
 PRIMARY KEY(monname,monnum),
 CONSTRAINT fk_monarch
     FOREIGN KEY (premonname, premonnum)
        REFERENCES monarch(monname, monnum);
```

Because the 1:1 relationship is recursive, you cannot insert Queen Victoria without first inserting King William IV. What you can do is first insert King William, without any reference to the preceding monarch (i.e., a null foreign key). The following code illustrates the order of record insertion so that the referential integrity constraint is obeyed.

```
INSERT INTO monarch (montype,monname, monnum,rgnbeg)
 VALUES
  ('King','William','IV','1830-06-26');
INSERT INTO monarch VALUES
  ('Queen','Victoria','I','1837-06-20','William','IV');
INSERT INTO monarch VALUES
  ('King','Edward','VII','1901-01-22','Victoria','I');
INSERT INTO monarch VALUES
  ('King','George','V','1910-05-06','Edward','VII');
INSERT INTO monarch
 VALUES
  ('King','Edward','VIII','1936-01-20','George','V');
INSERT INTO monarch VALUES
  ('King','George','VI','1936-12-11','Edward','VIII');
INSERT INTO monarch VALUES
 ('Queen','Elizabeth','II','1952-02-06','George','VI');
INSERT INTO monarch VALUES
 ('King','Charles','III','2022-09-08','Elizabeth','II');
```

❎ *Skill builder*

In a competitive bridge competition, the same pair of players play together for the entire tournament. Draw a data model to record details of all the players and the pairs of players.

Querying a recursive one-to-one relationship

Some queries on the monarch table demonstrate querying a recursive 1:1 relationship.

Who preceded Elizabeth II?

```
SELECT premonname, premonnum FROM monarch
    WHERE monname = 'Elizabeth' and monnum = 'II';
```

Table 6.8: 1 records

premonname	premonnum
George	VI

This is simple because all the data are in one row. A more complex query is:

Was Elizabeth II's predecessor a king or queen?

```
WITH
cur AS (SELECT * FROM monarch),
pre AS (SELECT * FROM monarch)
SELECT pre.montype FROM cur JOIN  pre
    ON cur.premonname = pre.monname
      AND cur.premonnum = pre.monnum
    WHERE cur.monname = 'Elizabeth'
      AND cur.monnum = 'II';
```

Table 6.9: 1 records

montype
King

Notice in the preceding query how to specify the ON clause when you have a composite key.

This is very similar to the query to find the salary of Nancy's boss. The `monarch` table is joined with itself to create a row that contains all the details to answer the query.

List the kings and queens of England in ascending chronological order.

```
SELECT montype, monname, monnum, rgnbeg
    FROM monarch ORDER BY rgnbeg;
```

Table 6.10: 8 records

montype	monname	monnum	rgnbeg
King	William	IV	1830-06-26
Queen	Victoria	I	1837-06-20
King	Edward	VII	1901-01-22

montype	monname	monnum	rgnbeg
King	George	V	1910-05-06
King	Edward	VIII	1936-01-20
King	George	VI	1936-12-11
Queen	Elizabeth	II	1952-02-06
King	Charles	III	2022-09-08

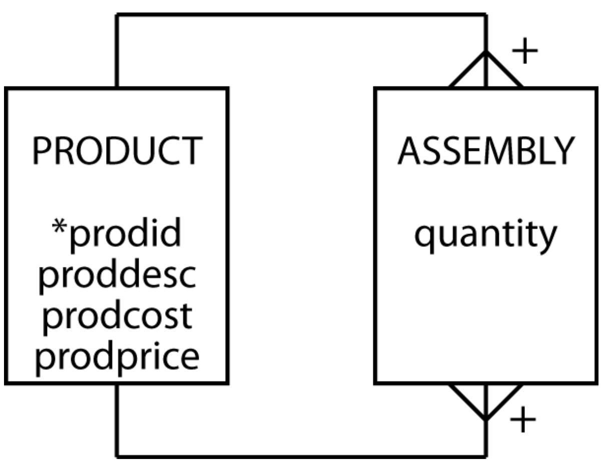
This is a simple query because `rgnbeg` is like a ranking column. It would not be enough to store just the year in `rgnbeg`, because two kings started their reigns in 1936; hence, the full date is required.

> ☒ *Skill builder*
>
> Who succeeded Queen Victoria?

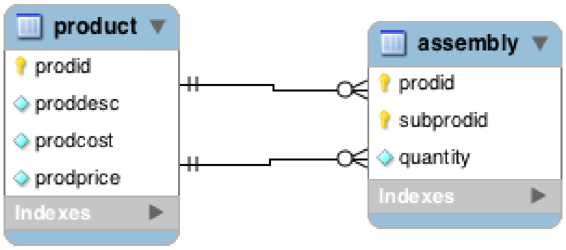
Modeling a recursive many-to-many relationship

The assembly of products to create other products is very common in business. Manufacturing even has a special term to describe it: a bill of materials. The data model is relatively simple once you realize that a product can appear as part of many other products and can be composed of many other products; that is, we have a recursive many-to-many (m:m) relationship for product. As usual, we turn an m:m relationship into two one-to-many (1:m) relationships. Thus, we get the data model displayed in the following figure.

A data model illustrating a recursive m:m relationship



MySQL Workbench version of a recursive m:m relationship



Tables product and assembly

*prodid	proddesc	prodcost	prodprice
1000	Animal photography kit		725
101	Camera	150	300
102	Camera case	10	15
103	70-210 zoom lens	125	200
104	28-85 zoom lens	115	185
105	Photographer's vest	25	40
106	Lens cleaning cloth	1	1.25
107	Tripod	35	45
108	16 GB SDHC memory card	30	37

quantity	**prodid*	**subprodid*
1	1000	101
1	1000	102
1	1000	103
1	1000	104
1	1000	105
2	1000	106
1	1000	107
10	1000	108

Mapping a recursive many-to-many relationship

Mapping follows the same procedure described previously, producing the two tables shown below. The SQL statements to create the tables are shown next. Observe that `assembly` has a composite key, and there are two foreign key constraints.

```
CREATE TABLE product (
    prodid          INTEGER,
    proddesc        VARCHAR(30),
    prodcost        DECIMAL(9,2),
```

```
    prodprice        DECIMAL(9,2),
        PRIMARY KEY(prodid));
```

```
CREATE TABLE assembly (
    quantity        INTEGER NOT NULL,
    prodid          INTEGER,
    subprodid       INTEGER,
 PRIMARY KEY(prodid, subprodid),
    CONSTRAINT fk_assembly_product
     FOREIGN KEY(prodid)
      REFERENCES product(prodid),
    CONSTRAINT fk_assembly_subproduct
     FOREIGN KEY(subprodid)
        REFERENCES product(prodid));
```

❎ *Skill builder*

An army is broken up into many administrative units (e.g., army, brigade, platoon). A unit can contain many other units (e.g., a regiment contains two or more battalions), and a unit can be part of a larger unit (e.g., a squad is a member of a platoon). Draw a data model for this situation.

Querying a recursive many-to-many relationship

List the product identifier of each component of the animal photography kit.

```
SELECT subprodid FROM product JOIN assembly
    ON product.prodid = assembly.prodid
    WHERE proddesc = 'Animal photography kit';
```

Table 6.13: 8 records

subprodid
101
102
103
104
105
106
107
108

Why are the values for `subprodid` listed in no apparent order? Remember, there is no implied ordering of rows in a table, and it is quite possible, as this example illustrates, for the rows to have what appears to be an unusual ordering. If you want to order rows, use the ORDER BY clause.

List the product description and cost of each component of the animal photography kit.

```
SELECT proddesc, prodcost FROM product
 WHERE prodid IN
    (SELECT subprodid FROM product JOIN assembly
     ON product.prodid = assembly.prodid
        WHERE proddesc = 'Animal photography kit');
```

In this case, first determine the `prodid` of those products in the animal photography kit (the inner query), and then report the description of these products. Alternatively, a three-way join can be done using two copies of `product`.

```
WITH
a AS (SELECT * FROM product),
b AS (SELECT * FROM product)
SELECT b.proddesc, b.prodcost FROM a JOIN assembly
 ON a.prodid = assembly.prodid
    JOIN b
     ON assembly.subprodid = b.prodid
      WHERE a.proddesc = 'Animal photography kit';
```

Table 6.14: 8 records

proddesc	prodcost
Camera	150
Camera case	10
70-210 zoom lens	125
28-85 zoom lens	115
Photographers vest	25
Lens cleaning cloth	1
Tripod	35
16 GB SDHC memory card	30

☒ *Skill builder*

How many lens cleaning cloths are there in the animal photography kit?

Summary

Relationships can be one-to-one and recursive. A recursive relationship is within a single entity rather than between entities. Recursive relationships are mapped to the relational model in the same way as other relationships. A self-referential foreign key constraint permits a foreign key reference to a key within the same table. Resolution of queries involving recursive relationships often requires a table to be joined with itself. Recursive many-to-many relationships occur in business in the form of a bill of materials.

Key terms and concepts

JOIN	Relationship
One-to-many (1:m) relationship	Relationship descriptor
One-to-one (1:1) relationship	Self-join
Recursive 1:1 relationship	Self-referential foreign key
Recursive 1:m relationship	Theta-join
Recursive m:m relationship	Update anomalies
Recursive relationship	Views
Referential integrity	Virtual table

Exercises

1. Draw data models for the following two problems:

   a. (i) A dairy farmer, who is also a part-time cartoonist, has several herds of cows. He has assigned each cow to a particular herd. In each herd, the farmer has one cow that is his favorite—often that cow is featured in a cartoon.

   (ii) A few malcontents in each herd, mainly those who feel they should have appeared in the cartoon, disagree with the farmer's choice of a favorite cow, whom they disparagingly refer to as the sacred cow. As a result, each herd now has elected a herd leader.

   b. The originator of a pyramid marketing scheme has a system for selling ethnic jewelry. The pyramid has three levels—gold, silver, and bronze. New associates join the pyramid at the bronze level. They contribute 30 percent of the revenue of their sales of jewelry to the silver chief in charge of their clan. In turn, silver chiefs contribute 30 percent of what they receive from bronze associates to the gold master in command of their tribe. Finally, gold masters pass on 30 percent of what they receive to the originator of the scheme.

   c. The legion, the basic combat unit of the ancient Roman army, contained 3,000 to 6,000 men, consisting primarily of heavy infantry (hoplites), supported by light infantry (velites), and sometimes by cavalry. The hoplites were drawn up in three lines. The hastati (youngest men) were in the first, the principes (seasoned troops) in the second, and the triarii (oldest men) behind them, reinforced by velites. Each line was divided into 10 maniples, consisting of two centuries (60 to 80 men per century) each. Each legion had a commander, and a century was commanded by a centurion. Julius Caesar, through one of his Californian channelers, has asked you to design a database to maintain details of soldiers. Of course, Julius is a little forgetful at times, and he has not supplied the titles of the officers who command maniples, lines, and hoplites, but he expects that you can handle this lack of fine detail.

   d. A travel agency is frequently asked questions about tourist destinations. For example, customers want to know details of the climate for a particular month, the population of the city, and other geographic facts. Sometimes they request the flying time and distance between two cities. The manager has asked you to create a database to maintain these facts.

e. The Center for the Study of World Trade keeps track of trade treaties between nations. For each treaty, it records details of the countries signing the treaty and where and when it was signed.

f. Design a database to store details about U.S. presidents and their terms in office. Also, record details of their date and place of birth, gender, and political party affiliation (e.g., Caluthumpian Progress Party). You are required to record the sequence of presidents so that the predecessor and successor of any president can be identified. How will you model the case of Grover Cleveland, who served nonconsecutive terms as president? Is it feasible that political party affiliation may change? If so, how will you handle it?

g. The IS department of a large organization makes extensive use of software modules. New applications are built, where possible, from existing modules. Software modules can also contain other modules. The IS manager realizes that she now needs a database to keep track of which modules are used in which applications or other modules. (Hint: It is helpful to think of an application as a module.)

h. Data modeling is finally getting to you. Last night you dreamed you were asked by Noah to design a database to store data about the animals on the ark. All you can remember from Sunday school is the bit about the animals entering the ark two-by-two, so you thought you should check the real thing. Take with you seven pairs of every kind of clean animal, a male and its mate, and two of every kind of unclean animal, a male and its mate, and also seven pair of every kind of bird, male and female. Genesis 7:2 Next time Noah disturbs your sleep, you want to be ready. So, draw a data model and make certain you record the two-by-two relationship.

2. Write SQL to answer the following queries using the DEPT and EMP tables described in this chapter:

   a. Find the departments where all the employees earn less than their boss.

   b. Find the names of employees who are in the same department as their boss (as an employee).

   c. List the departments having an average salary greater than $25,000.

   d. List the departments where the average salary of the employees, excluding the boss, is greater than $25,000.

   e. List the names and manager of the employees of the Marketing department who have a salary greater than $25,000.

   f. List the names of the employees who earn more than any employee in the Marketing department.

3. Write SQL to answer the following queries using the monarch table described in this chapter:

   a. Who succeeded Victoria I?

   b. How many days did Victoria I reign?

c. How many kings are there in the table?
d. Which monarch had the shortest reign?

4. Write SQL to answer the following queries using the product and assembly tables:
   a. How many different items are there in the animal photography kit?
   b. What is the most expensive item in the animal photography kit?
   c. What is the total cost of the components of the animal photography kit?
   d. Compute the total quantity for each of the items required to assemble 15 animal photography kits.

7 Data Modeling

Man is a knot, a web, a mesh into which relationships are tied. Only those relationships matter.

Antoine de Saint-Exupéry in *Flight to Arras*

Learning objectives

Students completing this chapter will be able to create a well-formed, high-fidelity data model.

Modeling

Modeling is widely used within business to learn about organizational problems and design solutions. To understand where data modeling fits within the broader context, it is useful to review the full range of modeling activities. The types of modeling methods follow the 5W-H model of journalism.[1]

A broad perspective on modeling

		Scope	Model	Technology
Motivation	Why	Goals	Business plan canvas	Groupware
People	Who	Business units	Organization chart	System interface
Time	When	Key events	PERT chart	Scheduling
Data	What	Key entities	Data model	Relational database
Network	Where	Locations	Logistics network	System architecture
Function	How	Key processes	Process model	Application software

Modeling occurs at multiple levels. At the highest level, an organization needs to determine the scope of its business by identifying the major elements of its environment, such as its goals, business units, where it operates, and critical events, entities, and processes. At the top level, textual models are frequently used. For example, an organization might list its major goals and business processes. A map will be typically used to display where the business operates.

[1] Roberto Franzosi, "On Quantitative Narrative Analysis," in Varieties of Narrative Analysis, ed. James A. Holstein and Jaber F. Gubrium (SAGE Publications, Inc., 2012), 75–96.

Once senior managers have clarified the scope of a business, models can be constructed for each of the major elements. Goals will be converted into a business plan, business units will be shown on an organizational chart, and so on. The key elements, from an IS perspective, are data and process modeling, which are typically covered in the core courses of an IS program.

Technology, the final stage, converts models into operational systems to support the organization. Many organizations rely extensively on email and Web technology for communicating business decisions. People connect to systems through an interface, such as a Web browser. Ensuring that events occur at the right time is managed by scheduling software. This could be implemented with operating system procedures that schedule the execution of applications. In some database management systems (DBMSs), triggers can be established. A trigger is a database procedure that is automatically executed when some event is recognized. For example, U.S. banks are required to report all deposits exceeding USD 10,000, and a trigger could be coded for this event.

Data models are typically converted into relational databases, and process models become computer programs. Thus, you can see that data modeling is one element of a comprehensive modeling activity that is often required to design business systems. When a business undergoes a major change, such as a reengineering project, many dimensions can be altered, and it may be appropriate to rethink many elements of the business, starting with its goals. Because such major change is very disruptive and costly, it occurs less frequently. It is more likely that data modeling is conducted as a stand-alone activity or part of process modeling to create a new business application.

Data modeling

You were introduced to the basic building blocks of data modeling in the earlier chapters of this section. Now it is time to learn how to assemble blocks to build a data model. Data modeling is a method for determining what data and relationships should be stored in the database. It is also a way of communicating a database design.

The goal of data modeling is to identify the facts that must be stored in a database. A data model is not concerned with how the data will be stored. This is the concern of those who implement the database. A data model is not concerned with how the data will be processed. This is the province of process modeling. The goal is to create a data model that is an accurate representation of data needs and real-world data relationships.

Building a data model is a partnership between a client, a representative of the eventual owners of the database, and a designer. Of course, there can be a team of clients and designers. For simplicity, we assume there is one client and one designer.

Drawing a data model is an iterative process of trial and revision. A data model is a working document that will change as you learn more about the client's needs and world. Your early versions are likely to be quite different from the final product. Use a product, such as MySQL Workbench, for drawing and revising a data model.

The building blocks

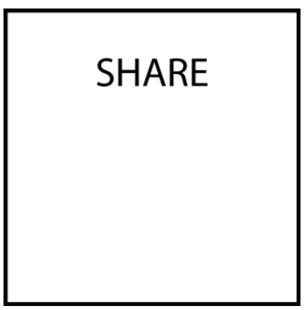
The purpose of a database is to store data about things, which can include facts (e.g., an exchange rate), plans (e.g., scheduled production of two-person tents for June), estimates (e.g., forecast of demand for smart phones), and a variety of other data. A data model describes these things and their relationships with other things using four components: entity, attribute, relationship, and identifier.

Entity

The entity is the basic building block of a data model. An entity is a thing about which data should be stored, something we need to describe. Each entity in a data model has a unique name that we write in singular form. Why singular? Because we want to emphasize that an entity describes an instance of a thing. Thus, we previously used the word SHARE to define an entity because it describes each instance of a share rather than shares in general.

We have already introduced the convention that an entity is represented by a rectangle, and the name of the entity is shown in uppercase letters, as follows.

The entity SHARE



A large data model might contain over a 1,000 entities. A database can easily contain hundreds of millions of instances (rows) for any one entity (table). Imagine the number of instances in a national tax department's database.

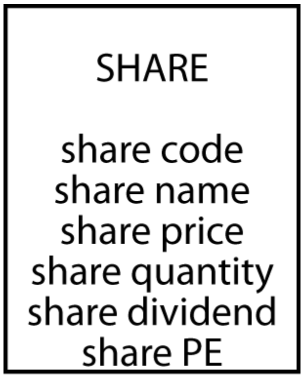
How do you begin to identify entities? One approach is to underline any *nouns* in the system proposal or provided documentation. Most nouns are possible entities, and underlining ensures that you do not overlook any potential entities. Start by selecting an entity that seems central to the problem. If you were designing a student database, you might start with the student. Once you have picked a central entity, describe it. Then move to the others.

Attribute

An attribute describes an entity. When an entity has been identified, the next step is to determine its attributes, that is, the data that should be kept to describe fully the entity. An attribute name is singular and unique within the data model. You may need to use a modifier to make an attribute name unique (e.g., "hire date" and "sale date" rather than just "date").

Our convention is that the name of an attribute is recorded in lowercase letters within the entity rectangle. The following figure illustrates that SHARE has attributes *share code*, *share name*, *share price*, *share quantity*, *share dividend*, and *share PE*. Notice the frequent use of the modifier "share". It is possible that other entities in the database might also have a price and quantity, so we use a modifier to create unique attribute names. Note also that *share code* is the identifier.

The entity SHARE with its attributes



Defining attributes generally takes considerable discussion with the client. You should include any attribute that is likely to be required for present or future decision making, but don't get carried away. Avoid storing unnecessary data. For example, to describe the entity STUDENT you usually record date of birth, but it is unlikely that you would store height. If you were describing an entity PATIENT, on the other hand, it might be necessary to record height, because that is sometimes relevant to medical decision making.

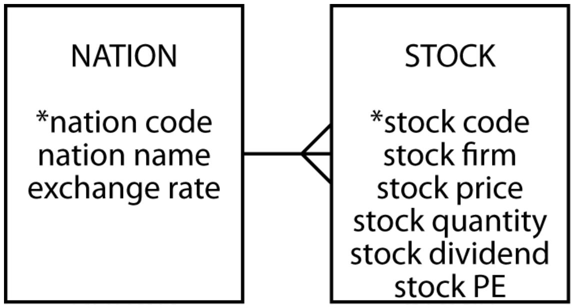
An attribute has a single value, which may be null. Multiple values are not allowed. If you need to store multiple values, it is a signal that you have a one-to-many (1:m) relationship and need to define another entity.

Relationship

Entities are related to other entities. If there were no relationships between entities, there would be no need for a data model and no need for a relational database. A simple, flat file (a single-entity database) would be sufficient. A relationship is binary. It describes a linkage between two entities and is represented by a line between them.

Because a relationship is binary, strictly speaking it has two relationship descriptors, one for each entity. Each relationship descriptor has a degree stating how many instances of the other entity may be related to each instance of the described entity. Consider the entities STOCK and NATION and their 1:m relationship (see the following figure). We have two relationship descriptors: *stocks of nation* for NATION and *nation of stock* for STOCK. The relationship descriptor *stocks of nation* has a degree of m because a nation may have zero or more listed stocks. The relationship descriptor *nation of stock* has a degree of 1 because a stock is listed in at most one nation. To reduce data model clutter, where necessary for clarification, use a single label for the pair of relationship descriptors. Experience shows this approach captures the meaning of the relationship and improves readability.

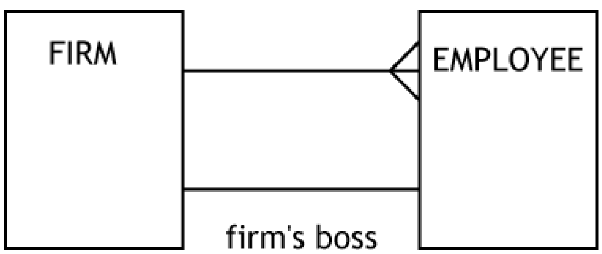
A 1:m relationship between STOCK and NATION



Because the meaning of relationships frequently can be inferred, there is no need to label every one; however, each additional relationship between two entities should be labeled to clarify meaning. Also, it is a good idea to label one-to-one (1:1) relationships, because the meaning of the relationship is not always obvious.

Consider the fragment in the following figure. The descriptors of the 1:m relationship can be inferred as a firm has employees and an employee belongs to a firm. the 1:1 relationship is clarified by labeling the 1:1 relationship as firm's boss.

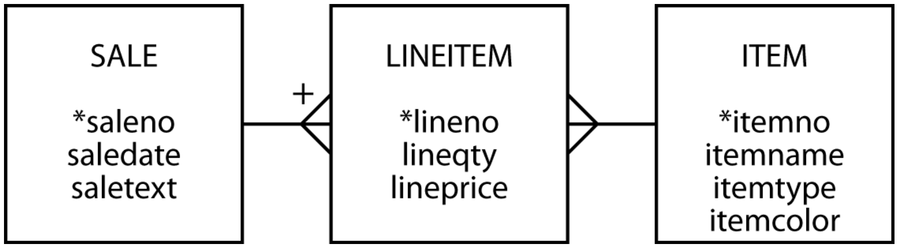
Relationship labeling



Identifier

An identifier uniquely distinguishes an instance of an entity. An identifier can be one or more attributes and may include the identifier of a related entity. When a related entity's identifier is part of an identifier, a plus sign is placed above the line closest to the entity being identified. In the following figure, an instance of the entity LINEITEM is identified by the composite of *lineno* and *saleno*, the identifier of SALE. The value *lineno* does not uniquely identify an instance of LINEITEM, because it is simply a number that appears on the sales form. Thus, the identifier must include *saleno* (the identifier of SALE). So, any instance of LINEITEM is uniquely identified by the composite *saleno* and *lineno*.

A related entity's identifier as part of the identifier



Occasionally, there will be several possible identifiers, and these are each given a different symbol. Our convention is to prefix an identifier with an asterisk (*). If there are multiple identifiers, use other symbols such as #, !, or &. Be careful: If you have too many possible identifiers, your model will look like comic book swearing. In most cases, you will have only one identifier.

No part of an identifier can be null. If this were permitted, there would be no guarantee that the other parts of the identifier were sufficiently unique to distinguish all instances in the database.

Data model quality

There are two criteria for judging the quality of a data model. It must be well-formed and have high fidelity.

A well-formed data model

A well-formed data model clearly communicates information to the client. Being well-formed means the construction rules have been obeyed. There is no ambiguity; all entities are named, and all entities have identifiers. If identifiers are missing, the client may make incorrect inferences about the data model. All relationships are recorded using the proper notation and labeled whenever there is a possibility of confusion.

Characteristics of a well-formed data model

All construction rules are obeyed.
There is no ambiguity.
All entities are named.
Every entity has an identifier.
All relationships are represented, using the correct notation.
Relationships are labeled to avoid misunderstanding.
All attributes of each entity are listed.
All attribute names are meaningful and unique.

All the attributes of an entity are listed because missing attributes create two types of problems. *First*, it is unclear what data will be stored about each instance. *Second*, the data model may be missing some relationships. Attributes that can have multiple values become entities. It is only by listing all of an entity's attributes during data modeling that these additional entities are recognized.

In a well-formed data model, all attribute names are meaningful and unique. The names of entities, identifiers, attributes, and relationships must be meaningful to the client because they are describe the client's world. Indeed, in nearly all cases they should be the client's everyday names. Take care in selecting words because they are critical to communicating meaning. The acid test for comprehension is to get the client to read the data model to other potential clients. Names need to be unique to avoid confusion.

A high-fidelity image

Music lovers aspire to own a high-fidelity stereo system—one that faithfully reproduces the original performance with minimal or no distortion. A data model is high-fidelity when it faithfully describes the world it is supposed to represent. All relationships are recorded and are of the correct degree. There are no compromises or distortions. If the real-world relationship is many-to-many (m:m), then so is the relationship shown in the data model. a well-formed, high-fidelity data model is complete, understandable, accurate, and syntactically correct.

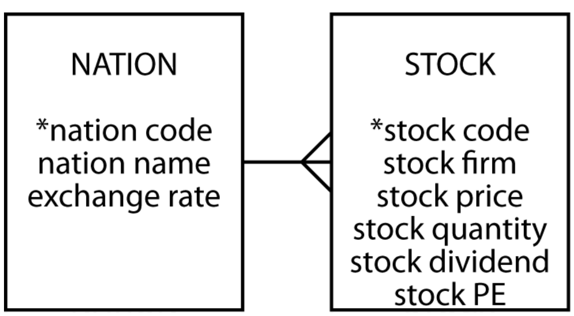
Quality improvement

A data model is an evolving representation. Each change should be an incremental improvement in quality. Occasionally, you will find a major quality problem at the data model's core and have to change the model considerably.

Detail and context

The quality of a data model can be determined only by understanding the context in which it will be used. Consider the data model (see the following figure) used in Chapter 4 to discuss the 1:m relationship. This fragment says a nation has many stocks. Is that really what we want to represent? Stocks are listed on a stock exchange, and a nation may have several stock exchanges. For example, the U.S. has the New York Stock Exchange and NASDAQ. Furthermore, some foreign stocks are listed on the New York Stock Exchange. If this is the world we have to describe, the data model is likely to differ from that shown in the figure. Try drawing the revised data model.

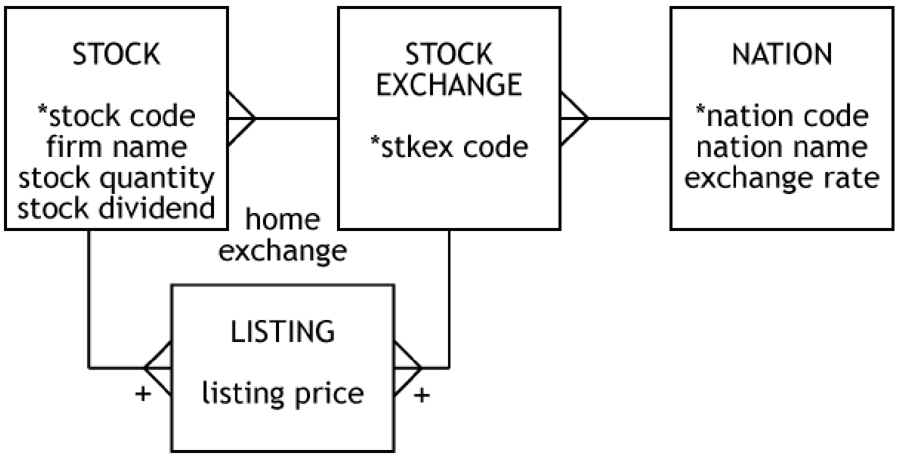
A 1:m relationship between STOCK and NATION



As you can see, the data model in the following figure is quite different from the initial data model of the preceding figure. Which one is better? They both can be valid models; it just depends on the world you are trying to represent and possible future queries. In the first case, the purpose was to determine the value of a portfolio. There was no interest in on which exchange stocks were listed or their home exchange. So the first model has high fidelity for the described situation.

The second data model would be appropriate if the client needed to know the home exchange of stocks and their price on the various exchanges where they are listed. The second data model is an improvement on the first if it incorporates the additional facts and relationships required. If it does not, then the additional detail is not worth the extra cost.

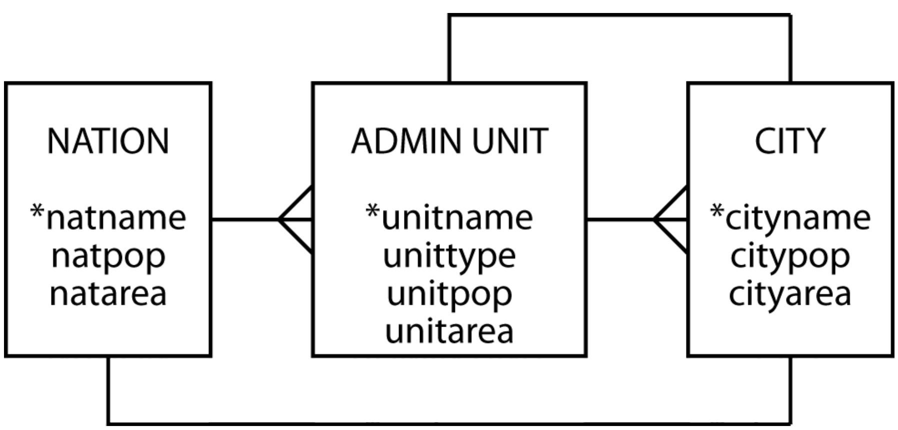
Revised NATION-STOCK data



A lesson in pure geography

A data model must be an accurate representation of the world you want to model. The data model must account for all the exceptions—there should be no impurities. Let's say you want to establish a database to store details of the world's cities. You might start with the data model depicted in the following figure.

A world's cities data model



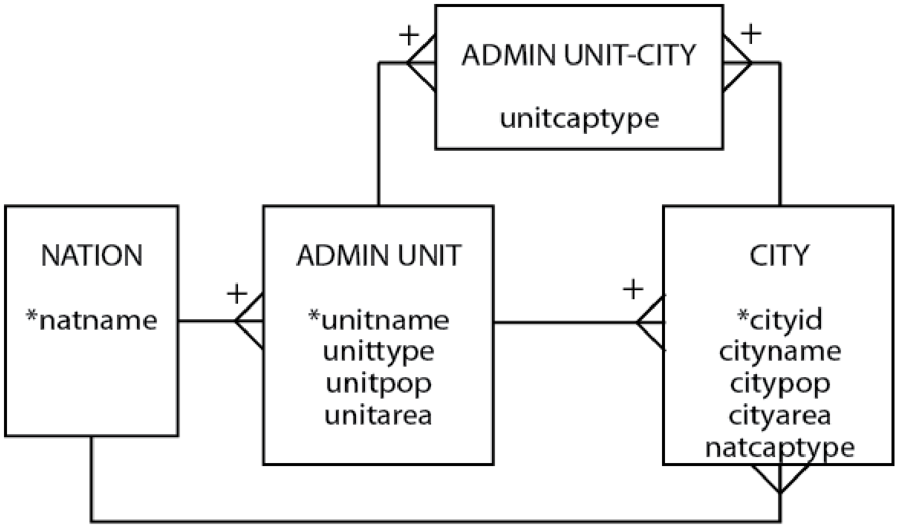
Before looking more closely at the data model, let's clarify the meaning of *unittype*. Because most countries are divided into administrative units that are variously called states, provinces, territories, and so forth, *unittype* indicates the type of administrative unit (e.g., state).

How many errors can you find in the initial data model?

Problems and solutions for the initial world's cities data model

	Problem	Solution
1	City names are not unique. There is an Athens in Greece, and the U.S. has an Athens in Georgia, Alabama, Ohio, Pennsylvania, Tennessee, and Texas.	To identify a city uniquely, you need to specify its administrative unit and country. Add a plus sign to the crow's feet between CITY and ADMIN UNIT and between ADMIN UNIT and NATION.
2	Administrative unit names are not necessarily unique. There used to be a Georgia in the old U.S.S.R., and there is a Georgia in the U.S. There is no guarantee that administrative unit names will always be unique.	To identify an administrative unit uniquely, you also need to know the country in which it is found. Add a plus sign to the crow's foot between ADMIN UNIT and NATION.
3	There is an unlabeled 1:1 relationship between CITY and ADMIN UNIT and CITY and NATION. What do these mean? They are supposed to indicate that an administrative unit has a capital, and a nation has a capital.	Label relationships (e.g., national capital city).
4	The assumption is that a nation has only one capital, but there are exceptions. South Africa has three capitals: Cape Town (legislative), Pretoria (administrative), and Bloemfontein (judicial). You need only one exception to lower the fidelity of a data model significantly.	Change the relationship between NATION and CITY to 1:m. Add an attribute natcaptype to CITY to distinguish between types of capitals.
5	The assumption is that an administrative unit has only one capital, but there are exceptions. At one point, Chandigarh was the capital of two Indian states, Punjab and Haryana. The Indian state of Jammu & Kashmir has two capitals: Jammu (summer) and Srinagar (winter).	Change the relationship between ADMIN UNIT and CITY to m:m by creating an associative entity and include a distinguishing attribute of unitcaptype.
6	Some values can be derived. National population, natpop, and area, natarea, are the sum of the regional populations, regpop, and areas, regarea, respectively. The same rule does not apply to regions and cities because not everyone lives in a city.	Remove the attributes natpop and natarea from NATION.

A revised world's cities data model



National capital

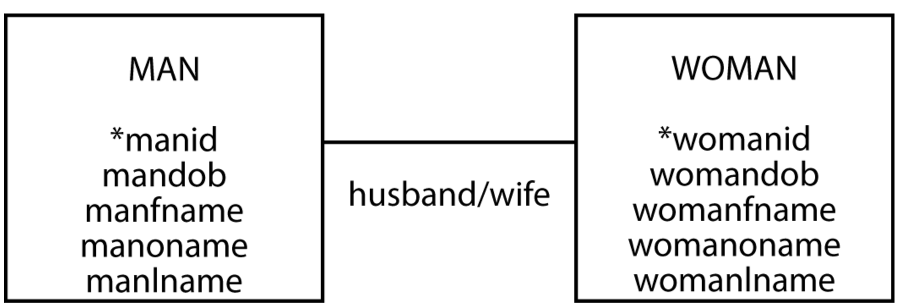
This geography lesson demonstrates how you often start with a simple model of low fidelity. By additional thinking about relationships and consideration of exceptions, you gradually create a high-fidelity data model.

> ❎ *Skill builder*
>
> Write SQL to determine which administrative units have two capitals and which have a shared capital.

Family matters

Families can be very complicated. It can be tricky to keep track of all those relations—maybe you need a relational database (this is the worst joke in the book; they improve after this). We start with a very limited view of marriage and gradually ease the restrictions to demonstrate how any and all aspects of a relationship can be modeled. An initial fragment of the data model is shown in the following figure. There are several things to notice about it.

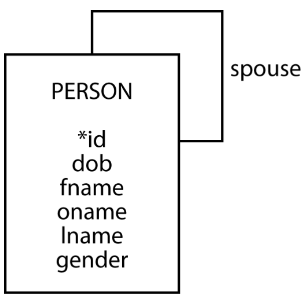
A man-woman data model



1. There is a 1:1 relationship between man and woman. The labels indicate that this relationship is marriage, but there is no indication of the marriage date. We are left to infer that the data model records the current marriage.
2. MAN and WOMAN have the same attributes. A prefix is used to make them unique. Both have an identifier (*id*), date of birth (*dob*), first name (*fname*), other names (*oname*), and last name (*name*).
3. Other names (*oname*) looks like a multivalued attribute, which is not allowed. Should *oname* be single or multivalue? This is a tricky decision. It depends on how these data will be used. If queries such as "find all men whose other names include Herbert" are likely, then a person's other names—kept as a separate entity that has a 1:m relationship for MAN and WOMAN—must be established. That is, a man or woman can have one or more other names. However, if you just want to store the data for completeness and retrieve it in its entirety, then *oname* is fine. It is just a text string. The key question to ask is, "What is the lowest level of detail possibly required for future queries?" Also, remember that SQL's REGEXP clause can be used to search for values within a text string.

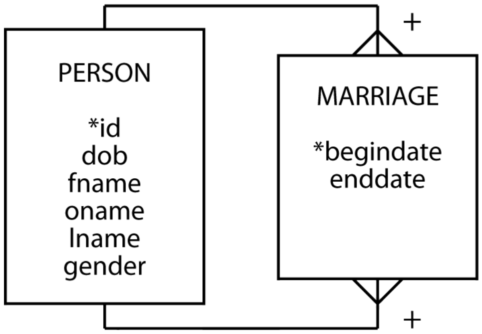
The use of a prefix to distinguish attribute names in different entities suggests you should consider combining the entities. In this case, we could combine the entities MAN and WOMAN to create an entity called PERSON. Usually when entities are combined, you have to create a new attribute to distinguish between the different types. In this example, the attribute *gender* is added. We can also generalize the relationship label to *spouse*. The revised data model appears in the following figure.

A PERSON data model



Now for a bit of marriage counseling. Marriage normally is a relationship between two people. Is that so? Well, some societies permit polygyny (one man can have many wives), others allow polyandry (one woman can have many husbands), and some permit same-sex marriages. So marriage, if we consider all the possibilities, is an m:m relationship between people, and partner might be a better choice than spouse for labeling the relationship Also, a person can be married more than once. To distinguish between different marriages, we really need to record the start and end date of each relationship and who was involved.

A marriage data model

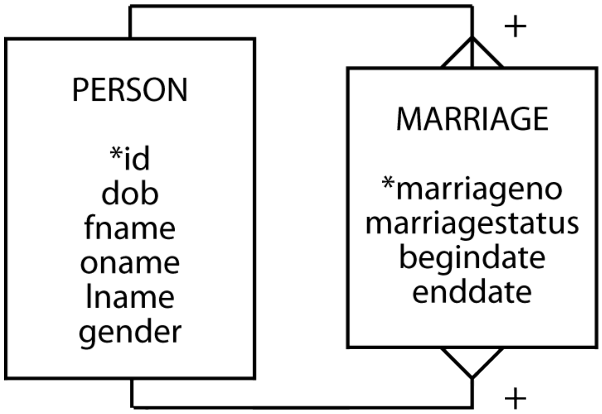


Marriage is an m:m relationship between two persons. It has attributes *begindate* and *enddate*. An instance of marriage is uniquely identified by a composite identifier: the two spouse identifiers and *begindate*. This means any marriage is uniquely identified by the composite of two person identifiers and the beginning date of the marriage. We need *begindate* as part of the identifier because the same couple might have more than one marriage (e.g., get divorced and remarry each other later). Furthermore, we can safely assume that it is impossible for a couple to get married, divorced, and remarried all on the one day. *Begindate* and *enddate* can be used to determine the current state of a marriage. If *enddate* is null, the marriage is current; otherwise, the couple has divorced.

This data model assumes a couple goes through some formal process to get married or divorced, and there is an official date for both of these events. What happens if they just gradually drift into cohabitation, and there is no official beginning date? Think about it. (The data model problem, that is—not cohabitation!) Many countries recognize this situation as a common-law marriage, so the data model needs to recognize it. The present data model cannot handle this situation because *begindate* cannot be null—it is an identifier. Instead, a new identifier is needed, and *begindate* should become an attribute.

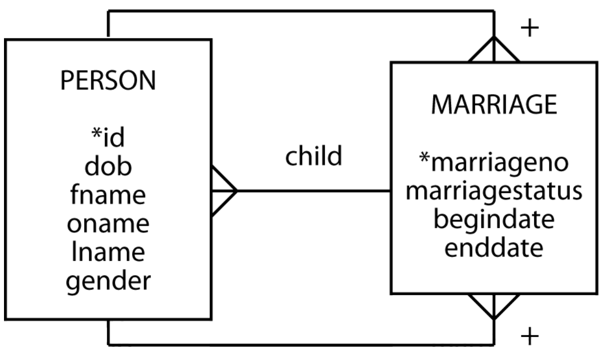
Two new attributes can handle a common-law marriage. *Marriageno* can count the number of times a couple has been married to each other. In the majority of cases, *marriageno* will be 1. *Marriagestatus* can record whether a marriage is current or ended. Now we have a data model that can also handle common-law marriages. This is also a high-quality data model in that the client does not have to remember to examine *enddate* to determine a marriage's current status. It is easier to remember to examine *marriagestatus* to check status. Also, we can allow a couple to be married, divorced, and remarried as many times as they like on the one day—which means we can now use the database in Las Vegas.

A revised marriage data model



All right, now that we have the couple successfully married, we need to start thinking about children. A marriage has zero or more children, and let's start with the assumption a child belongs to only one marriage. Therefore, we have a 1:m relationship between marriage and person to represent the children of a marriage.

A marriage with children data model



You might want to consider how the model would change to handle single-parent families, adopted children, and other aspects of human relationships.

> ☒ *Skill builder*
>
> The International Commission for Border Resolution Disputes requires a database to record details of which countries have common borders. Design the database. Incidentally, which country borders the most other countries?

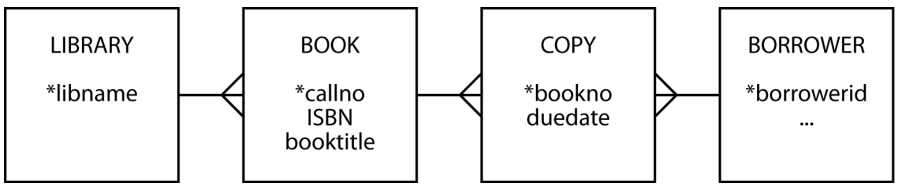
When's a book not a book?

Sometimes we have to rethink our ideas of physical objects. Consider a data model for a library.

A library data model fragment

The preceding fragment assumes that a person borrows a book. What happens if the library has two copies of the book? Do we add an attribute to BOOK called *copy number*? No, because we would introduce redundancy by repeating the same information for each book. What you need to recognize is that in the realm of data modeling, a book is not really a physical thing, but the copy is, because it is what you borrow.

A revised library data model fragment



As you can see, a book has many copies, and a copy is of one book. A book can be identified by *callno*, which is usually a Library of Congress number or Dewey number. A copy is identified by a *bookno*. This is a unique number allocated by the library to the copy of the book. If you look in a library book, you will generally find it pasted on the inside back cover and shown in numeric or bar code format. Notice that it is called *book number* despite the fact that it really identifies a copy of a book. This is because most people, including librarians, think of the copy as a book.

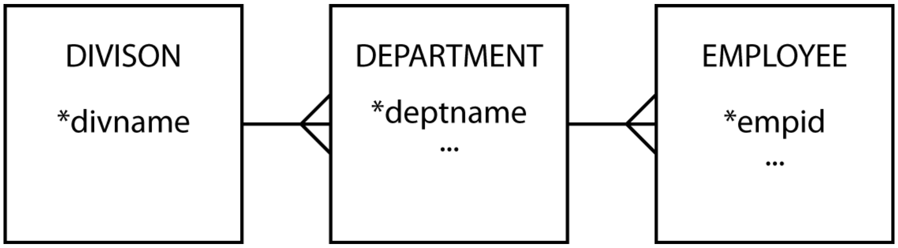
The International Standard Book Number (ISBN) uniquely identifies any instance of a book (not copy). Although it sounds like a potential identifier for BOOK, it is not. ISBNs were introduced in the second half of the twentieth century, and books published before then do not have an ISBN.

A history lesson

Many organizations maintain historical data (e.g., a person's job history or a student's enrollment record). A data model can depict historical data relationships just as readily as current data relationships.

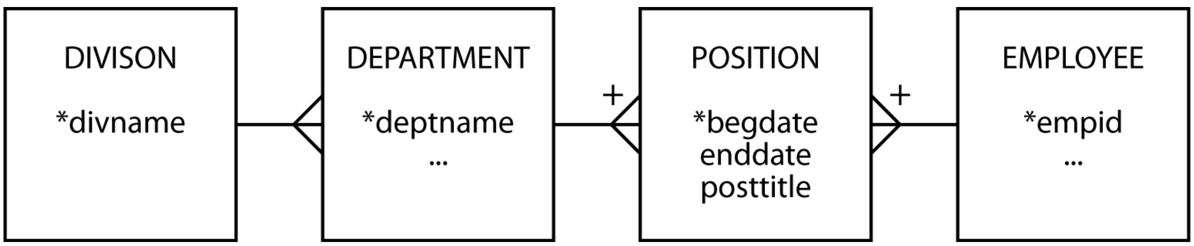
Consider the case of an employee who works for a firm that consists of divisions (e.g., production) and departments (e.g., quality control). The firm contains many departments, but a department belongs to only one division. At any one time, an employee belongs to only one department.

Employment history—take 1



The fragment in the figure can be amended to keep track of the divisions and departments in which a person works. While employed with a firm, a person can work in more than one department. Since a department can have many employees, we have an m:m relationship between DEPARTMENT and EMPLOYEE. We might call the resulting associative entity POSITION.

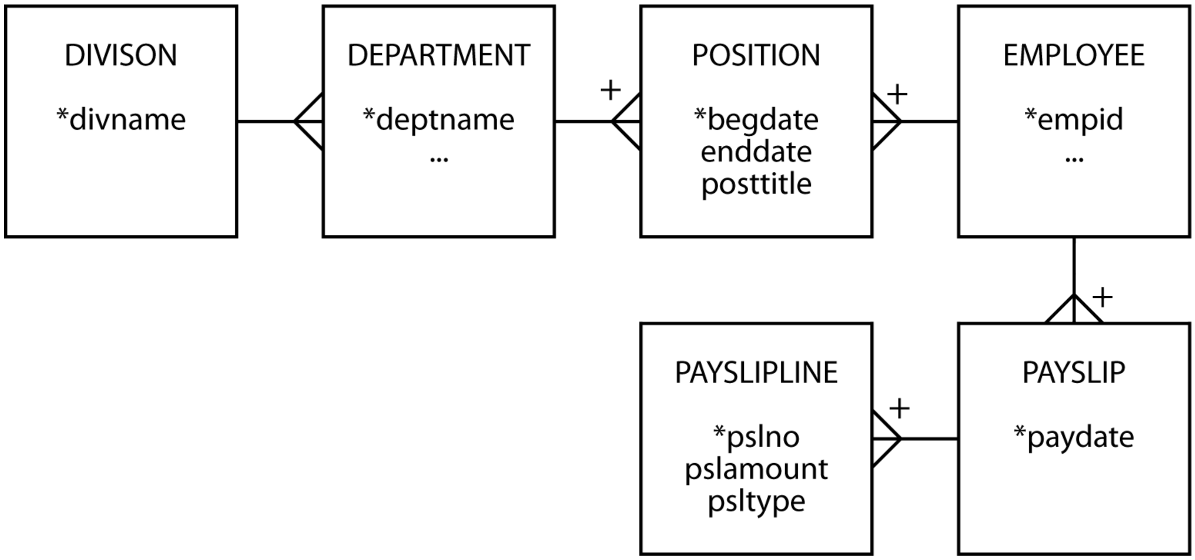
Employment history—take 2



The revised fragment records employee work history. Note that any instance of POSITION is identified by *begdate* and the identifiers for EMPLOYEE and DEPARTMENT. The fragment is typical of what happens when you move from just keeping current data to recording history. A 1:m becomes an m:m relationship to record history.

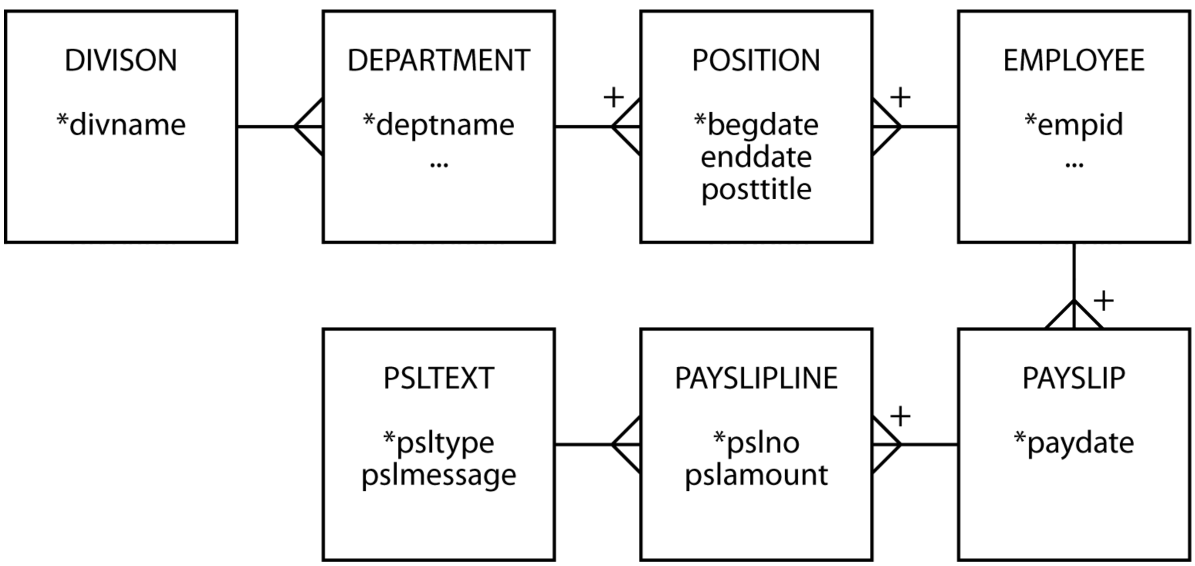
People who work get paid. How do we keep track of an employee's pay data? An employee has many pay slips, but a pay slip belongs to one employee. When you look at a pay slip, you will find it contains many items: gross pay and a series of deductions for tax, medical insurance, and so on. Think of a pay slip as containing many lines, analogous to a sales form. Now look at the revised data model.

Employment history—take 3



Typically, an amount shown on a pay slip is identified by a short text field (e.g., gross pay). PAYSLIPLINE contains an attribute *psltype* to identify the text that should accompany an amount, but where is the text? When dealing with codes like *psltype* and their associated text, the fidelity of a data model is improved by creating a separate entity, PSLTEXT, for the code and its text.

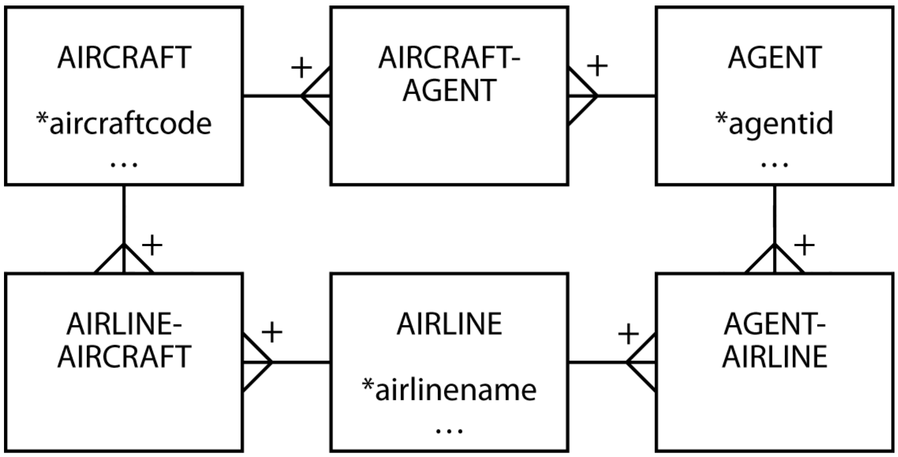
Employment history—take 4



A ménage à trois for entities

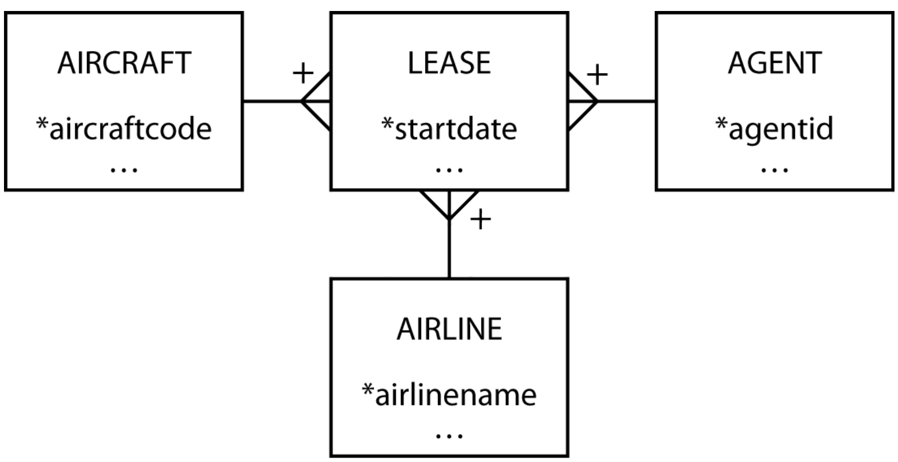
Consider aircraft leasing. A plane is leased to an airline for a specific period. When a lease expires, the plane can be leased to another airline. So, an aircraft can be leased many times, and an airline can lease many aircraft. Furthermore, there is an agent responsible for handling each deal. An agent can lease many aircraft and deal with many airlines. Over time, an airline will deal with many agents. When an agent reaches a deal with an airline to lease a particular aircraft, you have a transaction. If you analyze the aircraft leasing business, you discover there are three m:m relationships. You might think of these as three separate relationships.

An aircraft-airline-agent data model



The problem with three separate m:m relationships is that it is unclear where to store data about the lease. Is it stored in AIRLINE-AIRCRAFT? If you store the information there, what do you do about recording the agent who closed the deal? After you read the fine print and do some more thinking, you discover that a lease is the association of these three entities in an m:m relationship.

A revised aircraft-airline-agent data model



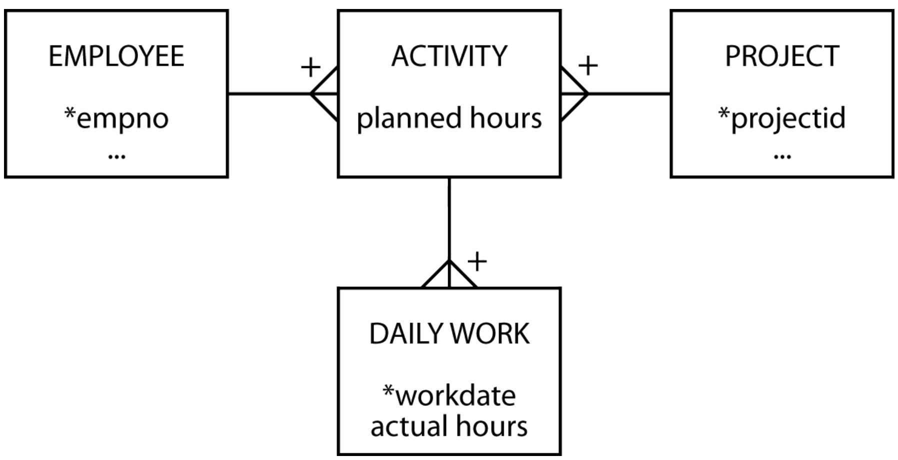
☒ *Skill builder*

Horse racing is a popular sport in some parts of the world. A horse competes in at most one race on a course at a particular date. Over time, a horse can compete in many races on many courses. A horse's rider is called a jockey, and a jockey can ride many horses and a horse can have many jockeys. Of course, there is only ever one jockey riding a horse at a particular time. Courses vary in their features, such as the length of the course and the type of surface (e.g., dirt or grass). Design a database to keep track of the results of horse races.

Project management—planning and doing

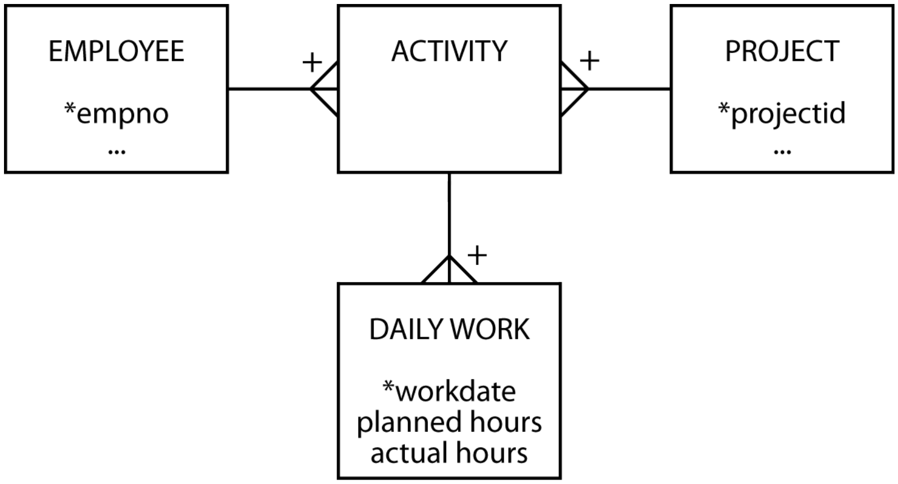
Project management involves both planned and actual data. A project is divided into a number of activities that use resources. Planning includes estimation of the resources to be consumed. When a project is being executed, managers keep track of the resources used to monitor progress and keep the project on budget. Planning data may not be as detailed as actual data and is typically fairly broad, such as an estimate of the number of hours that an activity will take. Actual data will be more detailed because they are usually collected by getting those assigned to the project to log a daily account of how they spent their time. Also, resources used on a project are allocated to a particular activity. For the purposes of this data model, we will focus on recording only time and nothing else.

A project management data model



Notice that *planned hours* is an attribute of ACTIVITY, and *actual hours* is an attribute of DAILY WORK. The hours spent on an activity are derived by summing *actual hours* in the associated DAILY WORK entity. This is a high-fidelity data model if planning is done at the activity level and employees submit daily worksheets. Planning can be done in greater detail, however, if planners indicate how many hours of each day each employee should spend on a project.

A revised project management data model



Now you see that *planned hours* and *actual hours* are both attributes of DAILY WORK. The message of this example, therefore, is not to assume that planned and actual data have the same level of detail, but do not be surprised if they do.

Cardinality

Some data modeling languages are quite precise in specifying the cardinality, or multiplicity, of a relationship. Thus, in a 1:m relationship, you might see additional information on the diagram. For example, the "many" end of the relationship might contain notation (such as 0,n) to indicate zero or more instances of the entity at the "many" end of the relationship.

Cardinality and modality options

Cardinality	Modality	Meaning
0,1	Optional	There can be zero or one instance of the entity relative to the other entity.
1,1	Mandatory	There is exactly one instance of the entity relative to the other entity.
1,n		The entity must have at least one and can have many instances relative to the other entity.

The data modeling method of this text, as you now realize, has taken a broad approach to cardinality (is it 1:1 or 1:m?). We have not been concerned with greater precision (is it 0,1 or 1,1?), because the focus has been on acquiring basic data modeling skills. Once you know how to model, you can add more detail. When learning to model, too much detail and too much terminology can get in the way of mastering this difficult skill. Also, it is far easier to sketch models on a whiteboard or paper when you have less to draw. Once you switch to a data modeling tool, then adding cardinality precision is easier and appropriate.

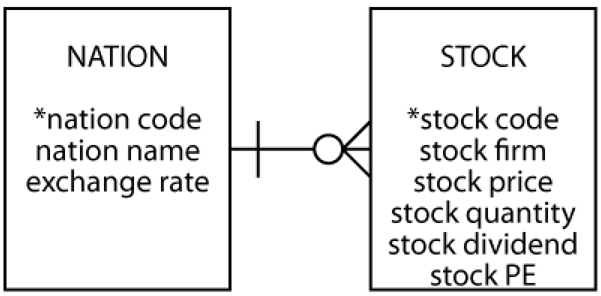
Modality

Modality, also known as optionality, specifies whether an instance of an entity must participate in a relationship. Cardinality indicates the range of instances of an entity participating in a relationship, while modality defines the minimum number of instances. Cardinality and modality are linked, as shown in the previous table . If an entity is optional, the minimum cardinality will be 0, and if mandatory, the minimum cardinality is 1.

By asking the question, "Does an occurrence of this entity require an occurrence of the other entity?" you can assess whether an entity is mandatory. The usual practice is to use "O" for optional and place it near the entity that is optional. Mandatory relationships are often indicated by a short line (or bar) at right angles to the relationship between the entities.

In the following figure, it is mandatory for an instance of STOCK to have an instance of NATION, and optional for an instance of NATION to have an instance of STOCK, which means we can record details of a nation for which stocks have not yet been purchased. During conversion of the data model to a relational database, the mandatory requirement (i.e., each stock must have a nation) is enforced by the foreign key constraint.

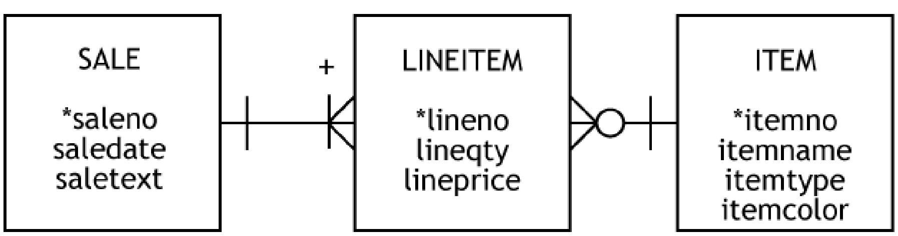
1:m relationship showing modality



Now consider an example of an m:m relationship. A SALE can have many LINEITEMs, and a LINEITEM has only one SALE. An instance of LINEITEM must be related to an instance of SALE, otherwise it can't exist. Similarly, it is mandatory for an instance of SALE to have an instance of LINEITEM, because it makes no sense to have a sale without any items being sold.

In a relational database, the foreign key constraint handles the mandatory relationship between instances of LINEITEM and SALE, The mandatory requirement between SALE and LINEITEM has to be built into the processing logic of the application that processes a sales transaction. Basic business logic requires that a sale include some items, so a sales transaction creates one instance of SALE and multiple instances of LINEITEM. It does not make sense to have a sale that does not sell something.

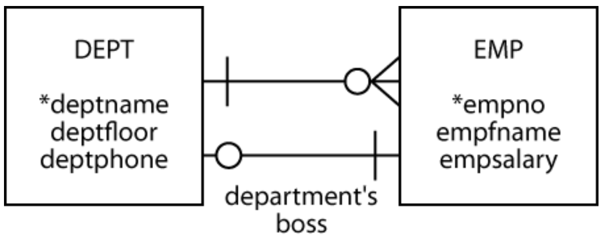
An m:m relationship showing modality



The relationship between ITEM and LINEITEM is similar in structure to that of NATION and STOCK, which we saw in the previous example. An instance of a LINEITEM has a mandatory requirement for an instance of ITEM. An instance of an ITEM can exist without the need for an instance of a LINEITEM (i.e., the items that have not been sold).

We gain further understanding of modality by considering a 1:1 relationship. We focus attention on the 1:1 because the 1:m relationship has been covered. The 1:1 implies that it is mandatory for an instance of DEPT to be related to one instance of EMP (i.e., a department must have a person who is the boss), and an instance of EMP is optionally related to one instance of DEPT (i.e., an employee can be a boss, but not all employees are departmental bosses).

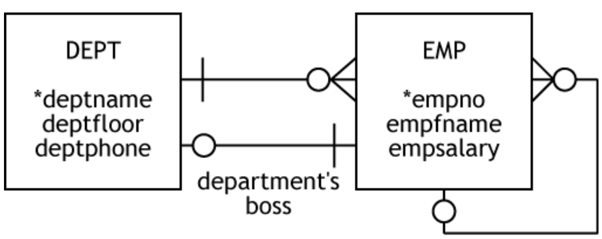
A 1:1 relationship showing modality



Earlier, when deciding where to store the foreign key for the 1:1 relationship, we settled on placing the foreign key in DEPT, because all departments have a boss. Now we have a rule. The foreign key goes with the entity for which the relationship is mandatory. When specifying the create statements, you will need to be aware of the chicken-and-egg connection between DEPT and EMP. We cannot insert an employee in EMP unless we know that person's department, and we cannot insert a department unless we have already inserted the boss for that department in EMP. We can get around this problem by using a deferrable foreign key constraint, but at this point we don't know enough about transaction processing to discuss this approach.

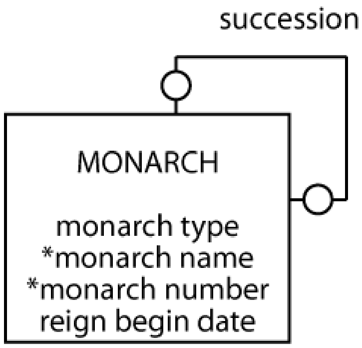
Let's now consider recursive relationships. The following figure shows a recursive 1:m between employees, representing that one employee can be the boss of many other employees and a person has one boss. It is optional that a person is a boss, and optional that everyone has a boss, mainly because there has to be one person who is the boss of everyone. However, we can get around this one exception by inserting employees in a particular order. By inserting the biggest boss first, we effectively make it mandatory that all employees have a boss. Nevertheless, data models cover every situation and exception, so we still show the relationship as optional.

1:m recursive with modality



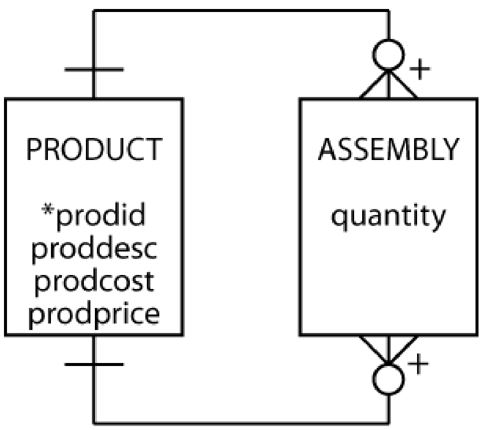
We rely again on the British monarchy. This time we use it to illustrate modality with a 1:1 recursive relationship. As the following figure shows, it is optional for a monarch to have a successor. We are not talking about the end of a monarchy, but rather how we address the data modeling issue of not knowing who succeeds the current monarch. Similarly, there must be a monarch who did not succeed someone (i.e., the first king or queen). Thus, both ends of the succession relationship have optional modality.

1:1 recursive with modality



Finally, in our exploration of modality, we examine the m:m recursive. The model indicates that it is optional for a product to have components and optional for a product to be a component in other products. However, every assembly must have associated products.

m:m recursive with modality



7.0.0.0.1 * Summary

Modality adds additional information to a data model, and once you have grasped the fundamental ideas of entities and relationships, it is quite straightforward to consider whether a relationship is optional or mandatory. When a relationship is mandatory, you need to consider what constraint you can add to a table's definition to enforce the relationship. As we have seen, in some cases the foreign key constraint handles mandatory relationships. In other cases, the logic for enforcing a requirement will be built into the application.

Entity types

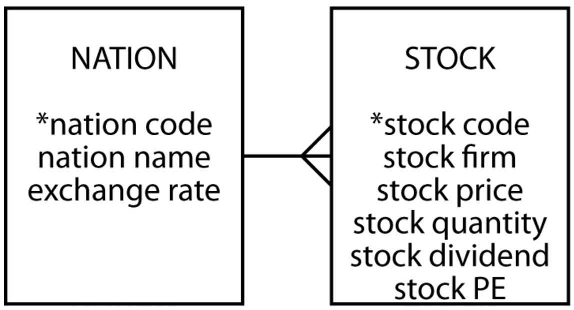
A data model contains different kinds of entities, which are distinguished by the format of their identifiers. Labeling each of these entities by type will help you to determine what questions to ask.

Independent entity

An independent entity is often central to a data model and foremost in the client's mind. Independent entities are frequently the starting points of a data model. Remember that in the investment database, the independent entities are STOCK and NATION. Independent entities typically have clearly distinguishable names because they occur so frequently in the client's world. In addition, they usually have a single identifier, such as *stock code* or *nation code*.

Independent entities are often connected to other independent entities in a 1:m or m:m relationship. The data model in the following figure shows two independent entities linked in a 1:m relationship.

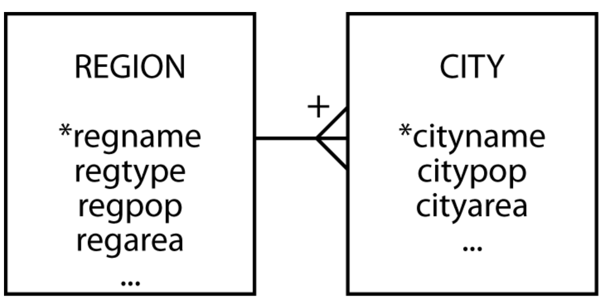
NATION and STOCK—independent entities



Weak or dependent entity

A weak entity (also known as a dependent entity) relies on another entity for its existence and identification. It is recognized by a plus on the weak entity's end of the relationship. CITY cannot exist without REGION. A CITY is uniquely identified by *cityname* and *regname*. If the composite identifier becomes unwieldy, creating an arbitrary identifier (e.g., cityno) will change the weak entity into an independent one.

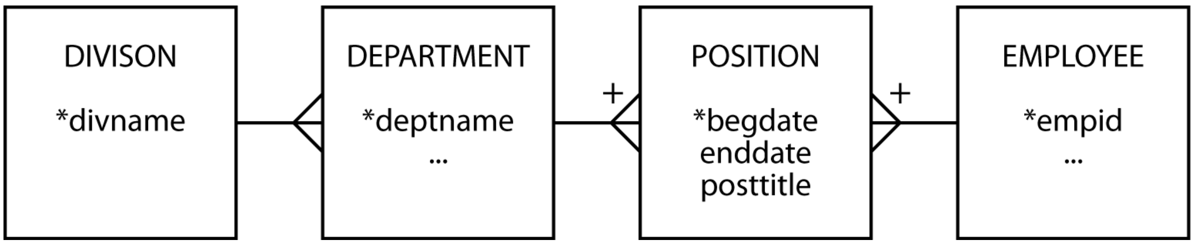
CITY—a weak entity



Associative entity

Associative entities are by-products of m:m relationships. They are typically found between independent entities. Associative entities sometimes have obvious names because they occur in the real world. For instance, the associative entity for the m:m relationship between DEPARTMENT and EMPLOYEE is usually called POSITION. If the associative entity does not have a common name, the two entity names are generally hyphenated (e.g., DEPARTMENT-EMPLOYEE). Always search for the appropriate name, because it will improve the quality of the data model. Hyphenated names are a last resort.

POSITION is an associative entity



Associative entities can show either the current or the historic relationship between two entities. If an associative entity's only identifiers are the two related entities' identifiers, then it records the current relationship between the entities. If the associative entity has some time measure (e.g., date or hour) as a partial identifier, then it records the history of the relationship. Whenever you find an associative entity, ask the client whether the history of the relationship should be recorded.

Creating a single, arbitrary identifier for an associative entity will change it to an independent one. This is likely to happen if the associative entity becomes central to an application. For example, if a personnel department does a lot of work with POSITION, it may find it more expedient to give it a separate identifier (e.g., *position number*).

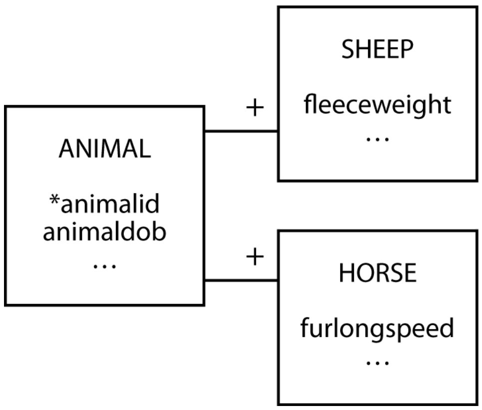
Aggregate entity

An aggregate entity is created when several different entities have similar attributes that are distinguished by a preceding or following modifier to keep their names unique. For example, because components of an address might occur in several entities (e.g., CUSTOMER and SUPPLIER), an aggregate address entity can be created to store details of all addresses. Aggregate entities usually become independent entities. In this case, we could use *address number* to identify an instance of address uniquely.

Subordinate entity

A subordinate entity stores data about an entity that can vary among instances. A subordinate entity is useful when an entity consists of mutually exclusive classes that have different descriptions. The farm animal database shown in the following figure indicates that the farmer requires different data for sheep and horses. Notice that each of the subordinate entities is identified by the related entity's identifier. You could avoid subordinate entities by placing all the attributes in ANIMAL, but then you make it incumbent on the client to remember which attributes apply to horses and which to sheep. This becomes an important issue for null fields. For example, is the attribute *hay consumption* null because it does not apply to sheep, or is it null because the value is unknown?

SHEEP and HORSE are subordinate entities



If a subordinate entity becomes important, it is likely to evolve into an independent entity. The framing of a problem often determines whether subordinate entities are created. Stating the problem as, "a farmer has many animals, and these animals can be horses or sheep," might lead to the creation of subordinate entities. Alternatively, saying that "a farmer has many sheep and horses" might lead to setting up SHEEP and HORSE as independent entities.

Generalization and aggregation

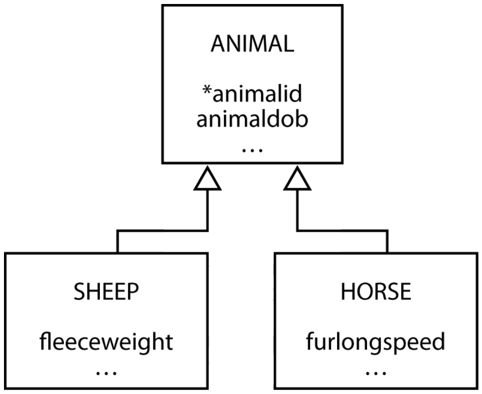
Generalization and aggregation are common ideas in many modeling languages, particularly object-oriented modeling languages such as the Unified Modeling Language (UML), which we will use in this section.

Generalization

A generalization is a relationship between a more general element and a more specific element. In the following figure, the general element is *animal*, and the specific elements are *sheep* and *horse*. A horse is a subtype of animal. A generalization is often called an "is a" relationship because the subtype element is a member of the generalization.

A generalization is directly mapped to the relational model with one table for each entity. For each of the subtype entities (i.e., SHEEP and HORSE), the primary key is that of the supertype entity (i.e., ANIMAL). You must also make this column a foreign key so that a subtype cannot be inserted without the presence of the matching supertype. A generalization is represented by a series of 1:1 relationships to weak entities.

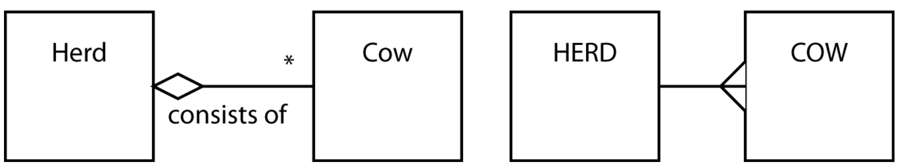
A generalization hierarchy in UML



Aggregation

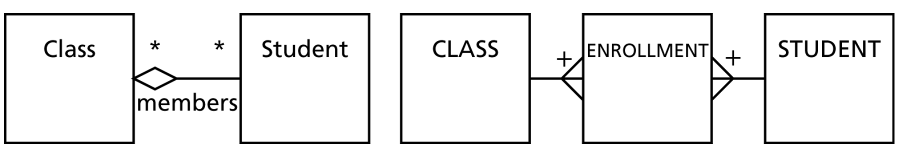
Aggregation is a part-whole relationship between two entities. Common phrases used to describe an aggregation are "consists of," "contains," and "is part of." The following figure shows an aggregation where a herd consists of many cows. Cows can be removed or added, but it is still a herd. An open diamond next to the whole denotes an aggregation. In data modeling terms, there is a 1:m relationship between herd and cow.

An aggregation in UML and data modeling



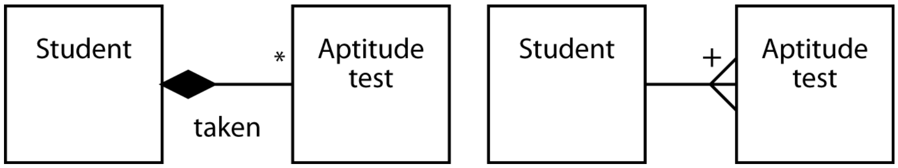
There are two special types of aggregation: shared and composition. With shared aggregation, one entity owns another entity, but other entities can own that entity as well. A sample shared aggregation is displayed in the following figure, which shows that a class has many students, and a student can be a member of many classes. Students, the parts in this case, can be part of many classes. An open diamond next to the whole denotes a shared aggregation, which we represent in data modeling as an m:m relationship.

Shared aggregation in UML and data modeling



In a composition aggregation, one entity exclusively owns the other entity. A solid diamond at the whole end of the relationship denotes composition aggregation. The appropriate data model is a weak entity, as shown in the following figure.

Composition aggregation in UML and data modeling



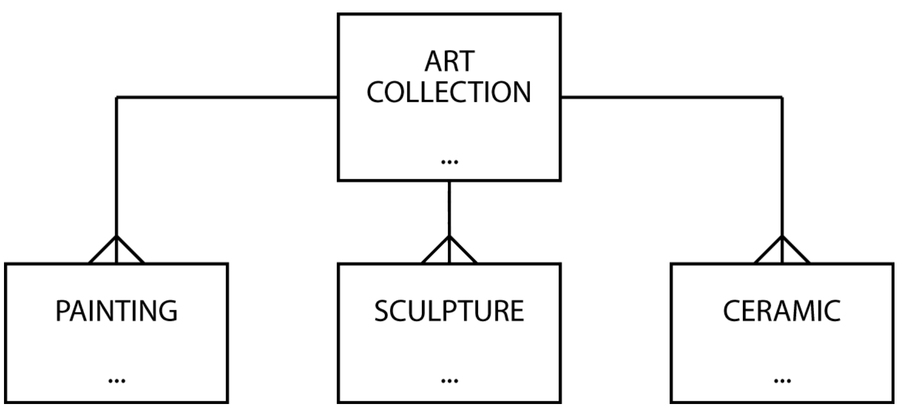
Data modeling hints

A high-fidelity data model takes time to develop. The client must explain the problem fully so that the database designer can understand the client's requirements and translate them into a data model. Data modeling is like prototyping; the database designer gradually creates a model of the database as a result of interaction with the client. Some issues will frequently arise in this progressive creation, and the following hints should help you resolve many of the common problems you will encounter.

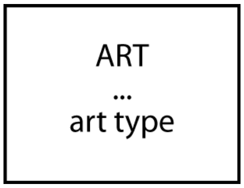
The rise and fall of a data model

Expect your data model to both expand and contract. Your initial data model will expand as you extend the boundaries of the application. You will discover some attributes will evolve into entities, and some 1:m relationships will become m:m relationships. It will grow because you will add entities, attributes, and relationships to allow for exceptions. Your data model will grow because you are representing the complexity of the real world. Do not try to constrain growth. Let the data model be as large as is necessary. As a rough rule, expect your final data model to grow to about two to three times the number of entities of your initial data model.

Expect your data model to contract as you generalize structures. The following fragment is typical of the models produced by novice data modelers. It can be reduced by recognizing that PAINTING, SCULPTURE, and CERAMIC are all types of art. A more general entity, ART, could be used to represent the same data. Of course, it would need an additional attribute to distinguish the different types of art recordings.



The shrunken data model



As you discover new entities, your data model will grow. As you generalize, your data model will shrink.

Identifier

If there is no obvious simple identifier, invent one. The simplest is a meaningless code (e.g., *person number* or *order number*). If you create an identifier, you can also guarantee its uniqueness.

Don't overwork an identifier. The worst case we have seen is a 22-character product code used by a plastics company that supposedly not only uniquely identified an item but told you its color, its manufacturing process, and type of plastic used to make it! Color, manufacturing process, and type of plastic are all attributes. This product code was unwieldy. Data entry error rates were extremely high, and very few people could remember how to decipher the code.

An identifier has to do only one thing: uniquely identify every instance of the entity. Sometimes trying to make it do double, or even triple, duty only creates more work for the client.

Position and order

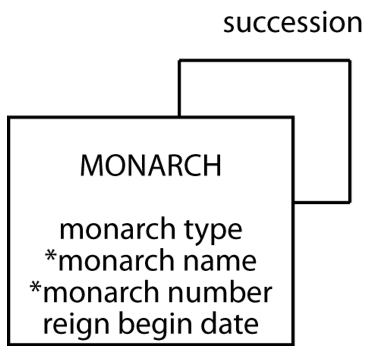
There is no ordering in a data model. Entities can appear anywhere. You will usually find a central entity near the middle of the data model only because you tend to start with prominent entities (e.g., starting with STUDENT when modeling a student information system). What really matters is that you identify all relevant entities.

Attributes are in no order. You find that you will tend to list them as they are identified. For readability, it is a good idea to list some attributes sequentially. For example, first name, other names, and last name are usually together. This is not necessary, but it speeds up verification of a data model's completeness.

Instances are also assumed to have no ordering. There is no first instance, next instance, or last instance. If you must recognize a particular order, create an attribute to record the order. For example, if ranking of potential investment projects must be recorded, include an attribute (*projrank*) to store this data. This does not mean the instances will be stored in *projrank* order, but it does allow you to use the ORDER BY clause of SQL to report the projects in rank order.

If you need to store details of a precedence relationship (i.e., there is an ordering of instances and a need to know the successor and predecessor of any instance), then use a 1:1 recursive relationship.

Using an attribute to record an ordering of instances



Attributes and consistency

Attributes must be consistent, retaining the same meaning for every instance. An example of an inconsistent attribute would be an attribute *stock info* that contains a stock's PE ratio or its ROI (return on investment). Another attribute, say *stock info code*, is required to decipher which meaning applies to any particular instance. The code could be "1" for PE and "2" for ROI. If one attribute determines the meaning of another, you have inconsistency. Writing SQL queries will be extremely challenging because inconsistent data increases query complexity. It is better to create separate attributes for PE and ROI.

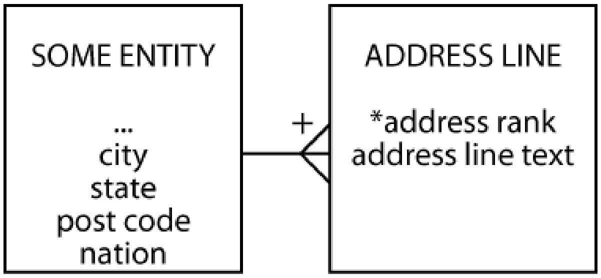
Names and addresses

An attribute is the smallest piece of data that will conceivably form part of a query. If an attribute has segments (e.g., a person's name), determine whether these could form part of a query. If so, then make them separate attributes and reapply the query test. When you apply the query test to *person name*, you will usually decide to create three attributes: *first name*, *other names*, and *last name*.

What about titles? There are two sorts of modifier titles: preceding titles (e.g., Mr., Mrs., Ms., and Dr.) and following titles (e.g., Jr. and III). These should be separate attributes, especially if you have divided *name* into separate attributes.

Addresses seem to cause more concern than names because they are more variant. Business addresses tend to be the most complicated, and foreign addresses add a few more twists. The data model fragment in the following figure works in most cases.

Handling addresses

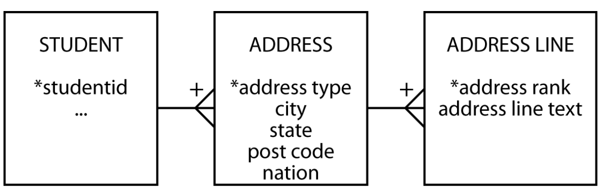


Common features of every address are city, state (province in Canada, county in Ireland), postal code (ZIP code in the United States), and nation. Some of these can be null. For example, Singapore does not have any units corresponding to states. In the United States, city and state can be derived from the zip code, but this is not necessarily true for other countries. Furthermore, even if this were true for every nation, you would need a different derivation rule for each country, which is a complexity you might want to avoid. If there is a lifetime guarantee that every address in the database will be for one country, then examine the possibility of reducing redundancy by just storing post code.

Notice that the problem of multiple address lines is represented by a 1:m relationship. An address line is a text string that appears as one line of an address. There is often a set sequence in which these are displayed. The attribute *address rank* records this order.

How do you address students? First names may be all right for class, but it is not adequate enough for student records. Students typically have multiple addresses: a home address, a school address, and maybe a summer address. The following data model fragment shows how to handle this situation. Any instance of ADDRESS LINE is identified by the composite of *studentid**, *addresstype*, and *address rank*.

Students with multiple addresses



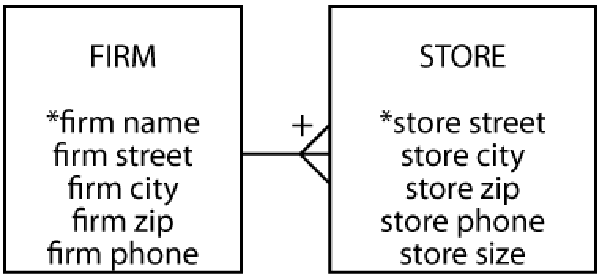
The identifier *address type* is used to distinguish among the different types of addresses. The same data model fragment works in situations where a business has different mailing and shipping addresses.

When data modeling, can you take a shortcut with names and addresses? It is time consuming to write out all the components of name and address. It creates clutter and does not add much fidelity. Our practical advice is to do two things. *First*, create a policy for all names and addresses (e.g., all names will be stored as three parts: first name, other names, last name). *Second*, use shorthand forms of attributes for names and addresses when they obey the policy. So from now on, we will sometimes use name and address as attributes with the understanding that when the database is created, the parts will become separate columns.

Single-instance entities

Do not be afraid of creating an entity with a single instance. Consider the data model fragment in the following figure which describes a single fast-food chain. Because the data model describes only one firm, the entity FIRM will have only one instance. The inclusion of this single instance entity permits facts about the firm to be maintained. Furthermore, it provides flexibility for expansion. If two fast-food chains combine, the data model needs no amendment.

FIRM—a single-instance entity



Picking words

Words are very important. They are all we have to make ourselves understood. Let the client choose the words, because the data model belongs to the client and describes the client's world. If you try to impose your words on the client, you are likely to create a misunderstanding.

Synonyms

Synonyms are words that have the same meaning. For example, task, assignment, and project might all refer to the same real-world object. One of these terms, maybe the one in most common use, needs to be selected for naming the entity. Clients need to be told the official name for the entity and encouraged to adopt this term for describing it. Alternatively, create views that enable clients to use their own term. Synonyms are not a technical problem. It is a social problem of getting clients to agree on one word.

Homonyms

Homonyms are words that sound the same but have different meanings. Homonyms can create real confusion. *Sale date* is a classic example. In business it can have several meanings. To the salespeople, it might be the day that the customer shakes hands and says, "We have a deal." For the lawyers, it is could be the day when the contract is signed, and for production, it might be the day the customer takes delivery. In this case, the solution is reasonably obvious; redefine *sale date* to be separate terms for each area (e.g., *sales date*, *contract date*, and *delivery date* for sales, legal, and production departments, respectively).

Homonyms cause real confusion when clients do not realize that they are using the same word for different entities or attributes. Hunt down homonyms by asking lots of questions and querying a range of clients.

Exception hunting

Go hunting for exceptions. Keep asking the client questions such as

- Is it always like this?
- Would there be any situations where this could be an m:m relationship?
- Have there ever been any exceptions?
- Are things likely to change in the future?

Always probe for exceptions and look for them in the examples the client uses. Redesigning the data model to handle exceptions increases fidelity.

Relationship labeling

Relationship labeling clutters a data model. In most cases, labels can be correctly inferred, so use labels only when there is a possibility of ambiguity.

Keeping the data model in shape

As you add to a data model, maintain fidelity. Do not add entities without also completing details of the identifier and attributes. By keeping the data model well formed, you avoid ambiguity, which frequently leads to miscommunication.

Used entities

Would you buy a used data model? Certainly, because a used data model is more likely to have higher fidelity than a brand new one. A used data model has been subjected to much scrutiny and revision and should be a more accurate representation of the real world.

Meaningful identifiers

An identifier is said to be meaningful when some attributes of the entity can be inferred from the identifier's value (e.g., a code of B78 for an item informs a clerk that the item is black). The word "meaningful" in everyday speech usually connotes something desirable, but many data managers agree that meaningful identifiers or codes create problems. While avoiding meaningful identifiers is generally accepted as good data management practice, they are still widely used. After a short description of some examples of meaningful identifiers, this section discusses the pros and cons of meaningful identifiers.

The invoice number "12dec0001" is a meaningful identifier. The first five positions indicate in which period the invoice was generated. The last four digits of the invoice number have a meaning. The 0001 indicates it was the first invoice sent in December. In addition, e-mail addresses, like mvdpas@bizzo.yx, have a meaning.

When coding a person's employment status, a designer might use the codes "f" and "p" for full- and part-time and another might use "1" and "2." The pair (f, p) is meaningful, but (1, 2) is not and puts the onus on the client to remember the meaning. The codes "f" and "p" are derived from the reality that they represent. They are the first letters of the words full and part. The "1" and "2" are not abstracted from reality, and therefore they do not have an intuitive meaning.

In determining whether an identifier is meaningful, one can look at the way new values of that identifier are generated. If the creation takes place on the basis of characteristics that appear in reality, the identifier is meaningful. That is why the identifier of the invoice "12dec0002," which is the identifier assigned to the second invoice generated in December 2012, is meaningful. It is also why the e-mail address rwatson@terry.uga.edu is meaningful

Meaningful identifiers clearly have some advantages and disadvantages, and these are now considered.

Advantages and disadvantages of meaningful identifiers

Advantages	Disadvantages
Recognizable and rememberable	Identifier exhaustion
Administrative simplicity	Reality changes
	Loss of meaningfulness

Advantages of meaningful identifiers

Recognizable and rememberable

People can often recognize and remember the significance of meaningful identifiers. If, for example, someone receives an e-mail from rwatson@terry.uga.edu, this person can probably deduce the sender's name and workplace. If a manufacturer, for instance, uses the last two digits of its furniture code to indicate the color (e.g., 08 = beech), employees can then quickly determine the color of a packed piece of furniture. Of course, the firm could also show the color of the furniture on the label, in which case customers, who are most unlikely to know the coding scheme, can quickly determine the color of the enclosed product.

Administrative simplicity

By using meaningful identifiers, administration can be relatively easily decentralized. Administering e-mail addresses, for instance, can be handled at the domain level. This way, one can avoid the process of synchronizing with other domains whenever a new e-mail address is created.

A second example is the EAN (European article number), the bar code on European products. Issuing EANs can be administered per country, since each country has a unique number in the EAN. When issuing a new number, a country need only issue a code that is not yet in use in that country. The method of contacting all countries to ask whether an EAN has already been issued is time consuming and open to error. On the other hand, creating a central database of issued EAN codes is an option. If every issuer of EAN codes can access such a database, alignment among countries is created and duplicates are prevented.

Disadvantages of meaningful identifiers

Identifier exhaustion

Suppose a company with a six-digit item identifier decides to use the first three digits to specify the product group (e.g., stationery) uniquely. Within this group, the remaining three digits are used to define the item (e.g., yellow lined pad). As a consequence, only one thousand items can be specified per product group. This problem remains even when some numbers in a specific product group, or even when entire product groups, are not used.

Consider the case when product group "010" is exhausted and is supplemented by the still unused product group code "940." What seems to be a simple quick fix causes problems, because a particular product group is not uniquely identified by a single identifier. Clients have to remember there is an exception.

A real-world example of identifier exhaustion is a holding company that identifies its subsidiaries by using a code, where the first character is the first letter of the subsidiary's name. When the holding company acquired its seventh subsidiary, the meaningfulness of the coding system failed. The newly acquired subsidiary name started with the same letter as one of the existing subsidiaries. The system had already run out of identifiers.

When existing identifiers have to be converted because of exhaustion, printed codes on labels, packages, shelves, and catalogs will have to be redone. Recoding is an expensive process and should be avoided.

Exhaustion is not only a problem with meaningful identifiers. It can happen with non-meaningful identifiers. The problem is that meaningful identifier systems tend to exhaust sooner. To avoid identifier exhaustion and maintain meaningful identifiers, some designers increase identifier lengths (e.g., four digits for product group).

Reality changes

The second problem of meaningful identifiers is that the reality they record changes. For example, a company changes its name. The College of Business at the University of Georgia was renamed the Terry College of Business. Email addresses changed (e.g., rwatson@cba.uga.edu became rwatson@terry.uga.edu). An identifier can remain meaningful over a long period only if the meaningful part rarely or never changes.

Non-meaningful identifiers avoid reality changes. Consider the case of most telephone billing systems, which use an account ID to identify a customer rather than a telephone number. This means a customer can change telephone numbers without causing any coding problems because telephone number is not the unique identifier of each customer.

A meaningful identifier can lose its meaningfulness

Consider the problems that can occur with the identifier that records both the color and the material of an article. Chipboard with a beech wood veneer is coded BW. A black product, on the other hand, is coded BL. Problems arise whenever there is an overlap between these characteristics. What happens with a product that is finished with a black veneer on beech wood? Should the code be BW or BL? What about a black-painted product that is made out of beech wood? Maybe a new code, BB for black beech wood, is required. There will always be employees and customers who do not know the meaning of these not-so-meaningful identifiers and attribute the wrong meaning to them.

The solution—non-meaningful identifiers

Most people are initially inclined to try to make identifiers meaningful. There is a sense that something is lost by using a simple numeric to identify a product or customer. Nothing, however, is lost and much is gained. Non-meaningful identifiers serve their sole purpose well—to identify an entity uniquely. Attributes are used to describe the characteristics of the entity (e.g., color, type of wood). A clear distinction between the role of identifiers and attributes creates fewer data management problems now and in the future.

Vehicle identification

In most countries, every road vehicle is uniquely identified. The Vehicle Identification Number (VIN) was originally described in ISO Standard 3779 in February 1977 and last revised in 1983. It is designed to identify motor vehicles, trailers, motorcycles, and mopeds. A VIN is 17 characters, A through Z and 0 through 9.

The European Union and the United States have different implementations of the standard. The U.S. VIN is divided into four parts

- World Manufacturer's Identification (WMI) - three characters
- Vehicle Description Section (VDS) - five characters
- Check digit
- Vehicle Identification Section (VIS) - eight characters

When decoded, a VIN specifies the country and year of manufacture; make, model, and serial number; assembly plant; and even some equipment specifications.

VINs are normally located in several locations on a car, but the most common places are in the door frame of the front doors, on the engine itself, around the steering wheel, or on the dash near the window.

What do you think of the VIN as a method of vehicle identification? How do you reconcile it with the recommendation to use meaningless identifiers? If you were consulted on a new VIN system, what would advise?

The seven habits of highly effective data modelers

There is often a large gap between the performance of *average* and *expert* data modelers. An insight into the characteristics that make some data modelers more skillful than others should improve your data modeling capabilities.

Immerse

Find out what the client wants by immersing yourself in the task environment. Spend some time following the client around and participate in daily business. Firsthand experience of the problem will give you a greater understanding of the client's requirements. Observe, ask questions, reflect, and talk to a wide variety of people (e.g., managers, operations personnel, customers, and suppliers). The more you learn about the problem, the better equipped you are to create a high-fidelity data model.

Challenge

Challenge existing assumptions; dig out the exceptions. Test the boundaries of the data model. Try to think about the business problem from different perspectives (e.g., how might the industry leader tackle this problem?). Run a brainstorming session with the client to stimulate the search for breakthrough solutions.

Generalize

Reduce the number of entities whenever possible by using generalized structures (remember the Art Collection model) to simplify the data model. Simpler data models are usually easier to understand and less costly to implement. Expert data modelers can see beyond surface differences to discern the underlying similarities of seemingly different entities.

Test

Test the data model by reading it to yourself and several people intimately familiar with the problem. Test both directions of every relationship (e.g., a farmer has many cows and a cow belongs to only one farmer). Build a prototype so that the client can experiment and learn with a concrete model. Testing is very important because it costs very little to fix a data model but a great deal to repair a system based on an incorrect data model.

Limit

Set reasonable limits to the time and scope of data modeling. Don't let the data modeling phase continue forever. Discover the boundaries early in the project and stick to these unless there are compelling reasons to extend the project. Too many projects are allowed to expand because it is easier to say *yes* than *no*. In the long run, however, you do the client a disservice by promising too much and extending the life of the project. Determine the core entities and attributes that will solve most of the problems, and confine the data model to this core. Keep sight of the time and budget constraints of the project.

Integrate

Step back and reflect on how your project fits with the organization's information architecture. Integrate with existing systems where feasible and avoid duplication. How does your data model fit with the corporate data model and those of other projects? Can you use part of an existing data model? A skilled data modeler has to see both the fine-grained detail of a project data model and the big picture of the corporate data resource.

Complete

Good data modelers don't leave data models ill-defined. All entities, attributes, and relationships are carefully defined, ambiguities are resolved, and exceptions are handled. Because the full value of a data model is realized only when the system is complete, the data modeler should stay involved with the project until the system is implemented. The data modeler, who generally gets involved in the project from its earliest days, can provide continuity through the various phases and ensure the system solves the problem.

Summary

Data modeling is both a technique for modeling data and its relationships and a graphical representation of a database. It communicates a database's design. The goal is to identify the facts that must be stored in a database. Building a data model is a partnership between a client, a representative of the eventual owners of the database, and a designer. The building blocks are an entity, attribute, identifier, and relationship. A well-formed data model, which means the construction rules have been obeyed, clearly communicates information to the client. A high-fidelity data model faithfully describes the world it represents.

A data model is an evolving representation. Each change should be an incremental improvement in quality. The quality of a data model can be determined only by understanding the context in which it will be used. A data model can model historical data relationships just as readily as current ones. Cardinality specifies the precise multiplicity of a relationship. Modality indicates whether a relationship is optional or mandatory. The five different types of entities are independent, dependent, associative, aggregate, and subordinate. Expect a data model to expand and contract. A data model has no ordering. Introduce an attribute if ordering is required. An attribute must have the same meaning for every instance. An attribute is the smallest piece of data that will conceivably form part of a query. Synonyms are words that have the same meaning; homonyms are words that sound the same but have different meanings. Identifiers should generally have no meaning. Highly effective data modelers immerse, challenge, generalize, test, limit, integrate, and complete.

Key terms and concepts

Aggregate entity	Homonym
Aggregation	Identifier
Associative entity	Independent entity
Attribute	Instance
Cardinality	Mandatory
Composite aggregation	Modality
Data model	Modeling
Data model quality	Optional
Dependent entity	Relationship
Determinant	Relationship descriptor
Domain	Relationship label

Entity	Shared aggregation
Generalization	Synonym
High-fidelity image	

References and additional readings

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Exercises

Short answers

1. What is data modeling?
2. What is a useful technique for identifying entities in a written description of a data modeling problem?
3. When do you label relationships?
4. When is a data model well formed, and when is it high-fidelity?
5. How do you handle exceptions when data modeling?
6. Describe the different types of entities.
7. Why might a data model grow?
8. Why might a data model contract?
9. How do you indicate ordering of instances in a data model?
10. What is the difference between a synonym and a homonym?

Data modeling

Create a data model from the following narratives, which are sometimes intentionally incomplete. You will have to make some assumptions. Make certain you state these alongside your data model. Define the identifier(s) and attributes of each entity.

1. The president of a book wholesaler has told you that she wants information about publishers, authors, and books.

2. A university has many subject areas (e.g., MIS, Romance languages). Professors teach in only one subject area, but the same subject area can have many professors. Professors can teach many different courses in their subject area. An offering of a course (e.g., Data Management 457, French 101) is taught by only one professor at a particular time.
3. Kids'n'Vans retails minivans for a number of manufacturers. Each manufacturer offers several models of its minivan (e.g., SE, LE, GT). Each model comes with a standard set of equipment (e.g., the Acme SE comes with wheels, seats, and an engine). Minivans can have a variety of additional equipment or accessories (radio, air-conditioning, automatic transmission, airbag, etc.), but not all accessories are available for all minivans (e.g., not all manufacturers offer a driver's side airbag). Some sets of accessories are sold as packages (e.g., the luxury package might include stereo, six speakers, cocktail bar, and twin overhead foxtails).
4. Steve operates a cinema chain and has given you the following information:

   "I have many cinemas. Each cinema can have multiple theaters. Movies are shown throughout the day starting at 11 a.m. and finishing at 1 a.m. Each movie is given a two-hour time slot. We never show a movie in more than one theater at a time, but we do shift movies among theaters because seating capacity varies. I am interested in knowing how many people, classified by adults and children, attended each showing of a movie. I vary ticket prices by movie and time slot. For instance, Lassie Get Lost is 50 cents for everyone at 11 a.m. but is 75 cents at 11 p.m."
5. A university gymnastics team can have as many as 10 gymnasts. The team competes many times during the season. A meet can have one or more opponents and consists of four events: vault, uneven bars, beam, and floor routine. A gymnast can participate in all or some of these events though the team is limited to five participants in any event.
6. A famous Greek shipping magnate, Stell, owns many container ships. Containers are collected at one port and delivered to another port. Customers pay a negotiated fee for the delivery of each container. Each ship has a sailing schedule that lists the ports the ship will visit over the next six months. The schedule shows the expected arrival and departure dates. The daily charge for use of each port is also recorded.
7. A medical center employs several physicians. A physician can see many patients, and a patient can be seen by many physicians, though not always on the one visit. On any particular visit, a patient may be diagnosed to have one or more illnesses.
8. A telephone company offers a 10 percent discount to any customer who phones another person who is also a customer of the company. To be eligible for the discount, the pairing of the two phone numbers must be registered with the telephone company. Furthermore, for billing purposes, the company records both phone numbers, start time, end time, and date of call.
9. Global Trading (GT), Inc. is a conglomerate. It buys and sells businesses frequently and has difficulty keeping track of what strategic business units (SBUs) it owns, in what nations it operates, and what markets it serves. For example, the CEO was recently surprised to find that GT owns 25 percent of Dundee's Wild Adventures, headquartered in Zaire, that has subsidiaries operating tours of Australia, Zaire, and New York. You have been commissioned to design a database to keep track of GT's businesses. The CEO has provided you with the following information:

SBUs are headquartered in one country, not necessarily the United States. Each SBU has subsidiaries or foreign agents, depending on local legal requirements, in a number of countries. Each subsidiary or foreign agent operates in only one country but can operate in more than one market. GT uses the standard industrial code (SIC) to identify a market (e.g., newspaper publishing). The SIC is a unique four-digit code.

While foreign agents operate as separate legal entities, GT needs to know in what countries and markets they operate. On the other hand, subsidiaries are fully or partly owned by GT, and it is important for GT to know who are the other owners of any subsidiary and what percentage of the subsidiary they own. It is not unusual for a corporation to have shares in several of GT's subsidiary companies and for several corporations to own a portion of a subsidiary. Multiple ownership can also occur at the SBU level.

10. A real estate investment company owns many shopping malls. Each mall contains many shops. To encourage rental of its shops, the company gives a negotiated discount to retailers who have shops in more than one mall. Each shop generates an income stream that can vary from month to month because rental is based on a flat rental charge and a negotiated percentage of sales revenue. Also, each shop has monthly expenses for scheduled and unscheduled maintenance. The company uses the data to compute its monthly net income per square meter for each shop and for ad hoc querying.

11. Draw a data model for the following table taken from a magazine that evaluates consumer goods. The reports follow a standard fashion of listing a brand and model, price, overall score, and then an evaluation of a series of attributes, which can vary with the product. For example, the sample table evaluates stereo systems. A table for evaluating microwave ovens would have a similar layout, but different features would be reported (e.g., cooking quality).

Brand and model	Price	Overall score	Sound quality	Taping quality	FM tuning	CD handling	Ease of use
Phillips SC-AK103	140	62	Very good	Good	Very good	Excellent	Fair
Panasonic MC-50	215	55	Good	Good	Very good	Very good	Good
Rio G300	165	38	Good	Good	Fair	Very good	Poor

12. Draw a data model for the following freight table taken from a mail order catalog. All values are in USD.

Merchandise subtotals	Regular delivery	Rush delivery	Express delivery
	7–10 days	4–5 business days	1–2 business days
Up to 30.00	4.95	9.95	12.45
30.01–65.00	6.95	11.95	15.45
65.01–125.00	8.95	13.95	20.45
125.01+	9.95	15.95	25.45

8 Normalization and other Data Modeling Methods

There are many paths to the top of the mountain, but the view is always the same.

Chinese Proverb

Learning objectives

Students completing this chapter will

- understand the process of normalization;
- be able to distinguish between different normal forms;
- recognize that different data modeling approaches, while they differ in representation methods, are essentially identical.

Multiple paths

There are often many ways to solve a problem, and different methods frequently produce essentially the same solution. When this is the case, the goal is to find the most efficient path. We believe that data modeling, as you have learned in the preceding chapters, is an efficient and easily learned approach to database design. There are, however, other paths to consider. One of these methods, normalization, was the initial approach to database design. It was developed as part of the theoretical foundation of the relational data model. It is useful to understand the key concepts of normalization because they advance your understanding of the relational model. Experience and research indicate, however, that data modeling is easier to master than normalization.

Data modeling first emerged as entity-relationship (E-R) modeling in a paper by Peter Pin-Shan Chen. He introduced two key database design concepts:

- Identify entities and the relationships between them.
- A graphical representation improves design communication.

Chen's core concepts spawned many species of data modeling. We briefly review, later in this chapter, Chen's E-R approach.

Normalization

Normalization is a method for increasing the quality of database design. It is also a theoretical base for defining the properties of relations. The theory gradually developed to create an understanding of the desirable properties of a relation. The goal of normalization is identical to that of data modeling—a high-fidelity design. The need for normalization seems to have arisen from the conversion of prior file systems into database format. Often, analysts started with the old file design and used normalization to design the new database. Now, designers are more likely to start with a clean slate and use data modeling.

Normal forms can be arrived at in several ways. The recommended approach is data modeling, as experience strongly indicates people find it is an easier path to high quality database design. If the principles of data modeling are followed faithfully, then the outcome should be a high-fidelity model and a normalized database. In other words, if you model data correctly, you create a normalized design. Nevertheless, modeling mistakes can occur, and normalization is a useful crosscheck for ensuring the soundness of a data model. Normalization also provides a theoretical underpinning to data modeling.

Normalization gradually converts a file design into normal form by the successive application of rules to move the design from first to fifth normal form. Before we look at these steps, it is useful to learn about functional dependency.

Functional dependency

A functional dependency is a relationship between attributes in an entity. It simply means that one or more attributes determine the value of another. For example, given a stock's code, you can determine its current PE ratio. In other words, PE ratio is functionally dependent on stock code. In addition, stock name, stock price, stock quantity, and stock dividend are functionally dependent on stock code. The notation for indicating that stock code functionally determines stock name is

stock code → stock name

An identifier functionally determines all the attributes in an entity. That is, if we know the value of stock code, then we can determine the value of stock name, stock price, and so on.

Formulae, such as yield = stock dividend/stock price*100, are a form of functional dependency. In this case, we have

(stock dividend, stock price) → yield

This is an example of full functional dependency because yield can be determined only from both attributes.

An attribute, or set of attributes, that fully functionally determines another attribute is called a determinant. Thus, stock code is a determinant because it fully functionally determines stock PE. An identifier, usually called a key when discussing normalization, is a determinant. Unlike a key, a determinant need not be unique. For example, a university could have a simple fee structure where undergraduate courses are $5000 and graduate courses are $7500. Thus, course type →

fee. Since there are many undergraduate and graduate courses, course type is not unique for all records.

There are situations where a given value determines multiple values. This multidetermination property is denoted as A ⊠ B and reads "A multidetermines B." For instance, a department multidetermines a course. If you know the department, you can determine the set of courses it offers. Multivalued dependency means that functional dependencies are multivalued.

Functional dependency is a property of a relation's data. We cannot determine functional dependency from the names of attributes or the current values. Sometimes, examination of a relation's data will indicate that a functional dependency does not exist, but it is by understanding the relationships between data elements we can determine functional dependency.

Functional dependency is a theoretical avenue for understanding relationships between attributes. If we have two attributes, say A and B, then three relations are possible, as shown in the following table.

Functional dependencies of two attributes

Relationship	Functional dependency	Relationship
They determine each other	A → B and B → A	1:1
One determines the other	A → B	1:m
They do not determine each other	A not → B and B not → A	m:m

One-to-one attribute relationship

Consider two attributes that determine each other (A → B and B → A), for instance a country's code and its name. Using the example of Switzerland, there is a one-to-one (1:1) relationship between CH and Switzerland: CH → Switzerland and Switzerland → CH. When two attributes have a 1:1 relationship, they must occur together in at least one table in a database so that their equivalence is a recorded fact.

One-to-many attribute relationship

Examine the situation where one attribute determines another (i.e., A → B), but the reverse is not true (i.e., B not → A), as is the case with country name and its currency unit. If you know a country's name, you can determine its currency, but if you know the currency unit (e.g., the euro), you cannot always determine the country (e.g., both Italy and Portugal use the euro). As a result, if A and B occur in the same table, then A must be the key. In our example, country name would be the key, and currency unit would be a nonkey column.

Many-to-many attribute relationship

The final case to investigate is when neither attribute determines the other (i.e., A not → B and B not → A). The relationship between country name and language is many-to-many (m:m). For example, Belgium has two languages (French and Flemish), and French is spoken in many countries. Thus, an associative entity between country and language is required to represent the m:m relationship.

As you can understand from the preceding discussion, functional dependency is an explicit form of presenting some of the ideas you gained implicitly in earlier chapters on data modeling. The next step is to delve into another theoretical concept underlying the relational model: normal forms.

Normal forms

Normal forms describe a classification of relations. Initial work by Codd identified first (1NF), second (2NF), and third (3NF) normal forms. Later researchers added Boyce-Codd (BCNF), fourth (4NF), and fifth (5NF) normal forms. Normal forms are nested like a set of Russian dolls, with the innermost doll, 1NF, contained within all other normal forms. The hierarchy of normal forms is 5NF, 4NF, BCNF, 3NF, 2NF, and 1NF. Thus, 5NF is the outermost doll.

A new normal form, domain-key normal form (DK/NF), appeared in 1981. When a relation is in DK/NF, there are no modification anomalies. Conversely, any relation that is free of anomalies must be in DK/NF. The difficult part is discovering how to convert a relation to DK/NF.

First normal form

A relation is in first normal form if and only if all columns are single-valued. In other words, 1NF states that all occurrences of a row must have the same number of columns. In data modeling terms, this means that an attribute must have a single value. An attribute that can have multiple values must be represented as a one-to-many (1:m) relationship. At a minimum, a data model will be in 1NF, because all attributes of an entity are required to be single-valued.

Second normal form

Second normal form is violated when a nonkey column is dependent on only a component of the primary key. This can also be stated as *a relation is in second normal form if and only if it is in first normal form, and all nonkey columns are dependent on the key*.

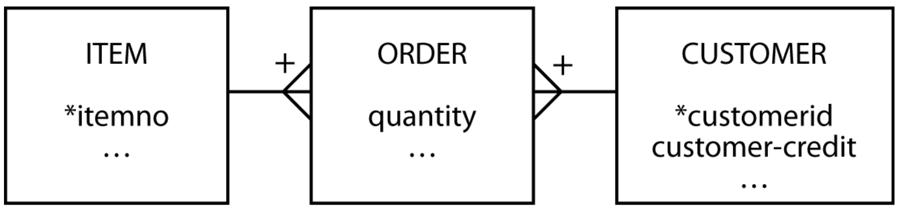
Consider the following table. The primary key of `order` is a composite of `itemno` and `customerid`. The problem is that `customer-credit` is a fact about `customerid` (part of the composite key) rather than the full key (`itemno+customerid`), or in other words, it is not fully functionally dependent on the primary key. An insert anomaly arises when you try to add a new customer to order. You cannot add a customer until that person places an order, because until then you have no value for item number, and part of the primary key will be null. Clearly, this is neither an acceptable business practice nor an acceptable data management procedure.

Analyzing this problem, you realize an item can be in many orders, and a customer can order many items—an m:m relationship. By drawing the data model in the following figure, you realize that *customer-credit* is an attribute of `customer`, and you get the correct relational mapping.

Second normal form violation

*itemno	*customerid	quantity	customer-credit
12	57	25	OK
34	679	3	POOR

Resolving second normal form violation



Third normal form

Third normal form is violated when a nonkey column is a fact about another nonkey column. Alternatively, *a relation is in third normal form if and only if it is in second normal form and has no transitive dependencies.*

The problem in the following table is that `exchange rate` is a fact about `nation`, a nonkey field. In the language of functional dependency, `exchange rate` is not fully functionally dependent on `stockcode`, the primary key.

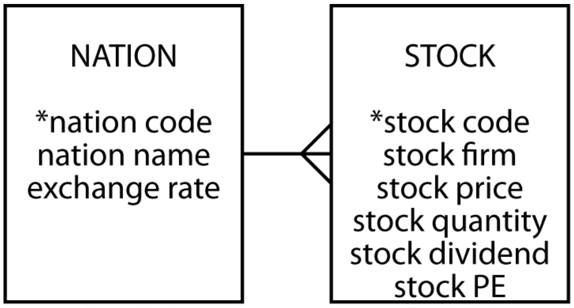
The functional dependencies are `stockcode` → `nation` → `exchange rate`. In other words, `exchange rate` is transitively dependent on STOCK, since `exchange rate` is dependent on `nation`, and `nation` is dependent on `stockcode`. The fundamental problem becomes very apparent when you try to add a new nation to the `stock` table. Until you buy at least one stock for that nation, you cannot insert the nation, because you do not have a primary key. Similarly, if you delete MG from the `stock` table, details of the USA exchange rate are lost. There are modification anomalies.

When you think about the data relationships, you realize that a nation has many stocks and a stock belongs to only one nation. Now the data model and relational map can be created readily
.

Third normal form violation

*stockcode	nation	exchange rate
MG	USA	0.67
IR	AUS	0.46

Resolving third normal form violation



⊠ *Skill builder*

You have been given a spreadsheet that contains details of invoices. The column headers for the spreadsheet are *date*, *invoice number*, *invoice amount*, *invoice tax*, *invoice total*, *cust number*, *custname*, *cust street*, *cust city*, *cust state*, *cust postal code*, *cust nation*, *product code*, *product price*, *product quantity*, *salesrep number*, *salesrep first name*, *salesrep last name*, *salesrep district*, *district name*, and *district size*.

Normalize this spreadsheet so that it can be converted to a high-fidelity relational database.

Boyce-Codd normal form

The original definition of 3NF did not cover a situation that, although rare, can occur. So Boyce-Codd normal form, a stronger version of 3NF, was developed. BCNF is necessary because 3NF does not cover the cases when

- A relation has multiple candidate keys.
- Those candidate keys are composite.
- The candidate keys overlap because they have at least one column in common.

Before considering an example, candidate key needs to be defined. Earlier we introduced the idea that an entity could have more than one potential unique identifier. These identifiers become candidate keys when the data model is mapped to a relational database. One of these candidates is selected as the primary key.

Consider the following case from a management consulting firm. A client can have many types of problems (e.g., finance, personnel), and the same problem type can be an issue for many clients. Consultants specialize and advise on only one problem type, but several consultants can advise on one problem type. A consultant advises a client. Furthermore, for each problem type, the client is advised by only one consultant. If you did not use data modeling, you might be tempted to create the following table.

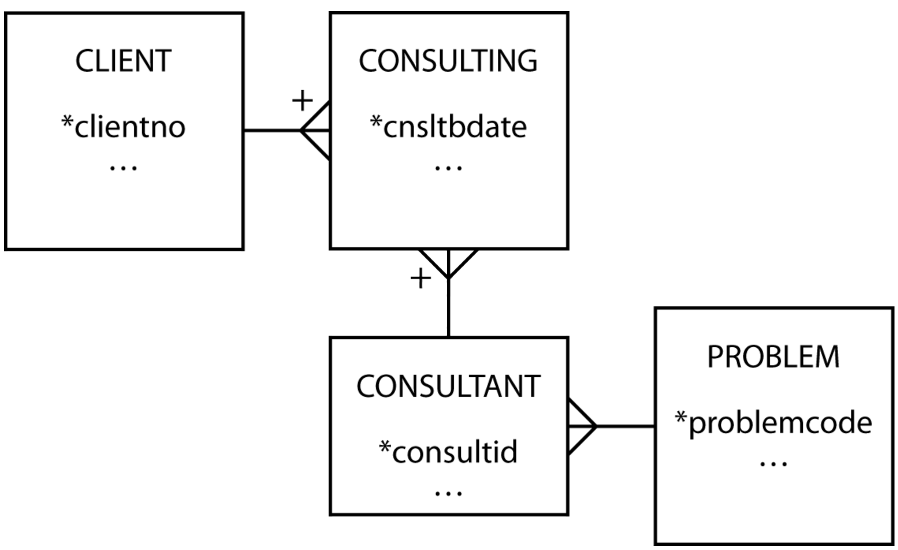
Boyce-Codd normal form violation

*client	*probtype	consultant
Alpha	Marketing	Gomez
Alpha	Production	Raginiski

The column `client` cannot be the primary key because a client can have several problem types; however, a client is advised by only one consultant for a specific problem type, so the composite key `client+probtype` determines `consultant`. Also, because a consultant handles only one type of problem, the composite key `client+consultant` determines `probtype`. So, both of these composites are candidate keys. Either one can be selected as the primary key, and in this case `client+probtype` was selected. Notice that all the previously stated conditions are satisfied—there are multiple, composite candidate keys that overlap. This means the table is 3NF, but not BCNF. This can be easily verified by considering what happens if the firm adds a new consultant. A new consultant cannot be added until there is a client—an insertion anomaly. The problem is that `consultant` is a determinant, `consultant→probtype`, but is not a candidate key. In terms of the phrasing used earlier, the problem is that part of the key column is a fact about a nonkey column. The precise definition is *a relation is in Boyce-Codd normal form if and only if every determinant is a candidate key*.

This problem is avoided by creating the correct data model and then mapping to a relational model.

Resolving Boyce-Codd normal form violation



Fourth normal form

Fourth normal form requires that a row should not contain two or more independent multivalued facts about an entity. This requirement is more readily understood after investigating an example.

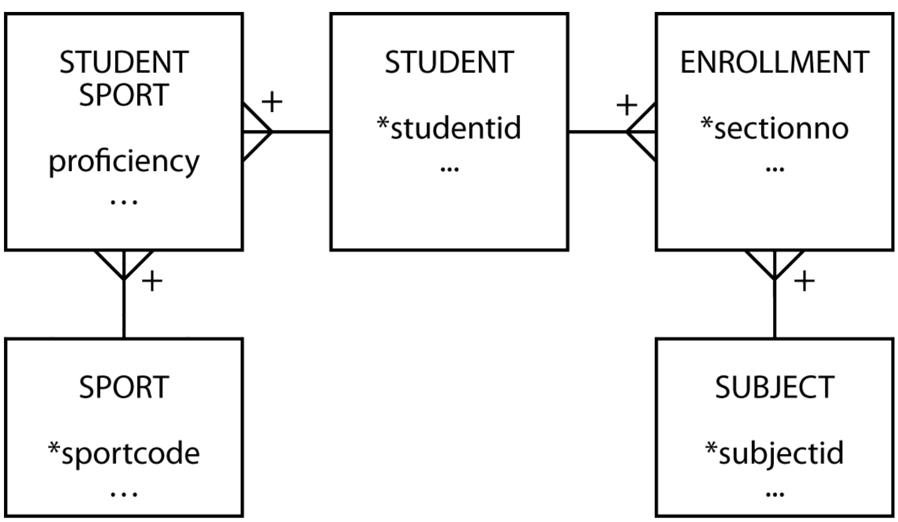
Consider students who play sports and study subjects. One way of representing this information is shown in the following table. Consider the consequence of trying to insert a student who did not play a sport. Sport would be null, and this is not permissible because part of the composite primary key would then be null—a violation of the entity integrity rule. You cannot add a new student until you know her sport and her subject. Modification anomalies are very apparent.

Fourth normal form violation

*studentid	*sport	*subject	...
50	Football	English	...
50	Football	Music	...
50	Tennis	Botany	...
50	Karate	Botany	...

This table is not in 4NF because sport and subject are independent multivalued facts about a student. There is no relationship between sport and subject. There is an indirect connection because sport and subject are associated with a student. In other words, a student can play many sports, and the same sport can be played by many students—a many-to-many (m:m) relationship between student and sport. Similarly, there is an m:m relationship between student and subject. It makes no sense to store information about a student's sports and subjects in the same table because sport and subject are not related. The problem arises because sport and subject are multivalued dependencies of student. The solution is to convert multivalued dependencies to functional dependencies. More formally, *a relation is in fourth normal form if it is in Boyce-Codd normal form and all multivalued dependencies on the relation are functional dependencies.* A data model sorts out this problem, and note that the correct relational mapping requires five tables.

Resolving fourth normal form violation

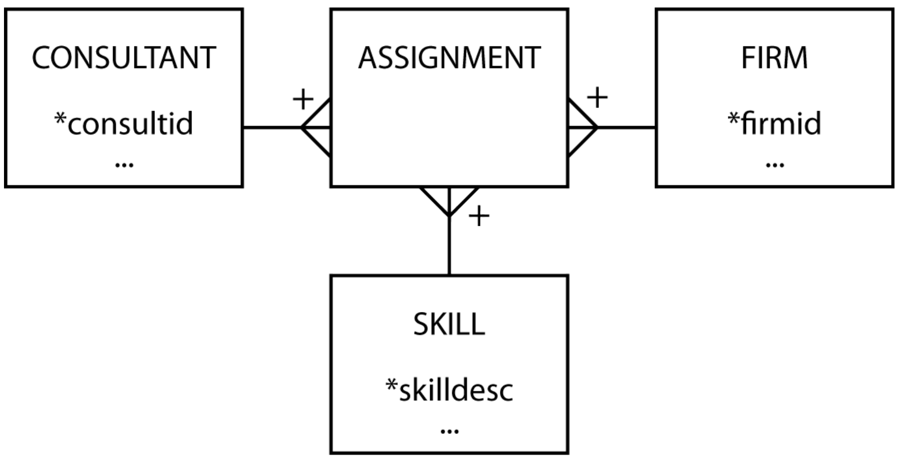


Fifth normal form

Fifth normal form deals with the case where a table can be reconstructed from other tables. The reconstruction approach is preferred, because it means less redundancy and fewer maintenance problems.

A consultants, firms, and skills problem is used to illustrate the concept of 5NF. The problem is that consultants provide skills to one or more firms and firms can use many consultants; a consultant has many skills and a skill can be used by many firms; and a firm can have a need for many skills and the same skill can be required by many firms. The data model for this problem has the ménage-à-trois structure which was introduced in Chapter 7.

The CONSULTANT-FIRM-SKILL data model without a rule



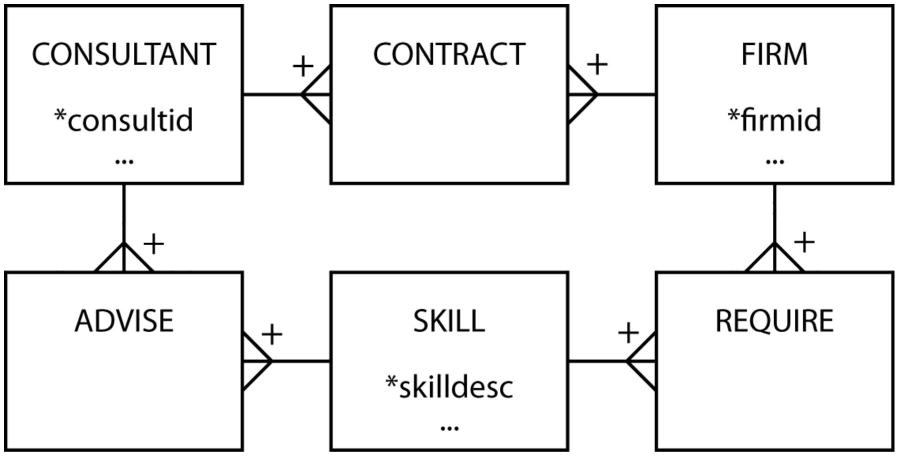
The relational mapping of the three-way relationships results in four tables, with the associative entity ASSIGNMENT mapping shown in the following table.

Relation table assignment

*consultid	*firmid	*skilldesc
Tan	IBM	Database
Tan	Apple	Data comm

The table is in 5NF because the combination of all three columns is required to identify which consultants supply which firms with which skills. For example, we see that Tan advises IBM on database and Apple on data communications. The data in this table cannot be reconstructed from other tables.

The preceding table is not in 5NF *if there is a rule of the following form*: If a consultant has a certain skill (e.g., database) and has a contract with a firm that requires that skill (e.g., IBM), then the consultant advises that firm on that skill (i.e., he advises IBM on database). Notice that this rule means we can infer a relationship, and we no longer need the combination of the three columns. As a result, we break the single three-entity m:m relationship into three two-entity m:m relationships. The revised data model after the introduction of the rule is:



Further understanding of 5NF is gained by examining the relational tables resulting from these three associative entities. Notice the names given to each of the associative entities. The table `contract` records data about the firms a consultant advises; `advise` describes the skills a consultant has; and `require` stores data about the types of skills each firm requires. To help understand this problem, examine the three tables below.

Relational table contract

*consultid	*firmid
Gonzales	Apple
Gonzales	IBM
Gonzales	NEC
Tan	IBM
Tan	NEC
Wood	Apple

Relational table advise

*consultid	*skilldesc
Gonzales	Database
Gonzales	Data comm
Gonzales	Groupware
Tan	Database
Tan	Data comm
Wood	Data comm

Relational table require

*firmid	*skilldesc
IBM	Data comm

*firmid	*skilldesc
IBM	Groupware
NEC	Data comm
NEC	Database
NEC	Groupware
Apple	Data comm

Consider joining `contract` and `advise`, the result of which we call `could advise` because it lists skills the consultant could provide if the firm required them. For example, Tan has skills in database and data communications, and Tan has a contract with IBM. If IBM requires database skills, Tan can handle it. We need to look at require to determine whether IBM requires advice on database; it does not.

Relational table could advise

*consultid	*firmid	*skilldesc
Gonzales	Apple	Database
Gonzales	Apple	Data comm
Gonzales	Apple	Groupware
Gonzales	IBM	Database
Gonzales	IBM	Data comm
Gonzales	IBM	Groupware
Gonzales	NEC	Database
Gonzales	NEC	Data comm
Gonzales	NEC	Groupware
Tan	IBM	Database
Tan	IBM	Data comm
Tan	NEC	Database
Tan	NEC	Data comm
Wood	Apple	Data comm

Relational table can advise

The join of `could advise` with `require` gives details of a firm's skill needs that a consultant can provide. The table `can advise` is constructed by directly joining `contract`, `advise`, and `require`. Because we can construct `can advise` from three other tables, the data are in 5NF.

*consultid	*firmid	*skilldesc
Gonzales	IBM	Data comm
Gonzales	IBM	Groupware
Gonzales	NEC	Database
Gonzales	NEC	Data comm
Gonzales	NEC	Groupware
Tan	IBM	Data comm
Tan	NEC	Database

*consultid	*firmid	*skilldesc
Tan	NEC	Data comm
Wood	Apple	Data comm

Since data are stored in three separate tables, updating is easier. Consider the case where IBM requires database skills. We only need to add one row to require to record this fact. In the case of can advise, we would have to add two rows, one for Gonzales and one for Tan.

Now we can give 5NF a more precise definition: *A relation is in fifth normal form if and only if every join dependency of the relation is a consequence of the candidate keys of the relation.*

Up to this point, data modeling has enabled you to easily avoid normalization problems. Fifth normal form introduces a complication, however. How can you tell when to use a single three-way associative entity or three two-way associative entities? If there is a constraint or rule that is applied to the relationships between entities, consider the possibility of three two-way associative entities. Question the client carefully whenever you find a ménage-à-trois. Check to see that there are no rules or special conditions.

Domain-key normal form

The definition of DK/NF builds on three terms: key, constraint, and domain. You already know a key is a unique identifier. A constraint is a rule governing attribute values. It must be sufficiently well-defined so that its truth can be readily evaluated. Referential integrity constraints, functional dependencies, and data validation rules are examples of constraints. A domain is a set of all values of the same data type. With the help of these terms, the concept of DK/NF is easily stated. *A relation is in domain-key normal form if and only if every constraint on the relation is a logical consequence of the domain constraints and the key constraints that apply to the relation*.

Note that DK/NF does not involve ideas of dependency; it just relies on the concepts of key, constraint, and domain. The problem with DK/NF is that while it is conceptually simple, no algorithm has been developed for converting relations to DK/NF. Hence, database designers must rely on their skills to create relations that are in DK/NF.

Conclusion

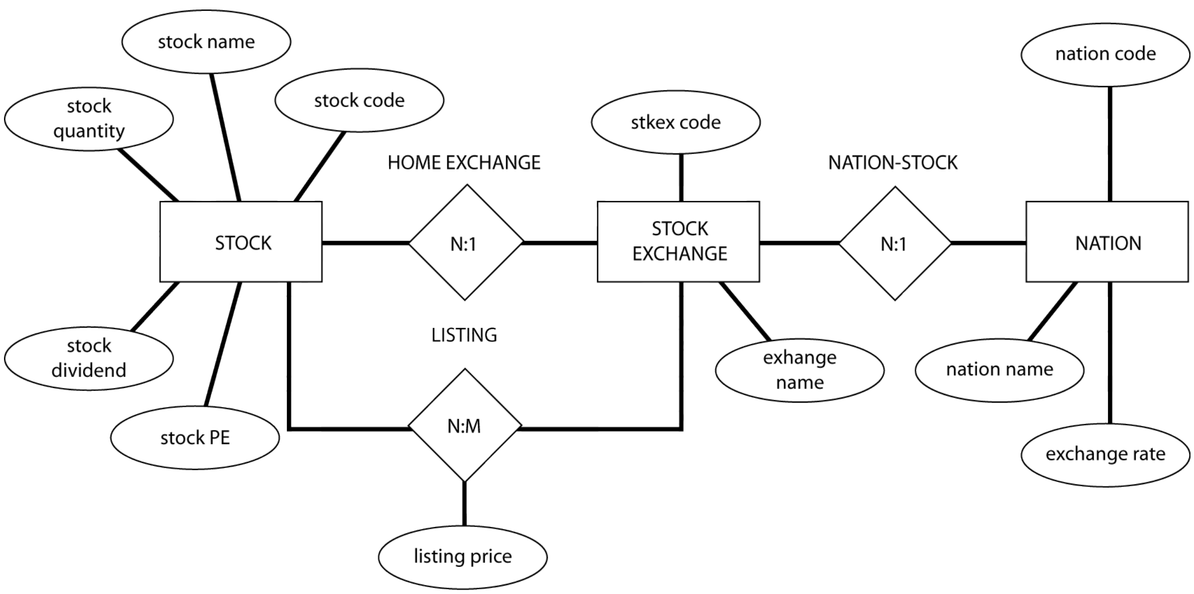
Normalization provides designers with a theoretical basis for understanding what they are doing when modeling data. It also alerts them to be aware of problems that they might not ordinarily detect when modeling. For example, 5NF cautions designers to investigate situations carefully (i.e., look for special rules), when their data model contains a ménage-à-trois.

Other data modeling methods

As mentioned previously, there are many species of data modeling. Here we consider one of the most widely known data modeling methods, the the E-R model developed by Chen. There is no standard for the E-R model, and it has been extended and modified in a number of ways.

As the following figure shows, an E-R model looks like the data models with which you are now familiar. Entities are shown by rectangles, and relationships are depicted by diamonds within which the cardinality of the relationship is indicated (e.g., there is a 1:m relationship between NATION and STOCK EXCHANGE). Cardinality can be 1:1, 1:m (conventionally shown as 1:N in E-R diagrams), and m:m (shown as M:N). Recursive relationships are also readily modeled. One important difference is that an m:m relationship is not shown as an associative entity; thus the database designer must convert this relationship to a table.

An E-R diagram



Attributes are shown as ellipses connected to the entity or relationship to which they belong (e.g., *stock name* is an attribute of STOCK). Relationships are named, and the name is shown above or below the relationship symbol. For example, LISTING is the name of the m:m relationship between STOCK and STOCK EXCHANGE. The method of recording attributes consumes space, particularly for large data models. It is more efficient to record attributes within an entity rectangle, as in the data modeling method you have learned.

> ☒ *Skill builder*
>
> Ken is a tour guide for trips that can last several weeks. He has requested a database that will enable him to keep track of the people who have been on the various tours he has led. He wants to be able to record his comments about some of his clients to remind him of extra attention he might need to pay to them on a future trip (e.g., Bill tends to get lost, Daisy has problems getting along with others). Some times people travel with a partner, and Ken wants to record this in his database.

Design a database using MySQL Workbench. Experiment with Object Notation and Relationship Notation (options of the Model tab) to get a feel for different forms of representing data models.

Conclusion

The underlying concepts of different data modeling methods are very similar. They all have the same goal: improving the quality of database design. They share common concepts, such as entity and relationship mapping. We have adopted an approach that is simple and effective. The method can be learned rapidly, novice users can create high-quality models, and it is similar to the representation style of MySQL Workbench. Also, if you have learned one data modeling method, you can quickly adapt to the nuances of other methods.

Summary

Normalization gradually converts a file design into normal form by successive application of rules to move the design from first to fifth normal form. Functional dependency means that one or more attributes determine the value of another. An attribute, or set of attributes, that fully functionally determines another attribute is called a *determinant*. First normal form states that all occurrences of a row must have the same number of columns. Second normal form is violated when a nonkey column is a fact about a component of the prime key. Third normal form is violated when a nonkey column is a fact about another nonkey column. Boyce-Codd normal form is a stronger version of third normal form. Fourth normal form requires that a row should not contain two or more independent multivalued facts about an entity. Fifth normal form deals with the case where a table can be reconstructed from data in other tables. Fifth normal form arises when there are special rules or conditions. A high-fidelity data model will be of high normal form.

One of the most widely known methods of data modeling is the E-R model. The basic concepts of most data modeling methods are very similar. All aim to improve database design.

Key terms and concepts

Alternate key	Functional dependency
Boyce-Codd normal form (BCNF)	Generalization hierarchy
Constraint	Inversion entry
Data model	Many-to-many attribute relationship
Determinant	Multidetermination
Domain	Multivalued dependency
Domain-key normal form (DK/NF)	Normalization
Entity	One-to-many attribute relationship
Entity-relationship (E-R) model	One-to-one attribute relationship
Fifth normal form (5NF)	Relationship

First normal form (1NF)	Second normal form (2NF)
Fourth normal form (1NF)	Third normal form (3NF)
Full functional dependency	

References and additional readings

Chen, P. 1976. The entity-relationship model—toward a unified view of data. *ACM Transactions on Database Systems* 1 (1):9–36.

Kent, W. 1983. A simple guide to five normal forms in relational database theory. *Communications of the ACM 26 (2): 120-125.*

Exercises

Short answers

1. What is normalization, and what is its goal?
2. How does DK/NF differ from earlier normal forms?
3. How does E-R differ from the data modeling method of this text?

Normalization and data modeling

Using normalization or E-R create data models from the following narratives, which are sometimes intentionally incomplete. You will have to make some assumptions. Make certain you state these assumptions alongside your data model. Define the identifier(s) and attributes of each entity.

1. The president of a book wholesaler has told you that she wants information about publishers, authors, and books.
2. A university has many subject areas (e.g., MIS, Romance languages). Professors teach in only one subject area, but the same subject area can have many professors. Professors can teach many different courses in their subject area. An offering of a course (e.g., Data Management 457, French 101) is taught by only one professor at a particular time.
3. Kids'n'Vans retails minivans for a number of manufacturers. Each manufacturer offers several models of its minivan (e.g., SE, LE, GT). Each model comes with a standard set of equipment (e.g., the Acme SE comes with wheels, seats, and an engine). Minivans can have a variety of additional equipment or accessories (radio, air conditioning, automatic transmission, airbag, etc.), but not all accessories are available for all minivans (e.g., not all manufacturers offer a driver's side airbag). Some sets of accessories are sold as packages (e.g., the luxury package might include stereo, six speakers, cocktail bar, and twin overhead foxtails).

4. Steve operates a cinema chain and has given you the following information:

   "I have many cinemas. Each cinema can have multiple theaters. Movies are shown throughout the day starting at 11 a.m. and finishing at 1 a.m. Each movie is given a two-hour time slot. We never show a movie in more than one theater at a time, but we do shift movies among theaters because seating capacity varies. I am interested in knowing how many people, classified by adults and children, attended each showing of a movie. I vary ticket prices by movie and time slot. For instance, *Lassie Get Lost* is 50 cents for everyone at 11 a.m. but is 75 cents at 11 p.m."

5. A telephone company offers a 10 percent discount to any customer who phones another person who is also a customer of the company. To be eligible for the discount, the pairing of the two phone numbers must be registered with the telephone company. Furthermore, for billing purposes, the company records both phone numbers, start time, end time, and date of call.

9 The Relational Model and Relational Algebra

Nothing is so practical as a good theory.

K. Lewin, 1945

Learning objectives

Students completing this chapter will

- know the structures of the relational model;
- understand relational algebra commands;
- be able to determine whether a DBMS is completely relational.

Background

The relational model, developed as a result of recognized shortcomings of hierarchical and network DBMSs, was introduced by Codd in 1970. As the major developer, Codd believed that a sound theoretical model would solve many practical problems that might arise.

In another article, Codd expounds the case for adopting the relational over earlier database models. There is a threefold thrust to his argument. *First*, earlier models forced the programmer to code at a low level of structural detail. As a result, application programs are more complex and took longer to write and debug. *Second*, no commands were provided for processing multiple records at one time. Earlier models did not provide the set-processing capability of the relational model. The set-processing feature means that queries can be more concisely expressed. *Third*, the relational model, through a query language such as structured query language (SQL), recognizes the clients' need to make ad hoc queries. The relational model and SQL permit an IS department to respond rapidly to unanticipated requests. It also meant that analysts could write queries. Thus, Codd's assertion that the relational model is a practical tool for increasing the productivity of IS departments is well founded.

The productivity increase arises from three of the objectives that drove Codd's research. The *first* was to provide a clearly delineated boundary between the logical and physical aspects of database management. Programming should be divorced from considerations of the physical representation of data. Codd labels this the data independence objective. The *second* objective was to create a simple model that is readily understood by a wide range of analysts and programmers.

This communicability objective promotes effective and efficient communication between clients and IS personnel. The *third* objective was to increase processing capabilities from record-at-a-time to multiple-records-at-a-time—the set-processing objective. Achievement of these objectives means fewer lines of code are required to write an application program, and there is less ambiguity in client-analyst communication.

The relational model has three major components:

- Data structures
- Integrity rules
- Operators used to retrieve, derive, or modify data

Data structures

Like most theories, the relational model is based on some key structures or concepts. We need to understand these in order to understand the theory.

Domain

A domain is a set of values all of the same data type. For example, the domain of nation name is the set of all possible nation names. The domain of all stock prices is the set of all currency values in, say, the range $0 to $10,000,000. You can think of a domain as all the legal values of an attribute.

In specifying a domain, you need to think about the smallest unit of data for an attribute defined on that domain. In Chapter 8, we discussed how a candidate attribute should be examined to see whether it should be segmented (e.g., we divide name into first name, other name, and last name, and maybe more). While it is unlikely that name will be a domain, it is likely that there will be a domain for first name, last name, and so on. Thus, a domain contains values that are in their *atomic* state; they cannot be decomposed further.

The practical value of a domain is to define what comparisons are permissible. Only attributes drawn from the same domain should be compared; otherwise it is a bit like comparing bananas and strawberries. For example, it makes no sense to compare a stock's PE ratio to its price. They do not measure the same thing; they belong to different domains. Although the domain concept is useful, it is rarely supported by relational model implementations.

Relations

A relation is a table of *n* columns (or *attributes*) and *m* rows (or *tuples*). Each column has a unique name, and all the values in a column are drawn from the same domain. Each row of the relation is uniquely identified. The order of columns and rows is immaterial.

The cardinality of a relation is its number of rows. The degree of a relation is the number of columns. For example, the relation `nation` (see the following figure) is of degree 3 and has a cardinality of 4. Because the cardinality of a relation changes every time a row is added or deleted, you can expect cardinality to change frequently. The degree changes if a column is added to a relation, but in terms of relational theory, it is considered to be a new relation. So, only a relation's cardinality can change.

A relational database with tables nation and stock

*natcode	natname	exchrate
AUS	Australia	0.46
IND	India	0.0228
UK	United Kingdom	1
USA	United States	0.67

*stkcode	stkfirm	stkprice	stkqty	stkdiv	stkpe	*natcode*
FC	Freedonia Copper	27.5	10,529	1.84	16	UK
PT	Patagonian Tea	55.25	12,635	2.5	10	UK
AR	Abyssinian Ruby	31.82	22,010	1.32	13	UK
SLG	Sri Lankan Gold	50.37	32,868	2.68	16	UK
ILZ	Indian Lead & Zinc	37.75	6,390	3	12	UK
BE	Burmese Elephant	0.07	154,713	0.01	3	UK
BS	Bolivian Sheep	12.75	231,678	1.78	11	UK
NG	Nigerian Geese	35	12,323	1.68	10	UK
CS	Canadian Sugar	52.78	4,716	2.5	15	UK
ROF	Royal Ostrich Farms	33.75	1,234,923	3	6	UK
MG	Minnesota Gold	53.87	816,122	1	25	USA
GP	Georgia Peach	2.35	387,333	0.2	5	USA
NE	Narembeen Emu	12.34	45,619	1	8	AUS
QD	Queensland Diamond	6.73	89,251	0.5	7	AUS
IR	Indooroopilly Ruby	15.92	56,147	0.5	20	AUS
BD	Bombay Duck	25.55	167,382	1	12	IN

Relational database

A relational database is a collection of relations or tables. A distinguishing feature of the relational model, is that there are no explicit linkages between tables. Tables are linked by common columns drawn on the same domain; thus, the portfolio database (see the preceding tables) consists of tables `stock` and `nation`. The 1:m relationship between the two tables is represented by the column `natcode` that is common to both tables. Note that the two columns need not have the same name, but they must be drawn on the same domain so that comparison is possible. In the case of an m:m relationship, while a new table must be created to represent the relationship, the principle of linking tables through common columns on the same domain remains in force.

Primary key

A relation's primary key is its unique identifier; for example, the primary key of `nation` is `natcode`. As you already know, a primary key can be a composite of several columns. The primary key guarantees that each row of a relation can be uniquely addressed.

Candidate key

In some situations, there may be several attributes, known as candidate keys, that are potential primary keys. Column `natcode` is unique in the `nation` relation, for example. We also can be fairly certain that two nations will not have the same name. Therefore, `nation` has multiple candidate keys: `natcode` and `natname`.

Alternate key

When there are multiple candidate keys, one is chosen as the primary key, and the remainder are known as alternate keys. In this case, we selected `natcode` as the primary key, and `natname` is an alternate key.

Foreign key

The foreign key is an important concept of the relational model. It is the way relationships are represented and can be thought of as the glue that holds a set of tables together to form a relational database. A foreign key is an attribute (possibly composite) of a relation that is also a primary key of a relation. The foreign key and primary key may be in different relations or the same relation, but both keys must be drawn from the same domain.

Integrity rules

The integrity section of the relational model consists of two rules. The entity integrity rule ensures that each instance of an entity described by a relation is identifiable in some way. Its implementation means that each row in a relation can be uniquely distinguished. The rule is

No component of the primary key of a relation may be null.

Null in this case means that the component cannot be undefined or unknown; it must have a value. Notice that the rule says "component of a primary key." This means every part of the primary key must be known. If a portion of the key cannot be defined, it implies that the particular entity it describes cannot be defined. In practical terms, it means you cannot add a nation to `nation` unless you also define a value for `natcode`.

The definition of a foreign key implies that there is a corresponding primary key. The referential integrity rule ensures that this is the case. It states

A database must not contain any unmatched foreign key values.

Simply, this rule means that you cannot define a foreign key without first defining its matching primary key. In practical terms, it would mean you could not add a Canadian stock to the `stock` relation without first creating a row in `nation` for Canada.

Notice that the concepts of foreign key and referential integrity are intertwined. There is not much sense in having foreign keys without having the referential integrity rule. Permitting a foreign key without a corresponding primary key means the relationship cannot be determined. Note that the referential integrity rule does not imply a foreign key cannot be null. There can be circumstances where a relationship does not exist for a particular instance, in which case the foreign key is null.

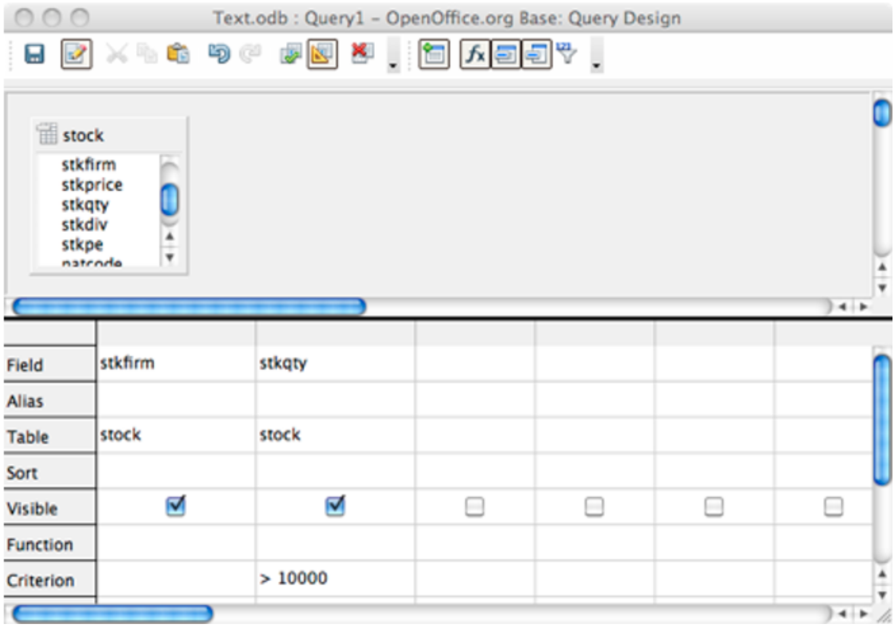
Manipulation languages

There are four approaches to manipulating relational tables, and you are already familiar with SQL, the major method.

Query-by-example (QBE), which describes a general class of graphical interfaces to a relational database to make it easier to write queries, is also commonly used. Less widely used manipulation languages are relational algebra and relational calculus. These languages are briefly discussed, with some attention given to relational algebra in the next section and SQL in the following chapter.

Query-by-example (QBE) is not a standard, and each vendor implements the idea differently. The general principle is to enable those with limited SQL skills to interrogate a relational database. Thus, the analyst might select tables and columns using drag and drop or by clicking a button. The following screen shot shows the QBE interface to LibreOffice, which is very similar to that of MS Access. It shows selection of the `stock` table and two of its columns, as well as a criterion for `stkqty`. QBE commands are translated to SQL prior to execution, and many systems allow you to view the generated SQL. This can be handy. You can use QBE to generate a portion of the SQL for a complex query and then edit the generated code to fine-tune the query.

Query-by-example with LibreOffice



Relational algebra has a set of operations similar to traditional algebra (e.g., add and multiply) for manipulating tables. Although relational algebra can be used to resolve queries, it is seldom employed, because it requires you to specify both what you want and how to get it. That is, you have to specify the operations on each table. This makes relational algebra more difficult to use than SQL, where the focus is on specifying what is wanted.

Relational calculus overcomes some of the shortcomings of relational algebra by concentrating on what is required. In other words, there is less need to specify how the query will operate. Relational calculus is classified as a nonprocedural language, because you do not have to be overly concerned with the procedures by which a result is determined.

Unfortunately, relational calculus can be difficult to learn, and as a result, language designers developed SQL and QBE, which are nonprocedural and more readily mastered. You have already gained some skills in SQL. Although QBE is generally easier to use than SQL, IS professionals need to master SQL for two reasons. *First*, SQL is frequently embedded in other programming languages, a feature not available with QBE. *Second*, it is very difficult, or impossible, to express some queries in QBE (e.g., divide). Because SQL is important, it is the focus of the next chapter.

Relational algebra

The relational model includes a set of operations, known as relational algebra, for manipulating relations. Relational algebra is a standard for judging data retrieval languages. If a retrieval language, such as SQL, can be used to express every relational algebra operator, it is said to be relationally complete.

Relational algebra operators

Operator	Description
Restrict	Creates a new table from specified rows of an existing table
Project	Creates a new table from specified columns of an existing table
Product	Creates a new table from all the possible combinations of rows of two existing tables
Union	Creates a new table containing rows appearing in one or both tables of two existing tables
Intersect	Creates a new table containing rows appearing in both tables of two existing tables
Difference	Creates a new table containing rows appearing in one table but not in the other of two existing tables
Join	Creates a new table containing all possible combinations of rows of two existing tables satisfying the join condition
Divide	Creates a new table containing xi such that the pair (xi, yi) exists in the first table for every yi in the second table

There are eight relational algebra operations that can be used with either one or two relations to create a new relation. The assignment operator (:=) indicates the name of the new relation. The relational algebra statement to create relation A, the union of relations B and C, is expressed as

```
A := B UNION C
```

Before we begin our discussion of each of the eight operators, note that the first two, restrict and project, operate on a single relation and the rest require two relations.

Restrict

Restrict extracts specified rows from a single relation. It takes a horizontal slice through a relation.

Project

Project extracts specified columns from a table. It takes a vertical slice through a table.

Product

Product creates a new relation from all possible combinations of rows in two other relations. It is sometimes called TIMES or MULTIPLY. The relational command to create the product of two tables is

The operation of product is illustrated in the following figure, which shows the result of A TIMES B.

Relational operator product

A		B		
V	W	X	Y	Z
v_1	w_1	x_1	y_1	z_1
v_2	w_2	x_2	y_2	z_2
v_3	w_3			

A TIMES B

V	W	X	Y	Z
v_1	w_1	x_1	y_1	z_1
v_1	w_1	x_2	y_2	z_2
v_2	w_2	x_1	y_1	z_1
v_2	w_2	x_2	y_2	z_2
v_3	w_3	x_1	y_1	z_1
v_3	w_3	x_2	y_2	z_2

Union

The union of two relations is a new relation containing all rows appearing in one or both relations. The two relations must be union compatible, which means they have the same column names, in the same order, and drawn on the same domains. Duplicate rows are automatically eliminated—they must be, or the relational model is no longer satisfied. The relational command to create the union of two tables is

Union is illustrated in the following figure. Notice that corresponding columns in tables A and B have the same names. While the sum of the number of rows in relations A and B is five, the union contains four rows, because one row (x_2, y_2) is common to both relations.

Relational operator union

A		B	
X	Y	X	Y
x_1	y_1	x_2	y_2
x_2	y_2	x_4	y_4
x_3	y_3		

A UNION B

X	Y
x_1	y_1
x_2	y_2
x_3	y_3
x_4	y_4

Intersect

The intersection of two relations is a new relation containing all rows appearing in both relations. The two relations must be union compatible. The relational command to create the intersection of two tables is

The result of A INTERSECT B is one row, because only one row (x_2, y_2) is common to both relations A and B.

Relational operator intersect

A		B	
X	Y	X	Y
x_1	y_1	x_2	y_2
x_2	y_2	x_4	y_4
x_3	y_3		

A INTERSECT B

X	Y
x_2	y_2

Difference

The difference between two relations is a new relation containing all rows appearing in the first relation but not in the second. The two relations must be union compatible. The relational command to create the difference between two tables is

The result of A MINUS B is two rows (see the following figure). Both of these rows are in relation A but not in relation B. The row containing (x1, y2) appears in both A and B and thus is not in A MINUS B.

Relational operator difference

A		B	
X	Y	X	Y
x_1	y_1	x_2	y_2

A		B	
x_2	y_2	x_4	y_4
x_3	y_3		

A MINUS B

X	Y
x_1	y_1
x_3	y_3

Join

Join creates a new relation from two relations for all combinations of rows satisfying the join condition. The general format of join is

where theta can be =, <>, >, >=, <, or <=.

The following figure illustrates A JOIN B WHERE W = Z, which is an equijoin because theta is an equals sign. Tables A and B are matched when values in columns W and Z in each relation are equal. The matching columns should be drawn from the same domain. You can also think of join as a product followed by restrict on the resulting relation.

Relational operator join

A		B		
V	W	X	Y	Z
v_1	wz_1	x_1	y_1	wz_1
v_2	wz_2	x_2	y_2	wz_2
v_3	wz_3			

A EQUIJOIN B

V	W	X	Y	Z
v_1	wz_1	x_1	y_1	wz_1
v_3	wz_3	x_2	y_2	wz_3

Divide

Divide is the hardest relational operator to understand. Divide requires that A and B have a set of attributes, in this case Y, that are common to both relations. Conceptually, A divided by B asks the question, "Is there a value in the X column of A (e.g., x_1) that has a value in the Y column of A for every value of y in the Y column of B?" Look first at B, where the Y column has values y_1 and y_2. When you examine the X column of A, you find there are rows (x_1, y_1) and (x_1, y_2). That is, for x_1, there is a value in the Y column of A for every value of y in the Y column of B. Thus, the result of the division is a new relation with a single row and column containing the value x_1.

Relational operator divide

A		B
X	Y	Y
x_1	y_1	y_1
x_1	y_3	y_2
x_1	y_2	
x_2	y_1	
x_3	y_3	

A DIVIDE B

X
x_1

A primitive set of relational operators

The full set of eight relational operators is not required. As you have already seen, join can be defined in terms of product and restrict. Intersection and divide can also be defined in terms of other commands. Indeed, only five operators are required: restrict, project, product, union, and difference. These five are known as *primitives* because these are the minimal set of relational operators. None of the primitive operators can be defined in terms of the other operators.

A fully relational database

The three components of a relational database system are structures (domains and relations), integrity rules (primary and foreign keys), and a manipulation language (relational algebra). A fully relational database system provides complete support for each of these components. Many commercial systems support SQL but do not provide support for domains. Such systems are not fully relational but are relationally complete.

In 1985, Codd established the 12 commandments of relational database systems (see the following table). In addition to providing some insights into Codd's thinking about the management of data, these rules can also be used to judge how well a database fits the relational model. The major impetus for these rules was uncertainty in the marketplace about the meaning of "relational DBMS." Codd's rules are a checklist for establishing the completeness of a relational DBMS. They also provide a short summary of the major features of the relational DBMS.

Codd's rules for a relational DBMS

Rules
The information rule
The guaranteed access rule
Systematic treatment of null values
Active online catalog of the relational model
The comprehensive data sublanguage rule
The view updating rule
High-level insert, update, and delete
Physical data independence
Logical data independence
Integrity independence
Distribution independence
The nonsubversion rule

The information rule

There is only one logical representation of data in a database. All data must appear to be stored as values in a table.

The guaranteed access rule

Every value in a database must be addressable by specifying its table name, column name, and the primary key of the row in which it is stored.

Systematic treatment of null values

There must be a distinct representation for unknown or inappropriate data. This must be unique and independent of data type. The DBMS should handle null data in a systematic way. For example, a zero or a blank cannot be used to represent a null. This is one of the more troublesome areas because null can have several meanings (e.g., missing or inappropriate).

Active online catalog of the relational model

There should be an online catalog that describes the relational model. Authorized users should be able to access this catalog using the DBMS's query language (e.g., SQL).

The comprehensive data sublanguage rule

There must be a relational language that supports data definition, data manipulation, security and integrity constraints, and transaction processing operations. Furthermore, this language must support both interactive querying and application programming and be expressible in text format. SQL fits these requirements.

The view updating rule

The DBMS must be able to update any view that is theoretically updatable.

High-level insert, update, and delete

The system must support set-at-a-time operations. For example, multiple rows must be updatable with a single command.

Physical data independence

Changes to storage representation or access methods will not affect application programs. For example, application programs should remain unimpaired even if a database is moved to a different storage device or an index is created for a table.

Logical data independence

Information-preserving changes to base tables will not affect application programs. For instance, no applications should be affected when a new table is added to a database.

Integrity independence

Integrity constraints should be part of a database's definition rather than embedded within application programs. It must be possible to change these constraints without affecting any existing application programs.

Distribution independence

Introduction of a distributed DBMS or redistribution of existing distributed data should have no impact on existing applications.

The nonsubversion rule

It must not be possible to use a record-at-a-time interface to subvert security or integrity constraints. You should not be able, for example, to write a Java program with embedded SQL commands to bypass security features.

Codd issued an additional higher-level rule, rule 0, which states that a relational DBMS must be able to manage databases entirely through its relational capacities. In other words, a DBMS is either totally relational or it is not relational.

Summary

The relational model developed as a result of recognized shortcomings of hierarchical and network DBMSs. Codd created a strong theoretical base for the relational model. Three objectives drove relational database research: data independence, communicability, and set processing. The relational model has domain structures, integrity rules, and operators used to retrieve, derive, or modify data. A domain is a set of values all of the same data type. The practical value of a domain is to define what comparisons are permissible. A relation is a table of *n* columns and *m* rows. The cardinality of a relation is its number of rows. The degree of a relation is the number of columns.

A relational database is a collection of relations. The distinguishing feature of the relational model is that there are no explicit linkages between tables. A relation's primary key is its unique identifier. When there are multiple candidates for the primary key, one is chosen as the primary key and the remainder are known as alternate keys. The foreign key is the way relationships are represented and can be thought of as the glue that binds a set of tables together to form a relational database. The purpose of the entity integrity rule is to ensure that each entity described by a relation is identifiable in some way. The referential integrity rule ensures that you cannot define a foreign key without first defining its matching primary key.

The relational model includes a set of operations, known as relational algebra, for manipulating relations. There are eight operations that can be used with either one or two relations to create a new relation. These operations are restrict, project, product, union, intersect, difference, join, and divide. Only five operators, known as primitives, are required to define all eight relational operations. An SQL statement can be translated to relational algebra and vice versa. If a retrieval language can be used to express every relational algebra operator, it is said to be relationally complete. A fully relational database system provides complete support for domains, integrity rules, and a manipulation language. Codd set forth 12 rules that can be used to judge how well a database fits the relational model. He also added rule 0—a DBMS is either totally relational or it is not relational.

Key terms and concepts

Alternate key	Join
Candidate key	Logical data independence
Cardinality	Nonsubversion rule

Catalog	Null
Communicability objective	Operators
Data independence	Physical data independence
Data structures	Primary key
Data sublanguage rule	Product
Degree	Project
Difference	Query-by-example (QBE)
Distribution independence	Referential integrity
Divide	Relational algebra
Domain	Relational calculus
Entity integrity	Set processing objective
Foreign key	Relational database
Fully relational database	Relational model
Guaranteed access rule	Relationally complete
Information rule	Relations
Integrity independence	Restrict
Integrity rules	Union
Intersect	View updating rule

References and additional readings

Codd, E. F. 1982. Relational database: A practical foundation for productivity. *Communications of the ACM* 25 (2):109–117.

Exercises

1. What reasons does Codd give for adopting the relational model?
2. What are the major components of the relational model?
3. What is a domain? Why is it useful?
4. What are the meanings of cardinality and degree?
5. What is a simple relational database?
6. What is the difference between a primary key and an alternate key?
7. Why do we need an entity integrity rule and a referential integrity rule?
8. What is the meaning of "union compatible"? Which relational operations require union compatibility?
9. What is meant by the term "a primitive set of operations"?
10. What is a fully relational database?
11. How well does LibreOffice's database satisfy Codd's rules.

10 SQL

The questing beast.

Sir Thomas Malory, *Le Morte D'Arthur*, 1470

Learning objectives

Students completing this chapter will have a detailed knowledge of SQL.

Structured query language

Structured query language (SQL) is widely used as a relational database language, and SQL skills are essential for data management in a world that is increasingly reliant on database technology. SQL originated in the IBM Research Laboratory in San Jose, California. Versions have since been implemented by commercial database vendors and open source teams for a wide range of operating systems. Both the American National Standards Institute (ANSI) and the International Organization for Standardization (ISO) have designated SQL as a standard language for relational database systems. Most data management systems have adopted an SQL style language to query data.

SQL is a complete database language. It is used for defining a relational database, creating views, and specifying queries. In addition, it allows for rows to be inserted, updated, and deleted. In database terminology, it is both a data definition language (DDL), a data manipulation language (DML), and a data control language (DCL). SQL, however, is not a complete programming language like Python, R, and Java. Because SQL statements can be embedded into general-purpose programming languages, SQL is often used in conjunction with such languages to create application programs. The embedded SQL statements handle the database processing, and the statements in the general-purpose language perform the necessary tasks to complete the application.

SQL is a declarative language, because you declare the desired results. Languages such as Java are procedural languages, because the programmer specifies each step the computer must execute. The SQL programmer can focus on defining what is required rather than detailing the process to achieve what is required. Thus, SQL programs are much shorter than their procedural equivalents.

You were introduced to SQL in Chapters 3 through 6. This chapter provides an integrated coverage of the language, pulling together the various pieces presented previously.

Data definition

The DDL part of SQL encompasses statements to operate on tables, views, and indexes. Before we proceed, however, the term “base table” must be defined. A base table is an autonomous, named table. It is autonomous because it exists in its own right; it is physically stored within the database. In contrast, a view is not autonomous because it is derived from one or more base tables and does not exist independently. A view is a virtual table. A base table has a name by which it can be referenced. This name is chosen when the base table is generated using the CREATE statement. Short-lived temporary tables, such as those formed as the result of a query, are not named.

Key

The concept of a key occurs several times within SQL. In general, a key is one or more columns identified as such in the description of a table, an index, or a referential constraint. The same column can be part of more than one key. For example, it can be part of a primary key and a foreign key. A composite key is an ordered set of columns of the same table. In other words, the primary key of `lineitem` is always the composite of (`lineno`, `saleno`) in that order, which cannot be changed.

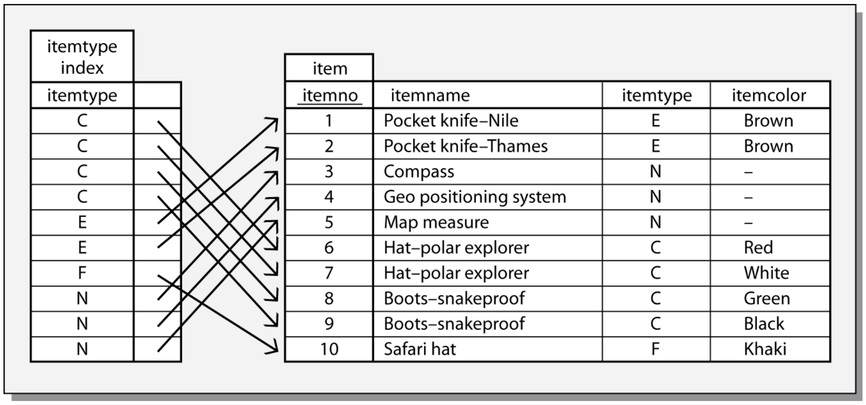
Comparing composite keys actually means that corresponding components of the keys are compared. Thus, application of the referential integrity rule—*the value of a foreign key must be equal to a value of the primary key* —means that each component of the foreign key must be equal to the corresponding component of the composite primary key.

So far, you have met primary and foreign keys. A unique key is another type of key. Its purpose is to ensure that no two values of a given column are equal. This constraint is enforced by the RDBMS during the execution of INSERT and UPDATE statements. A unique key is part of the index mechanism.

Index

Indexes are used to accelerate data access and ensure uniqueness. An index is an ordered set of pointers to rows of a base table. Think of an index as a table that contains two columns. The first column contains values for the index key, and the second contains a list of addresses of rows in the table. Since the values in the first column are ordered (i.e., in ascending or descending sequence), the index table can be searched quickly. Once the required key has been found in the table, the row’s address in the second column can be used to retrieve the data quickly. An index can be specified as being unique, in which case the RDBMS ensures that the corresponding table does not have rows with identical index keys.

An example of an index



Notation

A short primer on notation is required before we examine SQL commands.

1. Text in uppercase is required as is.
2. Text in lowercase denotes values to be selected by the query writer.
3. Statements enclosed within square brackets are optional.
4. | indicates a choice.
5. An ellipsis `...` indicates that the immediate syntactic unit may be repeated optionally more than once.

Creating a table

CREATE TABLE is used to define a new base table, either interactively or by embedding the statement in a host language. The statement specifies a table's name, provides details of its columns, and provides integrity checks. The syntax of the command is

```
CREATE TABLE base-table
    column-definition-block
    [primary-key-block]
    [referential-constraint-block]
    [unique-block];
```

Column definition

The column definition block defines the columns in a table. Each column definition consists of a column name, data type, and optionally the specification that the column cannot contain null values. The general form is

```
(column-definition [, ...])
```

where column-definition is of the form

```
column-name data-type [NOT NULL]
```

The NOT NULL clause specifies that the particular column must have a value whenever a new row is inserted.

Constraints

A constraint, part of CREATE TABLE, defines valid sets of values for a base table by placing limits on INSERT, UPDATE, and DELETE operations. Constraints can be named (e.g., `fk_stock_nation`) so that they can be turned on or off and modified. The four constraint variations apply to primary key, foreign key, unique values, and range checks.

Primary key constraint

The primary key constraint specifies the columns that constitute the primary key. Once a primary key is defined, the system enforces its uniqueness by checking that the primary key of any new row does not already exist. A table can have only one primary key. While it is not mandatory to define a primary key, it is good practice always to define a table's primary key, though it is not that common to name the constraint. The general form of the constraint is

```
[primary-key-name] PRIMARY KEY(column-name [asc|desc] [, ...])
```

The optional ASC or DESC clause specifies whether the values from this key are arranged in ascending or descending order, respectively.

For example:

```
pk_stock PRIMARY KEY(stkcode)
```

Foreign key constraint

The referential constraint block defines a foreign key, which consists of one or more columns that together must match a primary key of the specified table (or else be null). A foreign key value is null when any one of the columns in the row constituting the foreign key is null. Once the foreign key constraint is defined, the RDBMS will check every insert and update to ensure that the constraint is observed. The general form is

```
CONSTRAINT constraint-name FOREIGN KEY(column-name [,…])
    REFERENCES table-name(column-name [,…])
        [ON DELETE (RESTRICT | CASCADE | SET NULL)]
```

The constraint-name defines a referential constraint. You cannot use the same constraint-name more than once in the same table. Column-name identifies the column or columns that comprise the foreign key. The data type and length of foreign key columns must match exactly the data type and length of the primary key columns. The clause REFERENCES table-name specifies the name of an existing table, and its primary key, that contains the primary key, which cannot be the name of the table being created.

The ON DELETE clause defines the action taken when a row is deleted from the table containing the primary key. There are three options:

1. RESTRICT prevents deletion of the primary key row until all corresponding rows in a related table, one containing the foreign key, have been deleted. RESTRICT is the default and a cautious approach to data integrity.
2. CASCADE causes all the corresponding rows in the related table also to be deleted.
3. SET NULLS sets the foreign key to null for all corresponding rows in the related table.

For example:

```
CONSTRAINT fk_stock_nation FOREIGN KEY(natcode)
    REFERENCES nation(natcode)
```

Unique constraint

A unique constraint creates an index for the specified column or columns. A unique key is constrained so that no two of its values are equal. Columns appearing in a unique constraint must be defined as NOT NULL. Also, these columns should not be the same as those of the table's primary key, which is guaranteed uniqueness by its primary key definition. The constraint is enforced by the RDBMS during execution of INSERT and UPDATE statements. The general format is

```
UNIQUE constraint-name (column-name [ASC|DESC] [, …])
```

An example follows:

```
CONSTRAINT unq_stock_stkname UNIQUE(stkname)
```

Check constraint

A check constraint defines a set of valid values and can be set for a table or column.

Table constraints are defined in CREATE TABLE and ALTER TABLE statements. They can be set for one or more columns in a table. A table constraint, for example, might ensure that the selling prices is greater than the cost.

```
CREATE TABLE item (
  costPrice DECIMAL(9,2),
    sellPrice DECIMAL(9,2),
    CONSTRAINT profit_check CHECK (sellPrice > costPrice));
```

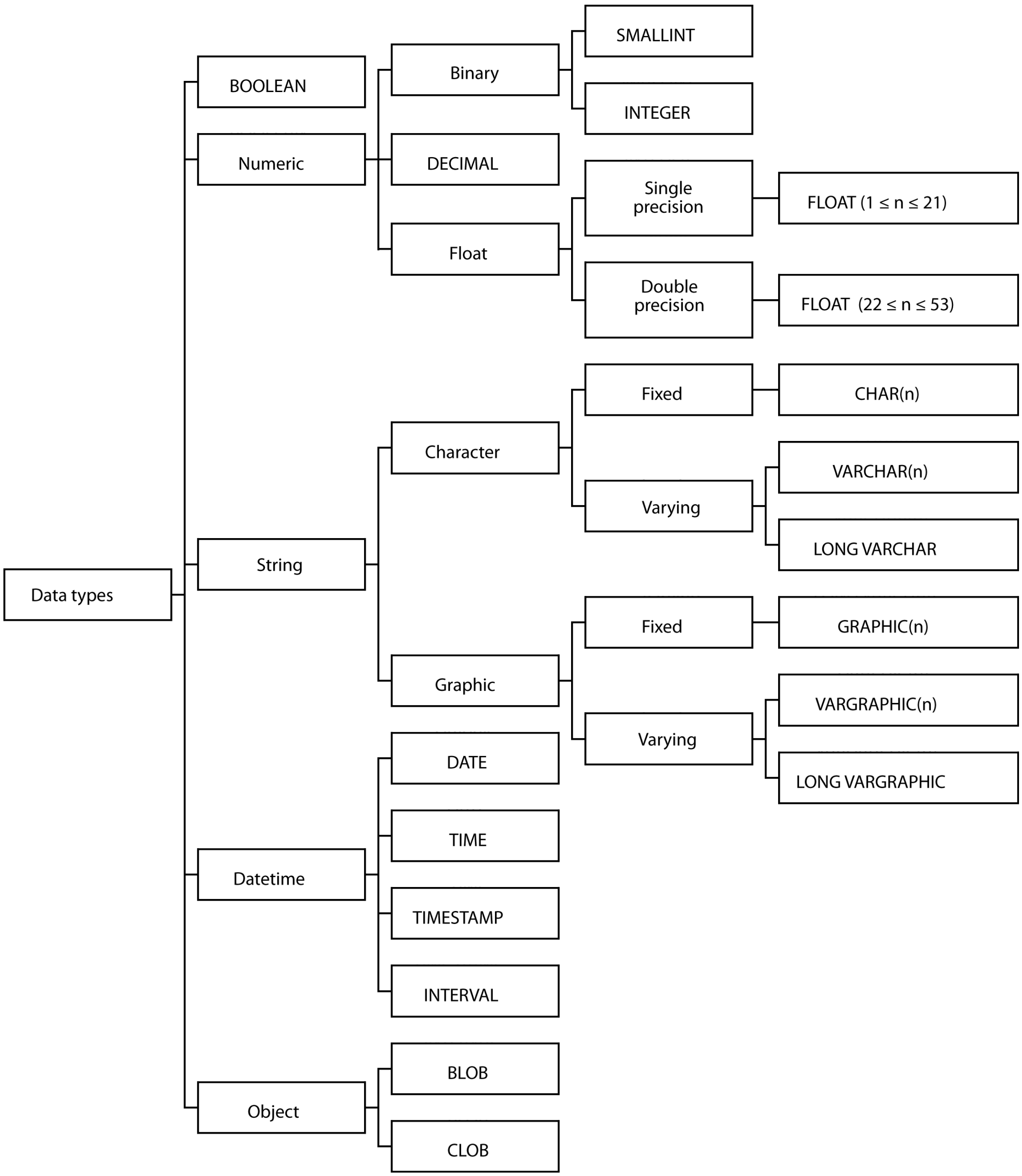
A column constraint is defined in a CREATE TABLE statement for a single column. In the following case, category is restricted to three values.

```
CREATE TABLE item (
  category CHAR(1) CONSTRAINT category_constraint
    CHECK (category IN ('B', 'L', 'S')));
```

Data types

Some of the variety of data types that can be used are depicted in the following figure and described in more detail in the following pages.

Data types



BOOLEAN

Boolean data types can have the values true, false, or unknown.

SMALLINT and INTEGER

Most commercial computers have a 32-bit word, where a word is a unit of storage. An integer can be stored in a full word or half a word. If it is stored in a full word (INTEGER), then it can be 31 binary digits in length. If half-word storage is used (SMALLINT), then it can be 15 binary digits long. In each case, one bit is used for the sign of the number. A column defined as INTEGER can store a number in the range -2^{31} to $2^{31}-1$ or -2,147,483,648 to 2,147,483,647. A column defined as SMALLINT can store a number in the range -2^{15} to $2^{15}-1$ or -32,768 to 32,767. Just remember that INTEGER is good for ±2 billion and SMALLINT for ±32,000.

FLOAT

Scientists often deal with numbers that are very large (e.g., Avogadro's number is 6.02252×10^{23}) or very small (e.g., Planck's constant is 6.6262×10^{-34} joule sec). The FLOAT data type is used for storing such numbers, often referred to as *floating-point* numbers. A single-precision floating-point number requires 32 bits and can represent numbers in the range -7.2×10^{75} to -5.4×10^{-79}, 0, 5.4×10^{-79} to 7.2×10^{75} with a precision of about 7 decimal digits. A double-precision floating-point number requires 64 bits. The range is the same as for a single-precision floating-point number. The extra 32 bits are used to increase precision to about 15 decimal digits.

In the specification FLOAT(n), if *n* is between 1 and 21 inclusive, single-precision floating-point is selected. If *n* is between 22 and 53 inclusive, the storage format is double-precision floating-point. If *n* is not specified, double-precision floating-point is assumed.

DECIMAL

Binary is the most convenient form of storing data from a computer's perspective. People, however, work with a decimal number system. The DECIMAL data type is convenient for business applications because data storage requirements are defined in terms of the maximum number of places to the left and right of the decimal point. To store the current value of an ounce of gold, you would possibly use DECIMAL(6,2) because this would permit a maximum value of $9,999.99. Notice that the general form is DECIMAL(p,q), where p is the total number of digits in the column, and q is the number of digits to the right of the decimal point.

CHAR and VARCHAR

Nonnumeric columns are stored as character strings. A person's family name is an example of a column that is stored as a character string. CHAR(n) defines a column that has a fixed length of n characters, where n can be a maximum of 255.

When a column's length can vary greatly, it makes sense to define the field as VARCHAR. A column defined as VARCHAR consists of two parts: a header indicating the length of the character string and the string. If a table contains a column that occasionally stores a long string of text (e.g., a message field), then defining it as VARCHAR makes sense. VARCHAR can store strings up to 65,535 characters long.

Why not store all character columns as VARCHAR and save space? There is a price for using VARCHAR with some relational systems. *First*, additional space is required for the header to indicate the length of the string. *Second*, additional processing time is required to handle a variable-length string compared to a fixed-length string. Depending on the RDBMS and processor speed, these might be important considerations, and some systems will automatically make an appropriate choice. For example, if you use both data types in the same table, MySQL will automatically change CHAR into VARCHAR for compatibility reasons.

There are some columns where there is no trade-off because all possible entries are always the same length. Canadian postal codes, for instance, are always six characters (e.g., the postal code for Ottawa is K1A0A1).

Data compression is another approach to the *space wars* problem. A database can be defined with generous allowances for fixed-length character columns so that few values are truncated. Data compression can be used to compress the file to remove *wasted* space. Data compression, however, is slow and will increase the time to process queries. You save space at the cost of time, and save time at the cost of space. When dealing with character fields, the database designer has to decide whether time or space is more important.

Times and dates

Columns that have a data type of DATE are stored as *yyyymmdd* (e.g., 2022-11-04 for November 4, 2022). There are two reasons for this format. *First*, it is convenient for sorting in chronological order. The common American way of writing dates (*mmddyy*) requires processing before chronological sorting. *Second*, the full form of the year should be recorded for exactness.

For similar reasons, it makes sense to store times in the form *hhmmss* with the understanding that this is 24-hour time (also known as European time and military time). This is the format used for data type TIME.

Some applications require precise recording of events. For example, transaction processing systems typically record the time a transaction was processed by the system. Because computers operate at high speed, the TIMESTAMP data type records date and time with microsecond accuracy. A timestamp has seven parts: year, month, day, hour, minute, second, and microsecond. Date and time are defined as previously described (i.e., *yyyymmdd* and *hhmmss*, respectively). The range of the microsecond part is 000000 to 999999.

Although times and dates are stored in a particular format, the formatting facilities that generally come with a RDBMS usually allow tailoring of time and date output to suit local standards. Thus for a U.S. firm, date might appear on a report in the form *mm/dd/yy*; for a European firm following the ISO standard, date would appear as *yyyy-mm-dd*.

SQL-99 introduced the INTERVAL data type, which is a single value expressed in some unit or units of time (e.g., 6 years, 5 days, 7 hours).

BLOB (binary large object)

BLOB is a large-object data type that stores any kind of binary data. Binary data typically consists of a saved spreadsheet, graph, audio file, satellite image, voice pattern, or any digitized data. The BLOB data type has no maximum size.

CLOB (character large object)

CLOB is a large-object data type that stores any kind of character data. Text data typically consists of reports, correspondence, chapters of a manual, or contracts. The CLOB data type has no maximum size.

> ☒ *Skill builder*
>
> What data types would you recommend for the following?
>
> 1. A book's ISBN
> 2. A photo of a product
> 3. The speed of light (2.9979×10^8 meters per second)
> 4. A short description of an animal's habitat
> 5. The title of a Japanese book
> 6. A legal contract
> 7. The status of an electrical switch
> 8. The date and time a reservation was made
> 9. An item's value in euros
> 10. The number of children in a family

Collation sequence

A RDBMS will typically support many character sets. so it can handle text in different languages. While many European languages are based on an alphabet, they do not all use the same alphabet. For example, Norwegian has some additional characters (e.g., æ ,ø, å) compared to English, and French accents some letters (e.g., é, ü, and â), which do not occur in English. Alphabet based languages have a collating sequence, which defines how to sort individual characters in a particular language. For English, it is the familiar A B C … X Y Z. Norwegian's collating sequence includes three additional symbols, and the sequence is A B C … X Y Z Æ Ø Å. When you define a database you need to define its collating sequence. Thus, a database being set up for exclusive use in Chile would opt for a Spanish collating sequence. You can specify a collation sequence at the database, table, and, column level. The usual practice is to specify at the database level.

```
CREATE DATABASE ClassicModels COLLATE latin1_general_cs;
```

The latin1_general character set is suitable for Western European languages. The cs suffix indicates that comparisons are case sensitive. In other words, a query will see the two strings 'abc' and 'Abc' as different, whereas if case sensitivity is turned off, the strings are considered identical. Case sensitivity is usually the right choice to ensure precision of querying.

Scalar functions

Most implementations of SQL include functions that can be used in arithmetic expressions, and for data conversion or data extraction. The following sampling of these functions will give you an idea of what is available. You will need to consult the documentation for your version of SQL to determine the functions it supports. For example, Microsoft SQL Server has more than 100 additional functions.

Some examples of SQL's built-in scalar functions

Function	Description
CURRENT_DATE()	Retrieves the current date
EXTRACT(date_time_part FROM expression)	Retrieves part of a time or date (e.g., YEAR, MONTH, DAY, HOUR, MINUTE, or SECOND)
SUBSTRING(str, pos, len)	Retrieves a string of length len starting at position pos from string str

Some examples for you to run

```
SELECT extract(day) FROM CURRENT_DATE());
```

```
SELECT SUBSTRING(`person first`, 1,1), `person last` FROM person;
```

A vendor's additional functions can be very useful. Remember, though, that use of a vendor's extensions might limit portability.

How many days' sales are stored in the sale table?

This sounds like a simple query, but you have to do a self-join and also know that there is a function, DATEDIFF, to determine the number of days between any two dates. Consult your RDBMS manual to learn about other functions for dealing with dates and times.

```
WITH
late AS (SELECT * FROM sale),
early AS (SELECT * FROM sale)
SELECT DISTINCT DATEDIFF(late.saledate,early.saledate) AS Difference
    FROM late JOIN early
```

```
        ON late.saledate =
            (SELECT MAX(saledate) FROM sale)
        AND early.saledate =
            (SELECT MIN(saledate) FROM sale);
```

The preceding query is based on the idea of joining `sale` with a copy of itself. The matching column from `late` is the latest sale's date (or MAX), and the matching column from `early` is the earliest sale's date (or MIN). As a result of the join, each row of the new table has both the earliest and latest dates.

Formatting

You will likely have noticed that some queries report numeric values with a varying number of decimal places. The FORMAT function gives you control over the number of decimal places reported, as illustrated in the following example where yield is reported with two decimal places.

```
SELECT shrfirm, shrprice, shrqty, FORMAT(shrdiv/shrprice*100,2)
  AS yield
    FROM share;
```

When you use format you create a string, but you often want to sort on the numeric value of the formatted field. The following example illustrates how to do this.

```
SELECT shrfirm, shrprice, shrqty, FORMAT(shrdiv/shrprice*100,2)
  AS yield FROM share
      ORDER BY shrdiv/shrprice*100 DESC;
```

Run the following code to see the difference.

```
SELECT shrfirm, shrprice, shrqty, FORMAT(shrdiv/shrprice*100,2)
  AS yield FROM share
      ORDER BY yield DESC;
```

Table commands

Altering a table

The ALTER TABLE statement has two purposes. *First,* it can add a single column to an existing table. *Second*, it can add, drop, activate, or deactivate primary and foreign key constraints. A base table can be altered by adding one new column, which appears to the right of existing columns. The format of the command is

```
ALTER TABLE base-table ADD column data-type;
```

Notice that there is no optional NOT NULL clause for column-definition with ALTER TABLE. It is not allowed because the ALTER TABLE statement automatically fills the additional column with null in every case. If you want to add multiple columns, you repeat the command. ALTER TABLE does not permit changing the width of a column or amending a column's data type. It can be used for deleting an unwanted column.

```
ALTER TABLE stock ADD stkrating CHAR(3);
```

ALTER TABLE is also used to change the status of referential constraints. You can deactivate constraints on a table's primary key or any of its foreign keys. Deactivation also makes the relevant tables unavailable to everyone except the table's owner or someone possessing database management authority. After the data are loaded, referential constraints must be reactivated before they can be automatically enforced again. Activating the constraints enables the RDBMS to validate the references in the data.

Dropping a table

A base table can be deleted at any time by using the DROP statement. The format is

```
DROP TABLE base-table;
```

The table is deleted, and any views or indexes defined on the table are also deleted.

Creating a view

A view is a virtual table. It has no physical counterpart but appears to the client as if it really exists. A view is defined in terms of other tables that exist in the database. The syntax is

```
CREATE VIEW view [column [,column] …)]
    AS subquery;
```

There are several reasons for creating a view. *First*, a view can be used to restrict access to certain rows or columns. This is particularly important for sensitive data. An organization's person table can contain both private data (e.g., annual salary) and public data (e.g., office phone number). A view consisting of public data (e.g., person's name, department, and office telephone number) might be provided to many people. Access to all columns in the table, however, might be confined to a small number of people. Here is a sample view that restricts access to a table.

```
CREATE VIEW stklist
    AS SELECT stkfirm, stkprice FROM stock;
```

Handling derived data is a second reason for creating a view. A column that can be computed from one or more other columns should always be defined by a view. Thus, a stock's yield would be computed by a view rather than defined as a column in a base table.

```
CREATE VIEW stk
    (stkfirm, stkprice, stkqty, stkyield)
    AS SELECT stkfirm, stkprice, stkqty, stkdiv/stkprice*100
        FROM stock;
```

A *third* reason for defining a view is to avoid writing common SQL queries. For example, there may be some joins that are frequently part of an SQL query. Productivity can be increased by defining these joins as views. Here is an example:

```
CREATE VIEW stkvalue
    (nation, firm, price, qty, value)
    AS SELECT natname, stkfirm, stkprice*exchrate, stkqty,
        stkprice*exchrate*stkqty FROM stock JOIN nation
            ON stock.natcode = nation.natcode;
```

The preceding example demonstrates how CREATE VIEW can be used to rename columns, create new columns, and involve more than one table. The column `nation` corresponds to `natname`, `firm` to `stkfirm`, and so forth. A new column, `price`, is created that converts all share prices from the local currency to British pounds.

Data conversion is a *fourth* useful reason for a view. The United States is one of the few countries that does not use the metric system, and reports for American managers often display weights and measures in pounds and feet, respectively. The database of an international company could record all measurements in metric format (e.g., weight in kilograms) and use a view to convert these measures for American reports.

When a CREATE VIEW statement is executed, the definition of the view is entered in the systems catalog. The subquery following AS, the view definition, is executed only when the view is referenced in an SQL command. For example, the following command would enable the subquery to be executed and the view created:

```
SELECT * FROM stkvalue WHERE price > 10;
```

```
SELECT natname, stkfirm, stkprice*exchrate, stkqty, stkprice*exchrate*stkqty
    FROM stock JOIN nation
        ON stock.natcode = nation.natcode
        WHERE stkprice*exchrate > 10;
```

Any table that can be defined with a SELECT statement is a potential view. Thus, it is possible to have a view that is defined by another view.

Dropping a view

DROP VIEW is used to delete a view from the system catalog. A view might be dropped because it needs to be redefined or is no longer used. It must be dropped before a revised version of the view is created. The syntax is

```
DROP VIEW view;
```

Remember, if a base table is dropped, all views based on that table are also dropped.

Creating an index

An index helps speed up retrieval (a more detailed discussion of indexing is covered later in this book). A column that is frequently referred to in a WHERE clause is a possible candidate for indexing. For example, if data on stocks were frequently retrieved using `stkfirm`, then this column should be considered for an index. The format for CREATE INDEX is

```
CREATE [UNIQUE] INDEX indexname
    ON base-table (column [order] [,column, [order]] …)
    [CLUSTER];
```

This next example illustrates use of CREATE INDEX.

```
CREATE UNIQUE INDEX stkfirmindx ON stock(stkfirm);
```

In the preceding example, an index called `stkfirmindx` is created for the table `stock`. Index entries are ordered by ascending (the default order) values of `stkfirm`. The optional clause UNIQUE specifies that no two rows in the base table can have the same value for `stkfirm`, the indexed column. Specifying UNIQUE means that the RDBMS will reject any insert or update operation that would create a duplicate value for `stkfirm`.

A composite index can be created from several columns, which is often necessary for an associative entity. The following example illustrates the creation of a composite index.

```
CREATE INDEX lineitemindx ON lineitem (lineno, saleno);
```

Dropping an index

Indexes can be dropped at any time by using the DROP INDEX statement. The general form of this statement is

```
DROP INDEX index;
```

Data manipulation

SQL supports four DML statements—SELECT, INSERT, UPDATE, and DELETE. Each of these is discussed in turn, with most attention focusing on SELECT because of the variety of ways in which it can be used. First, we need to understand why we must qualify column names and temporary names.

Qualifying column names

Ambiguous references to column names are avoided by qualifying a column name with its table name, especially when the same column name is used in several tables. Clarity is maintained by prefixing the column name with the table name. The following example demonstrates qualification of the `natcode`, which appears in both `stock` and `nation`.

```
SELECT stkfirm, stkprice FROM stock JOIN nation
    ON stock.natcode = nation.natcode;
```

Temporary names

Using the WITH clause, a table or view can be given a temporary name, or alias, that remains current for a query. Temporary names are used in a self-join to distinguish the copies of the table.

```
WITH
wrk AS (SELECT * FROM emp),
boss AS (SELECT * FROM emp)
SELECT wrk.empfname
    FROM wrk JOIN boss
        ON wrk.bossno = boss.empno;
```

A temporary name also can be used as a shortened form of a long table name. For example, `l` might be used merely to avoid having to enter `lineitem` more than once. If a temporary name is specified for a table or view, any qualified reference to a column of the table or view must also use that temporary name.

SELECT

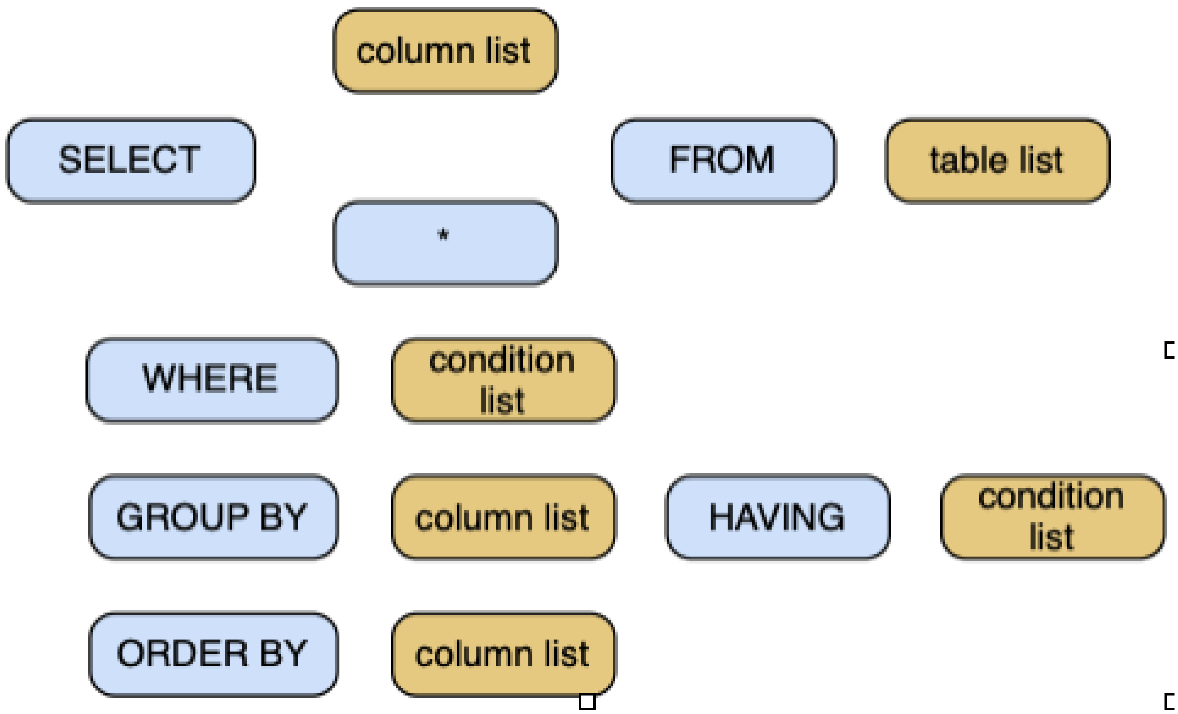
The SELECT statement is by far the most interesting and challenging of the four DML statements. It reveals a major benefit of the relational model: powerful interrogation capabilities. It is challenging because mastering the power of SELECT requires considerable practice with a wide range of queries. The major varieties of SELECT are presented in this section. The SQL Playbook, on the book's website, reveals the full power of the command.

The general format of SELECT is

```
SELECT [DISTINCT] item(s) FROM table(s)
    [WHERE condition]
    [GROUP BY column(s)] [HAVING condition]
    [ORDER BY column(s)];
```

Alternatively, we can diagram the structure of SELECT.

Structure of SELECT



Product

Product, or more strictly Cartesian product, is a fundamental operation of relational algebra. It is rarely used by itself in a query; however, understanding its effect helps in comprehending join. The product of two tables is a new table consisting of all rows of the first table concatenated with all possible rows of the second table. For example:

Form the product of stock and nation.

```
SELECT * FROM stock, nation;
```

Run the query and observe that the new table contains 64 rows (16*4), where `stock` has 16 rows and `nation` has 4 rows. It has 10 columns (7 + 3), where `stock` has 7 columns and `nation` has 3 columns. Note that each row in `stock` is concatenated with each row in `nation`.

Find the percentage of Australian stocks in the portfolio.

To answer this query, you need to count the number of Australian stocks, count the total number of stocks in the portfolio, and then compute the percentage. Computing each of the totals is a straightforward application of COUNT. If we save the results of the two counts as views, then we have the necessary data to compute the percentage. The two views each consist of a single-cell table (i.e., one row and one column). We create the product of these two views to get the data needed for computing the percentage in one row. The SQL is

```
CREATE VIEW austotal (auscount) AS
  SELECT COUNT(*) FROM nation JOIN stock
     ON natname = 'Australia'
     WHERE nation.natcode = stock.natcode;
```

```
CREATE VIEW total (totalcount) AS
  SELECT COUNT(*) FROM stock;
```

```
SELECT auscount/totalcount*100
  AS percentage FROM austotal, total;
```

```
CREATE VIEW total (totalcount) AS
    SELECT COUNT(*) FROM stock;
```

```
SELECT auscount*100/totalcount as Percentage
    FROM austotal, total;
```

The result of a COUNT is always an integer, and SQL will typically create an integer data type in which to store the results. When two variables have a data type of integer, SQL will likely use integer arithmetic for all computations, and all results will be integer. To get around the issue of integer arithmetic, we first multiply the number of Australian stocks by 100 before dividing by the total number of stocks. Because of integer arithmetic, you might get a different answer if you use the following SQL.

```
SELECT auscount/totalcount*100 as Percentage
    FROM austotal, total;
```

The preceding example was used to show when you might find product useful. You can also write the query as

```
SELECT (SELECT COUNT(*) FROM stock WHERE natcode = 'AUS')*100/
    (SELECT COUNT(*) FROM stock) as Percentage;
```

Inner join

Inner join, often referred to as join, is a powerful and frequently used operation. It creates a new table from two existing tables by matching on a column common to both tables. An equijoin is the simplest form of join; in this case, columns are matched on equality.

```
SELECT * FROM stock JOIN nation
    ON stock.natcode = nation.natcode;
```

There are other ways of expressing join that are more concise. For example, we can write

```
SELECT * FROM stock INNER JOIN nation USING (natcode);
```

The preceding syntax implicitly recognizes the frequent use of the same column name for matching primary and foreign keys.

A further simplification is to rely on the primary and foreign key definitions to determine the join condition, so we can write

```
SELECT * FROM stock NATURAL JOIN nation;
```

An equijoin creates a new table that contains two identical columns. If one of these is dropped, then the remaining table is called a natural join.

Theta join

As you now realize, join can be thought of as a product with a condition clause. There is no reason why this condition needs to be restricted to equality. There could easily be another comparison operator between the two columns. This general version is called a theta-join because theta is a variable that can take any value from the set '=', '<', '<=', '>', and '>='.

As you discovered earlier, there are occasions when you need to join a table to itself. To do this, make two copies of the table and give each of them a unique name.

Find the names of employees who earn more than their boss.

```
WITH wrk AS (SELECT * FROM emp),
     boss AS (SELECT * FROM emp)
SELECT wrk.empfname AS Worker, wrk.empsalary AS Salary,
  boss.empfname AS Boss, boss.empsalary AS Salary
FROM wrk JOIN boss
    ON wrk.bossno = boss.empno
    WHERE wrk.empsalary > boss.empsalary;
```

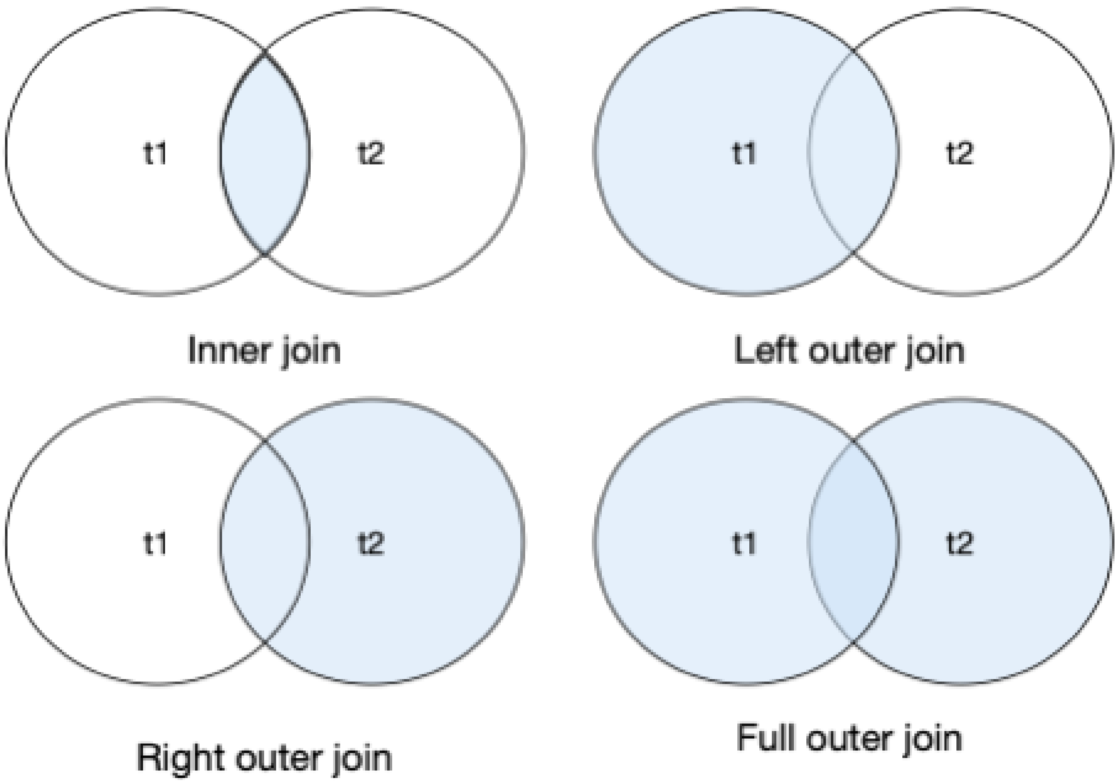
Table 10.2: 1 records

Worker	Salary	Boss	Salary
Sarah	56000	Brier	43000

Outer join

An inner join reports those rows where the primary and foreign keys match. There are also situations where you might want an outer join, which comes in three flavors as shown in the following figure.

Types of joins



A traditional join, more formally known as an inner join, reports those rows where the primary and foreign keys match. An outer join reports these matching rows and other rows depending on which form is used, as the following examples illustrate for the sample table.

t1		t2	
id	col1	id	col2
1	a	1	x
2	b	3	y
3	c	5	z

A left outer join is an inner join plus those rows from t1 not included in the inner join.

```
SELECT id, col1, col2 FROM t1 LEFT JOIN t2 USING (id)
```

id	col1	col2
1	a	x
2	b	null
3	c	y

Here is an example to illustrate the use of a left join.

For all brown items, report each sale. Include in the report those brown items that have appeared in no sales.

```
SELECT itemname, saleno, lineqty FROM item
    LEFT JOIN lineitem USING (itemno)
        WHERE itemcolor = 'Brown'
        ORDER BY itemname;
```

A right outer join is an inner join plus those rows from t2 not included in the inner join.

```
SELECT id, col1, col2 FROM t1 RIGHT JOIN t2 USING (id);
```

Id	col1	col2
1	a	x
3	c	y
5	null	z

A full outer join is an inner join plus those rows from t1 and t2 not included in the inner join.

```
SELECT id, col1, col2 FROM t1 FULL JOIN t2 USING (id);
```

id	col1	col2
1	a	x
2	b	null
3	c	y
5	null	z

MySQL does not support a full outer join, rather you must use a union of left and right outer joins.

```
SELECT id, col1, col2 FROM t1 LEFT JOIN t2 USING (id)
UNION
SELECT id, col1, col2 FROM t1 RIGHT JOIN t2 USING (id);
```

Simple subquery

A subquery is a query within a query. There is a SELECT statement nested inside another SELECT statement. Simple subqueries were used extensively in earlier chapters. For reference, here is a simple subquery used earlier:

```
SELECT stkfirm FROM stock
    WHERE natcode IN
        (SELECT natcode FROM nation
            WHERE natname = 'Australia');
```

Correlated subquery

A correlated subquery differs from a simple subquery in that the inner query must be evaluated more than once. Consider the following example described previously:

Find those stocks where the quantity is greater than the average for that country.

```
SELECT natname, stkfirm, stkqty FROM stock JOIN nation
ON stock.natcode = nation.natcode
WHERE stkqty >
    (SELECT AVG(stkqty) FROM stock
        WHERE stock.natcode = nation.natcode);
```

The requirement to compare a column against a function (e.g., average or count) of some column of specified rows of is usually a clue that you need to write a correlated subquery. In the preceding example, the stock quantity for each row is compared with the average stock quantity for that row's country.

Aggregate functions

SQL's aggregate functions increase its retrieval power. These functions were covered earlier and are only mentioned briefly here for completeness. The five aggregate functions are shown in the following table. Nulls in the column are ignored in the case of SUM, AVG, MAX, and MIN. COUNT(*) does not distinguish between null and non-null values in a column. Use COUNT(columnname) to exclude a null value in columnname.

Aggregate functions

Function	Description
COUNT	Counts the number of values in a column
SUM	Sums the values in a column
AVG	Determines the average of the values in a column
MAX	Determines the largest value in a column
MIN	Determines the smallest value in a column

Computing a median

A median is the midpoint of a frequency distribution of observed values. MySQL does not include median in its set of aggregate functions, but it can be computed.

Find median value for stock holdings.

To simplify coding, we first create a view v1 of sorted stock holdings with rows numbered.

CREATE VIEW v1 AS (SELECT stkfirm, SUM(stkprice*stkqty*exchrate) AS total, ROW_NUMBER() OVER(ORDER BY SUM(stkprice*stkqty*exchrate)) AS rownum FROM stock JOIN nation ON stock.natcode = nation.natcode GROUP BY stkfirm);

The next stage is to count the number of rows in view v1 to create view v2.

CREATE VIEW v2 As (SELECT COUNT(*) AS num_records FROM stock JOIN nation ON stock.natcode = nation.natcode);

If there an even number of rows, then the median is the average of the middle two. For an odd number, there is one middle row. We use the FLOOR function to determine which rows to use for computing the median. FLOOR computes the greatest integer less than or equal to a given value. For example, FLOOR(3.7) is 3.

Putting the pieces together we have:

SELECT AVG(total) AS Median FROM v1, v2 WHERE rownum IN (FLOOR((num_records + 1) / 2), FLOOR((num_records + 2) / 2));

GROUP BY and HAVING

The GROUP BY clause is an elementary form of control break reporting and supports grouping of rows that have the same value for a specified column and produces one row for each different value of the grouping column. For example,

Report by nation the total value of stockholdings.

```
SELECT natname, SUM(stkprice*stkqty*exchrate) AS total
    FROM stock JOIN nation ON stock.natcode = nation.natcode
        GROUP BY natname;
```

The HAVING clause is often associated with GROUP BY. It can be thought of as the WHERE clause of GROUP BY because it is used to eliminate rows for a GROUP BY condition. Both GROUP BY and HAVING are dealt with in-depth in Chapter 4.

REGEXP

The REGEXP clause supports pattern matching to find a defined set of strings in a character column (CHAR or VARCHAR). Refer to Chapters 3 and 4 for more details.

10.0.1 CASE

The CASE statement is used to implement a series of conditional clauses. In the following query, the first step creates a temporary table that records customers and their total orders. The second step classifies customers into four categories based on their total orders.

```
WITH temp AS
  (SELECT customerName, COUNT(*) AS orderCount
    FROM Orders JOIN Customers
      ON Customers.customerNumber = Orders.customerNumber
      GROUP BY customerName)
SELECT customerName, orderCount,
    CASE orderCount
      WHEN 1 THEN 'One-time Customer'
      WHEN 2 THEN 'Repeated Customer'
      WHEN 3 THEN 'Frequent Customer'
      ELSE 'Loyal Customer'
    end customerType
    FROM temp
ORDER BY customerName;
```

INSERT

There are two formats for INSERT. The first format is used to insert one row into a table.

Inserting a single record

The general form is

```
INSERT INTO table [(column [,column] …)]
    VALUES (literal [,literal] …);
```

For example,

```
INSERT INTO stock
    (stkcode,stkfirm,stkprice,stkqty,stkdiv,stkpe)
    VALUES ('FC','Freedonia Copper',27.5,10529,1.84,16);
```

In this example, `stkcode` is given the value "FC," `stkfirm` is "Freedonia Copper," and so on. The *n*th column in the table is the *n*th value in the list.

When the value list refers to all field names in the left-to-right order in which they appear in the table, then the columns list can be omitted. So, it is possible to write the following:

```
INSERT INTO stock
    VALUES ('FC','Freedonia Copper',27.5,10529,1.84,16);
```

If some values are unknown, then the INSERT can omit these from the list. Undefined columns will have nulls. For example, if a new stock is to be added for which the PE ratio is 5, the following INSERT statement would be used:

```
INSERT INTO stock
    (stkcode, stkfirm, stkPE)
    VALUES ('EE','Elysian Emeralds',5);
```

Inserting multiple records using a query

The second form of INSERT operates in conjunction with a subquery. The resulting rows are then inserted into a table. Imagine the situation where stock price information is downloaded from an information service into a table. This table could contain information about all stocks and may contain additional columns that are not required for the stock table. The following INSERT statement could be used:

```
INSERT INTO stock
    (stkcode, stkfirm, stkprice, stkdiv, stkpe)
    SELECT code, firm, price, div, pe
    FROM download WHERE code IN
    ('FC','PT','AR','SLG','ILZ','BE','BS','NG','CS','ROF');
```

Think of INSERT with a subquery as a way of copying a table. You can select the rows and columns of a particular table that you want to copy into an existing or new table.

UPDATE

The UPDATE command is used to modify values in a table. The general format is

```
UPDATE table
    SET column = scalar expression
        [, column = scalar expression] …
    [WHERE condition];
```

Permissible scalar expressions involve columns, scalar functions (see the section on scalar functions in this chapter), or constants. No aggregate functions are allowable.

Updating a single row

UPDATE can be used to modify a single row in a table. Suppose you need to revise your data after 200,000 shares of Minnesota Gold are sold. You would code the following:

```
UPDATE stock
    SET stkqty = stkqty - 200000
    WHERE stkcode = 'MG';
```

Updating multiple rows

Multiple rows in a table can be updated as well. Imagine the situation where several stocks change their dividend to £2.50. Then the following statement could be used:

```
UPDATE stock
    SET stkdiv = 2.50
    WHERE stkcode IN ('FC','BS','NG');
```

Updating all rows

All rows in a table can be updated by simply omitting the WHERE clause. To give everyone a 5 percent raise, use

```
UPDATE emp
    SET empsalary = empsalary*1.05;
```

Updating with a subquery

A subquery can also be used to specify which rows should be changed. Consider the following example. The employees in the departments on the fourth floor have won a productivity improvement bonus of 10 percent. The following SQL statement would update their salaries:

```
UPDATE emp
    SET empsalary = empsalary*1.10
    WHERE deptname IN
        (SELECT deptname FROM dept WHERE deptfloor = 4);
```

DELETE

The DELETE statement erases one or more rows in a table. The general format is

```
DELETE FROM table
    [WHERE condition];
```

Delete a single record

If all stocks with stkcode equal to “BE” were sold, then this row can be deleted using

```
DELETE FROM stock WHERE stkcode = 'BE';
```

Delete multiple records

If all Australian stocks were liquidated, then the following command would delete all the relevant rows:

```
DELETE FROM stock
    WHERE natcode in
    (SELECT natcode FROM nation WHERE natname = 'Australia');
```

Delete all records

All records in a table can be deleted by omitting the WHERE clause. The following statement would delete all rows if the entire portfolio were sold:

```
DELETE FROM stock;
```

This command is not the same as DROP TABLE because, although the table is empty, it still exists.

Delete with a subquery

Despite their sterling efforts in the recent productivity drive, all the employees on the fourth floor have been fired (the rumor is that they were fiddling the tea money). Their records can be deleted using

```
DELETE FROM emp
    WHERE deptname IN
        (SELECT deptname FROM dept WHERE deptfloor = 4);
```

SQL routines

SQL provides two types of routines—functions and procedures—that are created, altered, and dropped using standard SQL. Routines add flexibility, improve programmer productivity, and facilitate the enforcement of business rules and standard operating procedures across applications.

SQL function

A function is SQL code that returns a value when invoked within an SQL statement. It is used in a similar fashion to SQL's built-in functions. Consider the case of an Austrian firm with a database in which all measurements are in SI units (e.g., meters). Because its U.S. staff is not familiar with SI,[1] it decides to implement a series of user-defined functions to handle the conversion. Here is the function for converting from kilometers to miles. Note that MySQL requires that you include the word DETERMINISTIC for a function that always produces the same result for the same input parameters.

```
CREATE FUNCTION km_to_miles(km REAL)
    RETURNS REAL
    DETERMINISTIC
    RETURN 0.6213712*km;
```

The preceding function can be used within any SQL statement to make the conversion. For example:

```
SELECT km_to_miles(100);
```

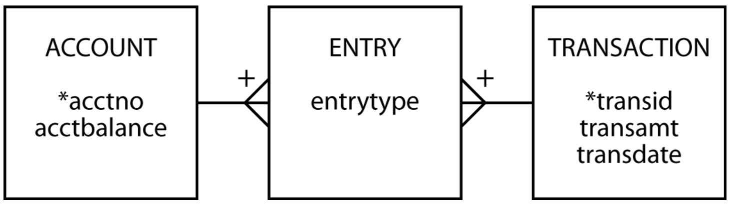
> ☒ *Skill builder*
>
> Create a table containing the average daily temperature in Tromsø, Norway, then write a function to convert Celsius to Fahrenheit (F = C*1.8 + 32), and test the function by reporting temperatures in C and F.
>
> The temperatures in month order: -4.7, -4.1, -1.9, 1.1, 5.6, 10.1, 12.7, 11.8, 7.7, 2.9, -1.5, -3.7

[1] The international system of units of measurement. SI is the from French *Système International*.

SQL procedure

A procedure is SQL code that is dynamically loaded and executed by a CALL statement, usually within a database application. We use an accounting system to demonstrate the features of a stored procedure, in which a single accounting transaction results in two entries (one debit and one credit). In other words, a transaction has multiple entries, but an entry is related to only one transaction. An account (e.g., your bank account) has multiple entries, but an entry is for only one account. Considering this situation results in the following data model.

A simple accounting system



The following are a set of steps for processing a transaction (e.g., transferring money from a checking account to a money market account):

1. Write the transaction to the transaction table so you have a record of the transaction.
2. Update the account to be credited by incrementing its balance in the account table.
3. Insert a row in the entry table to record the credit.
4. Update the account to be debited by decrementing its balance in the account table.
5. Insert a row in the entry table to record the debit.

Here is the code for a stored procedure to execute these steps. Note that the first line sets the delimiter to // because the default delimiter for SQL is a semicolon (;), which we need to use to delimit the multiple SQL commands in the procedure. The last statement in the procedure is thus END // to indicate the end of the procedure.

```
DELIMITER //
-- Define the input values
CREATE PROCEDURE transfer (
IN `Credit account` INTEGER,
IN `Debit account`  INTEGER,
IN  Amount          DECIMAL(9,2),
IN `Transaction ID` INTEGER)
LANGUAGE SQL
DETERMINISTIC
BEGIN
-- Save the transaction details
INSERT INTO transaction VALUES (`Transaction ID`, Amount, CURRENT_DATE);
UPDATE account
-- Increase the credit account
SET acctbalance = acctbalance + Amount
WHERE acctno = `Credit account`;
```

```
INSERT INTO entry VALUES (`Transaction ID`, `Credit account`, 'cr');
UPDATE account
-- Decrease the debit account
SET acctbalance = acctbalance - Amount
WHERE acctno = `Debit account`;
INSERT INTO entry VALUES (`Transaction ID`, `Debit account`, 'db');
END //
```

A CALL statement executes a stored procedure. The generic CALL statement for the preceding procedure is

```
CALL transfer(cracct, dbacct, amt, transno);
```

Thus, imagine that transaction 1005 transfers $100 to account 1 (the credit account) from account 2 (the debit account). The specific call is

```
CALL transfer(1,2,100,1005);
```

☒ *Skill builder*

1. Create the tables for the preceding data model, insert a some reows, and enter the code for the stored procedure. Now, test the stored procedure and query the tables to verify that the procedure has worked.
2. Write a stored procedure to add details of a gift to the donation database (see exercises in Chapter 5).

Trigger

A trigger is a form of stored procedure that executes automatically when a table's rows are modified. Triggers can be defined to execute either before or after rows are inserted into a table, when rows are deleted from a table, and when columns are updated in the rows of a table. Triggers can include virtual tables that reflect the row image before and after the operation, as appropriate. Triggers can be used to enforce business rules or requirements, integrity checking, and automatic transaction logging.

Consider the case of recording all updates to the `stock` table (see Chapter 4). First, you must define a table in which to record details of the change.

```
CREATE TABLE stock_log (
stkcode            CHAR(3),
old_stkprice       DECIMAL(6,2),
new_stkprice       DECIMAL(6,2),
old_stkqty         DECIMAL(8),
new_stkqty         DECIMAL(8),
update_stktime  TIMESTAMP NOT NULL,
    PRIMARY KEY(update_stktime));
```

The trigger writes a record to `stock_log` every time an update is made to `stock`. Two virtual tables (`old` and `new`) have details of the prior and current values of stock price (`old.stkprice` and `new.stkprice`) and stock quantity (`old.stkprice` and `new.stkprice`). The INSERT statement also writes the stock's identifying code and the time of the transaction.

```
DELIMITER //
CREATE TRIGGER stock_update
AFTER UPDATE ON stock
FOR EACH ROW BEGIN
INSERT INTO stock_log VALUES
    (OLD.stkcode, OLD.stkprice, NEW.stkprice,
    OLD.stkqty, NEW.stkqty, CURRENT_TIMESTAMP);
END //
```

> ☒ *Skill builder*
>
> Why is the primary key of `stock_log` not the same as that of stock?

Universal Unique Identifier (UUID)

A Universally Unique Identifier (UUID) is a generated number that is globally unique even if generated by independent programs on different computers. The probability that a UUID is not unique is close enough to zero to be negligible. More precisely, the probability of a duplicate within 103 trillion UUIDs is one in a billion.

A UUID is a 128-bit number generated by combining a timestamp and the generating computers's node id to create an identifier that it temporally and spatially different. A UUID is useful when you want to support different programs on different computers inserting rows in a distributed database.

```
SELECT UUID() AS UUID_Value;
```

Nulls—much ado about missing information

Nulls are overworked in SQL because they can represent several situations. Null can represent unknown information. For example, you might add a new stock to the database, but lacking details of its latest dividend, you leave the field null. Null can be used to represent a value that is inapplicable. For instance, the employee table contains a null value in bossno for Alice because she has no boss. The value is not unknown; it is not applicable for that field. In other cases, null might mean "no value supplied" or "value undefined." Because null can have multiple meanings, the client must infer which meaning is appropriate to the circumstances.

Do not confuse null with blank or zero, which are values. In fact, null is a marker that specifies that the value for the particular column is null. Thus, null represents no value.

The well-known database expert Chris Date has been outspoken in his concern about the confusion caused by nulls. His advice is that nulls should be explicitly avoided by specifying NOT NULL for all columns and by using codes to make the meaning of a value clear (e.g., "U" means "unknown," "I" means "inapplicable," and "N" means "not supplied").

Security

Data are a valuable resource for nearly every organization. Just as an organization takes measures to protect its physical assets, it also needs to safeguard its electronic assets—its organizational memory, including databases. Furthermore, it often wants to limit the access of authorized users to particular parts of a database and restrict their actions to particular operations.

Two SQL features are used to administer security procedures. A view, discussed earlier in this chapter, can restrict a client's access to specified columns or rows in a table, and authorization commands can establish a user's privileges.

The authorization subsystem is based on the concept of a privilege—the authority to perform an operation. For example, a person cannot update a table unless they have been granted the appropriate update privilege. The database administrator (DBA) is a master of the universe and has the highest privilege. The DBA can perform any legal operation. The creator of an object, say a base table, has full privileges for that object. Those with privileges can then use GRANT and REVOKE, commands included in SQL's data control language (DCL) to extend privileges to or rescind them from other users.

GRANT

The GRANT command defines a client's privileges. The general format of the statement is

```
GRANT privileges ON object TO users [WITH GRANT OPTION];
```

where "privileges" can be a list of privileges or the keyword ALL PRIVILEGES, and "users" is a list of user identifiers or the keyword PUBLIC. An "object" can be a base table or a view.

The following privileges can be granted for tables and views: SELECT, UPDATE, DELETE, and INSERT.

The UPDATE privilege specifies the particular columns in a base table or view that may be updated. Some privileges apply *only* to base tables. These are ALTER and INDEX.

The following examples illustrate the use of GRANT:

Give Alice all rights to the stock table.

```
GRANT ALL PRIVILEGES ON stock TO alice;
```

Permit the accounting staff, Todd and Nancy, to update the price of a stock.

```
GRANT UPDATE (stkprice) ON stock TO todd, nancy;
```

Give all staff the privilege to select rows from item.

```
GRANT SELECT ON item TO PUBLIC;
```

Give Alice all rights to view stk.

```
GRANT SELECT, UPDATE, DELETE, INSERT ON stk TO alice;
```

The WITH GRANT OPTION clause

The WITH GRANT OPTION command allows a client to transfer his privileges to another client, as this next example illustrates:

Give Ned all privileges for the item table and permit him to grant any of these to other staff members who may need to work with item.

```
GRANT ALL PRIVILEGES ON item TO ned WITH GRANT OPTION;
```

This means that Ned can now use the GRANT command to give other staff privileges. To give Andrew permission for select and insert on item, for example, Ned would enter

```
GRANT SELECT, INSERT ON item TO andrew;
```

REVOKE

What GRANT granteth, REVOKE revoketh. Privileges are removed using the REVOKE statement. The general format of this statement is

```
REVOKE privileges ON object FROM users;
```

These examples illustrate the use of REVOKE.

Remove Sophie's ability to select from item.

```
REVOKE SELECT ON item FROM sophie;
```

Nancy is no longer permitted to update stock prices.

```
REVOKE UPDATE ON stock FROM nancy;
```

Cascading revoke

When a REVOKE statement removes a privilege, it can result in more than one revocation. An earlier example illustrated how Ned used his WITH GRANT OPTION right to authorize Andrew to select and insert rows on item. The following REVOKE command

```
REVOKE INSERT ON item FROM ned;
```

automatically revokes Andrew's insert privilege.

The system catalog

The system catalog describes a relational database. It contains the definitions of base tables, views, indexes, and so on. The catalog itself is a relational database and can be interrogated using SQL. Tables in the catalog are called *system tables* to distinguish them from base tables, though conceptually these tables are the same. In MySQL, the system catalog is called information_schema. Some important system tables in this schema are tables, and columns, and these are used in the following examples. Note that the names of the system catalog tables vary with RDBMS implementations, so while the following examples illustrate use of system catalog tables, it is likely that you will have to change the table names for other RDBMSs.

The table TABLES contains details of all tables in the database. There is one row for each table in the database.

Find the table(s) with the most columns.

```
SELECT table_name, table_rows
    FROM information_schema.tables
        WHERE table_rows = (SELECT MAX(table_rows)
            FROM information_schema.tables);
```

The `COLUMN` table stores details about each column in the database.

What columns in what tables store dates?

```
SELECT table_name, column_name
    FROM information_schema.columns
        WHERE DATA_TYPE = 'date'
            ORDER BY table_name, column_name;
```

As you can see, querying the catalog is the same as querying a database. This is a useful feature because you can use SQL queries on the catalog to find out more about a database.

Natural language processing

Infrequent inquirers of a relational database may be reluctant to use SQL because they don't use it often enough to remain familiar with the language. While the QBE approach can make querying easier, a more natural approach is to use standard English. In this case, natural language processing (NLP) is used to convert ordinary English into SQL so the query can be passed to the relational database. The example in the table below shows the successful translation of a query to SQL. A natural language processor must translate a request to SQL and request clarification where necessary.

An example of natural language processing

English	SQL generated for MS Access
Which movies have won best foreign film sorted by year?	SELECT DISTINCT [Year], [Title] FROM [Awards] INNER JOIN [Movies] ON [Movies].[Movie ID] = [Awards].[Movie ID] WHERE [Category]='Best Foreign Film' and [Status]='Winner' ORDER BY [Year] ASC;

Connectivity and ODBC

Over time and because of differing needs, an organization is likely to purchase RDBMS software from a variety of vendors. Also, in some situations, mergers and acquisitions can create a multivendor RDBMS environment. Consequently, the SQL Access Group developed SQL Call-Level Interface (CLI), a unified standard for remote database access. The intention of CLI is to provide programmers with a generic approach for writing software that accesses a database. With the appropriate CLI database driver, any RDBMS server can provide access to client programs that use the CLI. On the server side, the RDBMS CLI driver is responsible for translating the CLI call into the server's access language. On the client side, there must be a CLI driver for each database to which it connects. CLI is not a query language but a way of wrapping SQL so it can be understood by a RDBMS. In 1996, CLI was adopted as an international standard and renamed X/Open CLI.

Open database connectivity (ODBC)

The de facto standard for database connectivity is Open Database Connectivity (ODBC), an extended implementation of CLI developed by Microsoft. This application programming interface (API) is cross-platform and can be used to access any RDBMS that has an ODBC driver. This enables a software developer to build and distribute an application without targeting a specific RDBMS. Database drivers are then added to link the application to the client's choice of RDBMS. For example, a desktop app running under Windows can use ODBC to access an Oracle RDBMS running on a Unix box.

There is considerable support for ODBC. Application vendors like it because they do not have to write and maintain code for each RDBMS; they can write one API. RDBMS vendors support ODBC because they do not have to convince application vendors to support their product. For database systems managers, ODBC provides vendor and platform independence. Although the ODBC API was originally developed to provide database access from MS Windows products, many ODBC driver vendors support Linux and Macintosh clients.

Most vendors also have their own SQL APIs. The problem is that most vendors, as a means of differentiating their RDBMS, have a more extensive native API protocol and also add extensions to standard ODBC. The developer who is tempted to use these extensions threatens the portability of the database.

ODBC introduces greater complexity and a processing overhead because it adds two layers of software. As the following figure illustrates, an ODBC-compliant application has additional layers for the ODBC API and ODBC driver. As a result, ODBC APIs can never be as fast as native APIs.

ODBC layers

Application
ODBC API
ODBC driver manager
Service provider API
Driver for RDBMS server
RDBMS server

Embedded SQL

SQL can be used in two modes. *First,* SQL is an interactive query language and database programming language. SELECT defines queries; INSERT, UPDATE, and DELETE to maintain a database. *Second*, any interactive SQL statement can be embedded in an application program.

This dual-mode principle is a very useful feature. It means that programmers need to learn one database query language, because the same SQL statements apply for both interactive queries and application statements. Programmers can also interactively examine SQL commands before embedding them in a program, a feature that can substantially reduce the time to write an application program.

Because SQL is not a complete programming language, however, it must be used with a traditional programming language to create applications. Common complete programming languages, such as and Java, support embedded SQL. If you are need to write application programs using embedded SQL, you will need training in both the application language and the details of how it communicates with SQL.

User-defined types

Versions of SQL prior to the SQL-99 specification had predefined data types, and programmers were limited to selecting the data type and defining the length of character strings. One of the basic ideas behind the object extensions of the SQL standard is that, in addition to the normal built-in data types defined by SQL, user-defined data types (UDTs) are available. A UDT is used like a predefined type, but it must be set up before it can be used.

The future of SQL

Since 1986, developers of database applications have benefited from an SQL standard, one of the more successful standardization stories in the software industry. Although most database vendors have implemented proprietary extensions of SQL, standardization has kept the language consistent, and SQL code is highly portable. Standardization was relatively easy when focused on the storage and retrieval of numbers and characters. Objects have made standardization more difficult.

Summary

Structured Query Language (SQL), a widely used relational database language, has been adopted as a standard by ANSI and ISO. It is a data definition language (DDL), data manipulation language (DML), and data control language (DCL). A base table is an autonomous, named table. A view is a virtual table. A key is one or more columns identified as such in the description of a table, an index, or a referential constraint. SQL supports primary, foreign, and unique keys. Indexes accelerate data access and ensure uniqueness. CREATE TABLE defines a new base table and specifies primary, foreign, and unique key constraints. Numeric, string, date, or graphic data can be stored in a column. BLOB and CLOB are data types for large fields. ALTER TABLE adds one new column to a table or changes the status of a constraint. DROP TABLE removes a table from a database. CREATE VIEW defines a view, which can be used to restrict access to data, report derived data, store commonly executed queries, and convert data. A view is created dynamically. DROP VIEW deletes a view. CREATE INDEX defines an index, and DROP INDEX deletes one.

Ambiguous references to column names are avoided by qualifying a column name with its table name. A table or view can be given a temporary name that remains current for a query. SQL has four data manipulation statements—SELECT, INSERT, UPDATE, and DELETE. INSERT adds one or more rows to a table. UPDATE modifies a table by changing one or more rows. DELETE removes one or more rows from a table. SELECT provides powerful interrogation facilities. The product of two tables is a new table consisting of all rows of the first table concatenated with all possible rows of the second table. Join creates a new table from two existing tables by matching on a column common to both tables. A subquery is a query within a query. A correlated subquery differs from a simple subquery in that the inner query is evaluated multiple times rather than once.

SQL's aggregate functions increase its retrieval power. GROUP BY supports grouping of rows that have the same value for a specified column. The REXEXP clause supports pattern matching. SQL includes scalar functions that can be used in arithmetic expressions, data conversion, or data extraction. Nulls cause problems because they can represent several situations—unknown information, inapplicable information, no value supplied, or value undefined. Remember, a null is not a blank or zero. The SQL commands, GRANT and REVOKE, support data security. GRANT authorizes a user to perform certain SQL operations, and REVOKE removes a user's authority.

The system catalog, which describes a relational database, can be queried using SELECT. SQL can be used as an interactive query language and as embedded commands within an application programming language. Natural language processing (NLP) and open database connectivity (ODBC) are extensions to relational technology that enhance its usefulness.

Key terms and concepts

Aggregate functions	GROUP BY
ALTER TABLE	Index
ANSI	INSERT
Base table	ISO
Complete database language	Join
Complete programming language	Key
Composite key	Natural language processing (NLP)
Connectivity	Null
Correlated subquery	Open database connectivity (ODBC)
CREATE FUNCTION	Primary key
CREATE INDEX	Product
CREATE PROCEDURE	Qualified name
CREATE TABLE	Referential integrity rule
CREATE TRIGGER	REVOKE
CREATE VIEW	Routine
Cursor	Scalar functions
Data control language (DCL)	Security
Data definition language (DDL)	SELECT
Data manipulation language (DML)	Special registers
Data types	SQL
DELETE	Subquery
DROP INDEX	Synonym
DROP TABLE	System catalog
DROP VIEW	Temporary names
Embedded SQL	Unique key
Foreign key	UPDATE
GRANT	View

References and additional readings

Date, C. J. 2003. *An introduction to database systems*. 8th ed. Reading, MA: Addison-Wesley.

Exercises

1. Why is it important that SQL was adopted as a standard by ANSI and ISO?
2. What does it mean to say “SQL is a complete database language”?

3. Is SQL a complete programming language? What are the implications of your answer?
4. List some operational advantages of a RDBMS.
5. What is the difference between a base table and a view?
6. What is the difference between a primary key and a unique key?
7. What is the purpose of an index?
8. Consider the three choices for the ON DELETE clause associated with the foreign key constraint. What are the pros and cons of each option?
9. Specify the data type (e.g., DECIMAL(6,2)) you would use for the following columns:
    a. The selling price of a house
    b. A telephone number with area code
    c. Hourly temperatures in Antarctica
    d. A numeric customer code
    e. A credit card number
    f. The distance between two cities
    g. A sentence using Chinese characters
    h. The number of kilometers from the Earth to a given star
    i. The text of an advertisement in the classified section of a newspaper
    j. A basketball score
    k. The title of a CD
    l. The X-ray of a patient
    m. A U.S. zip code
    n. A British or Canadian postal code
    o. The photo of a customer
    p. The date a person purchased a car
    q. The time of arrival of an e-mail message
    r. The number of full-time employees in a small business
    s. The text of a speech
    t. The thickness of a layer on a silicon chip
10. What is the difference between DROP TABLE and deleting all the rows in a table?
11. Give some reasons for creating a view.
12. When is a view created?
13. Write SQL codes to create a unique index on firm name for the share table defined in Chapter 3. Would it make sense to create a unique index for PE ratio in the same table?

14. What is the difference between product and join?
15. What is the difference between an equijoin and a natural join?
16. You have a choice between executing two queries that will both give the same result. One is written as a simple subquery and the other as a correlated subquery. Which one would you use and why?
17. What function would you use for the following situations?
    a. Computing the total value of a column
    b. Finding the minimum value of a column
    c. Counting the number of customers in the customer table
    d. Displaying a number with specified precision
    e. Reporting the month part of a date
    f. Displaying the second part of a time
    g. Retrieving the first five characters of a city's name
    h. Reporting the distance to the sun in feet
18. Write SQL statements for the following:
    a. Let Hui-Tze query and add to the nation table.
    b. Give Lana permission to update the phone number column in the customer table.
    c. Remove all of William's privileges.
    d. Give Chris permission to grant other users authority to select from the address table.
    e. Find the name of all tables that include the word sale.
    f. List all the tables created last year.
    g. What is the maximum length of the column city in the ClassicModels database? Why do you get two rows in the response?
    h. Find all columns that have a data type of SMALLINT.
19. What are the two modes in which you can use SQL?
20. Using the ClassicModels database, write an SQL procedure to change the credit limit of all customers in a specified country by a specified amount. Provide before and after queries to show your procedure works.
21. How do procedural programming languages and SQL differ in the way they process data? How is this difference handled in an application program? What is embedded SQL?
22. Using the ClassicModels database, write an SQL procedure to change the MSRP of all products in a product line by a specified percentage. Provide before and after queries to show your procedure works.

Section 3 Data Science and Advanced Data Management

Advancement only comes with habitually doing more than you are asked.

Gary Ryan Blair.[2]

The wiring of the world has given us ubiquitous networks and broadened the scope of issues that data management must now embrace. In everyday life, you might use a variety of networks (e.g., the Internet, 5G, WiFi, and bluetooth) to gain access to information wherever you might be and whatever time it is. As a result, data managers need to be concerned with both the spatial and temporal dimensions of data. Graph databases have grown in popularity because they are optimized for analyzing networks, such as social connections and supply chains. In a highly connected world, massive amounts of data are exchanged every minute between computers to enable a high level of global integration in economic and social activity. XML has emerged as the foundation for data exchange across many industries. It is a core technology for global economic development. On the social side, every day people generate millions of messages, photos, and videos that fuel services such as Twitter, Flickr, and YouTube.

Most organizations are interested in applying data science to analyzing the vast volumes of data they can access to learn about social trends, customers' opinions, and entrepreneurial opportunities. The discipline of data science combines data cleaning and transformation, statistical analysis, data visualization, and machine learning (ML) techniques. Organizations need extensive skills in collecting, processing, and interpreting the myriad data flows that intersect with their everyday business.

Organizational or business intelligence is the general term for describing an enterprise's efforts to collect, store, process, and interpret data from internal and external sources. It is the first stage of data-driven decision making. Once data have been captured and stored in an organizational repository, data science techniques can be applied.

In a world awash with data, visualization has become increasingly important for enabling executives to make sense of the business environment, to identify problems, and highlight potential new directions. Text mining is a popular tool for trying to make sense of data streams emanating from tweets and blogs. The many new sources of data and their high growth rate have made it more difficult to support real time analysis of the torrents of data that might contain valuable insights for an organization's managers. Fortunately, Hadoop distributed file system (HDFS) and cluster computing methods are a breakthrough in storing and processing data that enable faster processing at lower cost. Dashboards are widely used for presenting key information. Furthermore, the open source statistics and graphical package, R, provides a common foundation for handling text mining, data visualization, HDFS, and cluster computing. It has become another

[2] http://www.everythingcounts.com

component of the data manager's toolkit. The section concludes by illustrating to use Java to access a relational database.

The section covers the following topics.

- Spatial and temporal data management
- Graph databases
- XML
- Organizational intelligence
- Introduction to R
- Data visualization
- Text mining
- Cluster Computing
- Dashboards
- SQL and Java

11 Spatial and Temporal Data Management

Nothing puzzles me more than time and space; and yet nothing troubles me less, as I never think about them.

Charles Lamb, 1810.

Learning objectives

Students completing this chapter will

- be able to define and use a spatial database;
- be familiar with the issues surrounding the management of temporal data.

Spatial data

The introduction of ubiquitous networks and smartphones has led to the advent of location-based services. Customers expect information delivered based on, among other things, where they are. For example, a person touring the historic German city of Regensburg could receive information about its buildings and parks via their mobile phone in the language of choice. Their smartphone will determine their location and then select from a database details of the immediate environment. Data managers need to know how to manage the spatial data necessary to support location-based services.

Some aspect of time is an important fact to remember for many applications. Banks, for example, want to remember what dates customers made payments on their loans. Airlines need to recall for the current and future days who will occupy seats on each flight. Thus, the management of time-varying, or temporal, data is availed when a database management system has built-in temporal support. As a result, there has been extensive research on temporal data models and RDBMSs for more than a decade. The management of temporal data is another skill required of today's data management specialist.

The Open Geospatial Consortium, Inc. (OGC) is a nonprofit international organization developing standards for geospatial and location-based services. Its goal is to create open and extensible software application programming interfaces for geographic information systems (GIS) and other geospatial technologies. RDBMS vendors (e.g., MySQL) have implemented some of OGC's recommendations for adding spatial features to SQL. MySQL is gradually adding further GIS features as it develops its DBMS.

Managing spatial data

A spatial database is a data management system for the collection, storage, manipulation, and output of spatially referenced information. Also known as a geographic information system (GIS), it is an extended form of RDBMS. Geospatial modeling is based on three key concepts: theme, geographic object, and map.

A theme refers to data describing a particular topic (e.g., scenic lookouts, rivers, cities) and is the spatial counterpart of an entity. When a theme is presented on a screen or paper, it is commonly seen in conjunction with a map. Color may be used to indicate different themes (e.g., blue for rivers and black for roads). A map will usually have a scale, legend, and possibly some explanatory text.

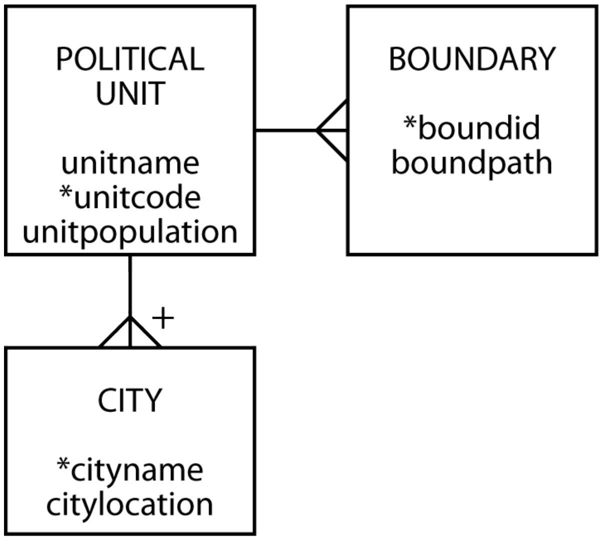
A geographic object is an instance of a theme (e.g., a river). Like an instance of an entity, it has a set of attributes. In addition, it has spatial components that can describe both geometry and topology. Geometry refers to the location-based data, such as shape and length, and topology refers to spatial relationships among objects, such as adjacency. Management of spatial data requires some additional data types to represent a point, line, and region.

Generic spatial data types

Data type	Dimensions	Example
Point	0	Scenic lookout
Line	1	River
Region	2	County

Consider the case where we want to create a database to store some details of political units. A political unit can have many boundaries. The United States, for example, has a boundary for the continental portion, one for Alaska, one for Hawaii, and many more to include places such as American Samoa. In its computer form, a boundary is represented by an ordered set of line segments (a path).

Data model for political units



SQL/MM Spatial

SQL/MM, also known as ISO 13249, is an extension of SQL to handle spatial data. It uses the prefix ST_ for tables, views, data types, and function names. Originally, this prefix meant *Spatial* and *Temporal*, because the intention was to develop a standard that combined spatial and temporal extensions to SQL. However, it was realized that temporal required a broader perspective and should be separate standard. Thus, think of ST_ as meaning *Spatial Type*.

MySQL has data types for storing geometric data, which are:

Type	Representation	Description
Point	POINT(x y)	A point in space (e.g., a city's location)
LineString	:LINESTRING(x1 y1,x2 y2,…)	A sequence of points with linear interpolation between points (e.g., a road)
Polygon	POLYGON((x1 y1,x2 y2,…), (x1 y1,x2 y2,…))	A polygon (e.g., a boundary) which has a single exterior boundary and zero or more interior boundaries (i.e., no holes)

Spatial Reference Support System (SRS)

A spatial reference system (SRS) is facilitates the location of geometric objects using coordinates. A specific SRS is identified by an SRID, which is an integer

There are three types of reference systems:

Projected

A projected SRS is a projection of a globe on a flat surface. Map makers have developed a variety of approaches, such as Mecator, to represent a portion of the earth on a page or screen. Each point on the flat surface is a place on the globe. A projected SRS typically shows a length legend, such as the distance in miles or kilometers.

Geographic

For a geographic SRS, the coordinates are latitude and longitude. The SRID is 4326. [1]

Cartesian

A Cartesian SRS, is an infinite flat plane with no specified units. The SRID is 0, and this is the default if you don't specify an SRS.

Data model mapping

The data model in the preceding figure is mapped to MySQL. By specifying a SRID of 0, Ireland is represented in the following map using a Cartesian SRS. Since Ireland is small relative the size of the earth, this is a reasonable approximation.

In the following definition of the database's tables, note two things. The boundpath column of boundary is defined with a data type of POLYGON and SRID of 0. The cityloc column of city is defined as a POINT. Otherwise, there is little new in the set of statements to create the tables.

Political unit database definition

```
CREATE TABLE political_unit (
    Unitname    VARCHAR(30) NOT NULL,
    Unitcode    CHAR(2),
    Unitpop   DECIMAL(6,2),
      PRIMARY KEY(unitcode));
```

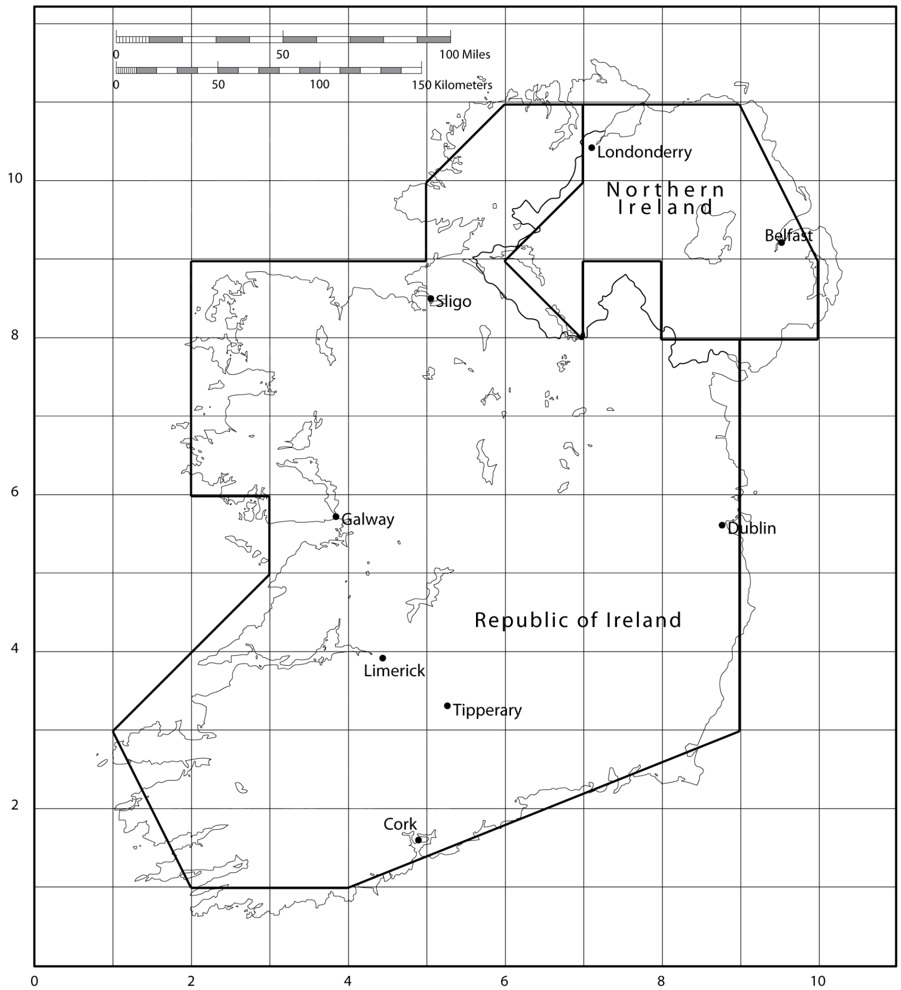
```
CREATE TABLE boundary (
    Boundid   INTEGER,
    Boundpath   POLYGON NOT NULL SRID 0,
    Unitcode    CHAR(2),
      PRIMARY KEY(boundid),
      CONSTRAINT fk_boundary_polunit FOREIGN KEY(unitcode)
        REFERENCES political_unit(unitcode));
```

[1] epsg.io/4326

```
CREATE TABLE city (
    Cityname     VARCHAR(30),
    Cityloc   POINT NOT NULL SRID 0,
    Unitcode     CHAR(2),
      PRIMARY KEY(unitcode,cityname),
      CONSTRAINT fk_city_polunit FOREIGN KEY(unitcode)
        REFERENCES political_unit(unitcode));
```

We now use the geographic entity of Ireland to demonstrate the application of spatial concepts. The island has two political units. The Republic of Ireland (Eire) governs the south, while Northern Ireland, a part of the United Kingdom, is in the north.

Map of Ireland



To represent these two political units within a spatial database, we need to define their boundaries. Typically, this is done by approximating the boundary by a single exterior polygon. In the preceding figure, you see a very coarse representation based on connecting intersection points of the overlay grid. The SRID needs to be specified for each geometric object, as for example where it is set to 0 when specifying Dublin's coordinates, `ST_GeomFROMText('POINT(9 6)', 0)`.

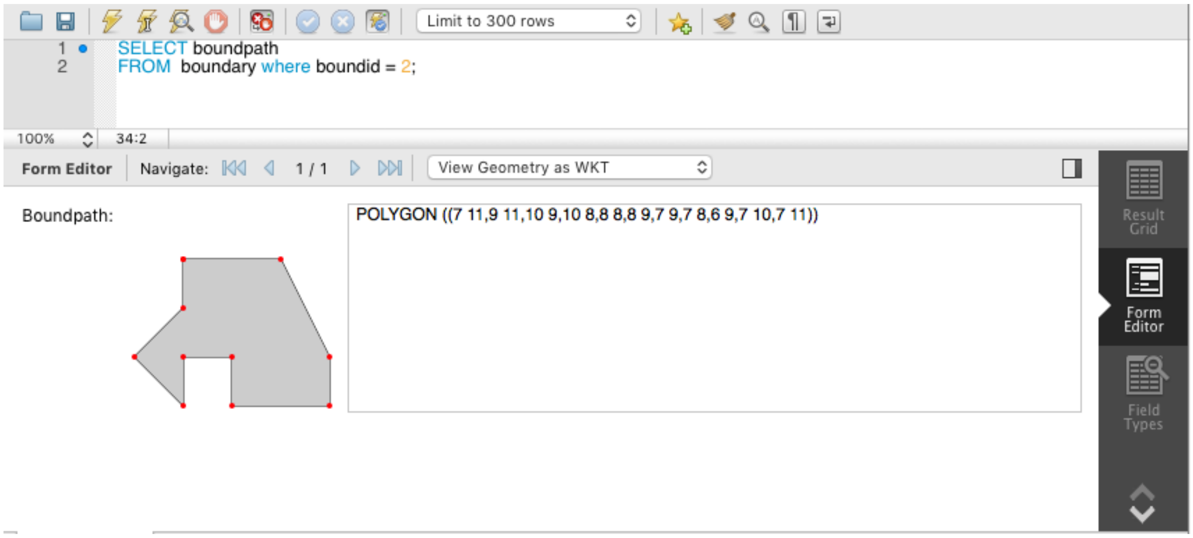
Insert statements for populating database

```
INSERT INTO political_unit VALUES
('Republic of Ireland','ie', 3.9);
INSERT INTO political_unit VALUES
('Northern Ireland','ni', 1.7);
INSERT INTO boundary VALUES
    (1,ST_GeomFROMText('POLYGON((9 8, 9 3, 4 1, 2 2, 1 3,
    3 5, 3 6, 2 6,2 9, 5 9, 5 10, 6 11, 7 11, 7 10, 6 9,
    7 8, 7 9, 8 9, 8 8, 9 8))', 0),'ie');
INSERT INTO boundary VALUES
    (2,ST_GeomFROMText('POLYGON((7 11, 9 11, 10 9, 10 8,
    8 8, 8 9, 7 9,7 8, 6 9, 7 10, 7 11))', 0),'ni');
INSERT INTO city VALUES
 ('Dublin',ST_GeomFROMText('POINT(9 6)', 0),'ie');
INSERT INTO city VALUES
 ('Cork',ST_GeomFROMText('POINT(5 2)', 0),'ie');
INSERT INTO city VALUES
 ('Limerick',ST_GeomFROMText('POINT(4 4)', 0),'ie');
INSERT INTO city VALUES
 ('Galway',ST_GeomFROMText('POINT(4 6)', 0),'ie');
INSERT INTO city VALUES
 ('Sligo',ST_GeomFROMText('POINT(5 8)', 0),'ie');
INSERT INTO city VALUES
 ('Tipperary',ST_GeomFROMText('POINT(5 3)', 0),'ie');
INSERT INTO city VALUES
 ('Belfast',ST_GeomFROMText('POINT(9 9)', 0),'ni');
INSERT INTO city VALUES
 ('Londonderry',ST_GeomFROMText('POINT(7 10)', 0),'ni');
```

The two sets of values for the column `boundary` define the boundaries of the Republic of Ireland and Northern Ireland. Because of the coarseness of this sample mapping, the Republic of Ireland has only one boundary. A finer-grained mapping would have multiple boundaries, such as one to include the Arran Islands off the west coast near Galway. Each city's location is defined by a point or pair of coordinates. `ST_GeomFromText` is an MySQL function to convert text into a geometry data form.

Workbench can show you the boundaries for you spatial database. See the following screenshot.

Boundary path as displayed by Workbench



☒ *Skill builder*

Create the three tables for the example and insert the rows listed in the preceding SQL code.

MySQL includes a number of geometry functions and operators for processing spatial data that simplify the writing of queries. A column's SRID value determines the method of calculating area or distance. Euclidean geometry is use for a flat plane (SRID = 0), and spherical geometry for latitude and longitude measures (SRID = 4326). For illustrative purposes, just a few of the geometric functions are described.

Some MySQL geometric functions

Function	Description
ST_X(Point)	The x-coordinate of a point
ST_Y(Point)	The y-coordinate of a point
ST_Distance(Point, Point)	The distance between two points
ST_NumPoints(LineString)	The number of points in a linestring
ST_Area(Polygon)	The area of a polygon

Once the database is established, we can do some queries to gain an understanding of the additional capability provided by the spatial additions. Before starting, examine the scale on the map and note that one grid unit is about 37.5 kilometers (23 miles). This also means that the area of one grid unit is 1406 km (526 square miles).

What is the area of the Republic of Ireland?

Because we approximate the border by a polygon, we use the area function and multiply the result by 1406 to convert to square kilometers.

```
SELECT ST_AREA(boundpath)*1406
  AS 'Area (km^2)' FROM political_unit JOIN boundary
    ON political_unit.unitcode = boundary.unitcode
      WHERE unitname = 'Republic of Ireland';
```

Table 11.4: 1 records

Area (km^2)
71706

How far, as the crow flies, is it from Sligo to Dublin?

You can measure the distance between two points using ST_Distance. You will need to multiply the result by 37.5 or 23 to convert to kilometers or miles, respectively.

```
WITH
  orig AS (SELECT * FROM city),
  dest AS (SELECT * FROM city)
SELECT ST_Distance(orig.cityloc,dest.cityloc)*37.5
  AS "Distance (kms)"
    FROM orig, dest
     WHERE orig.cityname = 'Sligo'
     AND dest.cityname = 'Dublin';
```

Table 11.5: 1 records

Distance (kms)
167.7051

What is the closest city to Limerick?

This query has a familiar structure. The inner query determines the minimum distance between Limerick and other cities. Notice that there is a need to exclude comparing the distance from Limerick to itself, which is zero.

```
WITH
  orig AS (SELECT * FROM city),
  dest AS (SELECT * FROM city)
SELECT dest.cityname FROM orig, dest
WHERE orig.cityname = 'Limerick'
AND ST_Distance(orig.cityloc,dest.cityloc)=
 (SELECT MIN(ST_Distance(orig.cityloc,dest.cityloc))
    FROM city orig, city dest
    WHERE orig.cityname = 'Limerick'
      AND dest.cityname <> 'Limerick');
```

Table 11.6: 1 records

Cityname
Tipperary

What is the westernmost city in Ireland?

The first thing to recognize is that by convention west is shown on the left side of the map, which means the westernmost city will have the smallest x-coordinate.

```
WITH
  west AS (SELECT * FROM city),
  other AS (SELECT * FROM city)
SELECT west.cityname FROM  west
WHERE NOT EXISTS
    (SELECT * FROM  other WHERE ST_X(other.cityloc)
      < ST_X(west.cityloc));
```

Table 11.7: 2 records

Cityname
Galway
Limerick

☒ *Skill builder*

1. What is the area of Northern Ireland? Because Northern Ireland is part of the United Kingdom and miles are still often used to measure distances, report the area in square miles.
2. What is the direct distance from Belfast to Londonderry in miles?
3. What is the northernmost city of the Republic of Ireland?

Geometry collections

A geometry collection is a data type for describing one or more geometries. It covers multiple points, strings, polygons, as well as their possible combinations.

MultiPoint

The multipoint data type records information about a set of points, such as the bus stops on campus. For example:

```
MULTIPOINT(9.0 6.1, 8.9 6.0)
```

MultiLineString

The MultiLineString data type records information about a set of line strings, such as the bus routes on campus. For example:

```
MULTILINESTRING((9 6, 4 6), (9 6, 5 2))
```

MULTIPOLYGON

The MultiPOLYGON data type records information about a set of polygons, such as the shapes of the buildings on campus. For example:

```
MULTIPOLYGON(((0 0,10 0,10 10,0 10,0 0)),
  ((5 5,7 5,7 7,5 7, 5 5)))
```

GEOMETRYCOLLECTION

The GEOMETRYCOLLECTION data type records information about a collection of geometries, such as the bus routes and stops on campus. For example:

```
GEOMETRYCOLLECTION(LINESTRING(15 15, 20 20),
 POINT(10 10), POINT(30 30))
```

You can insert data using `ST_GeomCollFromText`, as the following example illustrates:

```
INSERT INTO table VALUES
ST_GeomCollFromText('GEOMETRYCOLLECTION(POINT(1 1),
  LINESTRING(0 0,1 1,2 2,3 3,4 4))');
```

> ☒ *Skill builder*
>
> Modify the example database design to include:
>
> 1. Historic buildings in a city
> 2. Walking paths in a city
> 3. Use of the MULTIPOLYGON data type to indicate a political region's boundary

Geocoding using Google Maps

To get the latitude and longitude of a location, you can use Google Maps by following this procedure.

1. Go to maps.google.com.
2. Enter your address, zip code, airport code, or whatever you wish to geocode.
3. Click on the link that says 'link to this page.' It is on the right side, just above the upper right corner of the map.
4. The address bar (URL) will change. Examine the full link. For example: https://www.google.com/maps/place/Athens-Ben+Epps+Airport+-+AHN/@33.9519038,-83.3273184,17z/data=!3m1!4b1!4m5!3m4!1s0x88f66b676ce4ce85:0x749d5ade6813b384!8m2!3d33.9519038!4d-83.3251297.
5. The latitude and longitude are contained in the URL following AHN/@. In this case, latitude is: 33.9519038 and longitude: −83.3273184.

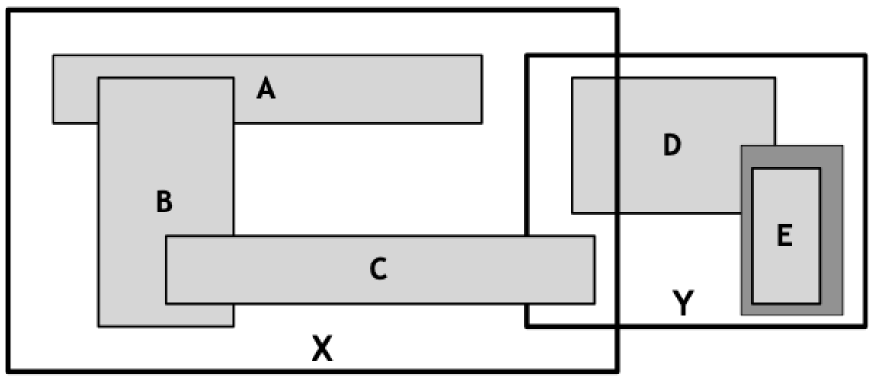
R-tree

Conventional RDBMSs were developed to handle one-dimensional data (numbers and text strings). In a spatial database, points, lines, and rectangles may be used to represent the location of retail outlets, roads, utilities, and land parcels. Such data objects are represented by sets of x, y or x, y, z coordinates. Other applications requiring the storage of spatial data include computer-aided design (CAD), robotics, and computer vision.

The B-tree, often used to store data in one-dimensional databases, can be extended to n dimensions, where $n \geq 2$. This extension of the B-tree is called an R-tree. As well as storing pointers to records in the sequence set, an R-tree also stores boundary data for each object. For a two-dimensional application, the boundary data are the x and y coordinates of the lower left and upper-right corners of the *minimum bounding* rectangle, the smallest possible rectangle enclosing the object. The index set, which contains pointers to lower-level nodes as in a B-tree, also contains data for the minimum bounding rectangle enclosing the objects referenced in the node. The data in an R-tree permit answers to such problems as *Find all pizza stores within 5 miles of the dorm.*

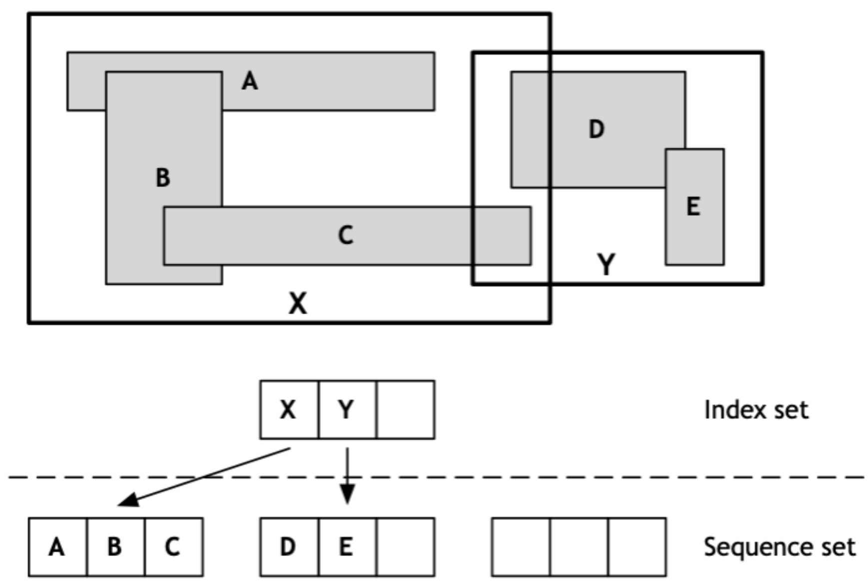
How an R-tree stores data is illustrated in the following figure, which depicts five two-dimensional objects labeled A, B, C, D, and E. Each object is represented by its minimum bounding rectangle (the objects could be some other form, such as a circle). Data about these objects are stored in the sequence set. The index set contains details of two intermediate rectangles: X and Y. X fully encloses A, B, and C. Y fully encloses D and E.

An R-tree with sample spatial data



An example demonstrates how these data are used to accelerate searching. Using a mouse, a person could outline a region on a map displayed on a screen. The minimum bounding rectangle for this region would then be determined and the coordinates used to locate geographic objects falling within the minimum boundary. Because an R-tree is an index, geographic objects falling within a region can be found rapidly. In the following figure, the drawn region (it shaded) completely covers object E. The R-tree software would determine that the required object falls within intermediate region Y, and thus takes the middle node at the next level of the R-tree. Then, by examining coordinates in this node, it would determine that E is the required object.

Searching an R-tree



As the preceding example illustrates, an R-tree has the same index structure as a B-tree. An R-tree stores data about *n*-dimensional objects in each node, whereas a B-tree stores data about a one-dimensional data type in each node. Both also store pointers to the next node in the tree (the index set) or the record (the sequence set).

This short introduction to spatial data has given you some idea of how the relational model can be extended to support geometric information. Most of the major RDBMS vendors support management of spatial data.

Managing temporal data

With a temporal database, stored data have an associated time period indicating when the item was valid or stored in the database. By attaching a timestamp to data, it becomes possible to store and identify different database states and support queries comparing these states. Thus, you might be able to determine the number of seats booked on a flight by 3 p.m. on January 21, 2011, and compare that to the number booked by 3 p.m. on January 22, 2011.

To appreciate the value of a temporal database, you need to know the difference between transaction and valid time and that bitemporal data combines both valid and transaction time.

- Transaction time is the timestamp applied by the system when data are entered and cannot be changed by an application. It can be applied to a particular item or row. For example, when changing the price of a product, one approach might be to update the existing product row with the new price. The old price would be lost unless it was stored explicitly. In contrast, with a temporal database, the old and new prices would automatically have separate timestamps. In effect, an additional row is inserted to store the new price and the time when the insert occurred. In a database, immmutable data cannot be (or shouldn't be) deleted or modified. Most traditional databases store data in a mutable format, meaning the database overwrites the older data when new data is available.
- Valid time is the actual time at which an item was or will be a valid or true value. Consider the case where a firm plans to increase its prices on a specified date. It might post new prices some time before their effective date. Valid time can be changed by an application.
- Bitemporal data records both the valid time and transaction time for a fact. It usually requires four extra columns to record the upper and lower bounds for valid time and transaction time.

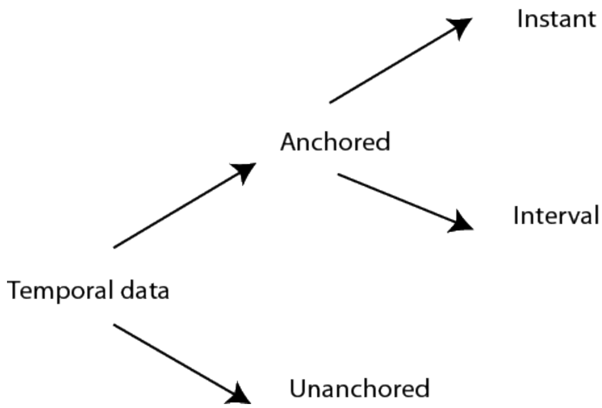
Valid time records when the change will take effect, and transaction time records when the change was entered. Storing transaction time is essential for database recovery because the DMBS can roll back the database to a previous state. Valid time provides a historical record of the state of the database. Both forms of time are necessary for a temporal database.

As you might expect, a temporal database will be somewhat larger than a traditional database because data are immmutable or never discarded, and new timestamped values are inserted so that there is a complete history of the values of an instance (e.g., the price of a product since it was first entered in the database). Thus, you can think of most of the databases we have dealt with previously as snapshots of a particular state of the database, whereas a temporal database is a record of all states of the database. As disk storage becomes increasingly cheaper and firms recognize the value of business intelligence, we are likely to see more attention paid to temporal database technology.

Times remembered

SQL supports several different data types for storing numeric values (e.g., integer and float), and a temporal database also needs a variety of data types for storing time values. The first level of distinction is to determine whether the time value is anchored or unanchored. Anchored time has a defined starting point (e.g., October 15, 1582), and unanchored time is a block of time with no specified start (e.g., 45 minutes).

Types of temporal data[2]



Anchored time is further split into an instant or interval. An instant is a moment in time (e.g., a date and time). In SQL, an instant can be represented by a date, time, or timestamp data type. An interval is the time between two specified instants, and can be defined as a value or a range with an upper and lower bound instant. For example, [2011-01-01, 2011-01-23] defines an interval in 2011 beginning January 1 and ending January 23.

Interval

SQL-99 introduced the INTERVAL data type, which has not yet been implemented in MySQL. INTERVAL is a single value expressed in some unit or units of time (e.g., 6 years, 5 days, 7 hours). A small example illustrates the use of INTERVAL for time values. Consider the rotational and orbital periods of the planets . The CREATE statement for this table is

```
CREATE TABLE planet (
    pltname.   VARCHAR(7),
    pltday     INTERVAL,
    pltyear    INTERVAL,
    PRIMARY KEY(pltname));
```

Planetary data

[2]Adapted from: Goralwalla, I. A., M. T. Özsu, and D. Szafron. 1998. *An object-oriented framework for temporal data models. In Temporal databases: research and practice*, edited by O. Etzion, S. Jajoda, and S. Sripada. Berlin: Springer-Verlag

Planet	Rotational period (hours)	Orbital period (hours)
Mercury	1407.51	0.24
Venus	–5832.44[3]	
Earth	23.93	1
Mars	24.62	1.88
Jupiter	9.92	11.86
Saturn	10.66	29.45
Uranus	17.24	84.02
Neptune	16.11	164.79
Pluto	153.28	247.92

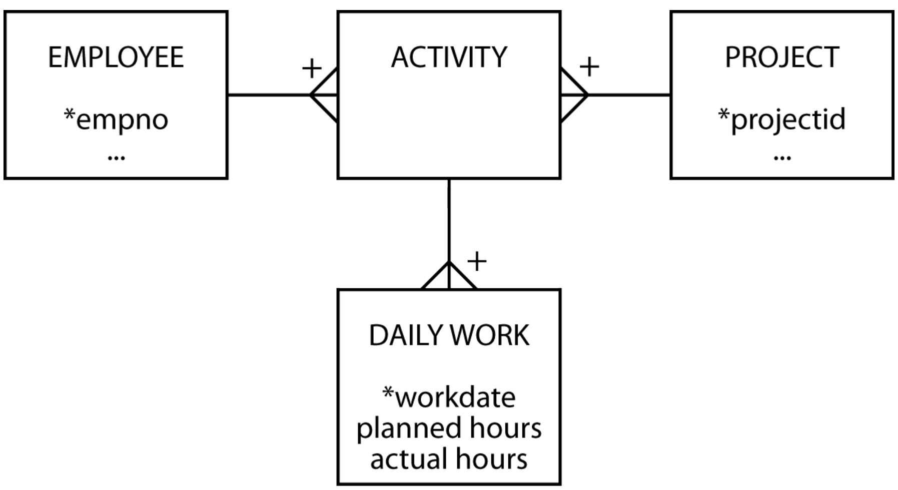
To insert the values for Mercury, you would use

```
INSERT INTO planet VALUES
 ('Mercury','1407.51 hours','0.24 years');
```

Modeling temporal data

You already have the tools for modeling temporal values. For example, the project management data model discussed in Chapter 7 and reproduced in the following figure contains temporal data.

A project management data model

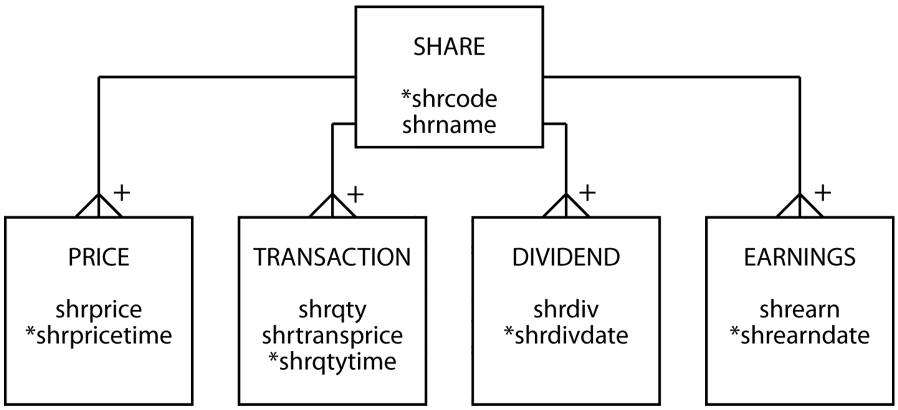


If we take the SHARE entity introduced very early in your data modeling experience, we can add temporal information to record the history of all values that are time-varying (i.e., price, quantity, dividend, and earnings). The data model to record temporal data is displayed. Firms pay dividends and report earnings only a few times per year, so we can associate a date with each value of dividend and earnings. Recording the history of trading transactions requires a

[3] Rotates in the opposite direction to the other planets

timestamp, because a person can make multiple trades in a day. Every time a share is bought or sold, a new row is inserted containing both the transaction quantity and price. The number owned can be derived by using SUM.

A temporal model of SHARE



Recording the share's price requires further consideration. If the intention is to record every change in price, then a time stamp is required as there will be multiple price changes in a day, and even in an few minutes, in busy trading. If there is less interest in the volatility of the stock and only the closing price for each day is of interest, then a date would be recorded.

You can add additional attributes to tables in a relational database to handle temporal data, but doing so does not make it a temporal database. The problem is that current relational implementations do not have built-in functions for querying time-varying data. Such queries can be difficult to specify in SQL.

A temporal database has additional features for temporal data definition, constraint specification, data manipulation, and querying. A step in this direction is the development of TSQL (Temporal Structured Query Language). Based on SQL, TSQL supports querying of temporal databases without specifying time-varying criteria. SQL:2011, the seventh revision of the SQL standard, has improved support for temporal data.

Summary

Spatial database technology stores details about items that have geometric features. It supports additional data types to describe these features, and has functions and operators to support querying. The new data types support point, line, and region values. Spatial technology is likely to develop over the next few years to support organizations offering localized information services.

Temporal database technology provides data types and functions for managing time-varying data. Transaction time and valid time are two characteristics of temporal data. Times can be anchored or unanchored and measured as an instant or as an interval.

Key terms and concepts

Anchored time	R-tree
Geographic object	Spatial data
Geographic information system (GIS)	Temporal data
Immutable	Theme
Interval	Transaction time
Map	Valid time
Mutable	

References and additional readings

Gibson, Rich, and Schuyler Erle. 2006. *Google maps hacks*. Sebastopol, CA: O'Reilly.

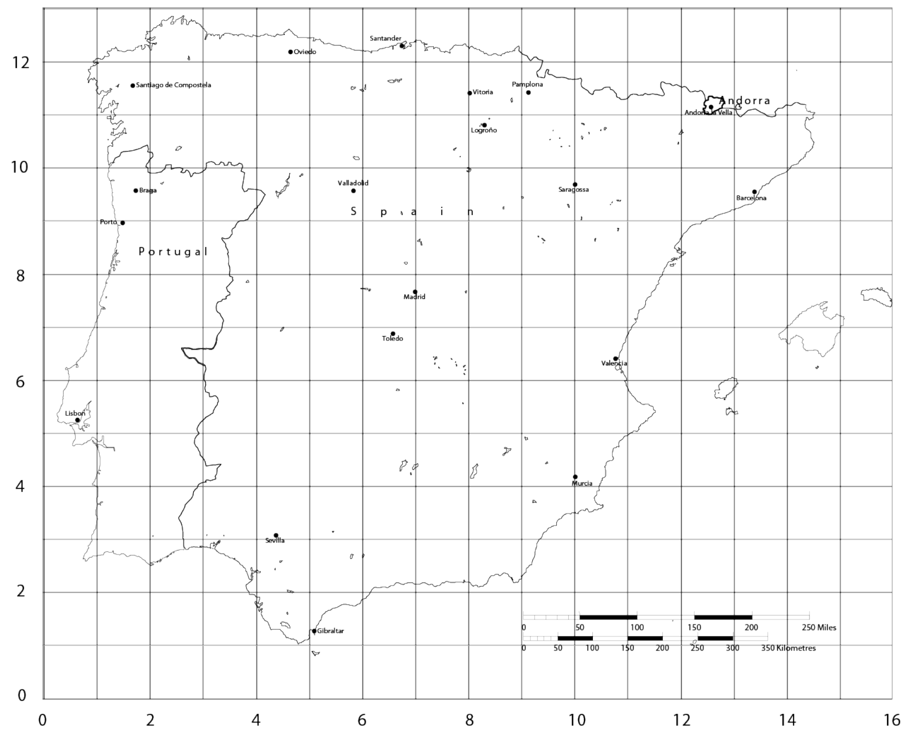
Rigaux, P., M. O. Scholl, and A. Voisard. 2002. *Spatial databases: with application to GIS*, The Morgan Kaufmann series in data management systems. San Francisco: Morgan Kaufmann Publishers.

Exercises

1. What circumstances will lead to increased use of spatial data?
2. A national tourist bureau has asked you to design a database to record details of items of interest along a scenic road. What are some of the entities you might include? How would you model a road? Draw the data model.
3. Using the map of the Iberian peninsula in the following figure, populate the spatial database with details of Andorra, Portugal, and Spain. Answer the following questions.
    a. What is the direct distance, or bee line, from Lisbon to Madrid?
    b. What is the farthest Spanish city from Barcelona?
    c. Imagine you get lost in Portugal and your geographic positioning system (GPS) indicates that your coordinates are (3,9). What is the nearest city?
    d. Are there any Spanish cities west of Braga?
    e. What is the area of Portugal?
    f. What is the southernmost city of Portugal?
4. Redesign the data model for political units assuming that your relational database does not support point and polygon data types.
5. For more precision and to meet universal standards, it would be better to use latitude and longitude to specify points and paths. You should also recognize that Earth is a globe and not flat. How would you enter latitude and longitude in MySQL?
6. When might you use transaction time and when might you use valid time?

7. Design a database to report basketball scores. How would you record time?
8. A supermarket chain has asked you to record what goods customers buy during each visit. In other words, you want details of each shopping basket. It also wants to know when each purchase was made. Design the database.
9. An online auction site wants to keep track of the bids for each item that a supplier sells. Design the database.
10. Complete the Google maps lab exercise listed on the book's Web site.

Iberian Peninsula



12 Graph Databases

When we use a network, the most important asset we get is access to one another.

Clay Shirky, *Cognitive Surplus: Creativity and Generosity in a Connected Age*, 2010

Learning objectives

Students completing this chapter will be able to

- define the features of a labelled property graph database;
- use a graph description language (GDL) to define nodes and relationships;
- use a graph database query language (GQL) to query a graph database;
- identify applications of a graph database.

A graph database

Relational database technology was developed to support the processing of business transactions and the querying of organizational data. As other applications, such social media developed, the labeled property database was introduced to support the processing of relationships between objects, such as people and organizations. Both relational and graph databases are ways of modeling the world, and storing and retrieving data. Like a relational DBMS, a graph DBMS, supports Create, Read, Update, and Delete (CRUD) procedures. Both can be used for online transaction processing and data analytics. The selection of one over the other is dependent on the purpose of the database and the nature of frequent queries. A graph database, for instance, is likely a better choice for supply chain analytics because of the network structure of a supply chain.

A graph is a set of nodes and relationships (edges in graph terminology). A node is similar to a relational row in that it stores data about an instance of an entity. In graph database terminology, a node has properties rather than attributes. Nodes can also have one or more labels, which are used to group nodes together and indicate their one or more roles in the domain of interest. Think of a group of nodes with a common label as an entity.

In a graph database, a relationship is explicitly defined to connect a pair of nodes, and can have properties, whereas, in a relational database, a relationship is represented by a pair of primary and foreign keys.

A graph description language (GDL) defines labels, nodes, and the properties of nodes and relationships. A GDL statement defines a specific entry in a graph database. It is like the INSERT statement of SQL. In a relational database you first define a table and then insert rows for specific instances, but in a graph database you start by defining nodes. There is no equivalent of the SQL CREATE TABLE command.

The properties of a node or relationship are specified as a key:value pair. A key is a unique identifier for some item of data (e.g., the NYSE code for a listed stock), and a value is data associated with the key (e.g., AAPL for Apple). When specifying properties of nodes or relationships, a key remains fixed and its values change for different instances. The following piece of code has two key-value pairs, and for the first, the key is StockCode and its value is "AR". Similarly, Price is a key with the value 31.82.

```
{StockCode: "AR", Price: 31.82}
```

Property data types

For the value component of a property's key:value pair, the possible data types are:

- Numeric: Integer or Float
- String
- Boolean
- Spatial: Point
- Temporal: Date, Time, LocalTime, DateTime, LocalDateTime, or Duration

A graph database is quite flexible because you can readily add nodes, relationships, and properties, while a relational database limits inserts of new data elements to the data type of columns previously defined for a table. Because there is no equivalent to defining a table in a graph database, you start by inserting nodes, relationships, and properties. Relationships are pliant, and a relationship could change from 1:m to m:m simply by adding a relationship that results in an m:m between two nodes. New additions can be made without the need to rewrite existing queries or recode applications.

Flexibility, like rigidity, has its pros and cons. Flexibility allows for new features of the environment to be quickly incorporated into a database, but at the same time it can lead to inconsistencies if nodes or properties of the same type have different keys. For example, the property for representing an employee's first name sometimes has a key of firstName and other times a key of fname. Rather than rushing into database creation, some initial modeling of the domain and the construction of a data dictionary is likely to be fruitful in the long run.

In summary, the key features of a labelled property graph database are:

- It consists of nodes and relationships;
- Nodes and relationships can have properties in the form of key:value pairs;
- A node can have one more labels;
- Relationships are between a pair of nodes;
- Relationships must be named.

Cypher is a combined graph description language (GDL) and graph query languages (GQL) for graph databases. Originally designed for the Neo4j graph database, it is now, in the form of Cypher 9, governed by the openCypher Implementation Group. Cypher is used in open source projects (e.g., Apache Spark) and commercial products (e.g., SAP HANA). These actions indicate that Cypher will likely emerge as the industry standard language for labelled property graphs. In parallel, ISO has launched a project to create a new query language for graph databases based on openCypher and other GQLs.

Neo4j – a graph database implementation

Neo4j is a popular labeled property graph database that supports Cypher and has a free community download. These features make it suitable for learning how to create and use a graph database. To get started, download Neo4j Desktop and follow the installation and launch guide to create a project and open your browser.

A single node

We'll start, as we did with the relational model, with a simple example of a set of nodes with the same label of Stock. There is no relationship between nodes. The following is a visualization of the data model. As the focus is on the graph structure, the properties of a node (a circle) are distributed around the edges of the model in rectangles.

A graph data model for a portfolio of stocks

The Cypher code for creating a node for Stock is:

```
CREATE (:Stock {StockCode: "AR", Firm: "Abyssinian Ruby",
Price: 31.82, Qty: 22020, Div: 1.32, PE: 13});
```

Inserting nodes

Usually, the data to populate a database exist in digital format, and if you can convert them to CSV format, such as an export of a spreadsheet, then you can use Cypher's LOAD CSV command. The following code will create the nodes for each of the rows in a remote CSV file and return a count of how many nodes were created. You can load a local file by specifying a path rather than a url.

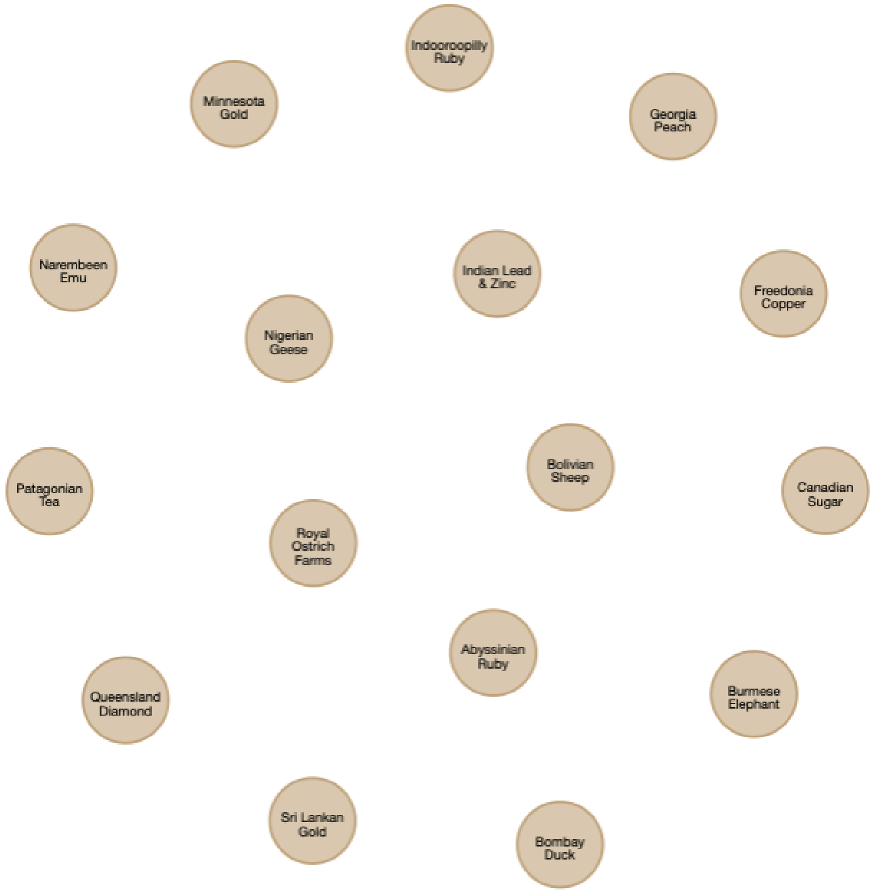
```
LOAD CSV WITH HEADERS FROM
"https://www.richardtwatson.com/data/stock.csv"
 AS row
CREATE (s:Stock {StockCode: row.stkcode,
 Firm: row.stkfirm,
    Price: toFloat(row.stkprice),
    Qty: toInteger(row.stkqty),
    Div: toFloat(row.stkdiv),
    PE: toInteger(row.stkpe)})
RETURN count(s);
```

The preceding code:

- Specifies the url of the external CSV file with the temporary name row;
- Creates a node with the label Stock and the temporary identifier s;
- Reads a row at a time and converts the format, as appropriate, since all data are read as character strings. For example, toFloat(row.stkprice) AS Price reads a cell in the stkprice column on the input file, converts it to float format and associates it with the key Price to create a key:value pair for the node identified by StockCode.

When the preceding code is executed, it creates 16 unconnected nodes, as shown in the following figure.

Visualization of unrelated nodes in graph



Querying a node

This section mimics Chapter Three's coverage of querying a single entity database. Many of the same queries are defined in Cypher code. As you should now have a clear idea of the results of a query, they are not shown in this chapter. You can alway run them with the Neo4j browser and look at the different forms of output it provides.

Displaying data for nodes with the same label

MATCH is Cypher's equivalent of SELECT. A MATCH statement can report the properties for a particular type of node. Each node has an associated temporary identifier which is usually short (e.g., s). In this case, RETURN s, lists all the properties of Stock.

List all Stock data

```
MATCH (s:Stock)
RETURN s;
```

Reporting properties

The Cypher code for the equivalent of a relational project defines the keys of the properties to be displayed. Notice how a key is prefixed with the temporary name for the node (i.e., s) to fully identify it (e.g., s.Firm) and the use of AS to rename it for reporting (e.g., s.Firm AS Firm)

Report a firm's name and price-earnings ratio.

```
MATCH (s:Stock)
RETURN s.Firm AS Firm, s.PE AS PE;
```

Reporting nodes

The Cypher code for the equivalent of a relational restrict also uses a WHERE clause to specify which nodes are reported. Neo4j supports the same arithmetic, Boolean, and comparison operators as SQL for use with WHERE.

Get all firms with a price-earnings ratio less than 12.

```
MATCH (s:Stock)
WHERE s.PE < 12
RETURN s;
```

Reporting properties and nodes

A single Cypher MATCH statement can specify which properties of which nodes to report.

List the name, price, quantity, and dividend of each firm where the share holding is at least 100,000.

```
MATCH (s:Stock)
WHERE s.Qty > 100000
RETURN s.Firm AS Firm, s.Price AS Price,
 s.Qty AS Quantity, s.Div AS Dividend;
```

IN for a list of values

As with SQL, the keyword IN is used with a list to specify a set of values.

Report data on firms with codes of FC, AR, or SLG.

```
MATCH (s:Stock)
WHERE s.StockCode IN ['FC','AR','SLG']
RETURN s;
```

> ☒ *Skill builder*
>
> List those shares where the value of the holding exceeds one million.

Ordering rows

In Cypher, the ORDER BY clause sorts based on the value of one or more properties.

List all firms where the PE is at least 10, and order the report in descending PE. Where PE ratios are identical, list firms in alphabetical order.

```
MATCH (s:Stock)
WHERE s.PE >= 10
RETURN s
ORDER BY s.PE DESC, s.Firm;
```

Derived data

Calculations can be included in a query.

Get firm name, price, quantity, and firm yield.

```
MATCH (s:Stock)
RETURN s.Firm AS Firm, s.Price AS Price,
 s.Qty AS Quantity, s.Div/s.Price*100 AS Yield;
```

Aggregate functions

Cypher has built-in functions similar to those of SQL, as the following two examples illustrate.

COUNT

How many firms are there in the portfolio?

```
MATCH (s:Stock)
RETURN count(s);
```

AVG

What is the average yield for the portfolio?

```
MATCH (s:Stock)
RETURN avg(s.Div/s.Price*100) As `Average yield`;
```

In the prior query, note how you use an angle quote (‘), rather than a straight quote, to specify a column header that contains spaces.

String handling

Cypher includes functions for string handling and supports regular expressions. The string functions are typical of those in other programming languages, such as toLower(), toUpper(), toString(), left(), right(), substring(), and replace(). For a complete list, see the Cypher manual.

Cypher supports regular expression using the syntax of Java's regular expressions.

List the names of firms with a double 'e'.

In the following code, the regular expression looks for any number of characters at the beginning or end of each string (.*) with two consecutive 'e's ([e]{2}) in between.

Notice use of the toLower function to convert the firm name to all lower case so this query will work with any variation on consecutive 'e's, such as 'GEese'.

```
MATCH (s:Stock)
WHERE toLower(s.Firm) =~ '.*[e]{2}.*'
RETURN s.Firm;
```

You can also express the query using the Cypher CONTAINS clause, as follows:

```
MATCH (s:Stock)
WHERE s.Firm CONTAINS 'ee'
RETURN s.Firm;
```

Subqueries

A subquery requires you to determine the answer to another query before you can write the query of ultimate interest. The WITH clause chains subqueries by forwarding the results from one subquery to the next. For example, to list all shares with a PE ratio greater than the portfolio average, you first must find the average PE ratio for the portfolio, and then use the computed value in a second query.

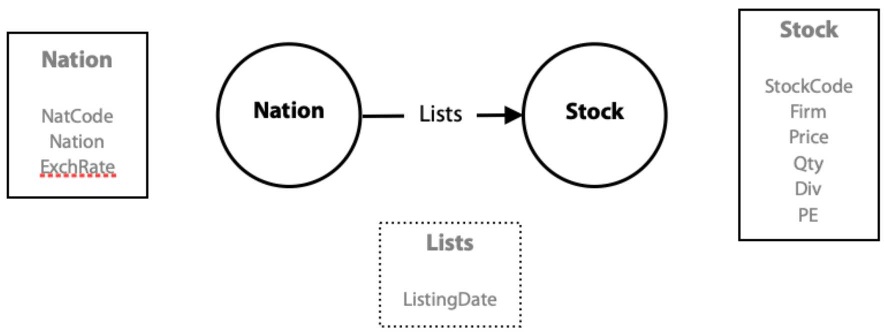
Report all firms with a PE ratio greater than the average for the portfolio.

```
MATCH (s:Stock)
WITH AVG(s.PE) AS AvgPE
MATCH (s:Stock)
WHERE s.PE > AvgPE
RETURN s.Firm AS FIRM, s.PE as PE;
```

A relationship between nodes

We will use the data model in Chapter Four that records details of stocks listed in difference countries for illustrating a 1:m relationship between nodes. When developing a graph model, common nouns become labels (e.g., stock and country) and verbs become relationships. In the phrase "a nations lists many stocks," we could extract the verb lists to use as a relationship name.

A graphical data model for an international portfolio of stocks



In this case, a country can list many stocks. First, we need to add four nation nodes to the graph database, as follows:

```
LOAD CSV WITH HEADERS FROM
"https://www.richardtwatson.com/data/nation.csv"
  AS row
CREATE (n:Nation {NationCode: row.natcode,
  Nation: row.natname, ExchRate: toFloat(row.exchrate)})
RETURN count(n);
```

Specifying relationships in Cypher

Relationships are represented in Cypher using an arrow, either -> or <–, between two nodes. A node can have relationships to itself (i.e., recursive). In Neo4j, all relationships are directed (i.e., they are -> or <–).

The nature of the relationship is defined within square brackets, such as [:LISTS] in the case where a nation lists a stock on its exchange:

```
(n:Nation)-[:LISTS]->(s:Stock)
```

If you want to refer to a relationship later in a query, you can define a temporary name. In the follow code sample, r is the temporary name for referring to the relationship LISTS.

```
MATCH (n:Nation)-[r:LISTS]->(s:Stock)
```

Relationships can also have properties. The Cypher code for stating that Bombay Duck was listed in India on 2019-11-10 is:

```
MATCH (s:Stock), (n:Nation)
WHERE s.StockCode = "BD" AND n.NationCode = "IND"
CREATE (n)-[r:LISTS {Listed: date('2019-11-10')}]->(s)
RETURN r;
```

The WHERE clause specifies that nodes Bombay Duck and India are related. The third line of code creates the relationship by stating one nation, abbreviated as n, can list many stocks, abbreviated as s. The name of the relationship, LISTS, has the temporary name of r, which is is used in the RETURN r statement.

Rather than have to match each country and its listed shares as separate code chunks as with Bombay Duck, we can reread the stock file, stock.csv, because it has a column containing the nation code of the listing country. We match this code with a Nation node having the same value for nation code to create the relationship. In other words, the Cypher code creates the relationship by reading each row of stock.csv and matching its value for row.natcode with a Nation node that has the same value for the key NatCode. This is the same logic as matching a primary and foreign key to join two tables.

```
LOAD CSV WITH HEADERS FROM
"https://www.richardtwatson.com/data/stock.csv"
 AS row
MATCH (n:Nation {NationCode: row.natcode})
MATCH (s:Stock {StockCode: row.stkcode})
CREATE (n)-[r:LISTS]->(s)
RETURN r;
```

Querying relationships

When defining relationship in a graph database, a programmer is effectively pre-specifying how two tables are joined. As a result, querying is slightly different from the relational style. Consider the following request:

Report the value of each stockholding in UK pounds. Sort the report by nation and firm.

The first step is define the relationship between the two nodes that contains the required properties to compute the value of the stockholding and then define the properties to be reported, the computation, and finally the sorting of the report.

```
MATCH (n:Nation)-[:LISTS]->(s:Stock)
RETURN n.Nation AS Nation, s.Firm AS Firm,
 s.Price AS Price, s.Qty as Quantity,
  round(s.Price*s.Qty*n.ExchRate) AS Value
ORDER BY Nation, Firm;
```

WITH—reporting by groups

The WITH clause permits grouping nodes and it produces one row for each different value of the grouping node. The following example computes the value of the shareholding in UK pounds for each nation.

Report by nation the total value of stockholdings.

```
MATCH (n:Nation)-[:LISTS]->(s:Stock)
WITH n, round(sum(s.Price*s.Qty*n.ExchRate)) as Value
RETURN n.Nation AS Nation, Value;
```

Cypher's built-in functions (COUNT, SUM, AVERAGE, MIN, and MAX) can be used similarly to their SQL partners. They are applied to a group of rows having the same value for a specified column.

Report the number of stocks and their total value by nation.

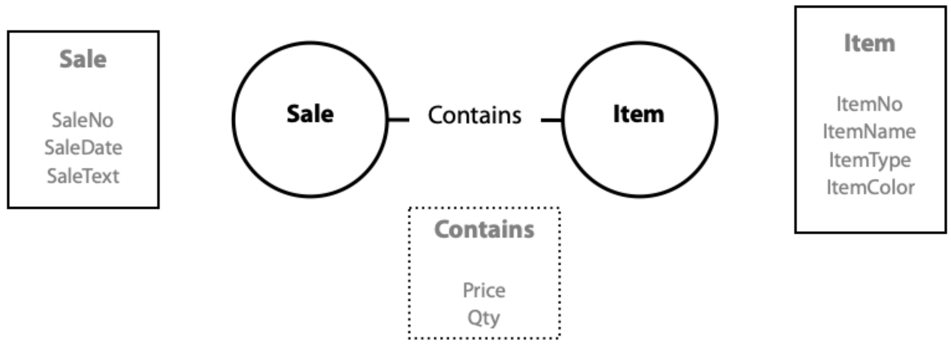
```
MATCH (n:Nation)-[:LISTS]->(s:Stock)
WITH n, count(s.StockCode) as Stocks,
 round(sum(s.Price*s.Qty*n.ExchRate)) as Value
RETURN n.Nation AS Nation, Stocks, Value;
```

> ☒ *Skill builder*
>
> Report by nation the total value of dividends.

Querying an m:m relationship

In a graph database, a relationship replaces the associative entity used in a relationship model for representing an m:m. In the following graph model we could have indicated that an item can appear in many sales and a sale can have many items. For bidirectional relationships, ignore the direction when querying rather than create two relations.

A graph data model for sales



The sales example discussed in Chapter Five illustrates how to handle a many-to-many situation. We first load these data and then define the relationship. Notice that SET is used to establish the values of price and quantity properties of the relationship, which in a relational model are attributes of the associative entity. In practice, as each transaction occurs, an entry would be generated for each item sold.

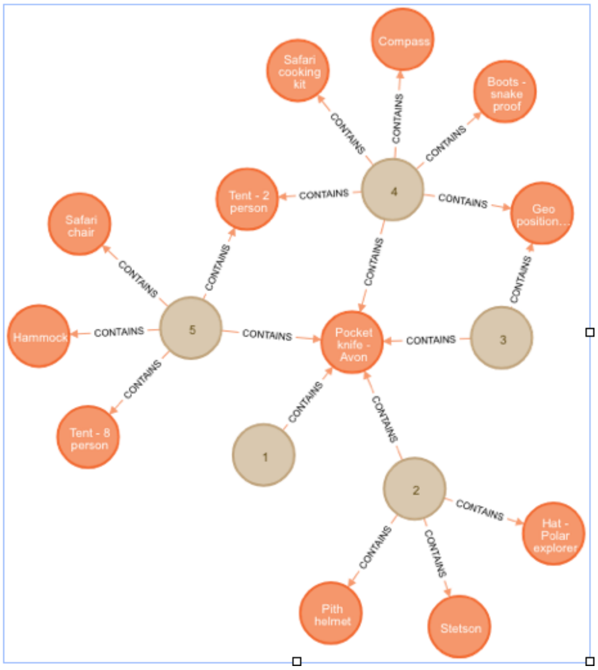
```
LOAD CSV WITH HEADERS FROM
"https://www.richardtwatson.com/data/item.csv"
 AS row
CREATE (i:Item {ItemNo: toInteger(row.itemno),
  ItemName: row.itemname, ItemType: row.itemtype,
  ItemColor: row.itemcolor})
RETURN count(i);

LOAD CSV WITH HEADERS FROM
"https://www.richardtwatson.com/data/sale.csv"
 AS row
CREATE (s:Sale {SaleNo: toInteger(row.saleno),
  SaleDate: date(row.saledate), SaleText: row.saletext})
RETURN count(s);

LOAD CSV WITH HEADERS FROM
"https://www.richardtwatson.com/data/receipt.csv"
 AS row
MATCH (s:Sale {SaleNo: toInteger(row.saleno)})
MATCH (i:Item {ItemNo: toInteger(row.itemno)})
CREATE (s)-[r:CONTAINS]->(i)
SET r.Price = toFloat(row.receiptprice),
 r.Qty = toInteger(row.receiptqty);
```

Once you have created the database, click on the CONTAINS relationship to get a visual of the database, as shown in the following figure. The nodes with numbers, SaleNo, are sales.

A view of the relationships between sales and items.



Here is an example of Cypher code for querying the graph for items and sales.

List the name, quantity, price, and value of items sold on January 16, 2011.

```
MATCH (s: Sale)-[r:CONTAINS]->(i: Item)
WHERE s.SaleDate = date(‘2011-01-16')
RETURN i.ItemName AS Item, r.Qty as Quantity,
 r.Price as Price, r.Qty*r.Price AS Total;
```

The preceding query could also be written as:

```
MATCH (s: Sale {SaleDate: date('2011-01-16')})-
  [r:CONTAINS]->(i: Item)
RETURN i.ItemName AS Item, r.Qty as Quantity,
  r.Price as Price, r.Qty*r.Price AS Total;
```

Does a relationship exist?

MATCH can be used to determine whether a particular relationship exists between two nodes by specifying the pattern of the sought relationship. The first query reports details of nodes satisfying a relationship.

Report all clothing items (type “C”) for which a sale is recorded.

```
MATCH (s: Sale)-[:CONTAINS]->
  (i:Item {ItemType: 'C'})
RETURN DISTINCT i.ItemName AS Item, i.ItemColor AS Color;
```

The second query reports details of nodes not satisfying a relationship.

Report all clothing items that have not been sold.

The query has a two stage process. First, identify all the items that have been sold and save their item numbers in SoldItems. Then, subtract this list from the the list of all items of type C to find the items not sold. This is similar to using a minus in SQL.

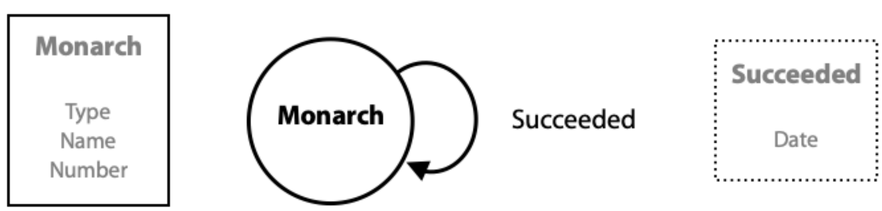
```
MATCH (s: Sale)-[:CONTAINS]->(i:Item {ItemType: 'C'})
WITH COLLECT (DISTINCT i.ItemNo) AS SoldItems
MATCH (i: Item)
WHERE i.ItemType = 'C' AND NOT (i.ItemNo IN SoldItems)
RETURN DISTINCT i.ItemName AS Item, i.ItemColor AS Color;
```

> ☒ *Skill builder*
>
> Report all red items that have not been sold.

Recursive relationships

As you will recall, in data modeling a recursive relationship relates an entity to itself. It maps one instance in the entity to another instance of that entity. In graph terms, recursion relates nodes with the same label. The following diagram represents the previously discussed 1:1 monarch succession as graph.

A graph model for monarch



To assist with understanding the monarch model, we repeat the prior data.

Recent British monarchs

Type	Name	Number	Reign begin
King	William	IV	1830-06-26
Queen	Victoria	I	1837-06-20
King	Edward	VII	1901-01-22
King	George	V	1910-05-06
King	Edward	VIII	1936-01-20

Type	Name	Number	Reign begin
King	George	VI	1936-12-11
Queen	Elizabeth	II	1952-02-06
King	Charles	III	2022-09-08

In the following Cypher code, observe the use of MATCH to connect each predecessor and successor monarch pair and the use of SET to define the succession date as a property of the succession relationship.

```
LOAD CSV WITH HEADERS FROM
"https://www.richardtwatson.com/data/monarch.csv"
 AS row
CREATE (m: Monarch {Type: row.montype, Name: row.monname,
  Number: row.monnum})
RETURN count(m);

MATCH (p:Monarch), (s:Monarch)
// p for predecessor and s for successor
WHERE p.Name = 'William' AND p.Number = 'IV'
AND s.Name = 'Victoria' AND s.Number = 'I'
CREATE (s)-[r:SUCCEEDED]->(p)
SET r.Date = date('1837-06-20')
RETURN(r);

MATCH (p:Monarch), (s:Monarch)
WHERE p.Name = 'Victoria' AND p.Number = 'I'
 AND s.Name = 'Edward' AND s.Number = 'VII'
CREATE (s)-[r:SUCCEEDED]->(p)
SET r.Date = date('1901-01-22')
RETURN(r);

MATCH (p:Monarch), (s:Monarch)
WHERE p.Name = 'Edward' AND p.Number = 'VII'
 AND s.Name = 'George' AND s.Number = 'V'
CREATE (s)-[r:SUCCEEDED]->(p)
SET r.Date = date('1910-05-06')
RETURN(r);

MATCH (p:Monarch), (s:Monarch)
WHERE p.Name = 'George' AND p.Number = 'V'
 AND s.Name = 'Edward' AND s.Number = 'VIII'
CREATE (s)-[r:SUCCEEDED]->(p)
SET r.Date = date('1936-01-20')
RETURN(r);

MATCH (p:Monarch), (s:Monarch)
WHERE p.Name = 'Edward' AND p.Number = 'VIII'
```

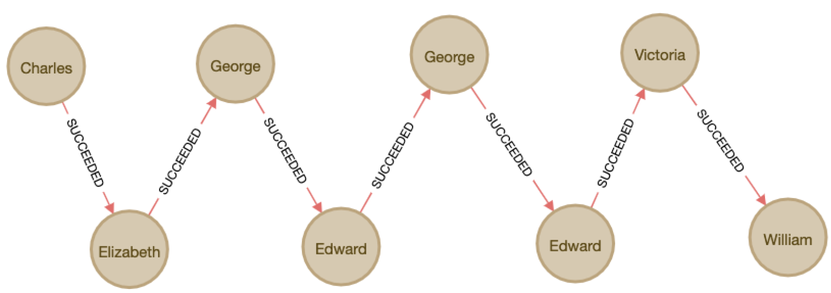
```
 AND s.Name = 'George' AND s.Number = 'VI'
CREATE (s)-[r:SUCCEEDED]->(p)
SET r.Date = date('1936-12-11')
RETURN(r);

MATCH (p:Monarch), (s:Monarch)
WHERE p.Name = 'George' AND p.Number = 'VI'
 AND s.Name = 'Elizabeth' AND s.Number = 'II'
CREATE (s)-[r:SUCCEEDED]->(p)
SET r.Date = date('1952-02-06')
RETURN r;

MATCH (p:Monarch), (s:Monarch)
WHERE p.Name = 'Elizabeth' AND p.Number = 'II'
 AND s.Name = 'Charles' AND s.Number = 'III'
CREATE (s)-[r:SUCCEEDED]->(p)
SET r.Date = date('2022-09-08')
RETURN r;
```

The following figure shows the graph produced by Neo4j.

Monarch succession graph



Querying a recursive relationship

Some queries on the monarch graph database demonstrate the ease of querying a recursive relationship. Observe how to concatenate strings by using a plus (+) sign.

Who preceded Victoria I?

```
MATCH (s)-[r:SUCCEEDED]->(p)
WHERE s.Name = 'Victoria'
RETURN (p.Type + ' ' + p.Name + ' ' + p.Number);
```

Who succeeded Victoria I?

```
MATCH (s)-[r:SUCCEEDED]->(p)
WHERE p.Name = 'Victoria'
RETURN (s.Type + ' ' + s.Name + ' ' + s.Number);
```

List the kings and queens of England in ascending chronological order.

```
MATCH (s)-[r:SUCCEEDED]->(p)
RETURN (s.Type + ' ' + s.Name + ' ' + s.Number)
ORDER BY r.Date;
```

We see the power of a Cypher for querying a recursive relationship with the following query that uses *2 in the relationship pattern to select the second node in a chain of relationships.

Who was Elizabeth II's predecessor's predecessor?

```
MATCH (s)-[r:SUCCEEDED*2]->(p)
WHERE s.Name = 'Elizabeth' and s.Number = 'II'
RETURN (p.Type + ' ' + p.Name + ' ' + p.Number);
```

We can also select a series of nodes in a chain, and in the following example the first to third are selected by specifying *1..3 in the relationship pattern.

Who were Elizabeth II's three immediate predecessors?

```
MATCH (s)-[r:SUCCEEDED*1..3]->(p)
WHERE s.Name = 'Elizabeth' and s.Number = 'II'
RETURN (p.Type + ' ' + p.Name + ' ' + p.Number);
```

The modeling and querying of 1:m and m:m recursive relationships are almost identical. Consider the case where an employee is the boss of other employees, then this could be expressed as:

```
MATCH (b:Employee), (e:Employee)
// b for boss and e for employee
WHERE b.EmpCode = 1 AND e.EmpCode IN [2, 15, 23]
CREATE (b)-[r:IS_BOSS_OF]->(e);
```

and a query might start with:

```
MATCH (b)-[r:IS_BOSS_OF]->(e)
```

For a recursive m:m, such as a bill of materials, we might write:

```
MATCH (a:Part), (p:Part)
// a for assembly and p for part
WHERE a.PartCode = 1 AND p.PartCode IN [2,35,4,19,121]
CREATE (a)-[r:CONTAINS]->p;
```

Indexes and constraints

To speed up processing, indexes can be created on labels and property combinations. For example, the following code indexes the Stock label on the values of StockCode.

```
CREATE INDEX ON :Stock(StockCode);
```

If you wanted to ensure all nation codes are unique, you would code:

```
CREATE CONSTRAINT ON (n:Nation) ASSERT n.NatCode IS UNIQUE;
```

Remove duplicates

As with SQL, DISTINCT will remove duplicates from the results of a query.

```
MATCH (s:Stock)
RETURN DISTINCT s.PE AS PE;
```

Delete all nodes and relationships

To start afresh, use the following code to delete all nodes and relationships:

```
MATCH (a)
OPTIONAL MATCH (a)-[r]-()
DELETE a, r;
```

Conclusion

Graph databases are suitable for a wide range of common business problems. Graph analytics, in general, is useful for addressing three types of questions: How do things spread? What are the capacities, costs, and control points? How do things interact, and will that change?[1]

Summary

A labeled property graph database consists of nodes and relationships. Both nodes and relationships can have properties. A relationship is explicitly defined to connect a pair of nodes, and can have properties. Nodes and relationships can have properties in the form of key:value pairs. Nodes can be given one or more labels to group them. A graph description language (GDL) defines nodes and relationships. A graph query language (GQL) enables querying. Cypher is a GDL and GQL. A graph database is a good choice when many queries are about the network of relationships between nodes.

[1]Needham, M., & Hodler, A. E. (2019). *Graph Algorithms: Practical Examples in Apache Spark and Neo4j*: O\'Reilly Media. ISBN: 1492047651

Key terms and concepts

Edge	Node
Graph	Property
Label	Relationship

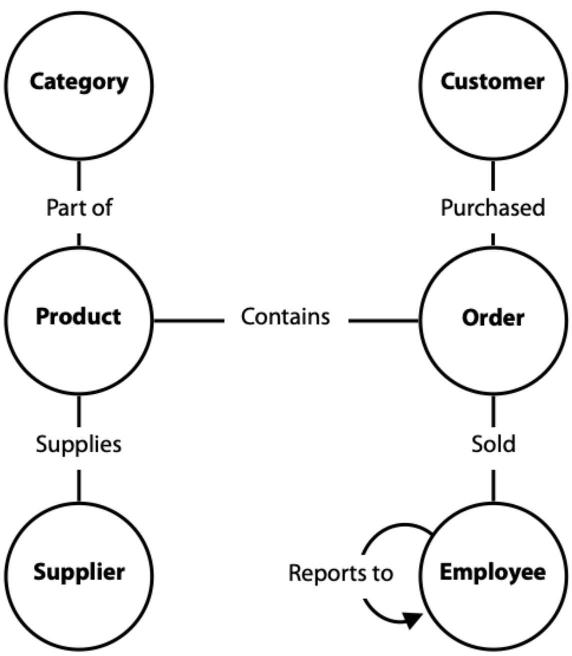
References and additional resources

Francis, N., Green, A., Guagliardo, P., Libkin, L., Lindaaker, T., Marsault, V., . . . Taylor, A. (2018). Cypher: An evolving query language for property graphs. Paper presented at the Proceedings of the 2018 International Conference on Management of Data. https://dl.acm.org/doi/10.1145/3183713.3190657.

Robinson, I., Webber, J., & Eifrem, E. (2013). *Graph databases*: O'Reilly Media, Inc. ISBN: 1449356249

The following exercises are based on the Northwind graph database, which you can create on your computer by running the supplied code.

Graph model for Northwind



The Northwind database has the following relationships:

- (order)-[:CONTAINS]->(product)
- (employee)-[:SOLD]->(order)
- (customer)-[:PURCHASED]->(order)

- (supplier)-[:SUPPLIES]->(product)
- (product)-[:PART_OF]->(category)
- (employee)-[:REPORTS_TO]->(manager)

Exercises

1. Write Cypher code for the following queries.
    a. How many employees are there in the company?
    b. Prepare a list of employees by last name, first name, and job title. Sort by last name.
    c. List the products that contain 'sauce' in their product description.
    d. In what category are sauces?
    e. List in alphabetical order those customers who have placed an order.
    f. List in alphabetical order those customers who have not placed an order.
    g. Which customers have purchased 'Chai'?
    h. List the amount ordered by each customer by the value of the order.
    i. List the products in each category.
    j. How many products in each category?
    k. What is the minimum value of a received order?
    l. Who is the customer who placed the minimum value order?
    m. Report total value of orders for Blauer See Delikatessen.
    n. Who reports to Andrew Fuller? Report by last name alphabetically and concatenate first and last names for each person.
    o. Report those employees who have sold to Blauer See Delikatessen.
    p. Report the total value of orders by year.
2. Basket of goods analysis: A common retail analytics task is to analyze each basket or order to learn what products are often purchased together. Report the names of products that appear in the same order three or more times.
3. ABC reporting: Compute the revenue generated by each customer based on their orders. Also, show each customer's revenue as a percentage of total revenue. Sort by customer name.
4. Same as Last Year (SALY) analysis: Compute the ratio for each product of sales for 1997 versus 1996.

13 XML: Managing Data Exchange

Words can have no single fixed meaning. Like wayward electrons, they can spin away from their initial orbit and enter a wider magnetic field. No one owns them or has a proprietary right to dictate how they will be used.

David Lehman, End of the Word, 1991

Learning objectives

Students completing this chapter will be able to

- define the purpose of XML;
- create an XML schema;
- code data in XML format;
- create an XML stylesheet;
- discuss data management options for XML documents.

Four problems

There are four central problems in data management: capture, storage, retrieval, and exchange. The focus for most of this book has been on storage (i.e., data modeling) and retrieval (i.e., SQL). Now it is time to consider capture and exchange. Capture has always been an important issue, and the guiding principle is to capture data once in the cheapest possible manner.

SGML

The Standard Generalized Markup Language (SGML) was designed to reduce the cost and increase the efficiency of document management. Its child, XML, has essentially replaced SGML. For example, the second edition of the *Oxford English Dictionary* was specified in SGML, and the third edition is stored in XML format.[1]

[1] Cowlishaw, M. F. (1987). Lexx—a programmable structured editor. *IBM Journal of Research and Development*, 31(1), 73–80.

A markup language embeds information about a document in the text. In the following example, the markup tags indicate that the text contains CD liner notes. Note also that the titles and identifiers of the mentioned CDs are explicitly identified.

Markup language

```
<cdliner>This uniquely creative collaboration between
Miles Davis and Gil Evans has already resulted in two
extraordinary albums:
<cdtitle>Miles Ahead</cdtitle><cdid>CL 1041</cdid> and
<cdtitle>Porgy and Bess</cdtitle><cdid>CL 1274</cdid>.
</cdliner>.
```

SGML is an International Standard (ISO 8879) that defines the structure of documents. It is a vendor-independent language that supports cross-system portability and publication for all media. Developed in 1986 to manage software documentation, SGML was widely accepted as the markup language for a number of information-intensive industries. As a metalanguage, SGML is the mother of both HTML and XML.

SGML illustrates four major advantages a markup language provides for data management:

- Reuse: Information can be created once and reused over and over. By storing critical documents in markup format, firms do not need to duplicate efforts when there are changes to documents. For example, a firm might store all its legal contracts in SGML.
- Flexibility: SGML documents can be published in any medium for a wide variety of audiences. Because SGML is content-oriented, presentation decisions are delayed until the output format is known. Thus, the same content could be printed, presented on the Web in HTML, or written to a DVD as a PDF.
- Revision: SGML enhances control over revision and enables version control. When stored in an SGML database, original data are archived alongside any changes. That means you know exactly what the original document contained and what changes were made.
- Format independence: SGML files are stored as text and can be read by many programs on all operating systems. Thus, it preserves textual information independent of how and when it is presented. SGML protects a firm's investment in documentation for the long term. Because it is now possible to display documentation using multiple media (e.g., Web and iPad), firms have become sensitized to the need to store documents in a single, independent manner that can then be converted for display by a particular medium.

SGML's power is derived from its recording of both text and the meaning of that text. A short section of SGML demonstrates clearly the features and strength of SGML. The tags surrounding a chunk of text describe its meaning and thus support presentation and retrieval. For example, the pair of tags <title> and </title> surrounding "XML: Managing Data Exchange" indicates that it is the chapter title.

SGML code

```
<chapter>
<no>18</no>
<title>XML: Managing Data Exchange</title>
<section>
<quote><emph type = '2'>Words can have no single fixed meaning.
Like wayward electrons, they can spin away from their initial
orbit and enter a wider magnetic field. No one owns them or has
a proprietary right to dictate how they will be used.</emph>
</quote>
</section>
</chapter>
```

Taking this piece of SGML, it is possible, using an appropriate stylesheet, to create a print version where the title of the chapter is displayed in Times, 16 point, bold, or a HTML version where the title is displayed in red, Georgia, 14 point, italics. Furthermore, the database in which this text is stored can be searched for any chapters that contain "Exchange" in their title.

Now, consider the case where the text is stored as HTML. How do you, with complete certainty, identify the chapter title? Do you extract all text contained by <h1> and </h1> tags? You will then retrieve "18" as a possible chapter title. What happens if there is other text displayed using <h1> and </h1> tags? The problem with HTML is that it defines presentation and has very little meaning. A similar problem exists for documents prepared with a word processor.

HTML code

```
<html>
<body>
<h1><b>18 </b></h1>
<h1><b>XML: Managing Data Exchange</b></h1>
<p><i>Words can have no single fixed meaning.
Like wayward electrons, they can spin away from their
initial orbit and enter a wider magnetic field.
No one owns them or has a proprietary right to
dictate how they will be used.</i>
</body>
</html>
```

By using embedded tags to record meaning, SGML makes a document platform-independent and greatly improves the effectiveness of searching. Despite its many advantages, there are some features of SGML that make implementation difficult and also limit the ability to create tools for information management and exchange. As a result, XML, a derivative of SGML, was developed.

XML

Extensible Markup Language (XML), a language designed to make information self-describing, retains the core ideas of SGML. You can think of XML as SGML for electronic commerce. Since the definition of XML was completed in early 1998 by the World Wide Web Consortium (W3C), the standard has spread rapidly because it solves a critical data management problem. XML is a metalanguage—a language to generate languages.

Despite having the same parent, there are major differences between XML and HTML.

XML vs. HTML

XML	HTML
Structured text	Formatted text
User-definable structure (extensible)	Predefined formats (not extensible)
Context-sensitive retrieval	Limited retrieval
Greater hypertext linking	Limited hypertext linking

HTML, an electronic-publishing language, describes how a Web browser should display text and images on a computer screen. It tells the browser nothing about the meaning of the data. For example, the browser does not know whether a piece of text represents a price, a product code, or a delivery date. Humans infer meaning from the context (e.g., August 8, 2012, is recognized as a date). Given the explosive growth of the Web, HTML clearly works well enough for exchanging data between computers and humans. It does not, however, work for exchanging data between computers, because computers are not smart enough to deduce meaning from context.

Successful data exchange requires that the meaning of the exchanged data be readily determined by a computer. The XML solution is to embed tags in a file to describe the data (e.g., insert tags into an order to indicate attributes such as price, size, quantity, and color). A browser, or program for that matter, can then recognize this document as a customer order. Consequently, it can do far more than just display the price. For example, it can convert all prices to another currency. More importantly, the data can be exchanged between computers and understood by the receiving system.

XML consists of rules (that anyone can follow to create a markup language (e.g., a markup language for financial data such as XBRL). Hence, the "eXtensible" in the XML name, indicating that the language can be easily extended to include new tags. In contrast, HTML is not extensible and its set of tags is fixed, which is one of the major reasons why HTML is easy to learn. The XML rules ensure that a type of computer program known as a parser can process any extension or addition of new tags.

XML rules

- Elements must have both an opening and a closing tag.
- Elements must follow a strict hierarchy with only one root element.
- Elements must not overlap other elements.
- Element names must obey XML naming conventions.
- XML is case sensitive.

Consider the credit card company that wants to send you your latest statement via the Internet so that you can load it into your financial management program. Since this is a common problem for credit card companies and financial software authors, these industry groups have combined to create Open Financial Exchange (OFX), a language for the exchange of financial data across the Internet.

XML has a small number of rules. Tags always come in pairs, as in HTML. A pair of tags surrounds each piece of data (e.g., <price>89.12</price>) to indicate its meaning, whereas in HTML ,they indicate how the data are presented. Tag pairs can be nested inside one another to multiple levels, which effectively creates a tree or hierarchical structure. Because XML uses Unicode (see the discussion in Chapter 20), it enables the exchange of information not only between different computer systems, but also across language boundaries.

The differences between HTML and XML are captured in the following examples for each markup language. Note that in the following table, HTML incorporates formatting instructions (i.e., the course code is bold), whereas XML describes the meaning of the data.

Comparison of HTML and XML coding

HTML	XML
MIST7600 Data Management 3 credit hours </course>	<course> <code>MIST7600</code> <title>Data Management</title> <credit>3</credit>

XML enables a shift of processing from the server to the browser. At present, most processing has to be done by the server because that is where knowledge about the data is stored. The browser knows nothing about the data and therefore can only present but not process. However, when XML is implemented, the browser can take on processing that previously had to be handled by the server.

Imagine that you are selecting a shirt from a mail-order catalog. The merchant's Web server sends you data on 20 shirts (100 Kbytes of text and images) with prices in U.S. dollars. If you want to see the prices in euros, the calculation will be done by the server, and the full details for the 20 shirts retransmitted (i.e., another 100 Kbytes are sent from the server to the browser). However, once XML is in place, all that needs to be sent from the server to the browser is the conversion rate of U.S. dollars to euros and a program to compute the conversion at the browser end. In most cases, less data will be transmitted between a server and browser when XML is in place. Consequently, widespread adoption of XML will reduce network traffic.

Execution of HTML and XML code

HTML	XML
Retrieve shirt data with prices in USD. Retrieve shirt data with prices in EUR.	Retrieve shirt data with prices in USD. Retrieve conversion rate of USD to EUR Retrieve script to convert currencies. Compute prices in EUR.

XML can also make searching more efficient and effective. At present, search engines look for matching text strings, and consequently return many links that are completely irrelevant. For instance, if you are searching for details on the Nomad speaker system, and specify “nomad” as the sought text string, you will get links to many items that are of no interest (e.g., The Fabulous Nomads Surf Band). Searching will be more precise when you can specify that you are looking for a product name that includes the text “nomad.” The search engine can then confine its attention to text contained with the tags <productname> and </productname>, assuming these tags are the XML standard for representing product names.

The major expected gains from the introduction of XML are

- Store once and format many ways—Data stored in XML format can be extracted and reformatted for multiple presentation styles (e.g., PDF, ePUB).
- Hardware and software independence—One format is valid for all systems. Capture once and exchange many times—Data are captured as close to the source as possible and never again (i.e., no rekeying).
- Accelerated targeted searching—Searches are more precise and faster because they use XML tags.
- Less network congestion—The processing load shifts from the server to the browser.

XML language design

XML lets developers design application-specific vocabularies. To create a new language, designers must agree on three things:

- The allowable tags
- The rules for nesting tagged elements
- Which tagged elements can be processed

The first two, the language’s vocabulary and structure, are typically defined in an XML schema. Developers use the XML schema to understand the meaning of tags so they can write software to process an XML file.

XML tags describe meaning, independent of the display medium. An XML stylesheet, another set of rules, defines how an XML file is automatically formatted for various devices. This set of rules is called an Extensible Stylesheet Language (XSL). Stylesheets allow data to be rendered in a variety of ways, such as Braille or audio for visually impaired people.

XML schema

An XML schema (or just schema for brevity) is an XML file associated with an XML document that informs an application how to interpret markup tags and valid formats for tags. The advantage of a schema is that it leads to standardization. Consistently named and defined tags create conformity and support organizational efficiency. They avoid the confusion and loss of time when the meaning of data is not clear. Also, when validation information is built into a schema, some errors are detected before data are exchanged.

XML does not require the creation of a schema. If a document is well formed, XML will interpret it correctly. A well-formed document follows XML syntax and has tags that are correctly nested.

A schema is a very strict specification, and any errors will be detected when parsing. A schema defines:

- The names and contents of all elements that are permissible in a certain document
- The structure of the document
- How often an element may appear
- The order in which the elements must appear
- The type of data the element can contain

DOM

The Document Object Model (DOM) is the model underlying XML. It is based on a tree (i.e., it directly supports one-to-one and one-to-many, but not many-to-many relationships). A document is modeled as a hierarchical collection of nodes that have parent/child relationships. The node is the primary object and can be of different types (such as document, element, attribute, text). Each document has a single document node, which has no parent, and zero or more children that are element nodes. It is a good practice to create a visual model of the XML document and then convert this to a schema, which is XML's formal representation of the DOM.

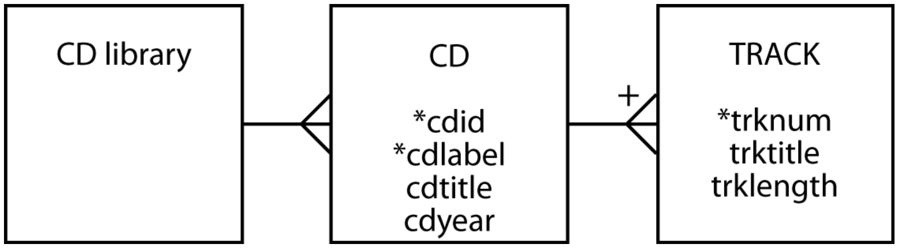
At this point, an example is the best way to demonstrate XML, schema, and DOM concepts. We will use the familiar CD problem that was introduced in Chapter 3. In keeping with the style of this text, we define a minimal amount of XML to get you started, and then more features are added once you have mastered the basics.

CD library case

The CD library case gradually develops, over several chapters, a data model for recording details of a CD collection, culminating in the model at the end of Chapter 6. Unfortunately, we cannot quickly convert this final model to an XML document model, because a DOM is based on a tree model. Thus, we must start afresh.

The model , in this case, is based on the observation that a CD library has many CDs, and a CD has many tracks.

CD library tree data model



A model is then mapped into a schema using the following procedure.

- Each entity becomes a complex element type.
- Each data model attribute becomes a simple element type.
- The one-to-many (1:m) relationship is recorded as a sequence.

The schema for the CD library follows. For convenience of exposition, the source code lines have been numbered, but these numbers are not part of a schema.[2]

Schema for CD library (cdlib.xsd)

```
<?xml version="1.0" encoding="UTF-8"?>
<xsd:schema xmlns:xsd='http://www.w3.org/2001/XMLSchema'>
<!--CD library-->
 <xsd:element name="cdlibrary">
  <xsd:complexType>
   <xsd:sequence>
    <xsd:element name="cd" type="cdType"
     minOccurs="1" maxOccurs="unbounded"/>
    </xsd:sequence>
  </xsd:complexType>
 </xsd:element>
<!--CD-->
  <xsd:complexType name="cdType">
   <xsd:sequence>
    <xsd:element name="cdid" type="xsd:string"/>
    <xsd:element name="cdlabel" type="xsd:string"/>
    <xsd:element name="cdtitle" type="xsd:string"/>
    <xsd:element name="cdyear" type="xsd:integer"/>
    <xsd:element name="track" type="trackType"
      minOccurs="1" maxOccurs="unbounded"/>
    </xsd:sequence>
    </xsd:complexType>
<!--Track-->
 <xsd:complexType name="trackType">
  <xsd:sequence>
    <xsd:element name="trknum" type="xsd:integer"/>
    <xsd:element name="trktitle" type="xsd:string"/>
```

[2] You should use an XML editor for creating XML files. I have not found a good open source product. Among the commercial products, my preference is for Oxygen, which you can get for a 30 days trial.

```
    <xsd:element name="trklen" type="xsd:time"/>
  </xsd:sequence>
 </xsd:complexType>
</xsd:schema>
```

There are several things to observe about the schema.

- All XML documents begin with an XML declaration {1}.[3] The encoding attribute (i.e., encoding="UTF-8") specifies what form of Unicode is used (in this case the 8-bit form).
- The XSD Schema namespace[4] is declared {2}.
- Comments are placed inside the tag pair {3}.
- The CD library is defined {4–10} as a complex element type, which essentially means that it can have embedded elements, which are a sequence of CDs in this case.
- A sequence is a series of child elements embedded in a parent, as illustrated by a CD library containing a sequence of CDs {7}, and a CD containing elements of CD identifier, label, and so forth {15–20}. The order of a sequence must be maintained by any XML document based on the schema.
- A sequence can have a specified range of elements. In this case, there must be at least one CD (minOccurs="1") but there is no upper limit (maxOccurs= "unbounded") on how many CDs there can be in the library {7}.
- An element that has a child (e.g., cdlibrary, which is at the 1 end of a 1:m) or possesses attributes (e.g., track) is termed a complex element type.
- A CD is represented by a complex element type {13–20}, and has the name cdType {13}.
- The element cd is defined by specifying the name of the complex type (i.e., cdType) containing its specification {7}.
- A track is represented by a complex type because it contains elements of track number, title, and length {24–30}. The name of this complex type is trackType {24}.
- Notice the reference within the definition of cd to the complex type trackType, used to specify the element track {19}.
- Simple types (e.g., cdid and cdyear) do not contain any elements, and thus the type of data they store must be defined. Thus, cdid is a text string and cdyear is an integer.

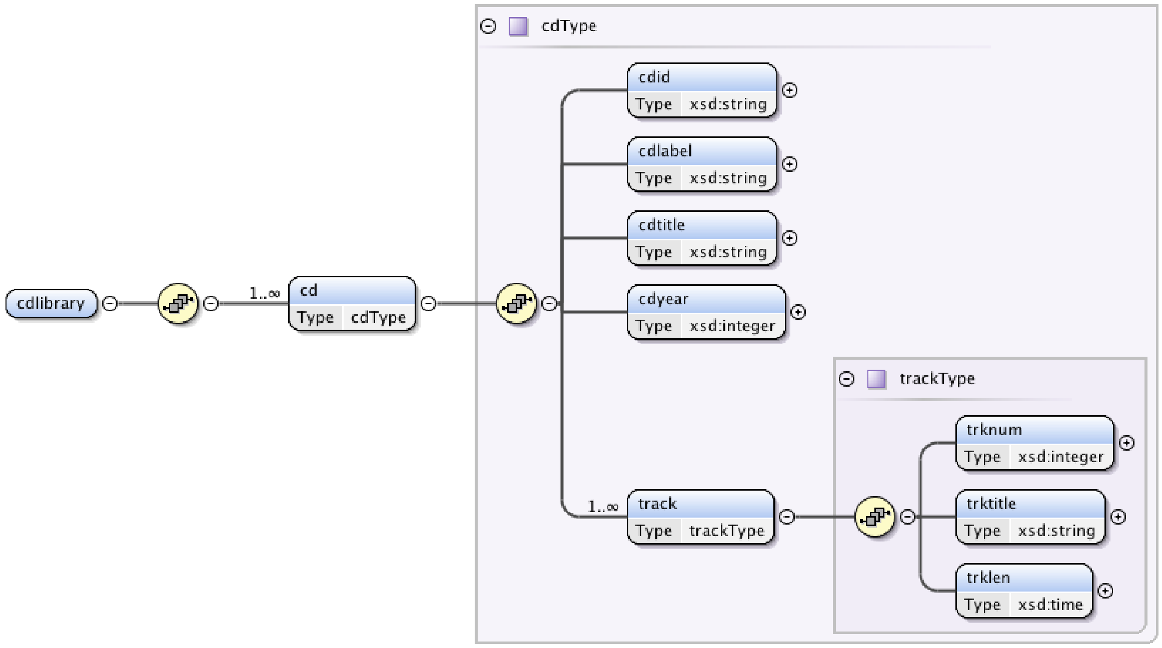
The purpose of a schema is to define the contents and structure of an XML file. It is also used to verify that an XML file has a valid structure and that all elements in the XML file are defined in the schema.

If you use an editor, you can possibly create a visual view of the schema.

A visual depiction of a schema as created by Oxygen

[3] In this chapter, numbers in {} refer to line numbers in the corresponding XML code.

[4] A namespace is a collection of valid names of attributes, types, and elements for a schema. Think of a namespace as a dictionary.



Some common data types are shown in the following table. The meaning is obvious in most cases for those familiar with SQL, except for uriReference. A Uniform Resource Identifier (URI) is a generalization of the URL concept.

Some common data types

Data type
string
boolean
anyURI
decimal
float
integer
time
date

We can now use the recently defined CDlibrary schema to describe a small CD library containing the CD information given in the following table.

Data for a small CD library

The XML for describing the CD library follows. There are several things to observe:

- All XML documents begin with an XML declaration.
- The declaration immediately following the XML declaration identifies the root element of the document (i.e., cdlibrary) and the schema (i.e., cdlib.xsd).

- Details of a CD are enclosed by the tags <cd> and </cd>.
- Details of a track are enclosed by the tags <track> and </track>.

XML for describing a CD (cdlib.xml)

```xml
<?xml version="1.0" encoding="UTF-8"?>
<cdlibrary xmlns:xsi=
  "http://www.w3.org/2001/XMLSchema-instance"
    xsi:noNamespaceSchemaLocation="cdlib.xsd">
    <cd>
        <cdid>A2 1325</cdid>
        <cdlabel>Atlantic</cdlabel>
        <cdtitle>Pyramid</cdtitle>
        <cdyear>1960</cdyear>
        <track>
            <trknum>1</trknum>
            <trktitle>Vendome</trktitle>
            <trklen>00:02:30</trklen>
        </track>
        <track>
            <trknum>2</trknum>
            <trktitle>Pyramid</trktitle>
            <trklen>00:10:46</trklen>
        </track>
    </cd>
    <cd>
        <cdid>D136705</cdid>
        <cdlabel>Verve</cdlabel>
        <cdtitle>Ella Fitzgerald</cdtitle>
        <cdyear>2000</cdyear>
        <track>
            <trknum>1</trknum>
            <trktitle>A tisket, a tasket</trktitle>
            <trklen>00:02:37</trklen>
        </track>
        <track>
            <trknum>2</trknum>
            <trktitle>Vote for Mr. Rhythm</trktitle>
            <trklen>00:02:25</trklen>
        </track>
        <track>
            <trknum>3</trknum>
            <trktitle>Betcha nickel</trktitle>
            <trklen>00:02:52</trklen>
        </track>
    </cd>
</cdlibrary>
```

As you now realize, the definition of an XML document is relatively straightforward. It is a bit tedious with all the typing of tags to surround each data element. Fortunately, there are XML editors that relieve this tedium.

☒ *Skill builder*

1. Use the Chrome browser to access this book's Web site XML page, and click on customerpayments.xml. You
   will see how this browser displays XML. Investigate what happens when you click on the grey triangles next to some entries.
2. Again, using Chrome, save the displayed XML code (Save Page As ...) as customer-payments.xml, and open it in a text editor.
3. Now, add details of the customer and payment data displayed in the following table to the beginning of the XML file. Open the saved file with Chrome, and verify your work.

Customer and payment data

AA Souvenirs, Yallingup, Western Australia

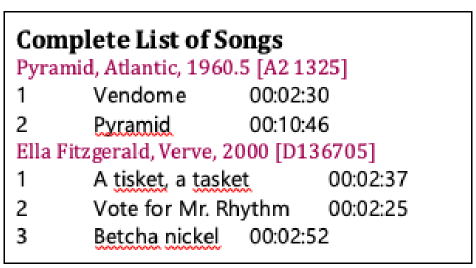
Check number	Amount	Date
QP45901	9387.45	2005-03-16
AG9984	3718.67	2005-07-24

XSL

As you now know from the prior exercise, the browser display of XML is not particularly useful. What is missing is a stylesheet that tells the browser how to display an XML file. The eXtensible Stylesheet Language (XSL) is used for defining the rendering of an XML file. An XSL document defines the rules for presenting an XML document's data. XSL is an application of XML, and an XSL file is also an XML file.

The power of XSL is demonstrated by applying the stylesheet that follows to the preceding XML.

Result of applying a stylesheet to CD library data


Complete List of Songs

Pyramid, Atlantic, 1960.5 [A2 1325]

1	Vendome	00:02:30
2	Pyramid	00:10:46

Ella Fitzgerald, Verve, 2000 [D136705]

1	A tisket, a tasket	00:02:37
2	Vote for Mr. Rhythm	00:02:25
3	Betcha nickel	00:02:52

Stylesheet for displaying an XML file of CD data (cdlib.xsl)

```
<?xml version="1.0" encoding="UTF-8"?>
<xsl:stylesheet version="1.0"
  xmlns:xsl="http://www.w3.org/1999/XSL/Transform">
    <xsl:output encoding="UTF-8"
      indent="yes" method="html" />
    <xsl:template match="/">
    <html>
        <head>
            <title> Complete List of Songs </title>
        </head>
    <body>
        <h1> Complete List of Songs </h1>
        <xsl:apply-templates select="cdlibrary" />
        </body>
        </html>
    </xsl:template>
    <xsl:template match="cdlibrary">
        <xsl:for-each select="cd">
            <br/>
            <font color="maroon">
                <xsl:value-of select="cdtitle" />
                ,
                <xsl:value-of select="cdlabel" />
                ,
                <xsl:value-of select="cdyear" />
                [
                <xsl:value-of select="cdid" />
                ] </font>
            <br/>
            <table>
    <xsl:for-each select="track">
        <tr>
            <td align="left">
                <xsl:value-of select="trknum" />
            </td>
            <td>
                <xsl:value-of select="trktitle" />
            </td>
            <td align="center">
                <xsl:value-of select="trklen" />
            </td>
        </tr>
    </xsl:for-each>
</table>
            <br/>
        </xsl:for-each>
    </xsl:template>
</xsl:stylesheet>
```

To use a stylesheet with an XML file, you must add a line of code to point to the stylesheet file. In this case, you add the following:

```
<?xml-stylesheet type=”text/xsl”
  href=”cdlib.xsl” media=”screen”?>
```

as the second line of cdlib.xml (i.e., it appears before <cdlibrary ... >). The added line of code points to cdlib.xsl as the stylesheet. This means that when the browser loads cdlib.xml, it uses the contents of cdlib.xsl to determine how to render the contents of cdlib.xml.

We now need to examine the contents of cdlib.xsl so that you can learn some basics of creating XSL commands. You will soon notice that all XSL commands are preceded by xsl:

- Tell the browser it is processing an XML file {1}
- Specify that the file is a stylesheet {2}
- Specify a template, which identifies which elements should be processed and how they are processed. The match attribute {4} indicates the template applies to the source node. Process the template {11} defined in the file {15–45}. A stylesheet can specify multiple templates to produce different reports from the same XML input.
- Specify a template to be applied when the XSL processor encounters the <cdlibrary> node {15}.
- Create an outer loop for processing each CD {16–44}.
- Define the values to be reported for each CD (i.e., title, label, year, and id) {19, 21, 23, 25}. The respective XSL commands select the values. For example, <xsl:value-of select=“cdtitle”/> specifies selection of cdtitle.
- Create an inner loop for processing the tracks on a particular CD {29–41}.
- Present the track data in tabular form using HTML table commands interspersed with XSL {28–42}.

☒ *Skill builder*

1. Use the Chrome browser to access this book’s Web site, navigate to the XML page, and download cdlib.xml and cdlib.xsl to a directory or folder on your machine. Use Save Page As ... for downloading.
2. Using a text editor, change the saved copy of cdlib.xml by inserting the following as the second line:
   <?xml-stylesheet type=“text/xsl” href=“cdlib.xsl” media=“screen”?>
3. Save the edited file in the same directory or folder as cdlib.xsl. Open the saved XML file with Chrome.

Converting XML

There are occasions when there is a need to convert an XML file:

- Transformation: conversion from one XML vocabulary to another (e.g., between financial languages FPML and finML)
- Manipulation: reordering, filtering, or sorting parts of a document
- Rendering in another language: rendering the XML file using another format

You have already seen how XSL can be used to transform XML for rendering as HTML. The original XSL has been split into three languages:

- XSLT for transformation and manipulation
- XSLT for rendition
- XPath for accessing the structure of an XML file

For a data management course, this is as far as you need to go with learning about XSL. Just remember that you have only touched the surface. To become proficient in XML, you will need an entire course on the topic.

XPath for navigating an XML document

XPath is a navigation language for an XML document. It defines how to select nodes or sets of nodes in a document. The first step to understanding XPath is to know about the different types of nodes. In the following XML document, the document node is <cdlibrary> {1}, <trktitle>Vendome</trktitle> {9} is an example of an element node, and <track length="00:02:30"> {7} is an instance of an attribute node.

An XML document

```
<cdlibrary>
    <cd>
        <cdid>A2 1325</cdid>
        <cdlabel>Atlantic</cdlabel>
        <cdtitle>Pyramid</cdtitle>
        <cdyear>1960</cdyear>
        <track length="00:02:30">
            <trknum>1</trknum>
            <trktitle>Vendome</trktitle>
        </track>
        <track length="00:10:46">
            <trknum>2</trknum>
            <trktitle>Pyramid</trktitle>
        </track>
    </cd>
</cdlibrary>
```

A family of nodes

Each element and attribute has one parent node. In the preceding XML document, cd is the parent of cdid, cdlabel, cdyear, and track. Element nodes may have zero or more children nodes. Thus cdid, cdlabel, cdyear, and track are the children of cd. Ancestor nodes are the parent, parent's parent, and so forth of a node. For example, cd and cdlibrary are ancestors of cdtitle. Similarly, we have descendant nodes, which are the children, children's children, and so on of a node. The descendants of cd include cdid, cdtitle, track, trknum, and trktitle. Finally, we have sibling nodes, which are nodes that share a parent. In the sample document, cdid, cdlabel, cdyear, and track are siblings.

Navigation examples

The examples in the following table give you an idea of how you can use XPath to extract data from an XML document. Our preference is to answer such queries using SQL, but if your data are in XML format, then XPath provides a means of interrogating the file.

XPath examples

Example	Result
/cdlibrary/cd[1]	Selects the first CD
//trktitle	Selects all the titles of all tracks
/cdlibrary/cd[last() -1]	Selects the second last CD
/cdlibrary/cd[last()]/track[last()]/trklen T	he length of the last track on the last CD
/cdlibrary/cd[cdyear=1960]	Selects all CDs released in 1960
/cdlibrary/cd[cdyear>1950]/cdtitle	Titles of CDs released after 1950

XQuery for querying an XML document

XQuery is a query language for XML, and thus it plays a similar role that SQL plays for a relational database. It is used for finding and extracting elements and attributes of an XML document. It builds on XPath's method for specifying navigation through the elements of an XML document. As well as being used for querying, XQuery can also be used for transforming XML to XHTML.

The first step is to specify the location of the XML file. In this case, we will use the cdlib.xml file, which is stored on the web site for this book. Using XPath notation it is relatively straightforward to list some values in an XML file

List the titles of CDs.

```
doc("http://www.richardtwatson.com/xml/cdlib.xml")
  /cdlibrary/cd/cdtitle
<?xml version="1.0" encoding="UTF-8"?>
<cdtitle>Pyramid</cdtitle>
<cdtitle>Ella Fitzgerald</cdtitle>
```

You can also use an XPath expression to select particular information.

List the titles of CDs released under the Verve label

```
doc("http://www.richardtwatson.com/xml/cdlib.xml")
  /cdlibrary/cd[cdlabel='Verve']/cdtitle
<?xml version="1.0" encoding="UTF-8"?>
<cdtitle>Ella Fitzgerald</cdtitle>
```

XQuery commands can also be written using an SQL like structure, which is called FLWOR, an easy way to remember 'For, Let, Where, Order by, Return.' Here is an example.

List the titles of tracks longer than 5 minutes

```
for $x in doc("http://www.richardtwatson.com/xml/cdlib.xml")
 /cdlibrary/cd/track
where $x/'track length' > "00:05:00"
order by $x/'trktitle'
return $x

<?xml version="1.0" encoding="UTF-8"?>
<track>
    <trknum>2</trknum>
    <trktitle>Pyramid</trktitle>
    <trklen>00:10:46</trklen>
</track>
```

If you want to just report the data without the tags, use return data($x).

Conclusion

XML has two main roles. The first is to facilitate the exchange of data between organizations and within those organizations that do not have integrated systems. Its second purpose is to support exchange between servers.

Mastery of XML is well beyond the scope of a single chapter. Indeed, it is a book-length topic, and hundreds of books have been written on XML. It is important to remember that the prime goal of XML is to support data interchange. If you would like to continue learning about XML, then consider the open content textbook (en.wikibooks.org/wiki/XML), which was created by students and is under continual revision. You might want to contribute to this book.

Summary

Electronic data exchange became more important with the introduction of the Internet. SGML, a precursor of XML, defines the structure of documents. SGML's value derives from its reusability, flexibility, support for revision, and format independence. XML, a derivative of SGML, is designed to support electronic commerce and overcome some of the shortcomings of SGML. XML supports data exchange by making information self-describing. It is a metalanguage because it is a language for generating other languages (e.g., finML). It provides substantial gains for the management and distribution of data. The XML language consists of an XML schema, document object model (DOM), and XSL. A schema defines the structure of a document and how an application should interpret XML markup tags. The DOM is a tree-based data model of an XML document. XSL is used to specify a stylesheet for displaying an XML document.

Key terms and concepts

Document object model (DOM)	Markup language
Document type definition (DTD)	Occurrence indicators
Electronic data interchange (EDI)	Standard generalized markup language (SGML)
Extensible markup language (XML)	XML database
Extensible stylesheet language (XSL)	XML schema
Hypertext markup language (HTML)	

References and additional readings

Watson, R. T., and others. 2004. *XML: managing data exchange*.

Exercises

1. A business has a telephone directory that records the first and last name, telephone number, and e-mail address of everyone working in the firm. Departments are the main organizing unit of the firm, so the telephone directory is typically displayed in department order, and shows for each department the contact phone and fax numbers and e-mail address.
   a. Create a hierarchical data model for this problem.
   b. Define the schema.
   c. Create an XML file containing some directory data.
   d. Create an XSL file for a stylesheet and apply the transformation to the XML file.
2. Create a schema for your university or college's course bulletin.
3. Create a schema for a credit card statement.
4. Create a schema for a bus timetable.
5. Using the portion of ClassicModels that has been converted to XML, answer the following questions using XPath.
   a. List all customers.

b. Who is the last customer in the file?
c. Select all customers in Sweden.
d. List the payments of more than USD 100,000.
e. Select the first payments by Toys4GrownUps.com.
f. What was the payment date for check DP677013?
g. Who paid with check DP677013?
h. What payments were received on 2003-12-04?
i. Who made payments on 2003-12-04?
j. List the numbers of all checks from customers in Denmark.

6. Using the portion of ClassicModels that has been converted to XML, answer the following questions using XQuery.
    a. List all customers.
    b. Who is the last customer in the file?
    c. Select all customers in Sweden sorted by customer name.
    d. List the payments of more than USD 100,000.
    e. Select the first payments by Toys4GrownUps.com.
    f. What was the payment date for check DP677013?
    g. Who paid with check DP677013?
    h. What payments were received on 2003-12-04?
    i. Who made payments on 2003-12-04?
    j. List the numbers of all checks from customers in Denmark.

14 Organizational Intelligence

There are three kinds of intelligence: One kind understands things for itself, the other appreciates what others can understand, the third understands neither for itself nor through others. This first kind is excellent, the second good, and the third kind useless.

Machiavelli, *The Prince*, 1513

Learning objectives

Students completing this chapter will be able to

- understand the principles of organizational intelligence;
- decide whether to use verification or discovery for a given problem;
- select the appropriate data analysis technique(s) for a given situation;

Information poverty

Too many companies are *data rich* but *information poor*. They collect vast amounts of data with their transaction processing systems, but they fail to turn these data into the necessary information to support managerial decision making. Many organizations make limited use of their data because they are scattered across many systems rather than centralized in one readily accessible, integrated data store. Technologies exist to enable organizations to create vast repositories of data that can be then analyzed to inform decision making and enhance operational performance.

Organizational intelligence is the outcome of an organization's efforts to collect, store, process, and interpret data from internal and external sources. The conclusions or clues gleaned from an organization's data stores enable it to identify problems or opportunities, which is the first stage of decision making.

An organizational intelligence system

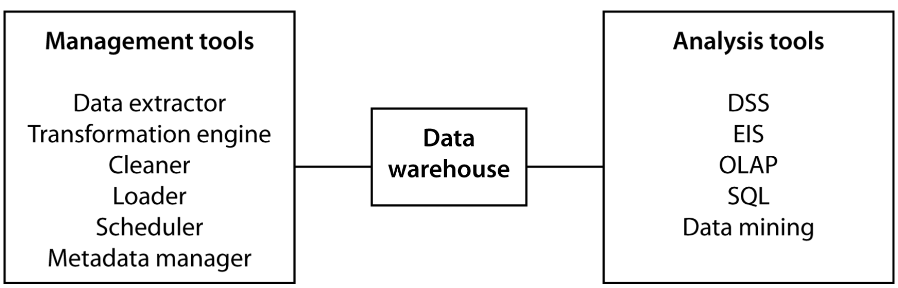
Transaction processing systems (TPSs) are a core component of organizational memory and thus an important source of data. Along with relevant external information, the various TPSs are the bedrock of an organizational intelligence system. They provide the raw facts that an organization can use to learn about itself, its competitors, and the environment. A TPS can generate huge volumes of data. In the United States, a telephone company may generate millions of records per day detailing the telephone calls it has handled. The hundreds of million credit cards on issue in the world generate billions of transactions per year. A popular Web site can have a hundred million hits per day. TPSs are creating a massive torrent of data that potentially reveals to an organization a great deal about its business and its customers.

Unfortunately, many organizations are unable to exploit, either effectively or efficiently, the massive amount of data generated by TPSs. Data are typically scattered across a variety of systems, in different database technologies, in different operating systems, and in different locations. The fundamental problem is that organizational memory is fragmented. Consequently, organizations need a technology that can accumulate a considerable proportion of organizational memory into one readily accessible system. Making these data available to decision makers is crucial to improving organizational performance, providing first-class customer service, increasing revenues, cutting costs, and preparing for the future. For many organizations, their memory is a major untapped resource—*an underused intelligence system containing undetected key facts about customers.* To take advantage of the mass of available raw data, an organization first needs to organize these data into one logical collection and then use software to sift through this collection to extract meaning.

The data warehouse or a data lake, a subject-oriented, integrated, time-variant, and nonvolatile set of data that supports decision making, is a key mean for harnessing organizational memory. *Subject* databases are designed around the essential entities of a business (e.g., customer) rather than applications (e.g., auto insurance). *Integrated* implies consistency in naming conventions, keys, relationships, encoding, and translation (e.g., gender is coded consistently across all relevant fields). *Time-variant* means that data are organized by various time periods (e.g., by months). Because a data warehouse is updated with a bulk upload, rather than as transactions occur, it contains *nonvolatile* data.

Data warehouses are enormous collections of data, often measured in petabytes, compiled by mass marketers, retailers, and service companies from the transactions of their millions of customers. Associated with a data warehouse are data management aids (e.g., data extraction), analysis tools (e.g., OLAP), and applications (e.g., executive information system).

The data warehouse



The data warehouse

Creating and maintaining the data warehouse

A data warehouse is a snapshot of an organization at a particular time. In order to create this snapshot, data must be extracted from existing systems, transformed, cleaned, and loaded into the data warehouse. In addition, regular snapshots must be taken to maintain the usefulness of the warehouse.

Extraction

Data from the operational systems, stored in operational data stores (ODS), are the raw material of a data warehouse. Unfortunately, it is not simply a case of pulling data out of ODSs and loading them into the warehouse. Operational systems were often written many years ago at different times. There was no plan to merge these data into a single system. Each application is independent or shares little data with others. The same data may exist in different systems with different names and in different formats. The extraction of data from many different systems is time-consuming and complex. Furthermore, extraction is not a one-time process. Data must be extracted from operational systems on an ongoing basis so that analysts can work with current data.

Transformation

Transformation is part of the data extraction process. In the warehouse, data must be standardized and follow consistent coding systems. There are several types of transformation:

- Encoding: Non-numeric attributes must be converted to a common coding system. Gender may be coded, for instance, in a variety of ways (e.g., m/f, 1/0, or M/F) in different systems, and do not take account of social changes that recognize other categories. The extraction program must transform data from each application to a single coding system (e.g., m/f/...).
- Unit of measure: Distance, volume, and weight can be recorded in varying units in different systems (e.g., centimeters or inches) and must be converted to a common system.
- Field: The same attribute may have different names in different applications (e.g., sales-date, sdate, or saledate), and a standard name must be defined.
- Date: Dates could be stored in a variety of ways. In Europe the standard for date is *dd/mm/yy*, in the U.S. it is *mm/dd/yy*, whereas the ISO standard is *yyyy-mm-dd*.

Cleaning

Unfortunately, some of the data collected from applications may be *dirty*—they contain errors, inconsistencies, or redundancies. There are a variety of reasons why data may need cleaning:

- The same record is stored by several departments. For instance, both Human Resources and Production have an employee record. Duplicate records must be deleted.

- Multiple records for a company exist because of an acquisition. For example, the record for Sun Microsystems should be removed because it was acquired by Oracle.
- Multiple entries for the same entity exist because there are no corporate data entry standards. For example, FedEx and Federal Express both appear in different records for the same company.
- Data entry fields are misused. For example, an address line field is used to record a second phone number.

Data cleaning starts with determining the dirtiness of the data. An analysis of a sample should indicate the extent of the problem and whether commercial data-cleaning tools are required. Data cleaning is unlikely to be a one-time process. All data added to the data warehouse should be validated in order to maintain the integrity of the warehouse. Cleaning can be performed using specialized software or custom-written code.

Loading

Data that have been extracted, transformed, and cleaned can be loaded into the warehouse. There are three types of data loads:

- Archival: Historical data (e.g., sales for the period 2011–2021) that is loaded once. Many organizations may elect not to load these data because of their low value relative to the cost of loading.
- Current: Data from current operational systems.
- Ongoing: Continual revision of the warehouse as operational data are generated. Managing the ongoing loading of data is the largest challenge for warehouse management. This loading is done either by completely reloading the data warehouse or by just updating it with the changes.

Scheduling

Refreshing the warehouse, which can take many hours, must be scheduled as part of a data center's regular operations. Because a data warehouse supports medium- to long-term decision making, it is unlikely that it would need to be refreshed more frequently than daily. For shorter decisions, operational systems are available. Some firms may decide to schedule less frequently after comparing the cost of each load with the cost of using data that are a few days old.

Metadata

A data dictionary is a reference repository containing *metadata* (i.e., *data about data*). It includes a description of each data type, its format, coding standards (e.g., volume in liters), and the meaning of the field. For the data warehouse setting, a data dictionary is likely to include details of which operational system created the data, transformations of the data, and the frequency of extracts. Analysts need access to metadata so that they can plan their analyses and learn about the contents of the data warehouse. If a data dictionary does not exist, it should be established and maintained as part of ensuring the integrity of the data warehouse.

Data warehouse technology

Selecting an appropriate data warehouse system is critical to support significant data analytics. Data analysis often requires intensive processing of large volumes of data, and large main memories are necessary for good performance. In addition, the system should be scalable so that as the demand for data analysis grows, the system can be readily upgraded.

Some organizations use Hadoop, which is covered in the chapter on cluster computing, as the foundation for a data warehouse. It offers speed and cost advantages over prior technology .

Exploiting data stores

Two approaches to analyzing a data store (i.e., a database or data warehouse) are data mining and data analytics. Before discussing each of these approaches, it is helpful to recognize the fundamentally different approaches that can be taken to exploiting a data store.

Verification and discovery

The verification approach to data analysis is driven by a hypothesis or conjecture about some relationship (e.g., customers with incomes in the range of $50,000–75,000 are more likely to buy minivans). The analyst then formulates a query to process the data to test the hypothesis. The resulting report will either support or disconfirm the theory. If the theory is disconfirmed, the analyst may continue to propose and test hypotheses until a target customer group of likely prospects for minivans is identified. Then, the minivan firm may market directly to this group because the likelihood of converting them to customers is higher than mass marketing to everyone. The verification approach is highly dependent on a persistent analyst eventually finding a useful relationship (i.e., who buys minivans?) by testing many hypotheses. Statistical methods support the verification approach.

Data mining uses the discovery approach. It sifts through the data in search of frequently occurring patterns and trends to report generalizations about the data. Data mining tools operate with minimal guidance from the client. They are designed to yield useful facts about business relationships efficiently from a large data store. The advantage of discovery is that it may uncover important relationships that no amount of conjecturing would have revealed and tested. Machine learning is a popular discovery tool when large volumes observations are available.

A useful analogy for thinking about the difference between verification and discovery is the difference between conventional and open-pit gold mining. A conventional mine is worked by digging shafts and tunnels with the intention of intersecting the richest gold vein. Verification is like conventional mining—some parts of the gold deposit may never be examined. The company drills where it believes there will be gold. In open-pit mining, everything is excavated and processed. Discovery is similar to open-pit mining—everything is examined. Both verification and discovery are useful; it is not a case of selecting one or the other. Indeed, analysts should use both methods to gain as many insights as possible from the data.

Comparison of verification and discovery

Verification	Discovery
What is the average sale for in-store and catalog customers?	What is the best predictor of sales?
What is the average high school GPA of students who graduate from college compared to those who do not?	What are the best predictors of college graduation?

OLAP

Edgar F. Codd, the father of the relational model, and some colleagues[1] proclaimed in 1993 that RDBMSs were never intended to provide powerful functions for data synthesis, analysis, and consolidation. This was the role of spreadsheets and special-purpose applications. He argued that analysts need data analysis tools that complement RDBMS technology, and they put forward the concept of online analytical processing (OLAP): the analysis of business operations with the intention of making timely and accurate analysis-based decisions.

Instead of rows and columns, OLAP tools provide multidimensional views of data, as well as some other differences. OLAP means fast and flexible access to large volumes of derived data whose underlying inputs may be changing continuously.

Comparison of TPS and OLAP applications

TPS	OLAP
Optimized for transaction volume	Optimized for data analysis
Process a few records at a time	Process summarized data
Real-time update as transactions occur	Batch update (e.g., daily)
Based on tables	Based on hypercubes
Raw data	Aggregated data
SQL	MDX

For instance, an OLAP tool enables an analyst to view how many widgets were shipped to each region by each quarter in 2012. If shipments to a particular region are below budget, the analyst can find out which customers in that region are ordering less than expected. The analyst may even go as far as examining the data for a particular quarter or shipment. As this example demonstrates, the idea of OLAP is to give analysts the power to view data in a variety of ways at different levels. In the process of investigating data anomalies, the analyst may discover new relationships. The operations supported by the typical OLAP tool include

- Calculations and modeling across dimensions, through hierarchies, or across members

[1] Codd, E. F., S. B. Codd, and C. T. Salley. 1993. Beyond decision support. Computerworld, 87–89.

- Trend analysis over sequential time periods
- Slicing subsets for on-screen viewing
- Drill-down to deeper levels of consolidation
- Drill-through to underlying detail data
- Rotation to new dimensional comparisons in the viewing area

An OLAP system should give fast, flexible, shared access to analytical information. Rapid access and calculation are required if analysts are to make ad hoc queries and follow a trail of analysis. Such quick-fire analysis requires computational speed and fast access to data. It also requires powerful analytic capabilities to aggregate and order data (e.g., summarizing sales by region, ordered from most to least profitable). Flexibility is another desired feature. Data should be viewable from a variety of dimensions, and a range of analyses should be supported.

Multidimensional database (MDDB)

OLAP is typically used with an multidimensional database (MDDB), a data management system in which data are represented by a multidimensional structure. The MDDB approach is to mirror and extend some of the features found in spreadsheets by moving beyond two dimensions. These tools are built directly into the MDDB to increase the speed with which data can be retrieved and manipulated. These additional processing abilities, however, come at a cost. The dimensions of analysis must be identified prior to building the database. In addition, MDDBs have size limitations that RDBMSs do not have and, in general, are an order of magnitude smaller than a RDBMS.

MDDB technology is optimized for analysis, whereas relational technology is optimized for the high transaction volumes of a TPS. For example, SQL queries to create summaries of product sales by region, region sales by product, and so on, could involve retrieving many of the records in a marketing database and could take hours of processing. A MDDB could handle these queries in a few seconds. TPS applications tend to process a few records at a time (e.g., processing a customer order may entail one update to the customer record, two or three updates to inventory, and the creation of an order record). In contrast, OLAP applications usually deal with summarized data.

Fortunately, RDBMS vendors have standardized on SQL, and this provides a commonality that allows analysts to transfer considerable expertise from one relational system to another. Similarly, MDX, originally developed by Microsoft to support multidimensional querying of an SQL server, has been implemented by a number of vendors for interrogating an MDDB.

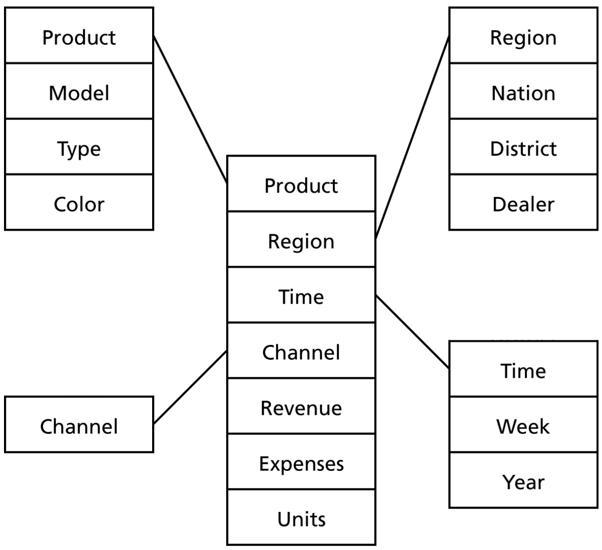
The current limit of MDDB technology is approximately 10 dimensions, which can be millions to trillions of data points.

ROLAP

An alternative to a physical MDDB is a *relational OLAP* (or ROLAP), in which case a multidimensional model is imposed on a relational model. As we discussed earlier, this is also known as a logical MDDB. Not surprisingly, a system designed to support OLAP should be superior to trying to retrofit relational technology to a task for which it was not specifically designed.

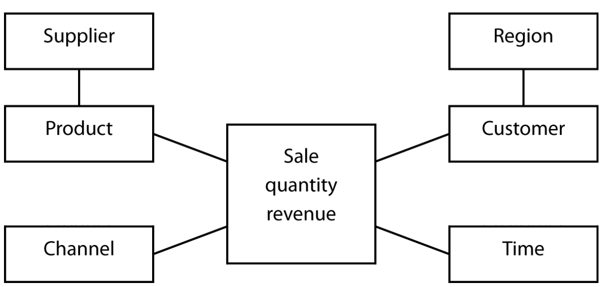
The star schema is used by some MDDBs to represent multidimensional data within a relational structure. The center of the star is a table storing multidimensional facts derived from other tables. Linked to this central table are the dimensions (e.g., region) using the familiar primary-key/foreign-key approach of the relational model. The following figure depicts a star schema for an international automotive company. The advantage of the star model is that it makes use of a RDBMS, a mature technology capable of handling massive data stores and having extensive data management features (e.g., backup and recovery). However, if the fact table is very large, which is often the case, performance may be slow. A typical query is a join between the fact table and some of the dimensional tables.

A star schema



A snowflake schema, more complex than a star schema, resembles a snowflake. Dimensional data are grouped into multiple tables instead of one large table. Space is saved at the expense of query performance because more joins must be executed. Unless you have good reasons, you should opt for a star over a snowflake schema.

A snowflake schema



Rotation, drill-down, and drill-through

MDDB technology supports rotation of data objects (e.g., changing the view of the data from "by year" to "by region" as shown in the following figure) and drill-down (e.g., reporting the details for each nation in a selected region as shown in the Drill Down figure), which is also possible with a relational system. Drill-down can slice through several layers of summary data to get to finer levels of detail. The Japanese data, for instance, could be dissected by region (e.g., Tokyo), and if the analyst wants to go further, Tokyo could be analyzed by store. In some systems, an analyst can drill through the summarized data to examine the source data within the organizational data store from which the MDDB summary data were extracted.

Rotation

		Region			
Year	Data	Asia	Europe	North America	Grand total
2010	Sum of hardware	97	23	198	318
	Sum of software	83	41	425	549
2011	Sum of hardware	115	28	224	367
	Sum of software	78	65	410	553
2012	Sum of hardware	102	25	259	386
	Sum of software	55	73	497	625
Total sum of hardware		314	76	681	1,071
Total sum of software		216	179	1,322	1717

Global regional results

Region	Sales variance (%)
Africa	105
Asia	57
Europe	122
North America	97
Pacific	85
South America	163

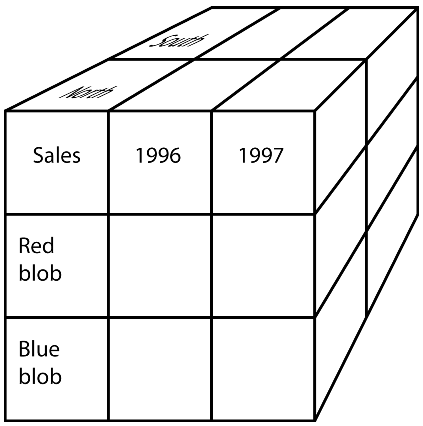
Asia drilldown

Region	Sales variance (%)
China	123
Japan	52
India	87
Singapore	95

The hypercube

From the analyst's perspective, a fundamental difference between MDDB and RDBMS is the representation of data. As you know from data modeling, the relational model is based on tables, and analysts must think in terms of tables when they manipulate and view data. The relational world is two-dimensional. In contrast, the hypercube is the fundamental representational unit of a MDDB. Analysts can move beyond two dimensions. To envisage this change, consider the difference between the two-dimensional blueprints of a house and a three-dimensional model. The additional dimension provides greater insight into the final form of the building.

A hypercube



Of course, on a screen or paper only two dimensions can be shown. This problem is typically overcome by selecting an attribute of one dimension (e.g., North region) and showing the other two dimensions (i.e., product sales by year). You can think of the third dimension (i.e., region in this case) as the page dimension—each page of the screen shows one region or slice of the cube.

Page				Columns
Region: North				Sales
		Red blob	Blue blob	Total
	2011			
Rows	2012			
Year	Total			

A three-dimensional hypercube display

A hypercube can have many dimensions. Consider the case of a furniture retailer who wants to capture six dimensions of data. Although it is extremely difficult to visualize a six-dimensional hypercube, it helps to think of each cell of the cube as representing a fact (e.g., the Atlanta store sold five Mt. Airy desks to a business in January).

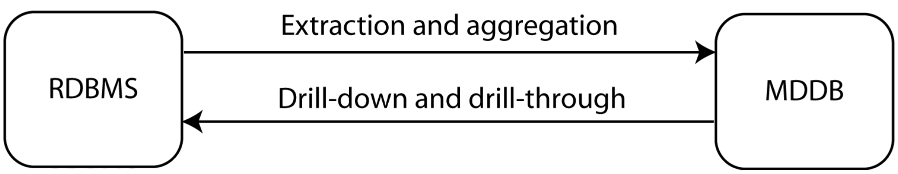
A six-dimensional hypercube

Dimension	Example
Brand	Mt. Airy
Store	Atlanta
Customer segment	Business
Product group	Desks
Period	January
Variable	Units sold

Similarly, a six-dimensional hypercube can be represented by combining dimensions (e.g., brand and store can be combined in the row dimension by showing stores within a brand).

A quick inspection of the table of the comparison of TPS and OLAP applications reveals that relational and multidimensional database technologies are designed for very different circumstances. Thus, the two technologies should be considered as complementary, not competing, technologies. Appropriate data can be periodically extracted from an RDBMS, aggregated, and loaded into an MDDB. Ideally, this process is automated so that the MDDB is continuously updated. Because analysts sometimes want to drill down to low-level aggregations and even drill through to raw data, there must be a connection from the MDDB to the RDBMS to facilitate access to data stored in the relational system.

The relationship between RDBMS and MDDB



Designing a multidimensional database

The multidimensional model, based on the hypercube, requires a different design methodology from the relational model. At this stage, there is no commonly used approach, such as the entity-relationship principle of the relational model. However, the method proposed by Thomsen [2] deserves consideration.

The starting point is to identify what must be tracked (e.g., sales for a retailer or revenue per passenger mile for a transportation firm). A collection of tracking variables is called a variable dimension.

The next step is to consider what types of analyses will be performed on the variable dimension. In a sales system, these may include sales by store by month, comparison of this month's sales with last month's for each product, and sales by class of customer. These types of analyses cannot be conducted unless the instances of each variable have an identifying tag. In this case, each sale must be tagged with time, store, product, and customer type. Each set of identifying factors is an identifier dimension. As a cross-check for identifying either type of dimension, use these six basic prompts.

[2] Thomsen, E. 1997. OLAP solutions: Building multidimensional information systems. New York, NY: Wiley.

Basic prompts for determining dimensions

Prompt	Example	Source
When?	June 5, 2013 10:27am	Transaction data
Where?	Paris	
What?	Tent	
How?	Catalog	
Who?	Young adult woman	Face recognition or credit card issuer
Why?	Camping trip to Bolivia	Social media
Outcome?	Revenue of €624.00	Transaction data

Most of the data related to the prompts can be extracted from transactional data. Face recognition software could be used to estimate the age and gender of the buyer in a traditional retail establishment. If the buyer uses a credit card, then such data, with greater precision, could be obtained from the bank issuing the credit card. In the case of why, the motivation for the purchase, the retailer can mine social exchanges made by the customer. Of course, this requires the retailer to be able to uniquely identify the buyer, through a store account or credit card, and use this identification to mine social media.

Variables and identifiers are the key concepts of MDDB design. The difference between the two is illustrated in the following table. Observe that time, an identifier, follows a regular pattern, whereas sales do not. Identifiers are typically known in advance and remain constant (e.g., store name and customer type), while variables change. It is this difference that readily distinguishes between variables and identifiers. Unfortunately, when this is not the case, there is no objective method of discriminating between the two. As a result, some dimensions can be used as both identifiers and variables.

A sales table

Identifier (time)	Variable sales (dollars)
10:00	523
11:00	789
12:00	1,256
13:00	4,128
14:00	2,634

+————–-+————–—+

There can be a situation when your intuitive notion of an identifier and variable is not initially correct. Consider a Web site that is counting the number of hits on a particular page. In this case, the identifier is hit and time is the variable because the time of each hit is recorded.

A hit table

Identifier (hit)	Variable (time)
1	9:34:45

Identifier (hit)	Variable (time)
2	9:34:57
3	9:36:12
4	9:41:56

The next design step is to consider the form of the dimensions. You will recall from statistics that there are three types of variables (dimensions in MDDB language): nominal, ordinal, and continuous. A nominal variable is an unordered category (e.g., region), an ordinal variable is an ordered category (e.g., age group), and a continuous variable has a numeric value (e.g., passenger miles). A hypercube is typically a combination of several types of dimensions. For instance, the identifier dimensions could be product and store (both nominal), and the variable dimensions could be sales and customers. A dimension's type comes into play when analyzing relationships between identifiers and variables, which are known as independent and dependent variables in statistics. The most powerful forms of analysis are available when both dimensions are continuous. Furthermore, it is always possible to recode a continuous variable into ordinal categories. As a result, wherever feasible, data should be collected as a continuous dimension.

Relationship of dimension type to possible analyses

		Identifier dimension	
		Continuous	Nominal or ordinal
Variable dimension	Continuous	Regression and curve fitting	Analysis of variance
		Sales over time	*Sales by store*
	Nominal or ordinal	Logistic regression	Contingency table analysis
		Customer response (yes or no) to the level of advertisng	*Number of sales by region*

This brief introduction to multidimensionality modeling has demonstrated the importance of distinguishing between types of dimensions and considering how the form of a dimension (e.g., nominal or continuous) will affect the choice of analysis tools. Because multidimensional modeling is a relatively new concept, you can expect design concepts to evolve. If you become involved in designing an MDDB, then be sure to review carefully current design concepts. In addition, it would be wise to build some prototype systems, preferably with different vendor implementations of the multidimensional concept, to enable analysts to test the usefulness of your design.

> ☒ *Skill builder*
>
> A national cinema chain has commissioned you to design a multidimensional database for its marketing department. What identifier and variable dimensions would you select?

Data mining

Data mining is the search for relationships and global patterns that exist in large databases but are hidden in the vast amounts of data. In data mining, an analyst combines knowledge of the data with advanced machine learning technologies to discover nuggets of knowledge hidden in the data. Data mining software can find meaningful relationships that might take years to find with conventional techniques. The software is designed to sift through large collections of data and, by using statistical and artificial intelligence techniques, identify hidden relationships. The mined data typically include electronic point-of-sale records, inventory, customer transactions, and customer records with matching demographics, usually obtained from an external source. Data mining does not require the presence of a data warehouse. An organization can mine data from its operational files or independent databases. However, data mining independent files will not uncover relationships that exist between data in different files. Data mining will usually be easier and more effective when the organization accumulates as much data as possible in a single data store, such as a data warehouse. Recent advances in processing speeds and lower storage costs have made large-scale mining of corporate data a reality.

Database marketing, a common application of data mining, is also one of the best examples of the effective use of the technology. Database marketers use data mining to develop, test, implement, measure, and modify tailored marketing programs. The intention is to use data to maintain a lifelong relationship with a customer. The database marketer wants to anticipate and fulfill the customer's needs as they emerge. For example, recognizing that a customer buys a new car every three or four years and with each purchase gets an increasingly more luxurious car, the car dealer contacts the customer during the third year of the life of the current car with a special offer on its latest luxury model.

Data mining uses

There are many applications of data mining:

- Predicting the probability of default for consumer loan applications. Data mining can help lenders reduce loan losses substantially by improving their ability to predict bad loans.
- Reducing fabrication flaws in VLSI chips. Data mining systems can sift through vast quantities of data collected during the semiconductor fabrication process to identify conditions that cause yield problems.
- Predicting audience share for television programs. A market-share prediction system allows television programming executives to arrange show schedules to maximize market share and increase advertising revenues.
- Predicting the probability that a cancer patient will respond to radiation therapy. By more accurately predicting the effectiveness of expensive medical procedures, health care costs can be reduced without affecting quality of care.
- Predicting the probability that an offshore oil well is going to produce oil. An offshore oil well may cost $30 million. Data mining technology can increase the probability that this investment will be profitable.

- Identifying quasars from trillions of bytes of satellite data. This was one of the earliest applications of data mining systems, because the technology was first applied in the scientific community.

Data mining functions

Based on the functions they perform, five types of data mining functions exist:

Associations

An association function identifies affinities existing among the collection of items in a given set of records. These relationships can be expressed by rules such as "72 percent of all the records that contain items A, B, and C also contain items D and E." Knowing that 85 percent of customers who buy a certain brand of wine also buy a certain type of pasta can help supermarkets improve use of shelf space and promotional offers. Discovering that fathers, on the way home on Friday, often grab a six-pack of beer after buying some diapers, enabled a supermarket to improve sales by placing beer specials next to diapers.

Sequential patterns

Sequential pattern mining functions identify frequently occurring sequences from given records. For example, these functions can be used to detect the set of customers associated with certain frequent buying patterns. Data mining might discover, for example, that 32 percent of female customers within six months of ordering a red jacket also buy a gray skirt. A retailer with knowledge of this sequential pattern can then offer the red-jacket buyer a coupon or other enticement to attract the prospective gray-skirt buyer.

Classifying

Classifying divides predefined classes (e.g., types of customers) into mutually exclusive groups, such that the members of each group are as *close* as possible to one another, and different groups are as *far* as possible from one another, where distance is measured with respect to specific predefined variables. The classification of groups is done before data analysis. Thus, based on sales, customers may be first categorized as *infrequent*, *occasional*, and *frequent*. ***A classifier could be used to identify those attributes, from a given set, that discriminate among the three types of customers. For example, a classifier might identify frequent customers as those with incomes above $50,000 and having two or more children. Classification functions have been used extensively in applications such as credit risk analysis, portfolio selection, health risk analysis, and image and speech recognition. Thus, when a new customer is recruited, the firm can use the classifying function to determine the customer's sales potential and accordingly tailor its market to that person.

Clustering

Whereas classifying starts with predefined categories, clustering starts with just the data and discovers the *hidden* categories. These categories are derived from the data. Clustering divides a dataset into mutually exclusive groups such that the members of each group are as *close* as possible to one another, and different groups are as *far* as possible from one another, where distance is measured with respect to all available variables. The goal of clustering is to identify categories. Clustering could be used, for instance, to identify natural groupings of customers by processing all the available data on them. Examples of applications that can use clustering functions are market segmentation, discovering affinity groups, and defect analysis.

Prediction

Prediction calculates the future value of a variable. For example, it might be used to predict the revenue value of a new customer based on that person's demographic variables.

These various data mining techniques can be used together. For example, a sequence pattern analysis could identify potential customers (e.g., red jacket leads to gray skirt), and then classifying could be used to distinguish between those prospects who are converted to customers and those who are not (i.e., did not follow the sequential pattern of buying a gray skirt). This additional analysis should enable the retailer to refine its marketing strategy further to increase the conversion rate of red-jacket customers to gray-skirt purchasers.

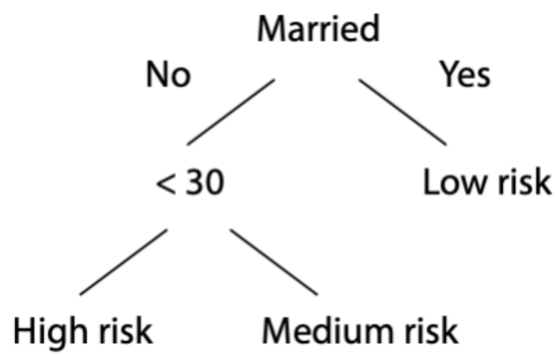
Data mining technologies

Data miners use technologies that are based on statistical analysis and data visualization.

Decision trees

Tree-shaped structures can be used to represent decisions and rules for the classification of a dataset. As well as being easy to understand, tree-based models are suited to selecting important variables and are best when many of the predictors are irrelevant. A decision tree, for example, can be used to assess the risk of a prospective renter of an apartment.

A decision tree



Genetic algorithms

Genetic algorithms are optimization techniques based on the concepts of biological evolution, and use processes such as genetic combination, mutation, and natural selection. Possible solutions for a problem compete with each other. In an evolutionary struggle of the survival of the fittest, the best solution survives the battle. Genetic algorithms are suited for optimization problems with many candidate variables (e.g., candidates for a loan).

K-nearest-neighbor method

The nearest-neighbor method is used for clustering and classification. In the case of clustering, the method first plots each record in *n*-dimensional space, where *n* attributes are used in the analysis. Then, it adjusts the weights for each dimension to cluster together data points with similar goal features. For instance, if the goal is to identify customers who frequently switch phone companies, the *k*-nearest-neighbor method would adjust weights for relevant variables (such as monthly phone bill and percentage of non-U.S. calls) to cluster switching customers in the same neighborhood. Customers who did not switch would be clustered some distance apart.

Neural networks

A neural network, mimicking the neurophysiology of the human brain, can learn from examples to find patterns in data and classify data. Although neural networks can be used for classification, they must first be trained to recognize patterns in a sample dataset. Once trained, a neural network can make predictions from new data. Neural networks are suited to combining information from many predictor variables; they work well when many of the predictors are partially redundant. One shortcoming of a neural network is that it can be viewed as a black box with no explanation of the results provided. Often managers are reluctant to apply models they do not understand, and this can limit the applicability of neural networks.

Data visualization

Data visualization can make it possible for the analyst to gain a deeper, intuitive understanding of data. Because they present data in a visual format, visualization tools take advantage of our capability to discern visual patterns rapidly. Data mining can enable the analyst to focus attention on important patterns and trends and explore these in depth using visualization techniques. Data mining and data visualization work especially well together.

SQL-99 and OLAP

SQL-99 includes extensions to the GROUP BY clause to support some of the data aggregation capabilities typically required for OLAP. Prior to SQL-99, the following questions required separate queries:

1. Find the total revenue.
2. Report revenue by location.
3. Report revenue by channel.
4. Report revenue by location and channel.

   ☒*Skill builder*

   Write SQL to answer each of the four preceding queries using the exped table, which is a sample of 1,000 sales transactions for a retailer.

Writing separate queries is time-consuming for the analyst and is inefficient because it requires multiple passes of the table. SQL-99 introduced GROUPING SETS, ROLLUP, and CUBE as a means of getting multiple answers from a single query and addressing some of the aggregation requirements necessary for OLAP.

Grouping sets

The GROUPING SETS clause is used to specify multiple aggregations in a single query and can be used with all the SQL aggregate functions. In the following SQL statement, aggregations by location and channel are computed. In effect, it combines questions 2 and 3 of the preceding list.

```
SELECT location, channel, SUM(revenue) FROM exped
    GROUP BY GROUPING SETS (location, channel);
```

location	channel	revenue
null	Catalog	108762
null	Store	347537
null	Web	27166
London	null	214334

location	channel	revenue
New York	null	39123
Paris	null	143303
Sydney	null	29989
Tokyo	null	56716

The query sums revenue by channel or location. The null in a cell implies that there is no associated location or channel value. Thus, the total revenue for catalog sales is 108,762, and that for Tokyo sales is 56,716.

Although GROUPING SETS enables multiple aggregations to be written as a single query, the resulting output is hardly elegant. It is not a relational table, and thus a view based on GROUPING SETS should not be used as a basis for further SQL queries.

Rollup

The ROLLUP option supports aggregation across multiple columns. It can be used, for example, to cross-tabulate revenue by channel and location.

```
SELECT location, channel, SUM(revenue)
    FROM exped
        GROUP BY ROLLUP (location, channel);
```

location	channel	revenue
null	null	483465
London	null	214334
New York	null	39123
Paris	null	143303
Sydney	null	29989
Tokyo	null	56716
London	Catalog	50310
London	Store	151015
London	Web	13009
New York	Catalog	8712
New York	Store	28060
New York	Web	2351
Paris	Catalog	32166
Paris	Store	104083
Paris	Web	7054
Sydney	Catalog	5471
Sydney	Store	21769
Sydney	Web	2749
Tokyo	Catalog	12103
Tokyo	Store	42610

location	channel	revenue
Tokyo	Web	2003

In the columns with null for location and channel, the preceding query reports a total revenue of 483,465. It also reports the total revenue for each location and revenue for each combination of location and channel. For example, Tokyo Web revenue totaled 2,003.

CUBE reports all possible values for a set of reporting variables. If SUM is used as the aggregating function, it will report a grand total, a total for each variable, and totals for all combinations of the reporting variables.

```
SELECT location, channel, SUM(revenue) FROM exped
 GROUP BY cube (location, channel);
```

location	channel	revenue
null	Catalog	108762
null	Store	347537
null	Web	27166
null	null	483465
London	null	214334
New York	null	39123
Paris	null	143303
Sydney	null	29989
Tokyo	null	56716
London	Catalog	50310
London	Store	151015
London	Web	13009
New York	Catalog	8712
New York	Store	28060
New York	Web	2351
Paris	Catalog	32166
Paris	Store	104083
Paris	Web	7054
Sydney	Catalog	5471
Sydney	Store	21769
Sydney	Web	2749
Tokyo	Catalog	12103
Tokyo	Store	42610
Tokyo	Web	2003

MySQL

MySQL supports a variant of CUBE. The MySQL format for the preceding query is

```
SELECT location, channel, FORMAT(SUM(revenue),0) FROM exped
    GROUP BY location, channel WITH ROLLUP;
```

> ☒*Skill builder*
>
> Using MySQL's ROLLUP capability, report the sales by location and channel for each item.

The SQL-99 extensions to GROUP BY are useful, but they certainly do not give SQL the power of a multidimensional database. It would seem that CUBE could be used as the default without worrying about the differences among the three options.

Conclusion

Data management is a rapidly evolving discipline. Where once the spotlight was clearly on TPSs and the relational model, there are now multiple centers of attention. In an information economy, the knowledge to be gleaned from data collected by routine transactions can be an important source of competitive advantage. The more an organization can learn about its customers by studying their behavior, the more likely it can provide superior products and services to retain existing customers and lure prospective buyers. As a result, data managers now have the dual responsibility of administering databases that keep the organization in business today and tomorrow. They must now master the organizational intelligence technologies described in this chapter.

Summary

Organizations recognize that data are a key resource necessary for the daily operations of the business and its future success. Recent developments in hardware and software have given organizations the capability to store and process vast collections of data. Data warehouse software supports the creation and management of huge data stores. The choice of architecture, hardware, and software is critical to establishing a data warehouse. The two approaches to exploiting data are verification and discovery. DSS and OLAP are mainly data verification methods. Data mining, a data discovery approach, uses statistical analysis techniques to discover *hidden* relationships. The relational model was not designed for OLAP, and MDDB is the appropriate data store to support OLAP. MDDB design is based on recognizing variable and identifier dimensions. SQL-99 includes extensions to GROUP BY to improve aggregation reporting.

Key terms and concepts

Association	Loading
Classifying	Management information system (MIS)
Cleaning	Metadata
Clustering	Multidimensional database (MDDB)
CUBE	Neural network

Continuous variable	Nominal variable
Database marketing	Object-relational
Data mining	Online analytical processing (OLAP)
Data visualization	Operational data store (ODS)
Data warehouse	Ordinal variable
Decision support system (DSS)	Organizational intelligence
Decision tree	Prediction
Discovery	Relational OLAP (ROLAP)
Drill-down	ROLLUP
Drill-through	Rotation
Extraction	Scheduling
Genetic algorithm	Sequential pattern
GROUPING SETS	Star model
Hypercube	Transaction processing system (TPS)
Identifier dimension	Transformation
Information systems cycle	Variable dimension
K-nearest-neighbor method	Verification

References and additional readings

Exercises

1. Identify data captured by a TPS at your university. Estimate how much data are generated in a year.
2. What data does your university need to support decision making? Does the data come from internal or external sources?
3. If your university were to implement a data warehouse, what examples of dirty data might you expect to find?
4. How frequently do you think a university should refresh its data warehouse?
5. Write five data verification questions for a university data warehouse.
6. Write five data discovery questions for a university data warehouse.
7. Imagine you work as an analyst for a major global auto manufacturer. What techniques would you use for the following questions?
    a. How do sports car buyers differ from other customers?
    b. How should the market for trucks be segmented?
    c. Where does our major competitor have its dealers?
    d. How much money is a dealer likely to make from servicing a customer who buys a luxury car?
    e. What do people who buy midsize sedans have in common?

f. What products do customers buy within six months of buying a new car?

g. Who are the most likely prospects to buy a luxury car?

h. What were last year's sales of compacts in Europe by country and quarter?

i. We know a great deal about the sort of car a customer will buy based on demographic data (e.g., age, number of children, and type of job). What is a simple visual aid we can provide to sales personnel to help them show customers the car they are most likely to buy?

8. An international airline has commissioned you to design an MDDB for its marketing department. Choose identifier and variable dimensions. List some of the analyses that could be performed against this database and the statistical techniques that might be appropriate for them.

9. A telephone company needs your advice on the data it should include in its MDDB. It has an extensive relational database that captures details (e.g., calling and called phone numbers, time of day, cost, length of call) of every call. As well, it has access to extensive demographic data so that it can allocate customers to one of 50 lifestyle categories. What data would you load into the MDDB? What aggregations would you use? It might help to identify initially the identifier and variable dimensions.

10. What are the possible dangers of data mining? How might you avoid these?

11. Download the file exped.xls from the book's web site and open it as a spreadsheet in LibreOffice. This file is a sample of 1,000 sales transactions for a retailer. For each sale, there is a row recording when it was sold, where it was sold, what was sold, how it was sold, the quantity sold, and the sales revenue. Use the PivotTable Wizard (Data>PivotTable) to produce the following report:

Sum of REVENUE	HOW			
WHERE	Catalog	Store	Web	Grand total
London	50,310	151,015	13,009	214,334
New York	8,712	28,060	2,351	39,123
Paris	32,166	104,083	7,054	143,303
Sydney	5,471	21,769	2,749	29,989
Tokyo	12,103	42,610	2,003	56,716
Grand Total	108,762	347,537	27,166	483,465

12. Continue to use the PivotTable Wizard to answer the following questions:

a. What was the value of catalog sales for London in the first quarter?

b. What percent of the total were Tokyo web sales in the fourth quarter?

c. What percent of Sydney's annual sales were catalog sales?

d. What was the value of catalog sales for London in January? Give details of the transactions.

e. What was the value of camel saddle sales for Paris in 2002 by quarter?

f. How many elephant polo sticks were sold in New York in each month of 2002?

15 Introduction to R

Statistics are no substitute for judgment

Henry Clay, U.S. congressman and senator

Learning objectives

Students completing this chapter will:

- Be able to use R for file handling and basic statistics;
- Be competent in the use of RStudio.

The R project

The R project supports ongoing development of R, a free software environment for statistical computing, data visualization, and data analytics. It is a highly-extensible platform, the R programming language is object-oriented, and R runs on the common operating systems. The adoption of R has grown in recent years, and is now the one of the most popular analytics platform.

RStudio is a commonly used integrated development environment (IDE) for R. It contains four windows. The upper-left window contains scripts, one or more lines of R code that constitute a task. Scripts can be saved and reused. It is good practice to save scripts as you will find you can often edit an existing script to meet the needs of a new task. The upper-right window provides details of all datasets created. It also useful for importing datasets and reviewing the history of R commands executed. The lower-left window displays the results of executed scripts. If you want to clear this window, then press control-L. The lower-right window can be used to show files on your system, plots you have created by executing a script, packages installed and loaded, and help information.

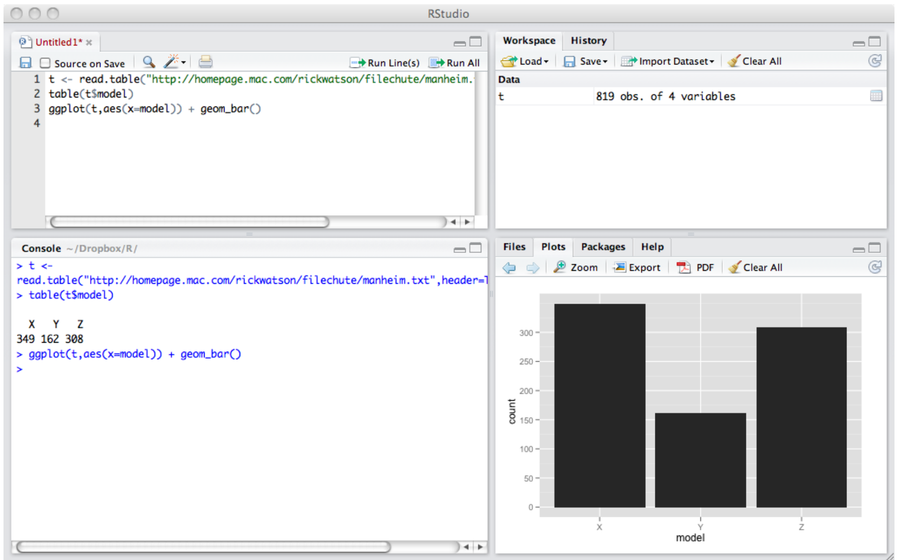
Creating a project

It usually makes sense to store all R scripts and data for a project in the same folder or directory. Thus, when you first start RStudio, create a new project.

Project > Create Project…

RStudio remembers the state of each window, so when you quit and reopen, it will restore the windows to their prior state. You can also open an existing project, which sets the path to the folder for that project. As a result, all saved scripts and files during a session are stored in that folder.

RStudio interface



Scripting

A script is a set of R commands. You can also think of it as a short program.

```
# CO2 parts per million (ppm) for 2000-2009
co2 <- c(369.40,371.07,373.17,375.78,377.52,
         379.76,381.85,383.71,385.57,384.78)
year <-  (2000:2009) # a range of values
# show values
co2
year
# compute mean and standard deviation
mean(co2)
sd(co2)
plot(year,co2)
```

The previous script

- Creates an object co2 with the values 369.40, 371.07, … , 348.78.
- Creates an object year with values 2000 through 2009.
- Displays in the lower-left window the values stored in these two objects.

- Computes the mean for each variable.
- Creates an x-y plot of year and co2, which is shown in the lower-right window.

  Note the use of <- for assigning values to an object. RStudio provides a keyboard command, Alt + - (Windows & Linux) or Option + - (Mac). In R, c is short for combine values.

  ☒ *Skill builder*

  Plot kWh per square foot by year for the following University of Georgia data.

year	square feet	kWh
2007	14,214,216	2,141,705
2008	14,359,041	2,108,088
2009	14,752,886	2,150,841
2010	15,341,886	2,211,414
2011	15,573,100	2,187,164
2012	15,740,742	2,057,364

  Data in R format

  year <- (2007:2012)

  sqft <- c(14214216, 14359041, 14752886, 15341886, 15573100, 15740742)

  kwh <- c(2141705, 2108088, 2150841, 2211414, 2187164, 2057364)

Datasets

An R dataset is the familiar table of the relational model. There is one row for each observation, and the columns contain the observed values or facts about each observation. R supports multiple data structures and data types.

Vector

A vector is a single row table where data are all of the same type (e.g., character, logical, numeric). In the following sample code, two numeric vectors are created.

```
co2 <-  c(369.40,371.07,373.17,375.78,377.52,
          379.76,381.85,383.71,385.57,384.78)
year <-  (2000:2009)
co2[2] # show the second value
```

Matrix

A matrix is a table where all data are of the same type. Because it is a table, a matrix has two dimensions, which need to be specified when defining the matrix. The sample code creates a matrix with 4 rows and 3 columns, as the results of the executed code illustrate.

```
m <- matrix(1:12, nrow=4,ncol=3)
m[4,3] # show the value in row 4, column 3
```

	[,1]	[,2]	[,3]
[1,]	1	5	9
[2,]	2	6	10
[3,]	3	7	11
[4,]	4	8	12

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Create a matrix with 6 rows and 3 columns containing the numbers 1 through 18.

Array

An array is a multidimensional table. It extends a matrix beyond two dimensions. Review the results of running the following code by displaying the array created.

```
a <-  array(letters[seq(1:24)], c(4,3,2))
a[1,1,1] # show the first value in the array
```

Data frame

While vectors, matrices, and arrays are all forms of a table, they are restricted to data of the same type (e.g., numeric). A data frame, like a relational table, can have columns of different data types. The sample code creates a data frame with character and numeric data types.

```
gender <- c("m","f","f")
age <- c(5,8,3)
df <-  data.frame(gender,age)
# show some data frame values
df[1,2] # a cell
df[1,] # a row
df[,2] # a column
```

List

The most general form of data storage is a list, which is an ordered collection of objects. It permits you to store a variety of objects together under a single name. In other words, a list is an object that contains other objects. Retrieve a list member with a *single square bracket* []. To reference a list member directly, use a *double square bracket* [[]].

```
l <-  list(co2,m,df)
# show a list member
l[3] # retrieves list member
l[[3]] # reference a list member
l[[1]][2] # second element of list 1
```

Logical operators

R supports the common logical operators, as shown in the following table.

Logical operator	Symbol
EQUAL	==
AND	&
OR	
NOT	!

Object

In R, an object is anything that can be assigned to a variable. It can be a constant, a function, a data structure, a graph, a times series, and so on. You find that the various packages in R support the creation of a wide range of objects and provide functions to work with these and other objects. A variable is a way of referring to an object. Thus, we might use the variable named *l* to refer to the list object defined in the preceding subsection.

Types of data

R can handle the four types of data: nominal, ordinal, interval, and ratio.

Nominal data, typically character strings, are used for classification (e.g., high, medium, or low).

Ordinal data represent an ordering and thus can be sorted (e.g., the seeding or ranking of players for a tennis tournament). The intervals between ordinal data are not necessarily equal. Thus, the top seeded tennis play (ranked 1) might be far superior to the second seeded (ranked 2), who might be only marginally better than the third seed (ranked 3).

Interval and *ratio* are forms of measurement data. The interval between the units of measure for interval data are equal. In other words, the distance between 50cm and 51cm is the same as the distance between 105cm and 106cm. Ratio data have equal intervals and a natural zero point. Time, distance, and mass are examples of ratio scales. Celsius and Fahrenheit are interval data types, but not ratio, because the zero point is arbitrary. As a result, 10ºC is not twice as hot as 5ºC. Whereas, Kelvin is a ratio data type because nothing can be colder than 0º K, a natural zero point.

In R, nominal and ordinal data types are also known as *factors*. Defining a column as a factor determines how its data are analyzed and presented. By default, factor levels for character vectors are created in alphabetical order, which is often not what is desired. To be precise, specify using the levels option.

```
rating <-   c('high','medium','low')
rating <-  factor(rating, order=T,
            levels = c('high','medium','low'))
```

Thus, the preceding code will result in changing the default reporting of factors from alphabetical order (i.e., high, low, and medium) to listing them in the specified order (i.e., high, medium, and low).

Missing values

Missing values in R are represented as NA, meaning not available. Infeasible values, such as the result of dividing by zero, are indicated by NaN, meaning not a number. Any arithmetic expression or function operating on data containing missing values will return NA. Thus `sum(c(1,NA,2))` will return NA.

To exclude missing values from calculations, use the option `na.rm = T`, which specifies the removal of missing values prior to calculations. Thus, `sum(c(1,NA,2),na.rm=T)` will return 3.

You can remove rows with missing data by using `na.omit()`, which will delete those rows containing missing values.

```
gender <- c("m","f","f","f")
age <- c(5,8,3,NA)
df <-  data.frame(gender,age)
df2 <-  na.omit(df)
```

Packages

A major advantage of R is that the basic software can be easily extended by installing additional packages, of which close to 20,000 exist. You can consult the R package directory to help find a package that has the functions you need. RStudio has an interface for finding and installing packages. See the Packages tab on RStudio's lower-right window.

Before running a script, you need to indicate which packages it needs, beyond the default packages that are automatically loaded. The library statement specifies that a package is required for execution. The following example uses the measurements package to handle the conversion of Fahrenheit to Celsius. The package's documentation provides details of how to use its various conversion options.

```
library(measurements) # previously installed
# convert F to C
conv_unit(100,'F','C')
```

☒ Skill builder

Install the measurements package and run the preceding code.

File handing

Files are the usual form of input for R scripts. Fortunately, R can handle a wide variety of input formats, including text (e.g., CSV), statistical package (e.g., SAS), and XML. A common approach is to use a spreadsheet to prepare a data file, export it as CSV, and then read it into R.

Reading a file

Files can be read from the local computer on which R is installed or the Internet, as the following sample code illustrates. We will use the readr library for handling files, so you will need to install it before running the following code.

```
library(readr)
# read a local file (this will not work on your computer)
t <- read_delim("Documents/R/Data/centralparktemps.txt",
      delim=",")
```

You can also read a remote file using a URL.

```
library(readr)
# read using a URL
url<-'http://www.richardtwatson.com/data/centralparktemps.txt'
t <- read_delim(url, delim = ',')
```

You must define the separator for data fields with the delim keyword (e.g., for a tab use `delim = 't'`).

Learning about a file

After reading a file, you might want to learn about its contents. First, you can click on the file's name in the top-right window. This will open the file in the top-left window. If it is a long file, only a portion, such as the first 1000 rows, will be displayed. Second, you can execute some R commands, as shown in the following code, to show the first few and last few rows. You can also report the dimensions of the file, its structure, and the type of object.

```
library(readr)
url<-'http://www.richardtwatson.com/data/centralparktemps.txt'
t <- read_delim(url, delim=',')
head(t) #  first few rows
tail(t) #  last few rows
dim(t) # dimension
str(t) # structure of a dataset
class(t) #type of object
```

Referencing columns

Columns within a table are referenced by using the format tablename$columnname. This is similar to the qualification method used in SQL. The following code shows a few examples. It also illustrates how to add a new column to an existing table.

```
library(measurements)
library(readr)
url<-'http://www.richardtwatson.com/data/centralparktemps.txt'
t <- read_delim(url, delim=',')
# qualify with table name to reference a column
mean(t$temperature)
max(t$year)
range(t$month)
# create a new column with the temperature in Celsius
t$Ctemp = round(conv_unit(t$temperature,'F','C'),1) # round to one decimal
```

Recoding

Some analyses might be facilitated by the recoding of data. For instance, you might want to split a continuous measure into two categories. Imagine you decide to classify all temperatures greater than or equal to 25ºC as 'hot' and the rest as 'other.' Here are the R command to create a new column in table t called Category.

```
t$Category <- ifelse(t$Ctemp >= 30, 'Hot','Other')
```

Deleting a column

You can delete a column by setting each of its values to NULL.

```
t$Category <-  NULL
```

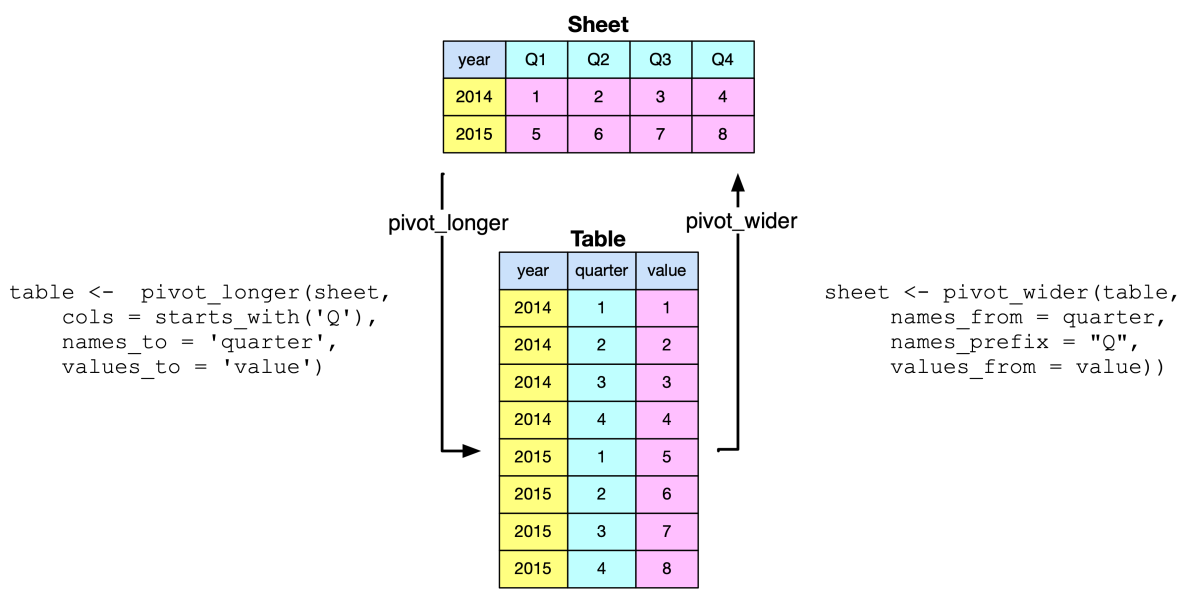
Reshaping a file

Data are not always in the shape that you want. For example, you might have a spreadsheet that, for each year, lists the quarterly observations (i.e., year and four quarterly values in one row). For analysis, you typically need to have a row for each distinct observation (e.g., year, quarter, value). *pivot_longer* converts a document from what is commonly called *wide* to *narrow* format. It is akin to normalization in that the new table has year and quarter as the identifier of each observation.

The pivot_longer() command specifies the file to be conveted to a normalized table, the columns of the input file to be pivoted (i.e., the columns starting with Q), their column name in the new file (i.e., quarter), and the name of the new column containg the spreadsheet's cells (i.e., value). Note that you also need convert the column quarter from character to integer.

The pivot_wider() command revserses the process by converting a table to a spreadsheet.

Reshaping a file with and pivoting




```
library(tidyverse)
url<-'http://www.richardtwatson.com/data/pivotExample.csv'
sheet <- read_csv(url)
table <- sheet |>
  pivot_longer(
    cols = starts_with('Q'),
```

```
    names_to = 'quarter',
    names_prefix = 'Q',
    names_transform = list(quarter = as.integer),
    values_to = 'value')
table
# table to sheet with pivot_wider
sheet <- pivot_wider(table,
    names_from = quarter,
    names_prefix = "Q",
    values_from = value)
sheet
```

Writing a file

R can write data in a few file formats. We just focus on text format in this brief introduction. The following code illustrates how to create a new column containing the temperature in C and renaming an existing column. The revised table is then written as a csv text file to the project's folder.

```
library(measurements)
library(readr)
url<-'http://www.richardtwatson.com/data/centralparktemps.txt'
t <- read_delim(url, delim=',')
# compute Celsius and round to one decimal place
t$Ctemp = round(conv_unit(t$temperature,'F','C'),1)
# rename third column to indicate Fahrenheit
colnames(t)[3] <-  'Ftemp'
write_csv(t,"centralparktempsCF.txt")
```

Data manipulation with dplyr

The dplyr package provides functions for efficiently manipulating data sets. By providing a series of basic data handling functions and use of the pipe function (|>),[1] dplyr implements a grammar for data manipulation. The pipe function is used to pass data from one operation to the next.

Some dplyr functions

Function	Purpose
filter()	Select rows
select()	Select columns
arrange()	Sort rows
summarize()	Compute a single summary statistic

[1]Short cut is Ctrl+Shift+M (Windows & Linux) or Cmd+Shift+M (Mac)

Function	Purpose
group_by()	Pair with summarize() to analyze groups within a dataset
inner_join()	Join two tables
mutate()	Create a new column

Here are some examples using dplyr with data frame t.

```
library(dplyr)
library(readr)
url<-'http://www.richardtwatson.com/data/centralparktemps.txt'
t <- read_delim(url, delim=',')
# a row subset
trow <-  filter(t, year == 1999)
# a column subset
tcol <-  select(t, year)
```

The following example illustrates application of the pipe function. The data frame t is piped to select(), and the results of select method passed onto filter(). The final output is stored in trowcol, which contains year, month, and Celsius temperature for the years 1990 through 1999.

```
# a combo subset and use of the pipe function
trowcol <-  t  |>
  select(year, month, temperature) |>
  filter(year > 1989 & year < 2000)
```

Sorting

You can also use dplyr for sorting.

```
t <-  arrange(t, desc(year),month)
```

☒ Skill builder

- View the web page of yearly CO_2 emissions (million metric tons) since the beginning of the industrial revolution.
- Create a new text file using R
- Clean up the file for use with R and save it as CO2.txt
- Import (Import Dataset) the file into R
- Plot year versus CO_2 emissions

Summarizing data

The dplyr function can be used for summarizing data in a specified way (e.g., mean, minimum, standard deviation). In the sample code, a file containing the mean temperature for each year is created. Notice the use of the pipe function to first group the data by year and then compute the mean for each group.

```
library(dplyr)
url<-'http://www.richardtwatson.com/data/centralparktemps.txt'
t <- read_delim(url, delim=',')
w <-  t  |>
  group_by(year)  |> |>
  summarize(averageF = mean(temperature))
```

Adding a column

The following example shows how to add a column and compute its average.

```
# add column
t <-  mutate(t, CTemp = (temperature-32)*5/9)
# summarize
summarize(t, mean(CTemp))
```

⊠ Skill builder

Create a file with the maximum temperature for each year.

Merging files

If there is a common column in two files, then they can be merged using dplyr.::inner_join().[2] This is the same as joining two tables using a primary key and foreign key match. In the following code, a file is created with the mean temperature for each year, and it is merged with CO_2 readings for the same set of years.

```
library(dplyr)
library(readr)
url<-'http://www.richardtwatson.com/data/centralparktemps.txt'
t <- read_delim(url, delim=',')
# average monthly temp for each year
a <-  t |>
  group_by(year) |>
  summarize(mean = mean(temperature))
# read yearly carbon data
# co2now.org/Current-CO2/CO2-Now/noaa-mauna-loa-co2-data.html)
```

[2]This is the R notation for indicating the package (dplyr) to which a method (inner_join) belongs.

```
url<-'http://www.richardtwatson.com/data/carbon1959-2011.txt'
carbon <- read_delim(url,  delim=',')
m <-  inner_join(a,carbon)
head(m)
```

Data manipulation with sqldf

The sqldf package enables use of the broad power of SQL to extract rows or columns from a data frame to meet the needs of a particular analysis. It provides essentially the same data manipulation capabilities as dplyr. The following example illustrates use of sqldf.

```
library(sqldf)
library(readr)
options(sqldf.driver = "SQLite") # to avoid a  RMySQL conflict
url<-'http://www.richardtwatson.com/data/centralparktemps.txt'
t <- read_delim(url, delim=',')
# a row subset
trowcol<- sqldf("select year, month, temperature
                from t where year > 1989 and year < 2000")
```

However, sqldf does not enable you to embed R functions within an SQL command. For this reason, dplyr is the recommended approach for data manipulation. However, there might be occasions when you find it more efficient to first execute a complex query in SQL and then do further analysis with dplyr.

Correlation coefficient

A correlation coefficient is a measure of the covariation between two sets of observations. In this case, we are interested in whether there is a statistically significant covariation between temperature and the level of atmospheric CO_2.[3]

The following example shows how to create reproducible analytics, whereby the results of the analysis are used to provide text for the report.

```
cor.test(m$mean, m$CO2)
```

The following results indicate that a correlation of .40 is a statistically significant as the p-value is less than 0.05, the common threshold for significance testing. Thus, we conclude that, because there is a small chance (p = .002997) of observing by chance such a value for the correlation coefficient, there is a relationship between mean temperature and the level of atmospheric CO2. Given that global warming theory predicts an increase in temperature with an increase in atmospheric CO2, we can also state that the observations support this theory. In other words, an increase in CO2 increases temperatures in Central Park.

[3] As I continually revise data files to include the latest observations, your answer might differ for this and other analyses.

```
Pearson's product-moment correlation
data:  m$mean and m$CO2
t = 3.1173, df = 51, p-value = 0.002997
95 percent confidence interval:
0.1454994 0.6049393
sample estimates:
    cor
0.4000598
```

When reporting correlation coefficients, you can you use the terms small, moderate, and large in accordance with the values specified in following table.

Effect size table

Correlation coefficient	Effect size
.10 - .30	Small
.30 - .50	Moderate
> .50	Large

If we want to understand the nature of the relationship, we could fit a linear model.

```
mod <- lm(m$mean ~ m$CO2)
summary(mod)
```

The following results indicate a linear model is significant ($p < .05$), and it explains 14.36% (adjusted multiple R-squared) of the variation between temperature and atmospheric CO_2. The linear equation is

$$temperature = 48.29 + 0.019208 * CO2$$

As CO_2 emissions are measured in parts per millions (ppm), an increase of 1.0 ppm predicts an annual mean temperature increase in Central Park of .01920 F°. Currently CO_2 emissions are increasing at about 2.0 ppm per year.

As a linear model explains about 14% of the variation, this suggests that there might other variables that should be considered (e.g., level of volcanic activity) and that the relationship might not be linear.

```
Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  48.291319    2.149937   22.462    <2e-16 ***
 m$CO2        0.019208    0.006162    3.117    0.003 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
Residual standard error: 1.016 on 51 degrees of freedom
Multiple R-squared:   0.16, Adjusted R-squared:  0.1436
F-statistic: 9.718 on 1 and 51 DF,  p-value: 0.002997
```

Database access

The DBI package provides a convenient way for a direct connection between R and a relational database, such as MySQL or PostgreSQL. Once the connection has been made, you can run an SQL query and load the results into a R data frame.

The dbConnect() function makes the connection. You specify the type of relational database, url, database name, userid, and password, as shown in the following code.[4]

```
library(DBI)
conn <- dbConnect(RMySQL::MySQL(),
        "www.richardtwatson.com",
        dbname="Weather", user="student", password="student")
# Query the database and create file t for use with R
t <- dbGetQuery(conn,"select * from record;")
head(t)
```

For security reasons, it is not a good idea to put database access details in your R code. They should be hidden in a file. I recommend that you create a csv file within your R code folder to containing database access parameters. First, create a new directory or folder (File > New Project > New Directory > Empty Project), called dbaccess for containing you database access files. Then, create a csvfile (Use File > New File > Text File) with the name weather_richardtwatson.csv in the newly created folder containing the following data:

```
url,dbname,user,password:
richardtwatson.com,Weather,student,student
```

The R code will now be:

```
# Database access
library(readr)
library(DBI)
url <-  'dbaccess/weather_richardtwatson.csv'
d <-  read_csv(url)
conn <- dbConnect(RMySQL::MySQL(),
          d$url, dbname=d$dbname,
          user=d$user, password=d$password)
t <- dbGetQuery(conn,"SELECT timestamp, airTemp from record;")
head(t)
```

Despite the prior example, I will continue to show database access parameters because you need them to run the sample code. However, in practice you should follow the security advice given.

[4] You will likely get a warning message of the form "unrecognized MySQL field type 7 in column 0 imported as character," because R does does recognize the first column as a timestamp. You can ignore it, but later you might need to convert the column to R's timestamp format.

Timestamps

Many data sets include a timestamp to indicate when an observation was recorded. A timestamp will show the data and time to the second or microsecond. The format of a standard timestamp is yyyy-mm-dd hh:mm:ss (e.g., 2010-01-31 03:05:46).

Some R functions, including those in the lubridate package, can detect a standard format timestamp and support operations for extracting parts of it, such as the year, month, day, hour, and so forth. The following example shows how to use lubridate to extract the month and year from a character string in standard timestamp format.

```
library(lubridate)
library(DBI)
conn <- dbConnect(RMySQL::MySQL(),
         "www.richardtwatson.com", dbname="Weather",
         user="student", password="student")
# Query the database and create file t for use with R
t <- dbGetQuery(conn,"select * from record;")
t$year <- year(t$timestamp)
t$month <- month(t$timestamp)
head(t)
```

Excel files

There are a number of packages with methods for reading an Excel file. Of these, readxl seems to be the simplest. However, it can handle only files stored locally, which is the case with most of the packages examined. If the required Excel spreadsheet is stored remotely, then download it and store it locally.

```
library(readxl)
library(httr)
# read remote file and store on disk
url <-  'http://www.richardtwatson.com/data/GDP.xlsx'
GET(url,write_disk('temp.xlsx',overwrite = TRUE))
e <-  read_excel('temp.xlsx',sheet = 1,col_names = TRUE)
```

R resources

The vast number of packages makes the learning of R a major challenge. The basics can be mastered quite quickly, but you will soon find that many problems require special features or the data need some manipulation. Once you learn how to solve a particular problem, make certain you save the script, with some embedded comments, so you can reuse the code for a future problem. There are books that you might find useful to have in electronic format on your computer or tablet, and one of these is listed at the end of the chapter. There are, however, many more books, both of a general and specialized nature. The R Reference Card is handy to keep nearby when you are writing scripts. I printed and laminated a copy, and it's in the top drawer of my desk. A useful website is Quick-R, which is an online reference for common tasks, such as those covered in this chapter.

R and data analytics

R is a platform for a wide variety of data analytics, including

- Statistical analysis
- Data visualization
- HDFS and cluster computing
- Text mining
- Energy Informatics
- Dashboards

You have probably already completed an introductory statistical analysis course, and you can now use R for all your statistical needs. In subsequent chapters, we will discuss data visualization, HDFS and cluster computing, and text mining.

R is also a programming language. You might find that in some situations, R provides a quick method for reshaping files and performing calculations.

Summary

R is a free software environment for statistical computing, data visualization, and data analytics. RStudio is a commonly used integrated development environment (IDE) for R. A script is a set of R commands. Store all R scripts and data for a project in the same folder or directory. An R dataset is a table that can be stored as a vector, matrix, array, data frame, and list. In R, an object is anything that can be assigned to a variable. R can handle the four types of data: nominal, ordinal, interval, and ratio. Nominal and ordinal data types are also known as factors. Defining a column as a factor determines how its data are analyzed and presented. Missing values are indicated by NA. R can handle a wide variety of input formats, including text (e.g., CSV), statistical package (e.g., SAS), and XML. Data can be reshaped. Gathering converts a document from what is commonly called wide to narrow format. Spreading takes a narrow file and converts it to wide format. Columns within a table are referenced using the format tablename$columname. R can write data to a file. A major advantage of R is that the basic software can be easily extended by installing additional packages. The dplyr packages adds functionality for data management and reporting. Learning R is a major challenge because of the many packages available.

Key terms and concepts

Aggregate	R
Array	Reshape
Data frame	Script
Data type	Spread
Factor	SQL
Gather	Tibble
List	Subset
Matrix	Vector
Package	

References

Wickham, H., & Grolemund, G. (2017). R for data science: O'Reilly.

Exercises

1. Access a car sales file which contains details of the sales of three car models: X, Y, and Z.

    a. Compute the number of sales for each type of model.

    b. Compute the number of sales for each type of sale.

    c. Report the mean price for each model.

    d. Report the mean price for each type of sale.

2. Use the 'Import Dataset' feature of RStudio to read electricity data, which contains details of electricity prices for a major city.[^intror-10] [^intror-10]: Note these prices have been transformed from the original values, but are still representative of the changes over time.

    a. What is the maximum cost?

    b. What is the minimum cost?

    c. What is the mean cost?

    d. What is the median cost?

3. Read the table containing details of the wealth of various countries and complete the following exercises.

    a. Sort the table by GDP per capita.

    b. What is the average GDP per capita?

    c. Compute the ratio of US GDP per capita to the average GDP per capita.

    d. What's the correlation between GDP per capita and wealth per capita?

4. Merge the data for weather (database weather discussed in the chapter) and electricity prices (Use RStudio's 'Import Dataset' to read electricity data and compute the correlation between temperature and electricity price. *Hint*: MySQL might return a timestamp with decimal seconds (e.g., 2010-01-01 01:00:00.0), and you can remove the rightmost two characters using substr(), so that the two timestamp columns are of the same format and length. Also, you need to ensure that the timestamps from the two data frames are of the same data type (e.g., both character).
5. Get the list of failed US banks.
   a. Determine how many banks failed in each state.
   b. How many banks were not acquired (hint: nrow() will count rows in a table)?
   c. How many banks were closed each year (hint: use strptime() and the lubridate package)?
6. Use Table01 reporting U.S. broccoli data on farms and area harvested. Get rid of unwanted rows to create a spreadsheet for the area harvested with one header row and the 50 states. Change cells without integer values to 0 and save the file in CSV format for reading with R.
   a. Reshape the data so that each observation contains state name, year, and area harvested.
   b. Add hectares as a column in the table. Round the calculation to two decimal places.
   c. Compute total hectares harvested each year for which data are available.
   d. Save the reshaped file.

16 Data visualization

The commonality between science and art is in trying to see profoundly - to develop strategies of seeing and showing.

Edward Tufte, *The Visual Display of Quantitative Information*

Learning objectives

Students completing this chapter will:

- Understand the principles of the grammar of graphics;
- Be able to use ggplot2 to create common business graphics;
- Be able to select data from a database for graphic creation;
- Be able to depict locations on a Google map.

Visual processing

Humans are particularly skilled at processing visual information because it is an innate capability, compared to reading which is a learned skill. When we evolved on the Savannah of Africa, we had to be adept at processing visual information (e.g., recognizing danger) and deciding on the right course of action (fight or flight). Our ancestors were those who were efficient visual processors and quickly detected threats and used this information to make effective decisions. They selected actions that led to survival. Those who were inefficient visual information processors did not survive to reproduce. Moreover, those with good visual skills failed to propagate if they made poor decisions relative to detected dangers. Consequently, we should seek opportunities to present information visually and play to our evolved strength. As people vary in their preference for visual and textual information, it often makes sense to support both types of reporting.

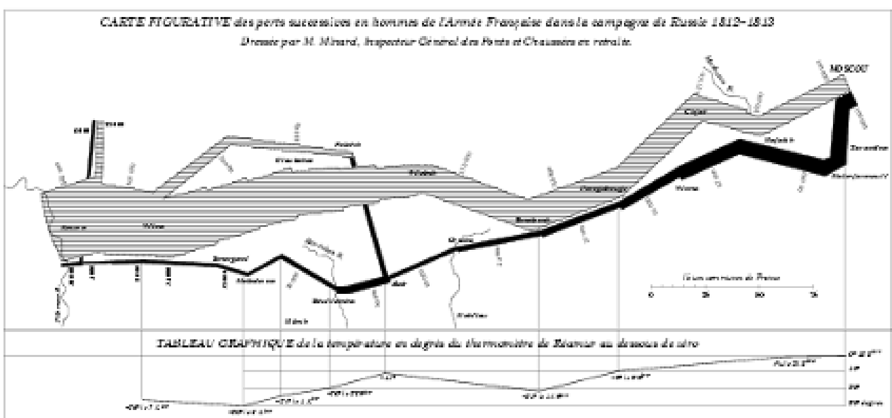
In order to learn how to visualize data, you need to become familiar with the grammar of graphics and ggplot2 (a popular R package for graphics). In line with the learning of data modeling and SQL, we will take an intertwined spiral approach. First we will tackle the grammar of graphics (the abstract) and then move to ggplot2 (the concrete). You will also learn how to take the output of an SQL query and feed it directly into ggplot2. The end result will be a comprehensive set of practical skills for data visualization.

The grammar of graphics

A grammar is a system of rules for generating valid statements in a language. A grammar makes it possible for people to communicate accurately and concisely. English has a rather complex grammar, as do most languages. In contrast, computer-related languages, such as SQL, have a relatively simple grammar because they are carefully designed for expressive power, consistency, and ease of use. Each of the dialects of data modeling also has a grammar, and each of these is quite similar in that they all have the same foundational elements: entities, attributes, identifiers, and relationships.

A grammar was designed by Wilkinson[1] for creating graphics to enhance their expressiveness and comprehensiveness. From a mathematical perspective, a graph is a set of points. A graphic is a physical representation of a graph. Thus, a graph can have many physical representations, and one of the skills you need to gain is to be able to judge what is a meaningful graphic for your clients. A grammar for graphics provides you with many ways of creating a graphic, just as the grammar of English gives you many ways of writing a sentence. Of course, we differ in our ability to convey information in English. Similarly, we also differ in our skills in representing a graph in a visual format. The aesthetic attributes of a graph determine its ability to convey information. For a graphic, aesthetics are specified by elements such as size and color. One of the most applauded graphics is Minard's drawing in 1861 of Napoleon's advance on and retreat from Russia during 1812. The dominating aspect of the graphic is the dwindling size of the French army as it battled winter, disease, and the Russian army. The graph shows the size of the army, its location, and the direction of its movement. The temperature during the retreat is drawn at the bottom of graphic.

Charles Joseph Minard's graphic of Napoleon's Russian expedition in 1812



Wilkinson's grammar is based on six elements:

1. *Data*: a set of data operations that creates variables from datasets;
2. *Trans*: variable transformations;
3. *Scale*: scale transformations;
4. *Coord*: a coordinate system;

[1]Wilkinson, L. (2005). *The grammar of graphics* (2nd ed.). New York: Springer.

5. *Element*: a graph and its aesthetic attributes;
6. *Guide*: one or more guides.

Interest in the grammar of data visualization has increased in recent years because of the growth in data. There is ongoing search to find ways to reveal clearly the information in large data sets. Vega is a recent formulation building on Wilkinson's work. In Vega, a visualization consists of basic properties of a graph (such as the width and height) and definitions of the data to visualize, scales for mapping to data to a visual form, axes for representing scales, and graphic marks (such as rectangles, circles, and arcs) for displaying the data.

ggplot2

ggplot2 is an implementation of Vega in R. Because it is based on a grammar, ggplot2 is a very powerful graphics tool for creating both simple and complex graphs. It is well-suited for generating multi-layered graphs because of its grammatical foundation. As a result, using ggplot2 you specify a series of steps (think of them as sentences) to create a graphic (think of it as a paragraph) to visually convey your message.

Data

Most structured data, which is what we require for graphing, are typically stored in spreadsheets or databases. In the prior chapter, you learned how to read a spreadsheet exported as a CSV file and access a database. These are also the skills you need for reading a file containing data to be visualized.

Transformation

A transformation converts data into a format suitable for the intended visualization. In this case, we want to depict the relative change in carbon levels since pre-industrial periods, when the value was 280 ppm. Here are sample R commands.

```
# compute the relative change in CO2
carbon$relCO2 = (carbon$CO2-280)/280
```

There are many ways that you might want to transform data. The preceding example just illustrates the general nature of a transformation. You can also think of SQL as a transformation process as it can compute new values from existing columns.

Coord

A coordinate system describes where things are located. A geopositioning system (GPS) reading of latitude and longitude describes where you are on the surface of the globe. It is typically layered onto a map so you can see where you are relative to your current location. Most graphs are plotted on a two-dimensional (2D) grid with x (horizontal) and y (vertical) coordinates. ggplot2 currently supports six 2D coordinate systems, as shown in the following table. The default coordinate system for most packages is Cartesian.

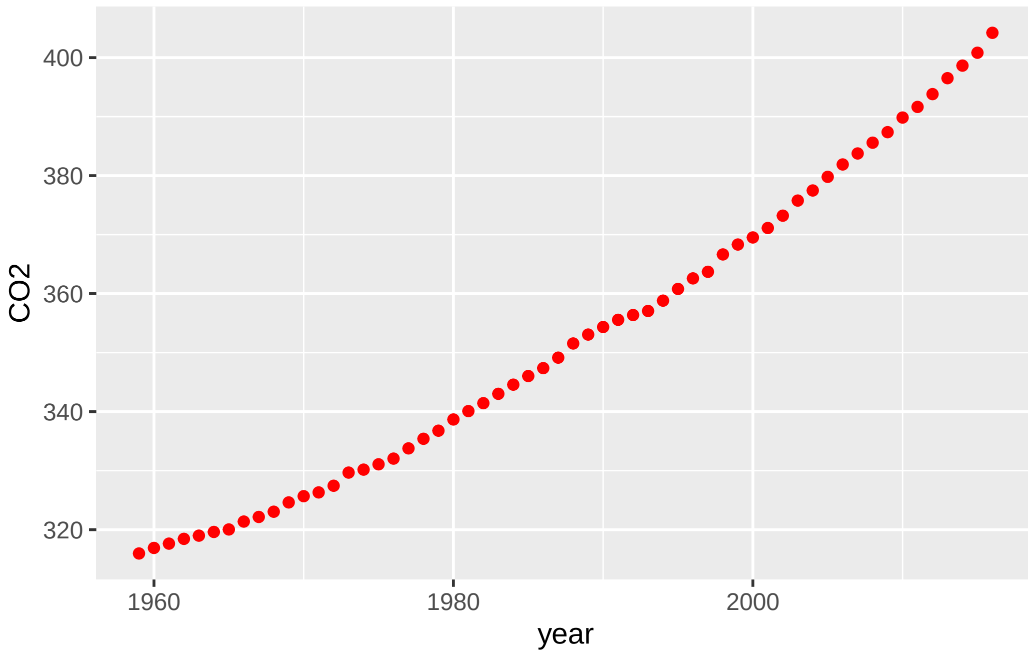
Coordinate systems

Name	Description
cartesian	Cartesian coordinates
equal	Equal scale Cartesian coordinates
flip	Flipped Cartesian coordinates
trans	Transformed Cartesian coordinates
map	Map projections
polar	Polar coordinates

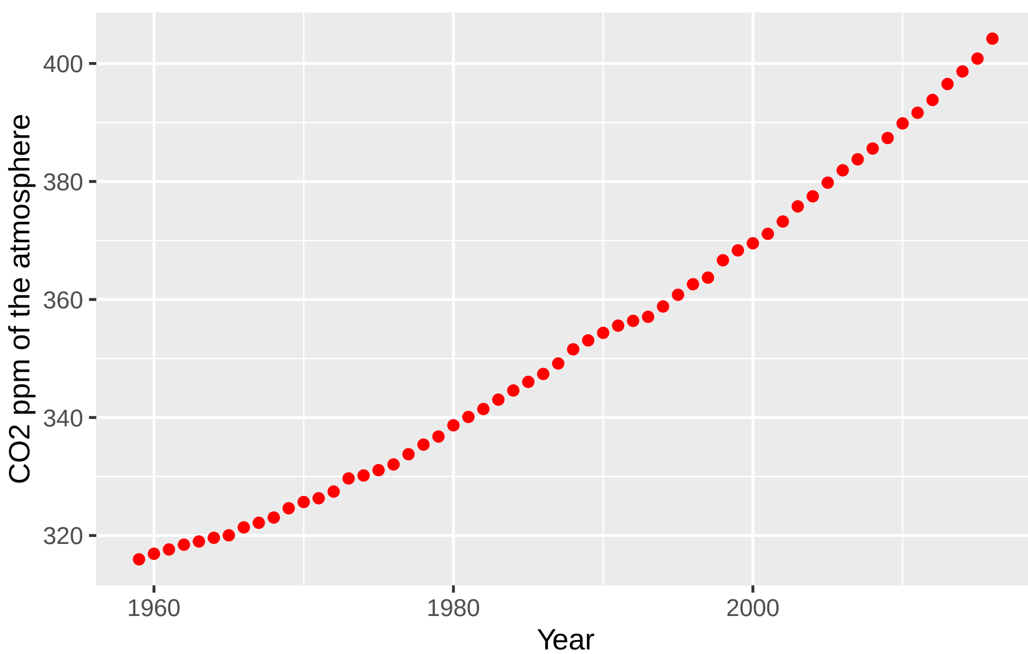
Element

An element is a graph and its attributes. Let's start with a simple scatterplot of year against CO_2 emissions. We do this in two steps applying the ggplot2 approach of building a graphic by adding layers.

```
library(tidyverse)
url <- 'http://www.richardtwatson.com/data/carbon.txt'
carbon <- read_csv(url)
# Select year(x) and CO2(y) for an x-y point plot
# Specify red points
ggplot(carbon,aes(year,CO2)) +
  geom_point(color='red')
```




```
# Add some axes labels
# ‘+’ is used to extend commands over one line
ggplot(carbon,aes(year,CO2)) +
  geom_point(color='red') +
  xlab('Year') +
  ylab('CO2 ppm of the atmosphere')
```



Graphics appear under the Plots tab of the bottom right window of RStudio. You can select the Export tab to save a graphic to a file or the clipboard. Also, notice that you can use left and right arrows of the Plots tab to cycle through graphics created in a session.

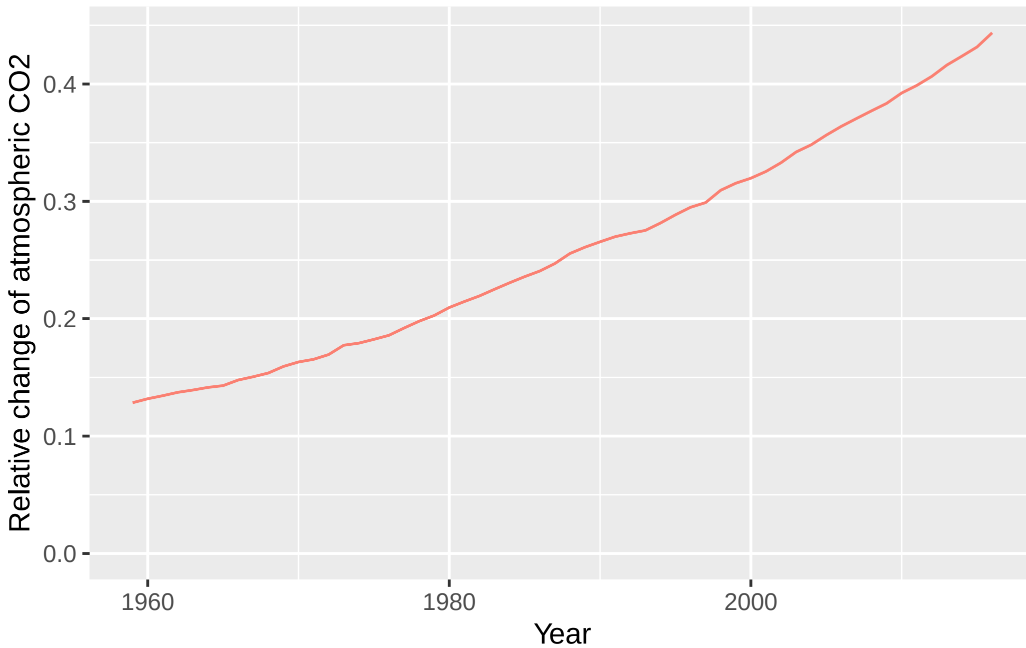
Zero point

It is usually a good idea to have a zero point for the y axis so you don't distort the slope of the line. In the following example, ylim() sets the range for y. Notice the use of max() to automatically set an upper limit for y based on its values.

```
library(tidyverse)
url <- 'http://www.richardtwatson.com/data/carbon.txt'
carbon <- read_delim(url, delim = ',')
```

```
Rows: 58 Columns: 2
-- Column specification --------------------------------------------------------
Delimiter: ","
dbl (2): year, CO2

i Use `spec()` to retrieve the full column specification for this data.
i Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

```
# # compute the relative change in CO2
carbon$relCO2 = (carbon$CO2-280)/280
ggplot(carbon,aes(year,relCO2)) +
  geom_line(color='salmon') +
  xlab('Year') +
  ylab('Relative change of atmospheric CO2') +
  ylim(0,max(carbon$relCO2))
```

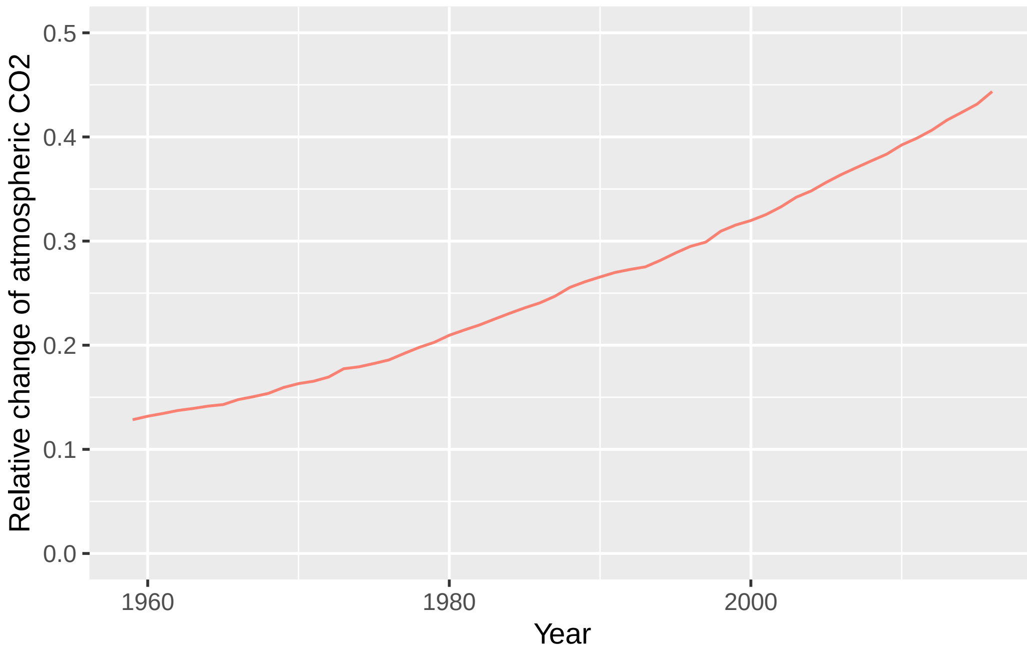


Axes and legends

Axes and legends are both forms of guides, which help the reader to understand a graphic. Readability enhancers such as axes, title, and tick marks are generated automatically based on the parameters specified in the ggplot2 command. You can override the defaults.

Let's redo the graphic with the relative change since the beginning of industrialization in the mid 18th century, when the level of CO2 was around 280 ppm. This time, we will create a line plot. We also add some titles for the axes and specify a format of four consecutive digits for displaying a year on the x-axis. We also move or offset the title for the y-axis a bit to the left to improve readability.

```
# compute  the relative change in CO2
carbon$relCO2 = (carbon$CO2-280)/280
ggplot(carbon,aes(year,relCO2)) + geom_line(color='salmon') +
 xlab('Year') +
 ylab('Relative change of atmospheric CO2') + ylim(0,.5)
```

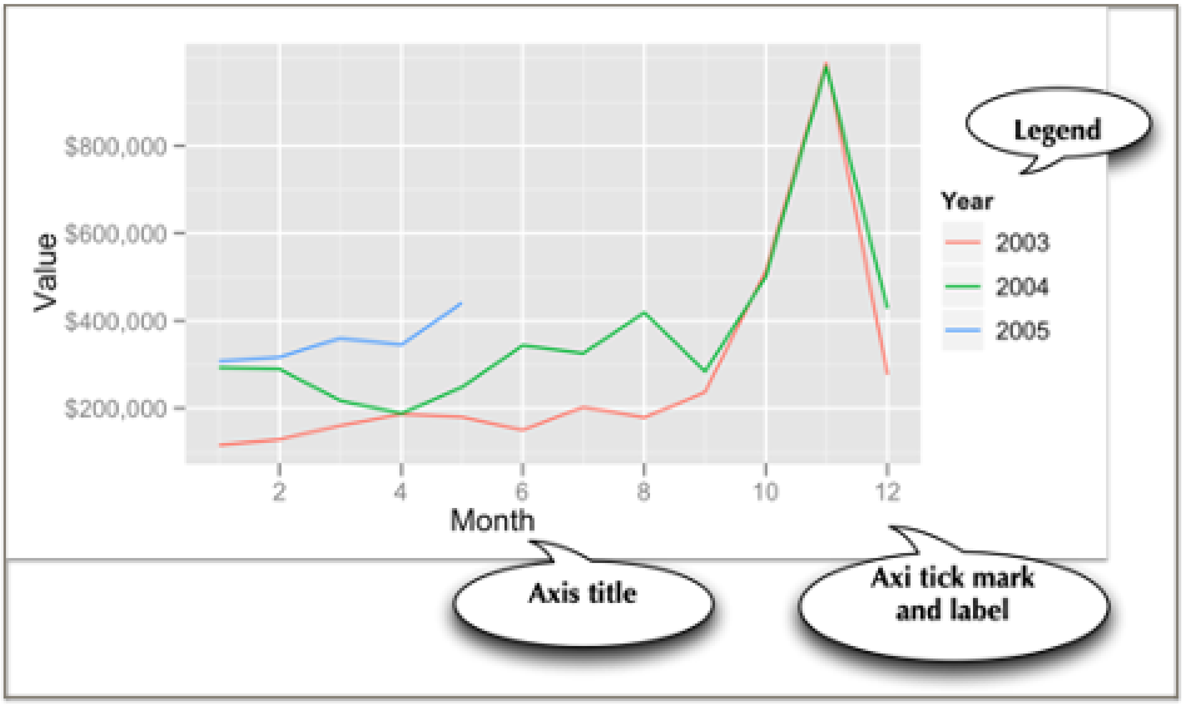


As the prior graphic shows, the present level of CO_2 in the atmosphere is now above 40 percent higher than the pre-industrial period and is continuing to grow.

Guides

Axes and legends are both forms of guides, which help the reader to understand a graphic. In ggplot2, legends and axes are generated automatically based on the parameters specified in the ggplot2 command. You have the capability to override the defaults for axes, but the legend is quite fixed in its format.

In the following graphic, for each axis there is a label and there are tick marks with values so that you eyeball a point on the graphic for its x and y values. The legend enables you to determine which color, in this case, matches each year. A legend could also use shape (e.g., a diamond) and shape size to aid matching.



☒ *Skill builder*

Create a line plot using the data in the following table.

year	1804	1927	1960	1974	1987	1999	2012	2022	2037
population (billions)	1	2	3	4	5	6	7	8	9

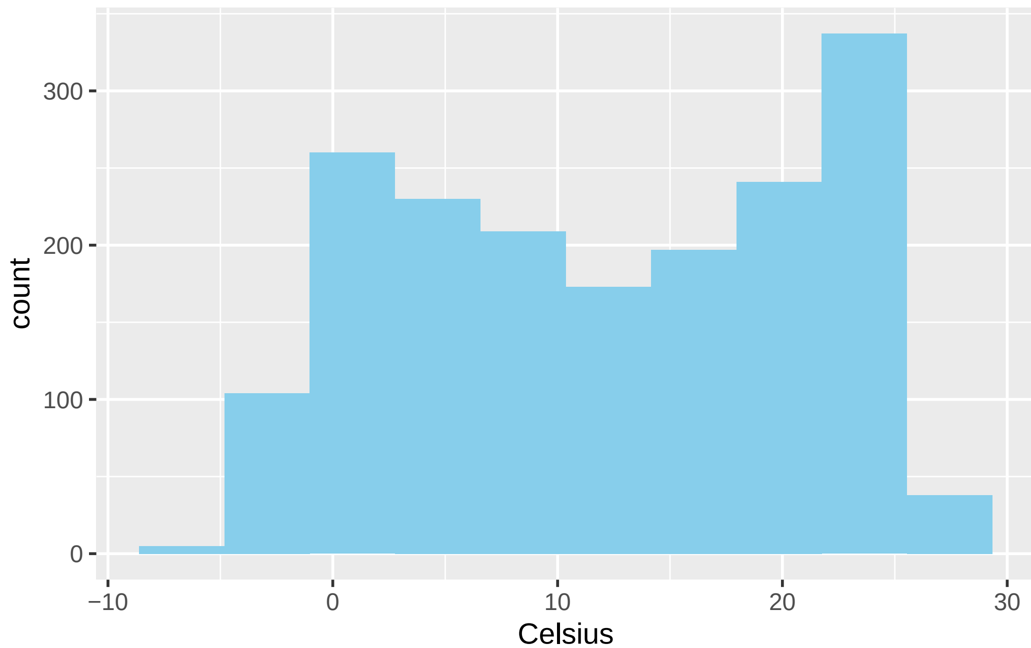
Some recipes

Learning the full power of ggplot2 is quite an undertaking, so here are a few recipes for visualizing data.

Histogram

Histograms are useful for showing the distribution of values in a single column. A histogram has a vertical orientation. The number of occurrences of a particular value in a column are automatically counted by the ggplot2 function. In the following sample code, we show the distribution of temperatures in Celsius for the Central Park temperature data. Notice that the Celsius conversion is rounded to an integer for plotting. Width specifies the size of the bin, which is two in this case. This means that the bin above the tick mark 10 contains all values in the range 9 to 11. There is a range of named colors you can use in ggplot2.

```r
options(readr.show_col_types = FALSE)
library(measurements)
library(ggplot2)
library(readr)
url <-  'http://www.richardtwatson.com/data/centralparktemps.txt'
t <- read_csv(url)
t$C <- conv_unit(t$temperature,'F','C')
ggplot(t,aes(C)) +
  geom_histogram(fill='skyblue', bins = 10) +
  xlab('Celsius')
```

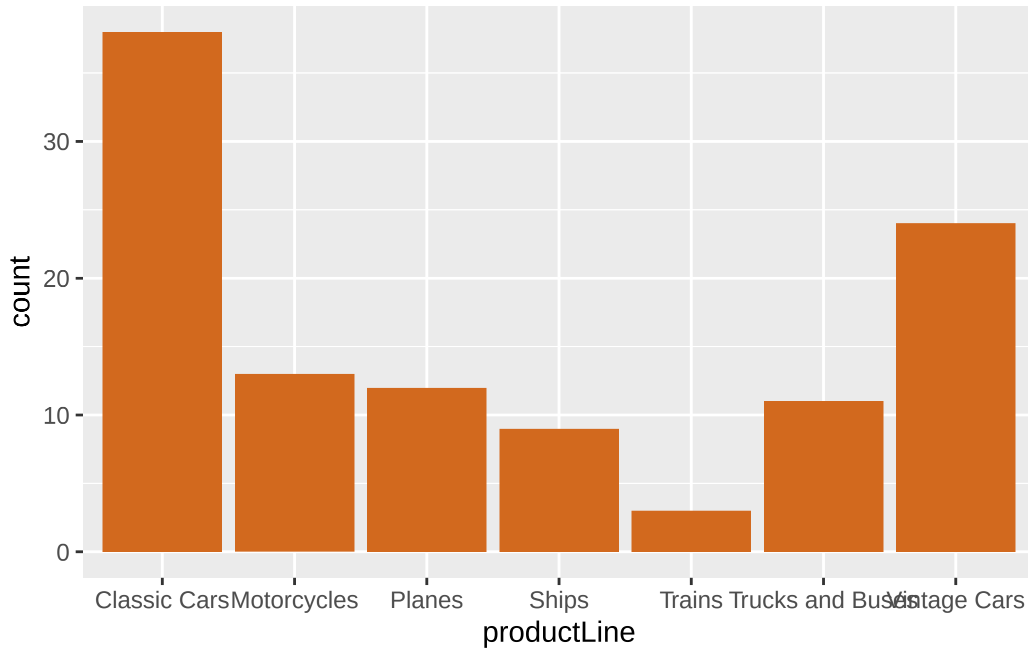


Bar graph

In the following example, we query a database to get data for plotting. Because the column selected for graphing, productLine is categorical, we need to use a bar graph.

```r
library(tidyverse)
library(DBI)
library(RMySQL)
conn <- dbConnect(RMySQL::MySQL(),
         'localhost', dbname = 'ClassicModels',
         user = 'student', password = 'student')
# Query the database and create file for use with R
d <- dbGetQuery(conn,'SELECT * from Products;')
# Plot the number of product lines
```

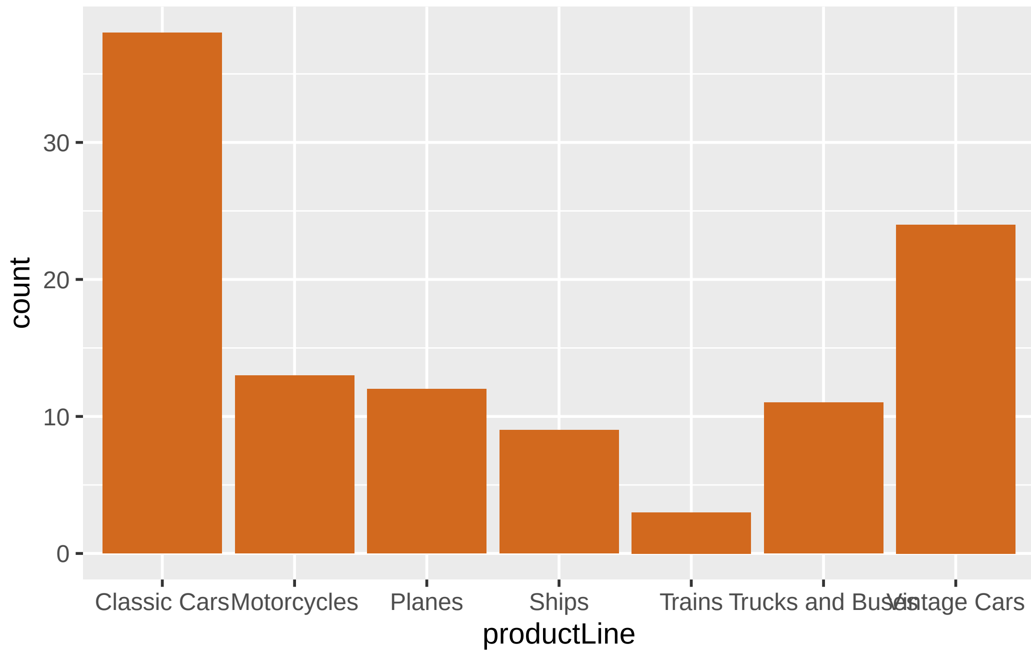
```
ggplot(d,aes(x=productLine)) +
  geom_bar(fill = 'chocolate')
```



Column graph

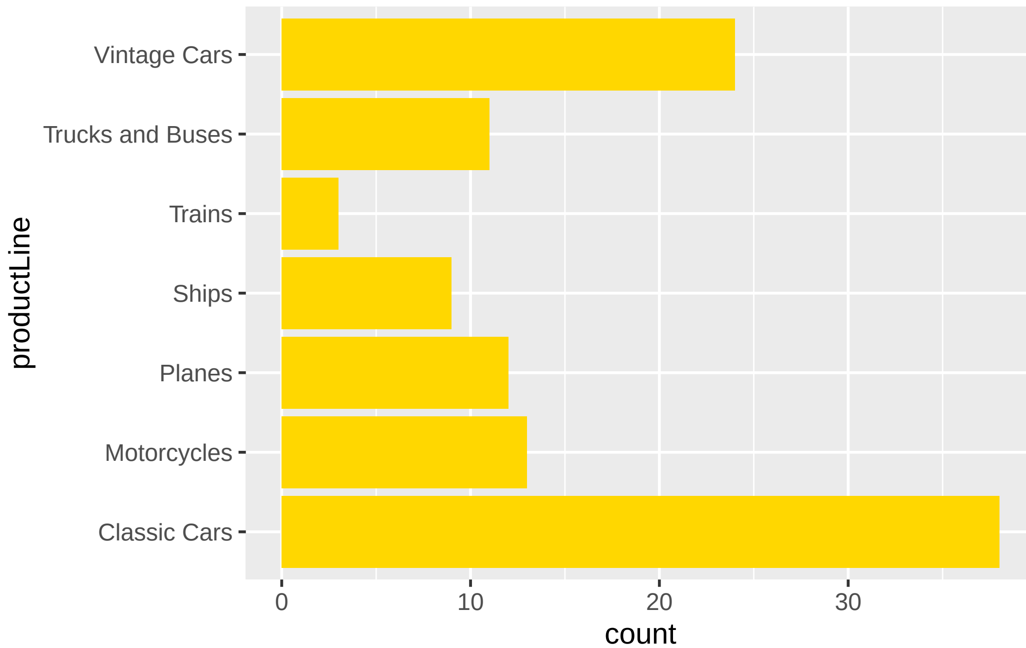
In the following example, we query a database to get data for plotting/ We then count the number of products in each productLine, and as we have counts a column graph is specified.

```
library(tidyverse)
library(DBI)
library(RMySQL)
conn <- dbConnect(RMySQL::MySQL(),
         'localhost', dbname = 'ClassicModels',
         user = 'student', password = 'student')
# Query the database and create file for use with R
d <- dbGetQuery(conn,'SELECT * from Products;')
da <-  d |>
  group_by(productLine) |>
  summarize(count = n())
ggplot(da,aes(productLine,count)) +
  geom_col(fill='chocolate')
```



Because ggplot2 is based on a grammar of graphics, with a few changes, you can create a bar graph of the same data.

```
library(tidyverse)
library(DBI)
library(RMySQL)
conn <- dbConnect(RMySQL::MySQL(),
         'localhost', dbname = 'ClassicModels',
         user = 'student', password = 'student')
# Query the database and create file for use with R
d <- dbGetQuery(conn,'SELECT * from Products;')
da <-  d |>
  group_by(productLine) |>
  summarize(count = n())
ggplot(d,aes(productLine)) +
  geom_bar(fill='gold') +
  coord_flip()
```



☒ Skill builder

Create a bar graph using the data in the following table. Set population as the weight for each observation.

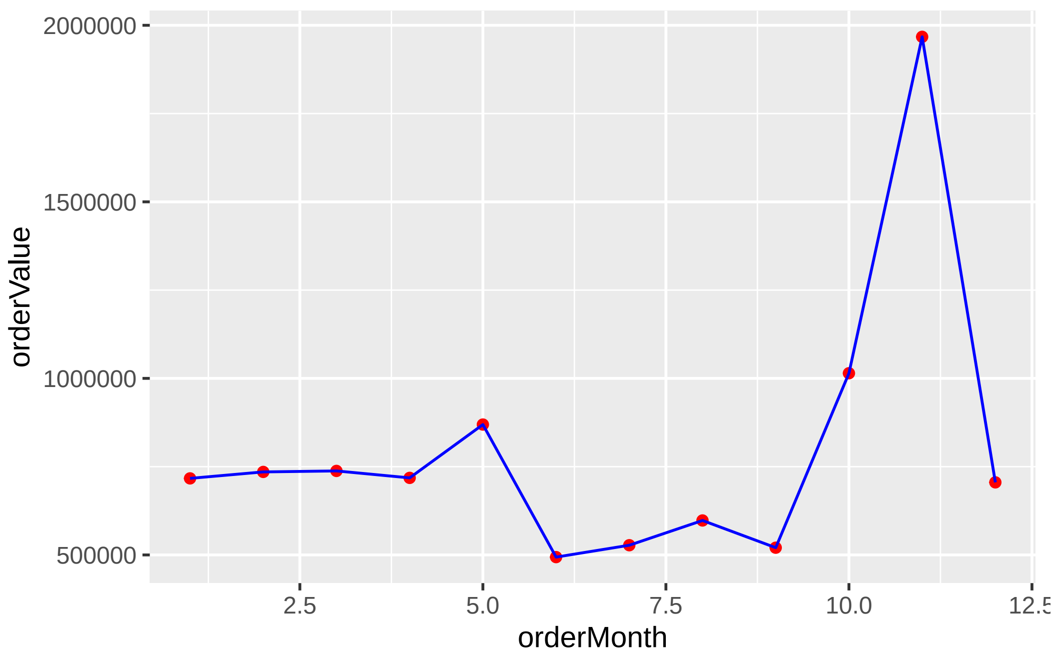
year	1804	1927	1960	1974	1987	1999	2012	2022	2037
population (billions)	1	2	3	4	5	6	7	8	9

Scatterplot

A scatterplot shows points on an x-y grid, which means you need to have a pair of numeric values.

```
library(tidyverse)
library(lubridate)
library(DBI)
library(RMySQL)
conn <- dbConnect(RMySQL::MySQL(),
         'localhost', dbname = 'ClassicModels',
         user = 'student', password = 'student')
d <- dbGetQuery(conn,"SELECT MONTH(orderDate) AS orderMonth,
  sum(quantityOrdered*priceEach) AS orderValue
  FROM Orders JOIN OrderDetails ON
  Orders.orderNumber = OrderDetails.orderNumber GROUP BY orderMonth;")
# Plot data orders by month
# Show the points and the line
```

```
ggplot(d,aes(x=orderMonth,y=orderValue)) +
  geom_point(color='red') +
  geom_line(color='blue')
```



It is sometimes helpful to show multiple scatterplots on the one grid. In ggplot, you can create groups of points for plotting. Sometimes, you might find it convenient to recode data so you can use different colors or lines to distinguish values in set categories. Let's examine grouping by year.

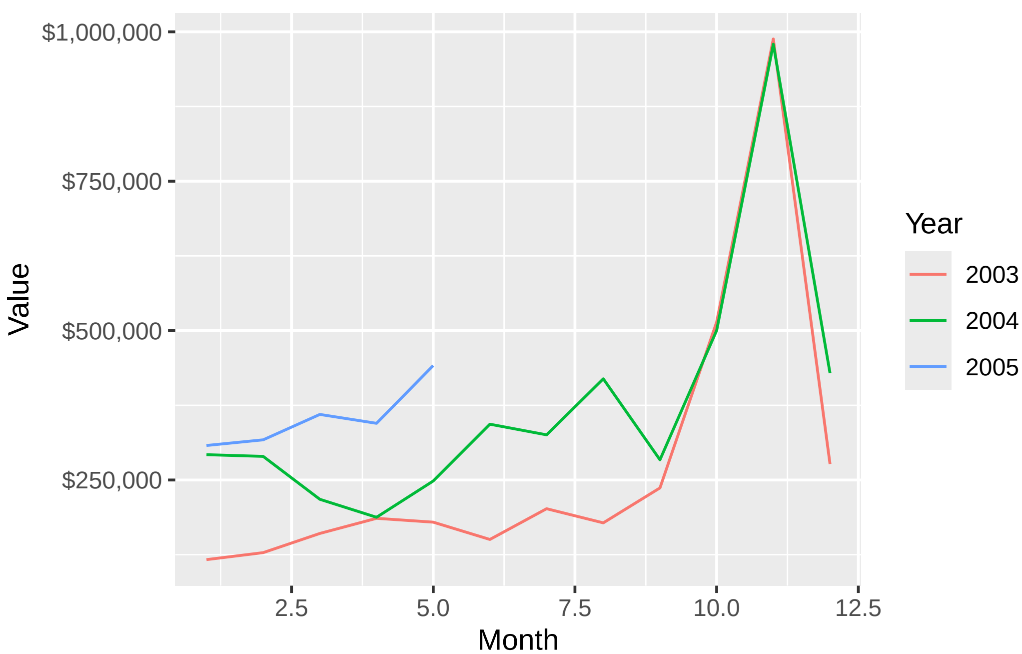
```
library(tidyverse)
library(lubridate)
library(DBI)
library(RMySQL)
library(scales)
```

```
Attaching package: 'scales'

The following object is masked from 'package:purrr':

    discard

The following object is masked from 'package:readr':

    col_factor
```

```
# Get the value of orders by year and month
conn <- dbConnect(RMySQL::MySQL(),
         'localhost', dbname = 'ClassicModels',
         user = 'student', password = 'student')
d <- dbGetQuery(conn,"SELECT YEAR(orderDate) AS orderYear,
                MONTH(orderDate) AS Month,
                sum((quantityOrdered*priceEach)) AS Value
                FROM Orders, OrderDetails
                WHERE Orders.orderNumber = OrderDetails.orderNumber
                 GROUP BY orderYear, Month;")
```

```
Warning in dbSendQuery(conn, statement, ...): Unsigned INTEGER in col 0
imported as numeric
```

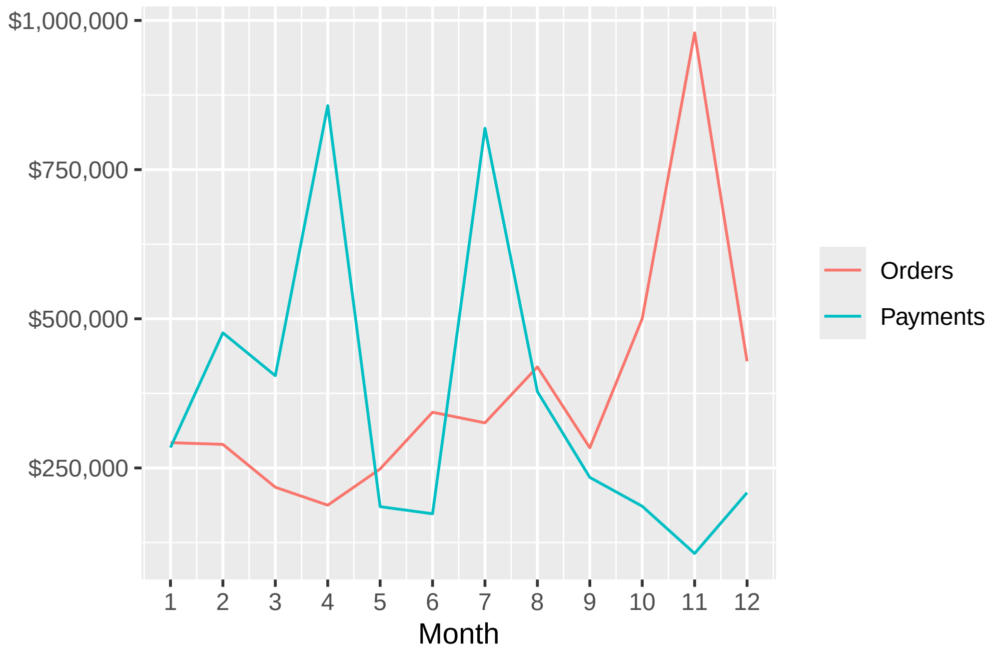
```
# Plot data orders by month and grouped by year
# ggplot expects grouping variables to be character, so convert
# load scales package for formatting as dollars
d$Year <- as.character(d$orderYear)
  ggplot(d,aes(x=Month,y=Value,group=Year)) +
  geom_line(aes(color=Year)) +
# Format as dollars
  scale_y_continuous(labels = dollar)
```



Sometimes the data that you want to graph will be in multiple files. Here is a case where we want to show ClassicCars' orders and payments by month on the same plot.

```r
library(tidyverse)
library(DBI)
library(RMySQL)
library(scales)
# Load the driver
conn <- dbConnect(RMySQL::MySQL(),
         'localhost', dbname = 'ClassicModels',
         user = 'student', password = 'student')
library(scales)
library(ggplot2)
orders <- dbGetQuery(conn,"SELECT MONTH(orderDate) AS month,
            SUM((quantityOrdered*priceEach)) AS orderValue
            FROM Orders, OrderDetails
            WHERE Orders.orderNumber = OrderDetails.orderNumber
            AND YEAR(orderDate) = 2004 GROUP BY Month;")
payments <- dbGetQuery(conn,"SELECT MONTH(paymentDate) AS month,
              SUM(amount) AS payValue FROM Payments
              WHERE YEAR(paymentDate) = 2004 GROUP BY MONTH;")
ggplot(orders,aes(x=month)) +
  geom_line(aes(y=orders$orderValue, color='Orders')) +
  geom_line(aes(y=payments$payValue, color='Payments')) +
  xlab('Month') + ylab('') +
  # Format as dollars and show each month
  scale_y_continuous(label = dollar)  +
  scale_x_continuous(breaks=c(1:12)) +
  # Remove the legend
  theme(legend.title=element_blank())
```

```
Warning: Use of `orders$orderValue` is discouraged.
i Use `orderValue` instead.
```

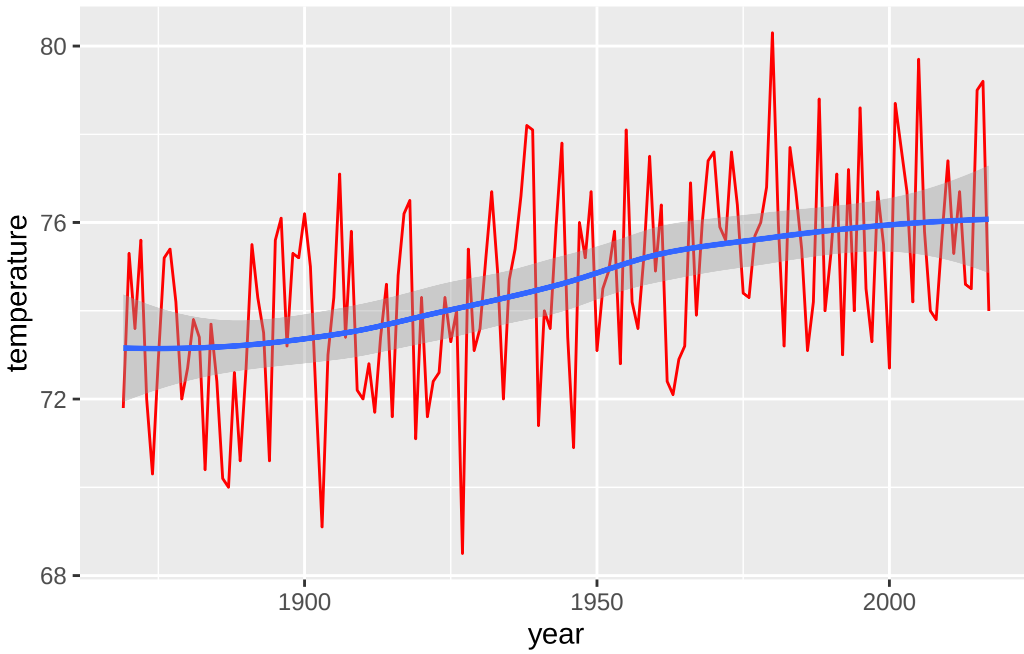


Smoothing

Smoothing helps to detect a trend in a line plot. The following example shows the average mean temperatures for August for Central Park.

```
library(tidyverse)
url <- 'http://www.richardtwatson.com/data/centralparktemps.txt'
t <- read_delim(url, delim=',')
# select the August data
ta <-  t |> filter(month == 8)
ggplot(ta,aes(year,temperature)) +
  geom_line(color="red") +
  geom_smooth()
```

```
`geom_smooth()` using method = 'loess' and formula = 'y ~ x'
```



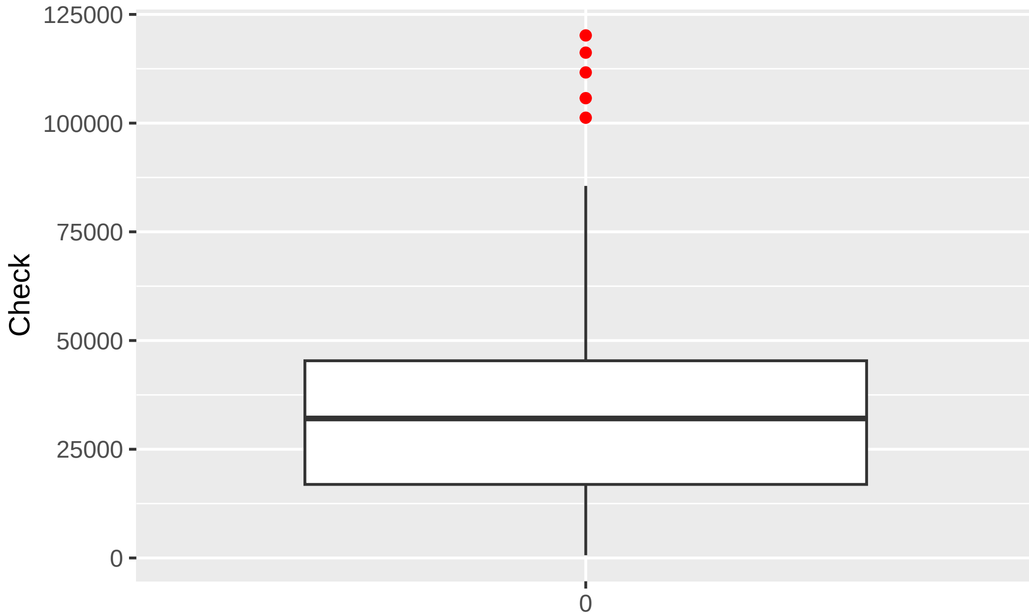
☒ Skill builder

Using the Central Park data, plot the temperatures for February and fit a straight line to the points. Use layer_model_predictions(). What do you observe?

Box Plot

A box plot is an effective means of displaying information about one or more variables. It shows minimum and maximum, range, lower quartile, median, and upper quartile for each variable. The following code creates a box plot for a single variable. Notice that we use factor(0) to indicate there is no grouping variable.

```
library(tidyverse)
library(DBI)
conn <- dbConnect(RMySQL::MySQL(),
         'localhost', dbname = 'ClassicModels',
         user = 'student', password = 'student')
d <- dbGetQuery(conn,"SELECT * from Payments;")
# Boxplot of amounts paid
ggplot(d,aes(factor(0),amount)) +
  geom_boxplot(outlier.colour='red') +
   xlab("") +
   ylab("Check")
```



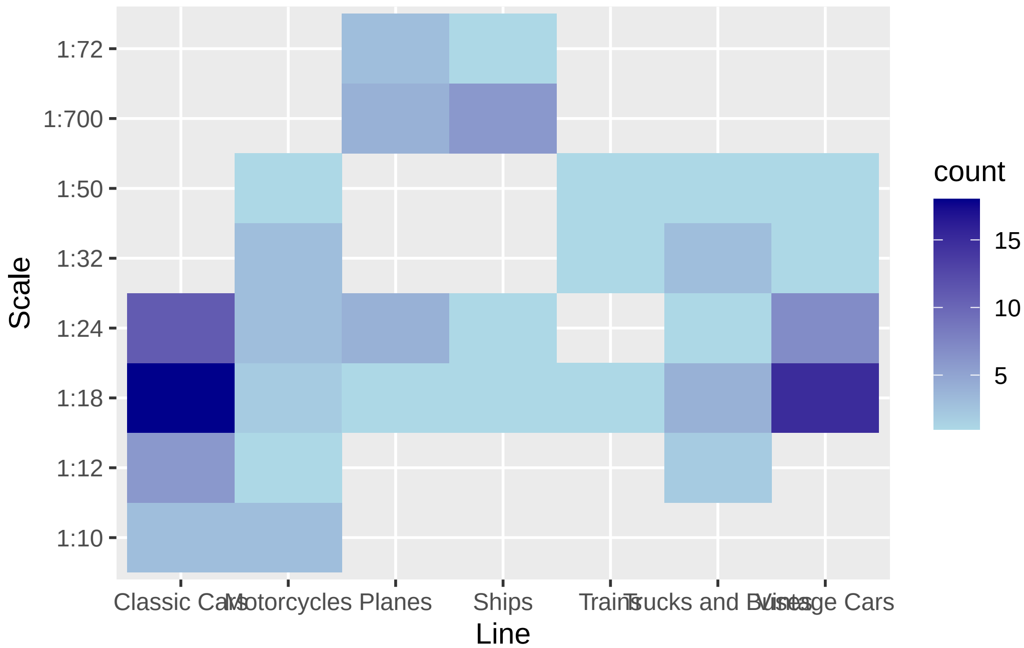
Heat map

A heat map visualizes tabular data. It is useful when you have two categorical variables cross tabulated. Consider the case for the ClassicModels database where we want to get an idea of the different number of model scales in each product line. We can get a quick picture with the following code.

```
library(tidyverse)
library(lubridate)
library(DBI)
library(RMySQL)
d <- dbGetQuery(conn,'SELECT * from Products;')
da <- d |> group_by(productLine, productScale) |>
 summarize(count = n())
```

```
`summarise()` has grouped output by 'productLine'. You can override using the
`.groups` argument.
```

```
ggplot(da,aes(productLine,productScale)) +
  geom_tile(aes(fill=count)) +
  scale_fill_gradient(low = 'light blue', high = 'dark blue') +
  xlab('Line') +
  ylab('Scale')
```



Geographic data

The ggmap package supports a variety of mapping systems, including Google maps. As you might expect, it offers many features, and we just touch on the basics in this example.

The Offices table in the ClassicModels database includes the latitude and longitude of each office in officeLocation, which has a datatype of POINT. The following R code can be used to mark each office on a Google map. After loading the required packages, a database query is executed to return the longitude and latitude for each office. Then, a Google map of the United States is displayed. The marker parameter specifies the name of the table containing the values for longitude and latitude. Offices that are not in the U.S. (e.g., Sydney) are ignored. Adjust zoom, an integer, to get a suitably sized map. Zoom can range from 3 (a continent) to 20 (a building).

You will need to a GoogleAPIkey to run this application on your computer.

```
# Google maps requires an [API key]
# (developers.google.com/maps/documentation/javascript/get-api-key).
library(tidyverse)
library(ggmap)
library(mapproj)
library(DBI)
library(RMySQL)
conn <- dbConnect(RMySQL::MySQL(),
         'localhost', dbname = 'ClassicModels',
         user = 'student', password = 'student')
# Google maps requires lon and lat, in that order, to create markers
```

```
d <- dbGetQuery(conn,"SELECT ST_Y(officeLocation) AS lon,
                ST_X(officeLocation) AS lat FROM Offices;")
t <- read_csv("GoogleAPIkey.txt")
register_google(key = t$key)
# show offices in the United States
# vary zoom to change the size of the map
map <-  get_googlemap('united states',marker=d,zoom=4)
ggmap(map) +
  labs(x = 'Longitude', y = 'Latitude') +
  ggtitle('US offices')
```

☒ Skill builder

Create the following maps. 1. Offices in Europe 2. Office location in Paris 3. Customers in the US 4. Customers in Sydney

R resources

The developer of ggplot2, Hadley Wickham, maintains a web site. Another useful web site for data visualization is FlowingData, which has an associated book, titled *Visualize This*. If you become heavily involved in visualization, we suggest you read some of the works of Edward Tufte. One of his books is listed in the references.

Summary

Because of evolutionary pressure, humans became strong visual processors. Consequently, graphics can be very effective for presenting information. The grammar of graphics provides a logical foundation for the construction of a graphic by adding successive layers of information. ggplot2 is a package implementing the grammar of graphics in R, the open source statistics platform. Data can be extracted from an MySQL database for processing and graphical presentation in R. Spatial data can be selected from a database and displayed on a Google map.

Key terms and concepts	
Bar chart	Graphic
Box plot	Heat map
dplyr	Histogram
ggplot2	Scatterplot
Grammar of graphics	Smooth
Graph	

References

Kabacoff, R. I. (2009). *R in action: data analysis and graphics with R*. Greenwich, CT: Manning Publications.

Kahle, D., & Wickham, H. (2013). ggmap : Spatial Visualization with ggplot. *The R Journal*.

Tufte, E. (1983). *The visual display of quantitative information*. Cheshire, CT: Graphics Press.

Yau, N. (2011). *Visualize this: the flowing data guide to design, visualization, and statistics*. Indianapolis, IN: Wiley.

Wilkinson, L. (2005). *The grammar of graphics* (2nd ed.). New York: Springer.

Exercises

1. Given the following data on the world's cargo carrying capacity in millions of dead weight tons (dwt)[2] for the given years, graph the relationship as a point plot. Add a linear prediction model to the graph. What is the approximate increase in the world capacity each year?

```
dwt <- c(2566, 3704, 4008, 5984, 7700, 8034, 8229, 7858, 8408, 8939)
year <- c(1970, 1980, 1990, 2000, 2006, 2007, 2008, 2009, 2010, 2011)
```

[2] Dead weight tonnage is a measure of how much weight, in tonnes, a ship can safely carry.

2. Create a graph showing the relative ocean shipping cost as a percentage of total cost for some common household items using the following data.

```
unitCost <-  c(700, 200, 150, 50, 15, 3, 1)
shipCost <-  c(10.00, 1.50, 1.00, 0.15, 0.15, 0.05, 0.01)
item <-  c('TV set', 'DVD player', 'Vacuum cleaner',
           'Scotch whisky', 'Coffee', 'Biscuits', 'Beer')
```

SQL input

3. Visualize in blue the number of items for each product scale.
4. Prepare a line plot with appropriate labels for total payments for each month in 2004.
5. Create a histogram with appropriate labels for the value of orders received from the Nordic countries (Denmark, Finland, Norway, Sweden).
6. Create a heatmap for product lines and Norwegian cities.
7. Show on a Google map the customers in Japan.
8. Show on a Google map the European customers who have never placed an order.

File input

9. Access sales data, for three car models: X, Y, and Z.
    a. Create a bar chart for sales of each model (X, Y , or Z)
    b. Create bar chart for sales by each form of sale (online or auction).
10. Use the 'Import Dataset' feature of RStudio to read electricity prices, for a major city.[3] Do a Box plot of cost. What do you conclude about cost?
11. Read wealth data for various countries. Create histograms for each of the wealth measures. Consult the ggplot2 color chart for a choice of colors.
12. Merge the data for weather and electricity prices. for a major city. The merged file should contain air temperature and electricity cost. Also, you need to convert air temperature from a factor to a numeric (hint: first convert to a character). As readr does not currently handle date and time stamps, use the following code to read the files.
    a. Compute the correlation between temperature and electricity price. What do you conclude?
    b. Graph the relationship between temperature and electricity price.
    c. Graph the relationship between temperature and electricity price when the temperature is 95ºF and above.
    d. Create a single graph showing the relationship between temperature and electricity price differentiating by color when the temperature is above or below 90ºF. (Hint: Trying recoding temperature).

[3] Note these prices have been transformed from the original values, but they are still representative of the changes over time.

17 Text Mining and Natural Language Processing

> From now on I will consider a language to be a set (finite or infinite) of sentences, each finite in length and constructed out of a finite set of elements. All natural languages in their spoken or written form are languages in this sense.
>
> Noam Chomsky, *Syntactic Structures*

Learning objectives

Students completing this chapter will:

- Have a realistic understanding of the capabilities of current text mining and NLP software;
- Be able to use R and associated packages for text mining and NLP.

The nature of language

Language enables humans to cooperate through information exchange. We typically associate language with sound and writing, but gesturing, which is older than speech, is also a means of collaboration. The various dialects of sign languages are effective tools for visual communication. Some species, such as ants and bees, exchange information using chemical substances known as pheromones. Of all the species, humans have developed the most complex system for cooperation, starting with gestures and progressing to digital technology, with language being the core of our ability to work collectively.

Natural language processing (NLP) focuses on developing and implementing software that enables computers to handle large scale processing of language in a variety of forms, such as written and spoken. While it is a relatively easy task for computers to process numeric information, language is far more difficult because of the flexibility with which it is used, even when grammar and syntax are precisely obeyed. There is an inherent ambiguity of written and spoken speech. For example, the word "set" can be a noun, verb, or adjective, and the *Oxford English Dictionary* defines over 40 different meanings. Irregularities in language, both in its structure and use, and ambiguities in meaning make NLP a challenging task. Be forewarned. Don't expect NLP to provide the same level of exactness and starkness as numeric processing. NLP output can be messy, imprecise, and confusing – just like the language that goes into an NLP program. One of the well-known maxims of information processing is "garbage-in, garbage-out." While language is not garbage, we can certainly observe that "ambiguity-in, ambiguity-out" is a truism. You can't start with something that is marginally ambiguous and expect a computer to turn it into a precise statement. Legal and religious scholars can spend years learning how to interpret a text and still reach different conclusions as to its meaning.

NLP, despite its limitations, enables humans to process large volumes of language data (e.g., text) quickly and to identify patterns and features that might be useful. A well-educated human with domain knowledge specific to the same data might make more sense of these data, but it might take months or years. For example, a firm might receive over a 1,000 tweets, 500 Facebook mentions, and 20 blog references in a day. It needs NLP to identify within minutes or hours which of these many messages might need human action.

Text mining and NLP overlap in their capabilities and goals. The ultimate objective is to extract useful and valuable information from text using analytical methods and NLP. Simply counting words in a document is a an example of text mining because it requires minimal NLP technology, other than separating text into words. Whereas, recognizing entities in a document requires prior extensive machine learning and more intensive NLP knowledge. Whether you call it text mining or NLP, you are processing natural language. We will use the terms somewhat interchangeably in this chapter.

The human brain has a special capability for learning and processing languages and reconciling ambiguities,[1] and it is a skill we have yet to transfer to computers. NLP can be a good servant, but enter its realm with realistic expectations of what is achievable with the current state-of-the-art.

Levels of processing

There are three levels to consider when processing language.

Semantics

Semantics focuses on the meaning of words and the interactions between words to form larger units of meaning (such as sentences). Words in isolation often provide little information. We normally need to read or hear a sentence to understand the sender's intent. One word can change the meaning of a sentence (e.g., "Help needed versus Help not needed"). It is typically an entire sentence that conveys meaning. Of course, elaborate ideas or commands can require many sentences.

Discourse

Building on semantic analysis, discourse analysis aims to determine the relationships between sentences in a communication, such as a conversation, consisting of multiple sentences in a particular order. Most human communications are a series of connected sentences that collectively disclose the sender's goals. Typically, interspersed in a conversation are one or more sentences from one or more receivers as they try to understand the sender's purpose and maybe interject

[1] Ambiguities are often the inspiration for puns. "You can tune a guitar, but you can't tuna fish. Unless of course, you play bass," by Douglas Adams

their thoughts and goals into the discussion. The points and counterpoints of a blog are an example of such a discourse. As you might imagine, making sense of discourse is frequently more difficult, for both humans and machines, than comprehending a single sentence. However, the braiding of question and answer in a discourse, can sometimes help to reduce ambiguity.

Pragmatics

Finally, pragmatics studies how context, world knowledge, language conventions, and other abstract properties contribute to the meaning of human conversation. Our shared experiences and knowledge often help us to make sense of situations. We derive meaning from the manner of the discourse, where it takes place, its time and length, who else is involved, and so forth. Thus, we usually find it much easier to communicate with those with whom we share a common culture, history, and socioeconomic status because the great collection of knowledge we jointly share assists in overcoming ambiguity.

Tokenization

Tokenization is the process of breaking a document into chunks (e.g., words), which are called tokens. Whitespaces (e.g., spaces and tabs) are used to determine where a break occurs. Tokenization typically creates a *bag of words* for subsequent processing. Many text mining functions use words as the foundation for analysis.

Counting words

To count the number of words in a string, simply count the number of times there are one or more consecutive spaces using the pattern "[:space:]+" and then add one, because the last word is not followed by a space.

```
library(stringr)
str_count("The dead batteries were given out free of charge",
          "[:space:]+") + 1
```

```
[1] 9
```

Sentiment analysis

Sentiment analysis is a popular and simple method of measuring aggregate feeling. In its simplest form, it is computed by giving a score of +1 to each "positive" word and -1 to each "negative" word and summing the total to get a sentiment score. A text is decomposed into words. Each word is then checked against a list to find its score (i.e., +1 or -1), and if the word is not in the list, it doesn't score.

A major shortcoming of sentiment analysis is that irony (e.g., "The name of Britain's biggest dog (until it died) was Tiny") and sarcasm (e.g., "I started out with nothing and still have most of it left") are usually misclassified. Also, a phrase such as "not happy" might be scored as +1 by a sentiment analysis program that simply examines each word and not those around it.

The sentimentr package offers an advanced implementation of sentiment analysis. It is based on a polarity table, in which a word and its polarity score (e.g., -1 for a negative word) are recorded. The default polarity table is provided by the syuzhet package. You can create a polarity table suitable for your context, and you are not restricted to 1 or -1 for a word's polarity score. Here are the first few rows of the default polarity table.

```
library(sentimentr)
library(syuzhet)
head(get_sentiment_dictionary())
```

```
         word value
1     abandon -0.75
2   abandoned -0.50
3   abandoner -0.25
4 abandonment -0.25
5    abandons -1.00
6    abducted -1.00
```

In addition, sentimentr supports valence shifters, which are words that alter or intensify the meaning of a polarizing word (i.e., a word appearing in the polarity table) appearing in the text or document under examination. Each word has a value to indicate how to interpret its effect (negators (1), amplifiers(2), de-amplifiers (3), and conjunction (4).

Now, let's see how we use the sentiment function. We'll start with an example that does not use valence shifters, in which case we specify that the sentiment function should not look for valence words before or after any polarizing word. We indicate this by setting n.before and n.after to 0. Our sample text consists of several sentences, as shown in the following code.

```
library(sentimentr)
library(syuzhet)
sample = c("You're awesome and I love you", "I hate and hate and hate.
So angry. Die!", "Impressed and amazed: you are peerless in your
achievement of unparalleled mediocrity.")
sentiment(sample, n.before=0, n.after=0, amplifier.weight=0)
```

```
Key: <element_id, sentence_id>
   element_id sentence_id word_count  sentiment
        <int>       <int>      <int>      <num>
1:          1           1          6  0.5511352
2:          2           1          6 -0.9185587
3:          2           2          2 -0.5303301
4:          2           3          1 -0.7500000
5:          3           1         12  0.6495191
```

Notice that the sentiment function breaks each element (the text between quotes in this case) into sentences, identifies each sentence in an element, and computes the word count for each of these sentences. The sentiment score is the sum of the polarity scores divided by the square root of the number of words in the associated sentence.

To get the overall sentiment for the sample text, use:

```r
library(sentimentr)
library(syuzhet)
sample = c("You're awesome and I love you", "I hate and hate and hate.
           So angry. Die!", "Impressed and amazed: you are peerless
           in your achievement of unparalleled mediocrity.")
y <- sentiment(sample,
n.before=0, n.after=0)
mean(y$sentiment)
```

```
[1] -0.1996469
```

When a valence shift is detected before or after a polarizing word, its effect is incorporated in the sentiment calculation. The size of the effect is indicated by the amplifier.weight, a sentiment function parameter with a value between 0 and 1. The weight amplifies or de-amplifies by multiplying the polarized terms by 1 + the amplifier weight. A negator flips the sign of a polarizing word. A conjunction amplifies the current clause and down weights the prior clause. Some examples in the following table illustrate the results of applying the code to a variety of input text. The polarities are -1 (crazy) and 1 (love). There is a negator (not), two amplifiers (very and much), and a conjunction (but). Contractions are treated as amplifiers and so get weights based on the contraction (.9 in this case) and amplification (.8) in this case.

```r
library(sentimentr)
library(syuzhet)
sample = c("You're awesome and I love you", "I hate and hate and hate.
So angry. Die!", "Impressed and amazed: you are peerless in your
achievement of unparalleled mediocrity.")
sentiment(sample, n.before = 2, n.after = 2,
          amplifier.weight=.8, but.weight = .9)
```

```
Key: <element_id, sentence_id>
   element_id sentence_id word_count  sentiment
        <int>       <int>      <int>      <num>
1:          1           1          6  0.5511352
2:          2           1          6 -0.9185587
3:          2           2          2 -0.5303301
4:          2           3          1 -0.7500000
5:          3           1         12  0.6495191
```

Type	Code	Text	Sentiment
		You're crazy, and I love you.	0
Negator	1	You're not crazy, and I love you.	0.57
Amplifier	2	You're crazy, and I love you very much.	0.21
De-amplifier	3	You're slightly crazy, and I love you.	0.23
Conjunction	4	You're crazy, but I love you.	0.45

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Run the following R code and comment on how sensitive sentiment analysis is to the n.before and n.after parameters.

```
library(sentimentr)
library(syuzhet)
sample = c("You're not crazy and I love you very much.")
sentiment(sample, n.before = 4, n.after=3, amplifier.weight=1)
```

```
Key: <element_id, sentence_id>
   element_id sentence_id word_count sentiment
        <int>       <int>      <int>     <num>
1:          1           1          9   0.24975
```

```
sentiment(sample, n.before = Inf, n.after=Inf, amplifier.weight=1)
```

```
Key: <element_id, sentence_id>
   element_id sentence_id word_count sentiment
        <int>       <int>      <int>     <num>
1:          1           1          9         0
```

What are the correct polarities for each word, and weights for negators, amplifiers and so on? It is a judgment call and one that is difficult to justify.

Sentiment analysis has given you an idea of some of the issues surrounding text mining. Let's now look at the topic in more depth and explore some of the tools available in tm, a general purpose text mining package for R. We will also use a few other R packages which support text mining and displaying the results.

Corpus

A collection of text is called a corpus. It is common to use N for the *corpus size*, the number of tokens, and V for the *vocabulary*, the number of distinct tokens.

In the following examples, our corpus consists of Warren Buffett's annual letters for 1998-2012 to the shareholders of Berkshire Hathaway for 1998-2012. The original letters, available in html or pdf, were converted to separate text files using Abbyy Fine Reader. Tables, page numbers, and graphics were removed during the conversion.

The following R code sets up a loop to read each of the letters and add it to a data frame. When all the letters have been read, they are turned into a corpus.

```
library(stringr)
library(tm)
library(NLP)
#set up a data frame to hold up to 100 letters
df <-  data.frame(num=100)
begin <-  1998 # date of first letter
i <-  begin
# read the letters
while (i < 2003) {
 y <- as.character(i)
 # create the file name
 f <- str_c('http://www.richardtwatson.com/BuffettLetters/',
            y, 'ltr.txt',delim='')
 # read the letter as on large string
 d <-  readChar(f,nchars=1e6)
 # add letter to the data frame
 df[i-begin+1,1] <-  i
 df[i-begin+1,2] <-  d
 i <-  i + 1
}
colnames(df) <- c('doc_id', 'text')
# create the corpus
letters <-  Corpus(DataframeSource(df))
num.letters <- dim(df)[1]
```

Readability

There are several approaches to estimating the readability of a selection of text. They are usually based on counting the words in each sentence and the number of syllables in each word. For example, the Flesch-Kincaid method uses the formula:

```
(11.8 * syllables: per: word) + (0.39 * words:per:sentence) - 15.59
```

It estimates the grade-level or years of education required of the reader. The bands are:

Score	Education level
13-16	Undergraduate
16-18	Masters
19-	PhD

The R package koRpus has a number of methods for calculating readability scores. You first need to tokenize the text using the package's tokenize function. Then complete the calculation.

```
library(koRpus)
library(koRpus.lang.en)
library(sylly)
#tokenize the first letter   after converting to character vector
txt <-  letters[[1]][1] # first element in the list
tagged.text <- tokenize(as.character(txt),format="obj",lang="en")
# score
readability(tagged.text, hyphen=NULL,index="FORCAST", quiet = TRUE)
```

```
FORCAST
  Parameters: default
       Grade: 9.89
         Age: 14.89

Text language: en
```

Preprocessing

Before commencing analysis, a text file typically needs to be prepared for processing. Several steps are usually taken.

Case conversion

For comparison purposes, all text should be of the same case. Conventionally, the choice is to convert to all lower case. First convert to UTF-8.

```
content_transformer <- function(x) iconv(x, to='UTF-8-MAC', sub='byte')
clean.letters <- tm_map(letters, content_transformer)
clean.letters <- tm_map(letters,tolower)
```

Punctuation removal

Punctuation is usually removed when the focus is just on the words in a text and not on higher level elements such as sentences and paragraphs.

```
clean.letters <- tm_map(clean.letters,removePunctuation)
```

Number removal

You might also want to remove all numbers.

```
clean.letters <- tm_map(clean.letters,removeNumbers)
```

Stripping extra white spaces

Removing extra spaces, tabs, and such is another common preprocessing action.

```
clean.letters <- tm_map(clean.letters,stripWhitespace)
```

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>
> Redo the readability calculation after executing the preprocessing steps described in the previous section. What do you observe?

Stop word filtering

Stop words are short common words that can be removed from a text without affecting the results of an analysis. Though there is no commonly agreed upon list of stop works, typically included are *the, is, be, and, but, to,* and *on*. Stop word lists are typically all lowercase, thus you should convert to lowercase before removing stop words. Each language has a set of stop words. In the following sample code, we use the SMART list of English stop words.

```
clean.letters <- tm_map(clean.letters,removeWords,stopwords("SMART"))
```

Specific word removal

There can also specify particular words to be removed via a character vector. For instance, you might not be interested in tracking references to *Berkshire Hathaway* in Buffett's letters. You can set up a dictionary with words to be removed from the corpus.

```
dictionary <- c("berkshire","hathaway", "million", "billion", "dollar")
clean.letters <- tm_map(clean.letters,removeWords,dictionary)
```

Word length filtering

You can also apply a filter to remove all words less than or greater than a specified lengths. The tm package provides this option when generating a term frequency matrix, something you will read about shortly.

Parts of speech (POS) filtering

Another option is to remove particular types of words. For example, you might scrub all adverbs and adjectives.

Stemming

Stemming reduces inflected or derived words to their stem or root form. For example, *cats* and *catty* stem to *cat*. *Fishlike* and *fishy* stem to *fish*. As a stemmer generally works by suffix stripping, so *catfish* should stem to *cat*. As you would expect, stemmers are available for different languages, and thus the language must be specified. Stemming can take a while to process.

```
stem.letters <- tm_map(clean.letters,stemDocument, language =
"english")
```

Following stemming, you can apply stem completion to return stems to their original form to make the text more readable. The original document that was stemmed, in this case, is used as the dictionary to search for possible completions. Stem completion can apply several different rules for converting a stem to a word, including "prevalent" for the most frequent match, "first" for the first found completion, and "longest" and "shortest" for the longest and shortest, respectively, completion in terms of characters

```
stem.letters <-  tm_map(clean.letters,stemDocument, language = "english")
```

Regex filtering

The power of regex (regular expressions) can also be used for filtering text or searching and replacing text. You might recall that we covered regex when learning SQL.

Word frequency analysis

Word frequency analysis is a simple technique that can also be the foundation for other analyses. The method is based on creating a matrix in one of two forms.

A term-document matrix contains one row for each term and one column for each document.

```
tdm <-  TermDocumentMatrix(stem.letters,control = list(minWordLength=3))
dim(tdm)
```

```
[1] 3993    5
```

```
# report those words occurring more than 100 times
findFreqTerms(tdm, lowfreq = 100, highfreq = Inf)
```

```
 [1] "busi"      "compani"   "cost"      "earn"      "float"     "general"
 [7] "insur"     "invest"    "loss"      "make"      "manag"     "oper"
[13] "report"    "sharehold" "time"      "year"      "—"
```

A document-term matrix contains one row for each document and one column for each term.

```
dtm <- DocumentTermMatrix(stem.letters,control = list(minWordLength=3))
dim(dtm)
```

```
[1]    5 3993
```

The function dtm() reports the number of distinct terms, the vocabulary, and the number of documents in the corpus.

Term frequency

Words that occur frequently within a document are usually a good indicator of the document's content. Term frequency (tf) measures word frequency.

tf_{td} = number of times term t occurs in document d.

Here is the R code for determining the frequency of words in a corpus.

```
library(SnowballC)
tdm <-  TermDocumentMatrix(stem.letters,control = list(minWordLength=3))
# convert term document matrix to a regular matrix to get word frequencies
m <-  as.matrix(tdm)
# sort on frequency of terms
v <- sort(rowSums(m), decreasing=TRUE)
# display the ten most frequent words
v[1:10]
```

```
   year    busi       — compani   manag    earn   insur    oper    cost    loss
    408     366     301     270     204     202     188     172     162     137
```

A probability density plot shows the distribution of words in a document visually. As you can see, there is a very long and thin tail because a very small number of words occur frequently. Note that this plot shows the distribution of words after the removal of stop words.

```
library(ggplot2)
# get the names corresponding to the words
names <- names(v)
# create a data frame for plotting
d <- data.frame(word=names, freq=v)
ggplot(d,aes(freq)) +
  geom_density(fill="salmon") +
  xlab("Frequency") +
  ylab("Density")
```

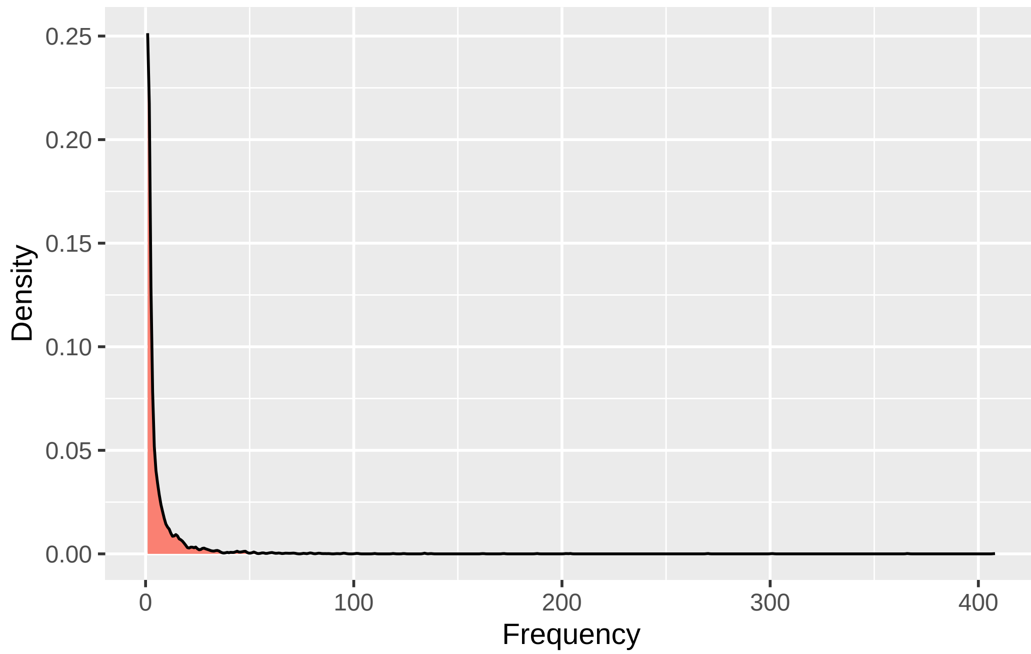

Figure 17.1: Probability density plot of word frequency

A word cloud is way of visualizing the most frequent words.

```
library(wordcloud)
library(RColorBrewer)
# select the color palette
pal = brewer.pal(5,"Accent")
# generate the cloud based on the 30 most frequent words
wordcloud(d$word, d$freq, min.freq=d$freq[30],colors=pal)
```

Figure 17.2: A word cloud

```
Warning in wordcloud(d$word, d$freq, min.freq = d$freq[30], colors = pal):
compani could not be fit on page. It will not be plotted.
```

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Start with the original letters corpus (i.e., prior to preprocessing) and identify the 20 most common words and create a word cloud for these words.

Co-occurrence and association

Co-occurrence measures the frequency with which two words appear together. In the case of document level association, if the two words both appear or neither appears, then the correlation or association is 1. If two words never appear together in the same document, their association is -1.

A simple example illustrates the concept. The following code sets up a corpus of five elementary documents.

```
library(tm)
data <-  c("word1", "word1 word2","word1 word2 word3",
           "word1 word2 word3 word4","word1 word2 word3 word4 word5")
corpus <-  VCorpus(VectorSource(data))
tdm <-  TermDocumentMatrix(corpus)
as.matrix(tdm)
```

```
       Docs
Terms    1 2 3 4 5
```

```
word1 1 1 1 1 1
word2 0 1 1 1 1
word3 0 0 1 1 1
word4 0 0 0 1 1
word5 0 0 0 0 1
```

We compute the correlation of rows to get a measure of association across documents.

```
# Correlation between word2 and word3, word4, and word5
cor(c(0,1,1,1,1),c(0,0,1,1,1))
```

```
[1] 0.6123724
```

```
cor(c(0,1,1,1,1),c(0,0,0,1,1))
```

```
[1] 0.4082483
```

```
cor(c(0,1,1,1,1),c(0,0,0,0,1))
```

```
[1] 0.25
```

Alternatively, use the findAssocs function, which computes all correlations between a given term and all terms in the term-document matrix and reports those higher than the correlation threshold.

```
library(tm)
# find associations greater than 0.1
findAssocs(tdm,"word2",0.1)
```

```
$word2
word3 word4 word5
 0.61  0.41  0.25
```

Now that you have an understanding of how association works across documents, here is an example for the corpus of Buffett letters.

```
# Select the first ten letters
tdm <- TermDocumentMatrix(stem.letters[1:10])
# compute the associations
findAssocs(tdm, "invest",0.90)
```

Cluster analysis

Cluster analysis is a statistical technique for grouping together sets of observations that share common characteristics. Objects assigned to the same group are more similar in some way than those allocated to another cluster. In the case of a corpus, cluster analysis groups documents based on their similarity. Google, for instance, uses clustering for its news site.

The general principle of cluster analysis is to map a set of observations in multidimensional space. For example, if you have seven measures for each observation, each will be mapped into seven-dimensional space. Observations that are close together in this space will be grouped together. In the case of a corpus, cluster analysis is based on mapping frequently occurring words into a multidimensional space. The frequency with which each word appears in a document is used as a weight, so that frequently occurring words have more influence than others.

There are multiple statistical techniques for clustering, and multiple methods for calculating the distance between points. Furthermore, the analyst has to decide how many clusters to create. Thus, cluster analysis requires some judgment and experimentation to develop a meaningful set of groups.

The following code computes all possible clusters using the Ward method of cluster analysis. A term-document matrix is sparse, which means it consists mainly of zeroes. In other words, many terms occur in only one or two documents, and the cell entries for the remaining documents are zero. In order to reduce the computations required, sparse terms are removed from the matrix. You can vary the sparse parameter to see how the clusters vary.

```
# Cluster analysis
# name the columns for the letter's year
tdm <- TermDocumentMatrix(stem.letters[1:num.letters])
upper.bound <- 1998 + num.letters - 1
colnames(tdm) <-  1998:upper.bound
# Remove sparse terms
tdm1 <- removeSparseTerms(tdm, 0.5)
# transpose the matrix
tdmtranspose <-  t(tdm1)
cluster = hclust(dist(tdmtranspose)) # plot the tree
plot(cluster)
```

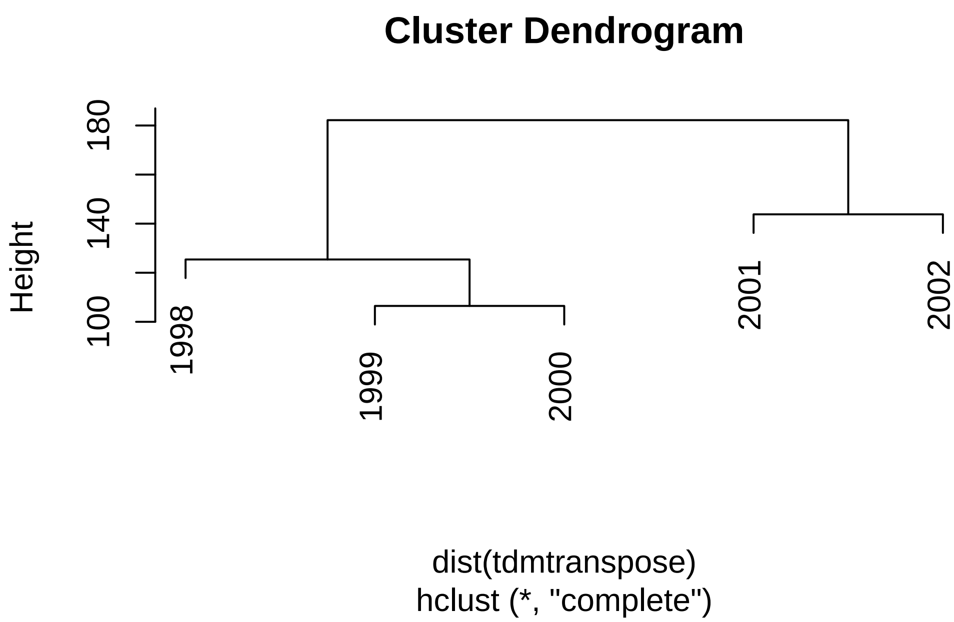

Figure 17.3: Dendrogram for Buffett letters from 1998-2012

The cluster analysis is shown in the following figure as a dendrogram, a tree diagram, with a leaf for each year. Clusters seem to from around consecutive years. Can you think of an explanation?

Topic modeling

Topic modeling is a set of statistical techniques for identifying the themes that occur in a document set. The key assumption is that a document on a particular topic will contain words that identify that topic. For example, a report on gold mining will likely contain words such as "gold" and "ore." Whereas, a document on France, would likely contain the terms "France," "French," and "Paris."

The package topicmodels implements topic modeling techniques within the R framework. It extends tm to provide support for topic modeling. It implements two methods: latent Dirichlet allocation (LDA), which assumes topics are uncorrelated; and correlated topic models (CTM), an extension of LDA that permits correlation between topics.[2] Both LDA and CTM require that the number of topics to be extracted is determined a priori. For example, you might decide in advance that five topics gives a reasonable spread and is sufficiently small for the diversity to be understood.[3]

Words that occur frequently in many documents are not good at distinguishing among documents. The weighted term frequency inverse document frequency (tf-idf) is a measure designed for

[2] The mathematics of LDA and CTM are beyond the scope of this text. For details, see Grün, B., & Hornik, K. (2011). Topicmodels: An R package for fitting topic models. *Journal of Statistical Software*, 40(13), 1-30.

[3] Humans have a capacity to handle about 7±2 concepts at a time. Miller, G. A. (1956). The magical number seven, plus or minus two: some limits on our capacity for processing information. *The Psychological Review*, 63(2), 81-97.

determining which terms discriminate among documents. It is based on the term frequency (tf), defined earlier, and the inverse document frequency.

Inverse document frequency

The inverse document frequency (idf) measures the frequency of a term across documents.

$$idf_t = \log_2 \frac{m}{df_t}$$

Where m = number of documents (i.e., rows in the case of a term-document matrix); df_t = number of documents containing term *t.*

If a term occurs in every document, then its idf = 0, whereas if a term occurs in only one document out of 15, its idf = 3.91.

To calculate and display the idf for the letters corpus, we can use the following R script.

```
# calculate idf for each term
library(slam)
library(ggplot2)
idf <-  log2(nDocs(dtm)/col_sums(dtm > 0))
# create dataframe for graphing
df.idf <-  data.frame(idf)
ggplot(df.idf,aes(idf)) + geom_histogram(fill="chocolate") +
  xlab("Inverse document frequency")
```

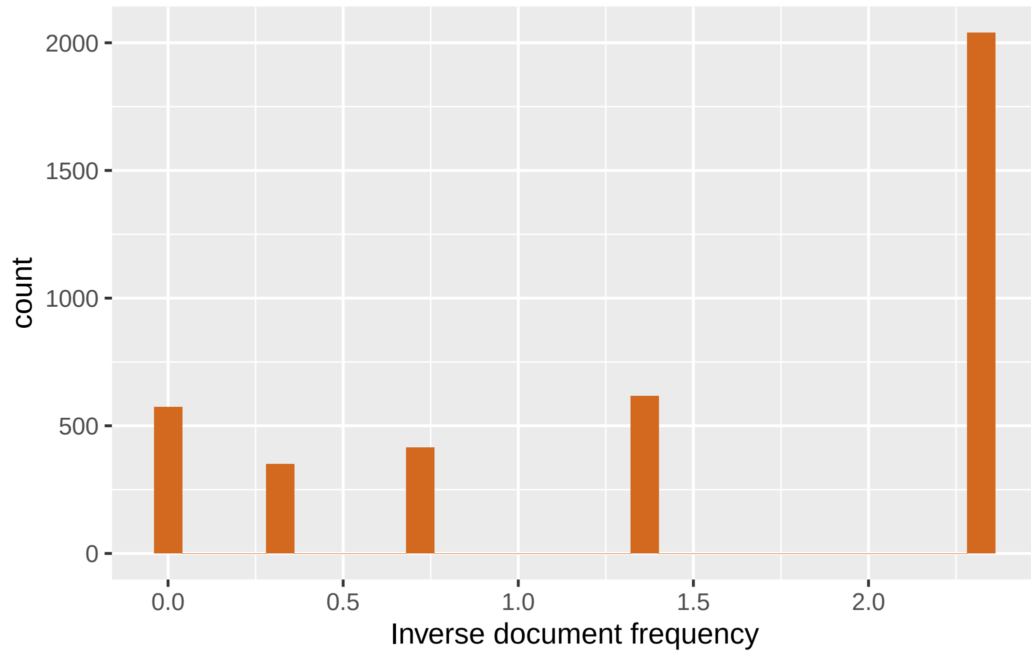

Figure 17.4: Inverse document frequency (corpus has 15 documents)

The generated graphic shows that about 5,000 terms occur in only one document (i.e., the idf = 3.91) and less than 500 terms occur in every document. The terms with an idf in the range 1 to 2 are likely to be the most useful in determining the topic of each document.

Term frequency inverse document frequency (tf-idf)

The weighted term frequency inverse document frequency (tf-idf or $\boxtimes_{td}$) is calculated by multiplying a term's frequency (tf) by its inverse document frequency (idf).

$$\omega_{td} = tf_{td} \bullet \log_2 \frac{m}{df_t}$$

Where tf_{td} = frequency of term *t* in document *d*.

Topic modeling with R

Prior to topic modeling, pre-process a text file in the usual fashion (e.g., convert to lower case, remove punctuation, and so forth). Then, create a document-term matrix.

The mean term frequency-inverse document frequency (tf-idf) is used to select the vocabulary for topic modeling. We use the median value of tf-idf for all terms as a threshold.

```
library(topicmodels)
library(slam)
# calculate tf-idf for each term
tfidf <-  tapply(dtm$v/row_sums(dtm)[dtm$i],
                 dtm$j, mean) * log2(nDocs(dtm)/col_sums(dtm > 0))
# report dimensions (terms)
dim(tfidf)
```

```
[1] 3993
```

```
# report median to use as cut-off point
median(tfidf)
```

```
[1] 0.0003923501
```

The goal of topic modeling is to find those terms that distinguish a document set. Thus, terms with low frequency should be omitted because they don't occur often enough to define a topic. Similarly, those terms occurring in many documents don't differentiate between documents.

A common heuristic is to select those terms with a tf-idf > median(tf-idf). As a result, we reduce the document-term matrix by keeping only those terms above the threshold and eliminating rows that have zero terms. Because the median is a measure of central tendency, this approach reduces the number of columns by roughly half.

```
# select columns with tf-idf > median
dtm <- dtm[,tfidf >= median(tfidf)]
#select rows with rowsum > 0
dtm <- dtm[row_sums(dtm) > 0,]
# report reduced dimension
dim(dtm)
```

```
[1]    5 2260
```

As mentioned earlier, the topic modeling method assumes a set number of topics, and it is the responsibility of the analyst to estimate the correct number of topics to extract. It is common practice to fit models with a varying number of topics, and use the various results to establish a good choice for the number of topics. The analyst will typically review the output of several models and make a judgment on which model appears to provide a realistic set of distinct topics. Here is some code that starts with five topics.

```
# set number of topics to extract
k <- 5 # number of topics
SEED <- 2010 # seed for initializing the model rather than the default random
# try multiple methods - takes a while for a big corpus
TM <- list(VEM = LDA(dtm, k = k, control = list(seed = SEED)),
VEM_fixed = LDA(dtm, k = k, control =
```

```
                  list(estimate.alpha = FALSE, seed = SEED)),
Gibbs = LDA(dtm, k = k, method = "Gibbs",
         control = list(seed = SEED, burnin = 1000,
                        thin = 100, iter = 1000)),
CTM = CTM(dtm, k = k, control = list(seed = SEED,
         var = list(tol = 10^-3), em = list(tol = 10^-3))))
topics(TM[["VEM"]], 1)
```

```
1998 1999 2000 2001 2002
   4    1    1    2    3
```

```
terms(TM[["VEM"]], 5)
```

```
     Topic 1     Topic 2      Topic 3    Topic 4    Topic 5
[1,] "intrins"   "risk"       "deriv"    "eja"      "terror"
[2,] "repurchas" "fruit"      "contract" "count"    "bois"
[3,] "eja"       "finova"     "committe" "quarter"  "larsonjuhl"
[4,] "goodwil"   "bill"       "risk"     "aksarben" "loom"
[5,] "bill"      "bankruptci" "compens"  "swing"    "simplifi"
```

The output indicates that the first three letter (1998-2000) are about topic 4, the fourth (2001) topic 2, and so on.

Topic 1 is defined by the following terms: thats, bnsf, cant, blacksholes, and railroad. As we have seen previously, some of these words (e.g., thats and cant, which we can infer as being that's and can't) are not useful differentiators, and the dictionary could be extended to remove them from consideration and topic modeling repeated. For this particular case, it might be that Buffett's letters don't vary much from year to year, and he returns to the same topics in each annual report.

> ☒ *Skill builder*
>
> Experiment with the topicmodels package to identify the topics in Buffett's > letters. You might need to use the dictionary feature of text mining to remove selected words from the corpus to develop a meaningful distinction between topics.

Named-entity recognition (NER)

Named-entity recognition (NER) places terms in a corpus into predefined categories such as the names of persons, organizations, locations, expressions of times, quantities, monetary values, and percentages. It identifies some or all mentions of these categories, as shown in the following figure, where an organization, place, and date are recognized.

Named-entity recognition example

Tags are added to the corpus to denote the category of the terms identified.

The Olympics were in London in 2012.

There are two approaches to developing an NER capability. A *rules-based* approach works well for a well-understood domain, but it requires maintenance and is language dependent. *Statistical classifiers*, based on machine learning, look at each word in a sentence to decide whether it is the start of a named-entity, a continuation of an already identified named-entity, or not part of a named-entity. Once a named-entity is distinguished, its category (e.g., place) must be identified and surrounding tags inserted.

Statistical classifiers need to be trained on a large collection of human-annotated text that can be used as input to machine learning software. Human-annotation, while time-consuming, does not require a high level of skill. It is the sort of task that is easily parallelized and distributed to a large number of human coders who have a reasonable understanding of the corpus's context (e.g., able to recognize that London is a place and that the Olympics is an organization). The software classifier need to be trained on approximately 30,000 words.

The accuracy of NER is dependent on the corpus used for training and the domain of the documents to be classified. For example, NER is based on a collection of news stories and is unlikely to be very accurate for recognizing entities in medical or scientific literature. Thus, for some domains, you will likely need to annotate a set of sample documents to create a relevant model. Of course, as times change, it might be necessary to add new annotated text to the learning script to accommodate new organizations, place, people and so forth. A well-trained statistical classifier applied appropriately is usually capable of correctly recognizing entities with 90 percent accuracy.

NER software

OpenNLP is an Apache Java-based machine learning based toolkit for the processing of natural language in text format. It is a collection of natural language processing tools, including a sentence detector, tokenizer, parts-of-speech(POS)-tagger, syntactic parser, and named-entity detector. The NER tool can recognize people, locations, organizations, dates, times. percentages, and money. You will need to write a Java program to take advantage of the toolkit. The R package, openNLP, provides an interface to OpenNLP.

Future developments

Text mining and natural language processing are developing areas and you can expect new tools to emerge. Document summarization, relationship extraction, advanced sentiment analysis, and cross-language information retrieval (e.g., a Chinese speaker querying English documents and getting a Chinese translation of the search and selected documents) are all areas of research that will likely result in generally available software with possible R versions. If you work in this area, you will need to continually scan for new software that extends the power of existing methods and adds new text mining capabilities.

Summary

Language enables cooperation through information exchange. Natural language processing (NLP) focuses on developing and implementing software that enables computers to handle large scale processing of language in a variety of forms, such as written and spoken. The inherent ambiguity in written and spoken speech makes NLP challenging. Don't expect NLP to provide the same level of exactness and starkness as numeric processing. There are three levels to consider when processing language: semantics, discourse, and pragmatics.

Sentiment analysis is a popular and simple method of measuring aggregate feeling. Tokenization is the process of breaking a document into chunks. A collection of text is called a corpus. The Flesch-Kincaid formula is a common way of assessing readability. Preprocessing, which prepares a corpus for text mining, can include case conversion, punctuation removal, number removal, stripping extra white spaces, stop word filtering, specific word removal, word length filtering, parts of speech (POS) filtering, Stemming, and regex filtering.

Word frequency analysis is a simple technique that can also be the foundation for other analyses. A term-document matrix contains one row for each term and one column for each document. A document-term matrix contains one row for each document and one column for each term. Words that occur frequently within a document are usually a good indicator of the document's content. A word cloud is way of visualizing the most frequent words. Co-occurrence measures the frequency with which two words appear together. Cluster analysis is a statistical technique for grouping together sets of observations that share common characteristics. Topic modeling is a set of statistical techniques for identifying the topics that occur in a document set. The inverse document frequency (idf) measures the frequency of a term across documents. Named-entity recognition (NER) places terms in a corpus into predefined categories such as the names of persons, organizations, locations, expressions of times, quantities, monetary values, and percentages. Statistical classification is used for NER. OpenNLP is an Apache Java-based machine learning-based toolkit for the processing of natural language in text format. Document summarization, relationship extraction, advanced sentiment analysis, and cross-language information retrieval are all areas of research.

Key terms and concepts

Association	Readability
Cluster analysis	Regex filtering
Co-occurrence	Sentiment analysis
Corpus	Statistical classification
Dendrogram	Stemming

Document-term matrix	Stop word filtering
Flesch-Kincaid formula	Stripping extra white spaces
Inverse document frequency	Term-document matrix
KNIME	Term frequency
Named-entity recognition (NER)	Term frequency inverse document frequency
Natural language processing (NLP)	Text mining
Number removal	Tokenization
OpenNLP	Topic modeling
Parts of speech (POS) filtering	Word cloud
Preprocessing	Word frequency analysis
Punctuation removal	Word length filtering

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Feinerer, I., Hornik, K., & Meyer, D. (2008). Text mining infrastructure in R. *Journal of Statistical Software*, 25(5), 1–54.

Grün, B., & Hornik, K. (2011). topicmodels: An R package for fitting topic models. *Journal of Statistical Software*, 40(13), 1–30.

Ingersoll, G., Morton, T., & Farris, L. (2012). *Taming Text: How to find, organize and manipulate it*. Greenwich, CT: Manning Publications.

Exercises

1. Take the recent annual reports for UPS and convert them to text using an online service, such as.

   Complete the following tasks:

   1. Count the words in the most recent annual report.
   2. Compute the readability of the most recent annual report.
   3. Create a corpus.
   4. Preprocess the corpus.
   5. Create a term-document matrix and compute the frequency of words in the corpus.
   6. Construct a word cloud for the 25 most common words.
   7. Undertake a cluster analysis, identify which reports are similar in nature, and see if you can explain why some reports are in different clusters.
   8. Build a topic model for the annual reports.

2. Merge the annual reports for Berkshire Hathaway (i.e., Buffett's letters) and UPS into a single corpus.
    1. Undertake a cluster analysis and identify which reports are similar in nature.
    2. Build a topic model for the combined annual reports.
    3. Do the cluster analysis and topic model suggest considerable differences in the two sets of reports?

18 Cluster Computing

> *Let us change our traditional attitude to the construction of programs: Instead of imagining that our main task is to instruct a computer what to do, let us concentrate rather on explaining to humans what we want the computer to do*
>
> Donald E. Knuth, *Literate Programming*, 1984

Learning objectives

Students completing this chapter will:

- Understand the paradigm shift in decision-oriented data processing;
- Understand the principles of cluster computing

A paradigm shift

There is much talk of big data, and much of it is not very informative. Rather a lot of big talk but not much smart talk. Big data is not just about greater variety and volumes of data at higher velocity, which is certainly occurring. The more important issue is the paradigm shift in data processing so that large volumes of data can be handled in a timely manner to support decision making. The foundations of this new model is the shift to cluster computing, which means using large numbers of commodity processors for massively parallel computing.

We start by considering what is different between the old and new paradigms for decision data analysis. Note that we are not considering transaction processing, for which the relational model is a sound solution. Rather, we are interested in the processing of very large volumes of data at a time, and the relational model was not designed for this purpose. It is suited for handling transactions, which typically involve only a few records. The multidimensional database (MDDB) is the “old” approach for large datasets and cluster compute is the “new.”

Another difference is the way data are handled. The old approach is to store data on a high speed disk drive and load it into computer memory for processing. To speed up processing, the data might be moved to multiple computers to enable parallel processing and the results merged into a single file. Because data files are typically much larger than programs, moving data from disks to computers is time consuming. Also, high performance disk storage devices are expensive. The new method is to spread a large data file across multiple commodity computers, possibly using *Hadoop Distributed File System* (HDFS), and then send each computer a copy of the program to run in parallel. The results from the individual jobs are then merged. While data still need to be moved to be processed, they are moved across a high speed data channel within a computer rather than the lower speed cables of a storage network.

Old	New
Data to the program	Program to the data
Mutable data	Immutable data
Special purpose hardware	Commodity hardware

The drivers

Exploring the drivers promoting the paradigm shift is a good starting point for understanding this important change in data management. First, you will recall that you learned in Chapter 1 that decision making is the central organizational activity. Furthermore, because data-driven decision making increases organizational performance, many executives are now demanding data analytics to support their decision making.

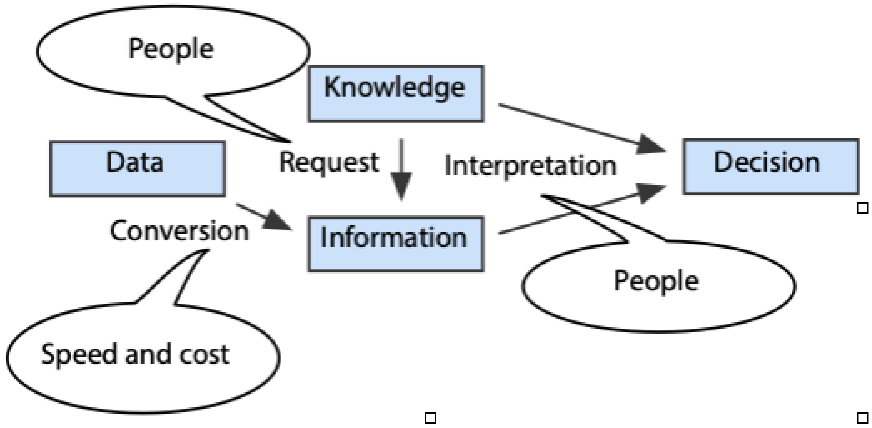
Second, as we also explained in Chapter 1, there is a societal shift in dominant logic as we collectively recognize that we need to focus on reducing environmental degradation and carbon emissions. Service and sustainability dominant logics are both data intensive. Customer service decisions are increasingly based on the analysis of large volumes of operational and social data. Sustainability oriented decisions also require large volumes of operational data, which are combined with environmental data collected by massive sensor networks to support decision making that reduces an organization's environmental impact.

Third, the world is in the midst of a massive data generating digital transformation. Large volumes of data are collected about the operation on an aircraft's jet engines, how gamers play massively online games, how people interact in social media space, and the operation of cell phone networks, for example. The digital transformation of life and work is creating a bits and bytes tsunami.

The bottleneck and its solution

In a highly connected and competitive world, speedy high quality decisions can be a competitive advantage. However, large data sets can take some time and expense to process, and so as more data are collected, there is a the danger that decision making will gradually slow down and its quality lowered. Data analytics becomes a bottleneck when the conversion of data to information is too slow. Second, decision quality is lowered when there is a dearth of skills for determining what data should be converted to information and interpreting the resulting conversion. We capture these problems in the elaboration of a diagram that was introduced in Chapter 1, which now illustrates the causes of the conversion, request, and interpretation bottlenecks.

Data analytics bottleneck



The people skills problem is being addressed by the many universities that have added graduate courses in data analytics. The Lambda Architecture[1] is a proposed general solution to the speed and cost problem.

Lambda Architecture

We will now consider the three layers of the Lambda Architecture: batch, speed, and serving.

The batch layer

Batch computing describes the situation where a computer works on one or more large tasks with minimal interruption. Because early computers were highly expensive and businesses operated at a different tempo, batch computing was common in the early days of information systems. The efficiency gains of batch computing mainly come from uninterrupted sequential file processing. The computer spends less time waiting for data to be retrieved from disks, particularly with Hadoop where files are stored in 64Mb chunks. Batch computing is very efficient, though not timely, and the Lambda Architecture takes advantage of this efficiency.

The batch layer is used to precompute queries by running them with the most recent version of a dataset. The precomputed results are saved and can then be used as required. For example, a supermarket chain might want to know how often each pair of products appears in each shopper's basket for each day for each store. These data might help it to set cross-promotional activities within a store (e.g., a joint special on steak and mashed potatoes). The batch program could precompute the count of joint sales for each pair of items for each day for each store in a given date range. This highly summarized data could then be used for queries about customers' baskets (e.g., how many customers purchased both shrimp and grits in the last week in all Georgia stores?). The batch layer works with a dataset essentially consisting of every supermarket receipt because this is the record of a customer's basket. This dataset is also stored by the batch layer. HDFS is well-suited for handling the batch layer, as you will see later, but it is not the only option.

[1] Marz, N., & Warren, J. (2012). *Big Data*: Manning Publications.

New data are appended to the master dataset to preserve is immutability, so that it remains a complete record of transactions for a particular domain (e.g., all receipts). These incremental data are processed the next time the batch process is restarted.

The batch layer can be processing several batches simultaneously. It typically keeps recomputing batch views using the latest dataset every few hours or maybe overnight.

The serving layer

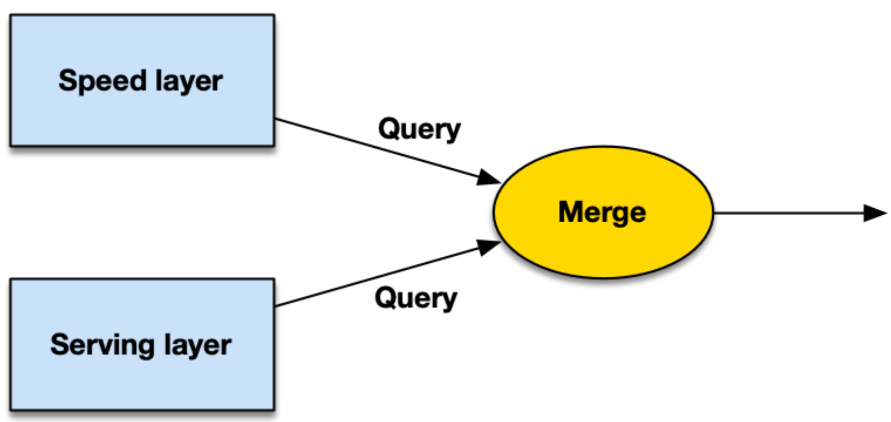
The serving layer processes views computed by the batch layer so they can be queried. Because the batch layer produces a flat file, the serving layer indexes it for random access. The serving layer also replaces the old batch output with the latest indexed batch view when it is received from the batch layer. In a typical Lambda Architecture system, there might be several or more hours between batch updates.

The combination of the batch and serving layers provides for efficient reporting, but it means that any queries on the files generated by the batch layer might be several or more hours old. We have efficiency but not timeliness, for which we need the speed layer.

Speed layer

Once a batch recompute has started running, all newly collected data cannot be part of the resulting batch report. The purpose of the speed layer is to process incremental data as they arrive so they can be merged with the latest batch data report to give current results. Because the speed layer modifies the results as each chunk of data (e.g., a transaction) is received, the merge of the batch and speed layer computations can be used to create real-time reports.

Merging speed and serving layer results to create a report (source: (Marz and Warren 2012))



Putting the layers together

We now examine the process in detail.

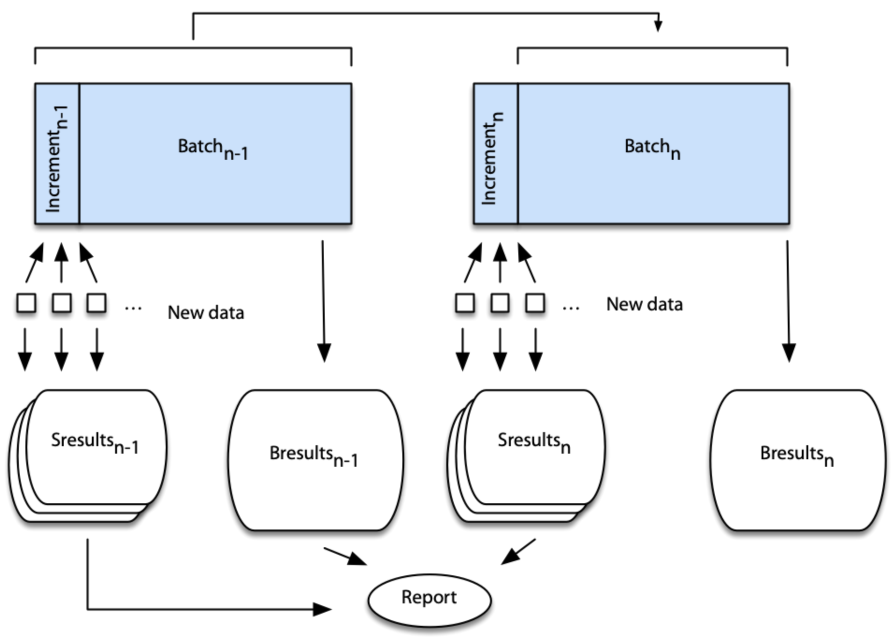
Assume $batch_{n-1}$ has just been processed.

1. During the processing of $batch_{n-1}$, $increment_{n-1}$ was created from the records received. The combination of these two data sets creates $batch_n$.
2. As the data for $increment_{n-1}$ were received, speed layer ($Sresults_{n-1}$) were dynamically re-computed.
3. A current report can be created by combining speed layer and batch layer results (i.e., $Sresults_{n-1}$ and $Bresults_{n-1}$).

Now, assume batch computation resumes with $batch_n$.

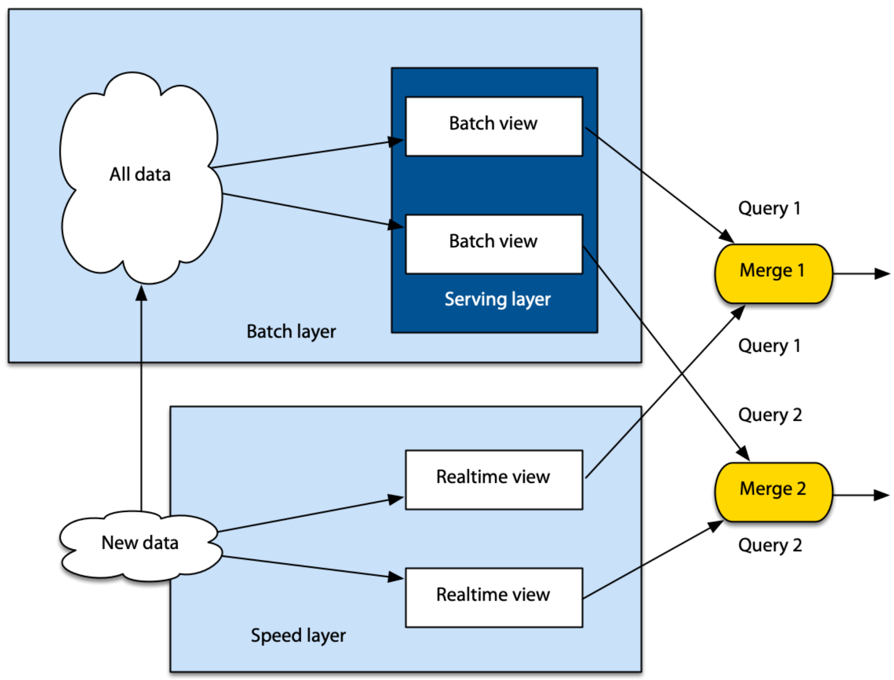
1. $Sresults_n$ are computed from the data collected ($increment_n$) while $batch_n$ is being processing.
2. Current reports are based on $Bresults_{n-1}$, $Sresults_{n-1}$, and $Sresults_n$.
3. At the end of processing $batch_n$, $Sresults_{n-1}$ can be discarded because $Bresults_n$ includes all the data from $batch_{n-1}$ and $increment_{n-1}$.

The preparation of a real-time report using batch and speed layer results when processing $batch_n$



In summary, the batch layer pre-computes reports using all the currently available data. The serving layer indexes the results of the batch layers and creates views that are the foundation for rapid responses to queries. The speed layer does incremental updates as data are received. Queries are handled by merging data from the serving and speed layers.

Lambda Architecture (source: (Marz and Warren 2012))



Benefits of the Lambda Architecture

The Lambda Architecture provides some important advantages for processing large datasets, and these are now considered.

Robust and fault-tolerant

Programming for batch processing is relatively simple and also it can easily be restarted if there is a problem. Replication of the batch layer dataset across computers increases fault tolerance. If a block is unreadable, the batch processor can shift to the identical block on another node in the cluster. Also, the redundancy intrinsic to a distributed file system and distributed processors provides fault-tolerance.

The speed layer is the complex component of the Lambda Architecture. Because complexity is isolated to this layer, it does not impact other layers. In addition, since the speed layer produced temporary results, these can be discarded in the event of an error. Eventually the system will right itself when the batch layer produces a new set of results, though intermediate reports might be a little out of date.

Low latency reads and updates

The speed layer overcomes the long delays associated with batch processing. Real-time reporting is possible through the combination of batch and speed layer outputs.

Scalable

Scalability is achieved using a distributed file system and distributed processors. To scale, new computers with associated disk storage are added.

Support a wide variety of applications

The general architecture can support reporting for a wide variety of situations.

Extensible

New data types can be added to the master dataset or new master datasets created. Furthermore, new computations can be added to the batch and speed layers to create new views.

Ad hoc queries

On the fly queries can be run on the output of the batch layer provided the required data are available in a view.

Minimal maintenance

The batch and serving layers are relatively simple programs because they don't deal with random updates or writes. Simpler code requires less maintenance.

Debuggable

Batch programs are easier to debug because you can have a clear link between the input and output. Data immutability means that debugging is easier because no records have been overwritten during batch processing.

Relational and Lambda Architectures

Relational technology supports both transaction processing and data analytics. As a result, it needs to be more complex than the Lambda Architecture. Separating out data analytics from transaction processing simplifies the supporting technology and makes it suitable for handling large volumes of data efficiently. Relational systems can continue to support transaction processing and, as a byproduct, produce data that are fed to Lambda Architecture based business analytics.

Hadoop

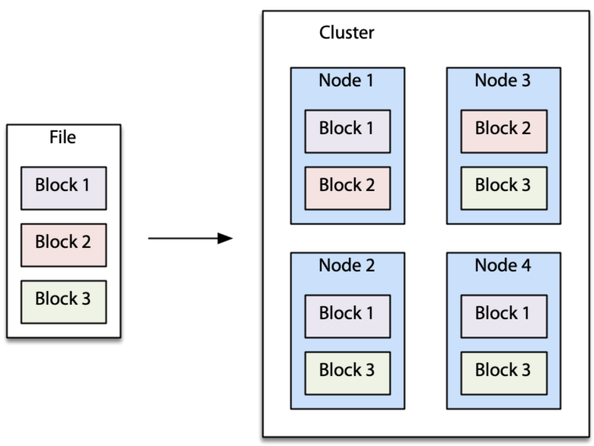
Hadoop, an Apache project, supports distributed processing of large data sets across a cluster of computers. A Hadoop cluster consists of many standard processors, nodes, with associated main memory and disks. They are connected by Ethernet or switches so they can pass data from node to node. Hadoop is highly scalable and reliable. It is a suitable technology for the batch layer of the Lambda architecture. Hadoop is a foundation for data analytics, machine learning, search ranking, email anti-spam, ad optimization, and other areas of applications which are constantly emerging.

A market analysis projects that the Hadoop market is growing at 48% per year.[2] An early study[3] asserts that, "Hadoop is the only cost-sensible and scalable open source alternative to commercially available Big Data management packages. It also becomes an integral part of almost any commercially available Big Data solution and de-facto industry standard for business intelligence (BI)."

Hadoop distributed file system (HDFS)

HDFS is a highly scalable, fault-toleration, distributed file system. When a file is uploaded to HDFS, it is split into fixed sized blocks of at least 64MB. Blocks are replicated across nodes to support parallel processing and provide fault tolerance. As the following diagram illustrates, an original file when written to HDFS is broken into multiple large blocks that are spread across multiple nodes. HDFS provides a set of functions for converting a file to and from HDFS format and handling HDFS.

Splitting of file across a HDFS cluster.



On each node, blocks are stored sequentially to minimize disk head movement. Blocks are grouped into files, and all files for a dataset are grouped into a single folder. As part of the simplification to support batch processing, there is no random access to records and new data are added as a new file.

[2] Hadoop Market - Forecast(2022 - 2027

[3] (Hadoop Market Forecast 2017-2022

Scalability is facilitated by the addition of new nodes, which means adding a few more pieces of inexpensive commodity hardware to the cluster. Appending new data as files on the cluster also supports scalability.

HDFS also supports partitioning of data into folders for processing at the folder level. For example, you might want all employment related data in a single folder.

Spark

Spark is an Apache project for cluster computing that was initiated at the University of California Berkeley and later transferred to Apache as an open source project. Spark's distributed file system, *resilient distributed dataset* (RDD), has similar characteristics to HDFS. Spark can also interface with HDFS and other distributed file systems. For testing and development, Spark has a local mode, that can work with a local file system.

Spark includes several component, including Spark SQL for SQL-type queries, Spark streaming for real-time analysis of event data as it is received, and a machine learning (ML) library. This library is designed for in-memory processing and is approximately 10 times faster than disk-based equivalent approaches. Distributed graph processing is implemented using GraphX.

Computation with Spark

Spark applications can be written in Java, Scala, Python, and R. In our case, we will use sparklyr, an R interface to Spark. This package provides a simple, easy to use set of commands for exposing the distributed processing power of Spark to those familiar with R. In particular, it supports dplyr for data manipulation of Spark datasets and access to Sparks ML library.

Before starting with sparklyr, you need to check that you have latest version of Java on your machine. Use RStudio to install sparklyr. For developing and testing on your computer, install a local version of Spark.

```
library(sparklyr)
spark_install(version='2.4')
```

Use the `spark_connect` function to connect to Spark either locally or on a remote Spark cluster. The following code shows how to specify local Spark connection (sc).

```
library(sparklyr)
sc <- spark_connect(master = "local")
```

Tabulation

In this example, we have a list of average monthly temperatures for New York's Central Park and we want to determine how often each particular temperature occurred.

Average monthly temperatures since 1869 are read, and temperature is rounded to an integer for the convenience of tabulation.

```
library(dplyr)
library(readr)
url <-  "http://www.richardtwatson.com/data/centralparktemps.txt"
t <- read_delim(url, delim=',')
# tabulate frequencies for temperature
t %>%
  mutate(Fahrenheit = round(temperature,0)) %>%
  group_by(Fahrenheit) %>%
  summarize(Frequency = n())
```

Spark example

By using dplyr in the prior R code, we can copy and paste and add a few commands for the Spark implementation. The major differences are the creation of a Spark connection (sc) and copying the R tibble to Spark with copy-to. Also, note that you need to sort the resulting tibble, which is not required in regular R.

```
library(dplyr)
library(readr)
spark_install(version='2.4')
sc <- spark_connect(master = "local",
                    spark_home=spark_home_dir(version = '2.4'))
url <-  "http://www.richardtwatson.com/data/centralparktemps.txt"
t <- read_delim(url, delim=',')
t_tbl <- copy_to(sc,t)
t_tbl %>%
  mutate(Fahrenheit = round(temperature,0)) %>%
  group_by(Fahrenheit) %>%
  summarize(Frequency = n()) %>%
  arrange(Fahrenheit)
```

It you observe the two sets of output carefully, you will note that the results are not identical. It is because rounding can vary across systems. The IEEE Standard for Floating-Point Arithmetic IEEE 754 states on rounding, "if the number falls midway it is rounded to the nearest value with an even (zero) least significant bit." Compare the results for round(12.5,0) and round(13.5,0). R follows the IEEE standard, but Spark apparently does not.

> ☒ *Skill builder*
>
> Aedo the tabulation example with temperatures in Celsius.

Basic statistics with Spark

We now take the same temperature dataset and calculate mean, min, and max monthly average temperatures for each year and put the results in a single file.

Spark example

```
library(dplyr)
library(readr)
url <-  "http://www.richardtwatson.com/data/centralparktemps.txt"
t <- read_delim(url, delim=',')
# report minimum, mean, and maximum by year
t %>%
  group_by(year) %>%
  summarize(Min=min(temperature),
            Mean = round(mean(temperature),1),
            Max = max(temperature))
```

Spark example

Again, the use of dplyr makes the conversion to Spark simple.

```
library(sparklyr)
library(tidyverse)
spark_install(version='2.4')
sc <- spark_connect(master = "local",
                    spark_home=spark_home_dir(version = '2.4'))
url <-  "http://www.richardtwatson.com/data/centralparktemps.txt"
t <- read_delim(url, delim=',')
t_tbl <- copy_to(sc,t)
# report minimum, mean, and maximum by year
# Sparkly warning if you do not specify how to handle missing values
t_tbl %>%
  group_by(year) %>%
  summarize(Min=min(temperature, na.rm = T),
            Mean = round(mean(temperature, na.rm = T),1),
            Max = max(temperature, na.rm = T)) %>%
  arrange(year)
```

☒ Skill builder

A [file][http://people.terry.uga.edu/rwatson/data/electricityprices2010_14.csv of electricity costs for a major city contains a timestamp and cost separated by a comma. Compute the minimum, mean, and maximum costs.

Summary

Big data is a paradigm shift to new file structures, such as HDFS and RDD, and algorithms for the parallel processing of large volumes of data. The new file structure approach is to spread a large data file across multiple commodity computers and then send each computer a copy of the program to run in parallel. The drivers of the transformation are the need for high quality data-driven decisions, a societal shift in dominant logic, and a digital transformation. The speed and cost of converting data to information is a critical bottleneck as is a dearth of skills for determining what data should be converted to information and interpreting the resulting conversion. The people skills problem is being addressed by universities' graduate courses in data analytics. The Lambda Architecture, a solution for handling the speed and cost problem, consists of three layers: speed, serving, and batch. The batch layer is used to precompute queries by running them with the most recent version of the dataset. The serving layer processes views computed by the batch layer so they can be queried. The purpose of the speed layer is to process incremental data as they arrive so they can be merged with the latest batch data report to give current results. The Lambda Architecture provides some important advantages for processing large datasets. Relational systems can continue to support transaction processing and, as a byproduct, produce data that are fed to Lambda Architecture based business analytics.

Hadoop supports distributed processing of large data sets across a cluster of computers. A Hadoop cluster consists of many standard processors, nodes, with associated main memory and disks. HDFS is a highly scalable, fault-toleration, distributed file system. Spark is a distributed computing method for scalable and fault-tolerant cluster computation.

Key terms and concepts

Batch layer	Lambda Architecture
Bottleneck	Parallelism
Cluster computing	Serving layer
Hadoop	Spark
HDFS	Speed layer
Immutable data	

References and additional readings

Lam, C. (2010). *Hadoop in action*: Manning Publications.

Marz, N., & Warren, J. (2012). *Big Data*: Manning Publications.

Exercises

1. Write Spark code for the following situations.

a. Compute the square and cube of the numbers in the range 1 to 25. Display the results in a data frame.

b. Using the average monthly temperatures for New York's Central Park, compute the maximum, mean, and average temperature in Celsius for each month.

c. Using the average monthly temperatures for New York's Central Park, compute the max, mean, and min for August. You will need to use subsetting, as discussed in this chapter.

d. Using the electricity price data, compute the average hourly cost.

e. Read the national GDP file, which records GDP in millions, and count how many countries have a GDP greater than or less than 10,000 million.

19 Dashboards

I think, aesthetically, car design is so interesting - the dashboards, the steering wheels, and the beauty of the mechanics. I don't know how any of it works, I don't want to know, but it's inspirational.

Paloma Picasso, designer, 2013.[1]

Learning objectives

Students completing this chapter will:

- Understand the purpose of dashboards;
- Be able to use the R package shinydashboard to create a dashboard.

The value of dashboards

A dashboard is a web page or mobile app screen designed to present important information, primarily visual format, that can be quickly and easily comprehended. Dashboards are often used to show the current status, such as the weather app you have on your smart phone. Sometimes, a dashboard can also show historical data as a means of trying to identify long term trends. Key economic indicators for the last decade or so might be shown graphically to help strategic planners identify major shifts in economic activity. In a world overflowing with data, dashboards are an information system for summarizing and presenting key data. They can be very useful for maintaining situation awareness, by providing information about key environmental measures of the current situation and possible future developments.

A dashboard typically has a header, sidebar and body

Header

There is a header across the top of a page indicating the purpose of the dashboard, and additional facts about the content, such as the creator. A search engine is a common element of a header. A header can also contain tabs to various sources of information or reports (e.g., social media or Fortune 1000 companies).

[1] AZ Quotes

Sidebar

A sidebar usually contains features that enable the body of the report to be customized to the viewer's needs. There might be filters to fine-tune what is displayed. Alternatively, there can be links to select information on a particular topic. In the following example, the sidebar contains some high level summary data, such as the number of documents in a category.

Body

The body of a dashboard contains the information selected via a sidebar. It can contained multiple panes, as shown in the following example, that display information in a variety of ways. The body of the following dashboard contains four types of visuals (a multiple time series graph, a donut style pie chart, a map, and a relationship network). It also shows a list of documents satisfying the specified criteria and a word cloud of these documents.

I encourage you to visit the ecoresearch.net dashboard. It is an exemplar and will give you some idea of the diversity of ways in which information can be presented and the power of a dashboard to inform.

A dashboard

Designing a dashboard

The purpose of a dashboard is to communicate, so the first step is to work with the client to determine the key performance indicators (KPIs), visuals, or text that should be on the dashboard. Your client will have some ideas as to what is required, and by asking good questions and prototyping, you can clarify needs.

You will need to establish that high quality data sources are available for conversion into the required information. If data are not available, you will have to work with other IS professionals to establish them, or you might conclude that it is infeasible to try to meet some requirements. You should keep the client informed as you work through the process of resolving data source issues. Importantly, you should make the client aware of any data quality problems. Sometimes your client might have to settle for less than desirable data quality in order to get some idea of directional swings.

Try several ways of visualizing data to learn what suits the client. The ggplot2 package works well with shinydashboard, the dashboard package we will learn. Also, other R packages, such as dygraphs, can be deployed for graphing time series, a frequent dashboard element for showing trends and turning points. Where possible, use interactivity to enable the client to customize as required (e.g., let the client select the period of a time series).

Design for ease of navigation and information retrieval. Simplicity should generally be preferred to complexity. Try to get chunks of information that should be viewed at the same time on the same page, and put other collections of cohesive information on separate tabs.

Use colors consistently and in accord with general practice. For example, red is the standard color for danger, so a red information box should contain only data that indicate a key problem (e.g., a machine not working or a major drop in a KPI). Consistency in color usage can support rapid scanning of a dashboard to identify the attention demanding situations.

Study dashboards that are considered as exhibiting leading business practices or are acknowledged as exemplars. Adopt or imitate the features that work well.

Build a prototype as soon as you have a reasonable idea of what you think is required and release it to your client. This will enable the client to learn what is possible and for you to get a deeper understanding of the needs. Learn from the response to the prototype, redesign, and release version 2. Continue this process for a couple of iterations until the dashboard is accepted.

Dashboards with R

R requires two packages, shiny and shinydashboard to create a dashboard. Also, you must use RStudio to run your R script. Shiny is a R package for building interactive web applications in R. It was contributed to the R project by RStudio. It does not require knowledge of traditional web development tools such as HTML, CSS, or JavaScript. Shinydashboard uses Shiny to create dashboards, but you you don't need to learn Shiny. Examining some examples of dashboards built with shinydashboard will give you an idea of what is feasible.

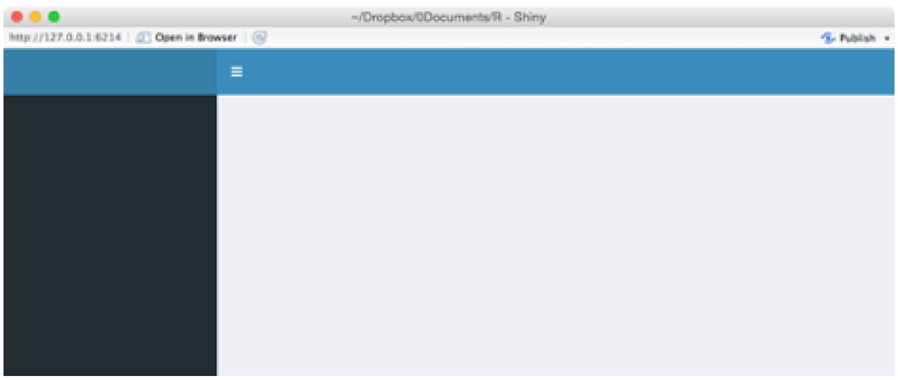
The basics

In keeping with the style of this book, we will start by creating a minimalist dashboard without any content. There are three elements: header, sidebar, and body. It this case, they are all null. Together, these three elements create the UI (user interface) of a dashboard page. The dynamic side of the page, the server, is also null. A dashboard is a Shiny app, and the final line of code runs the application.

A UI script defines the layout and appearance of dashboard's web page. The server script contains commands to run the dashboard app and to make a page dynamic.

```
library(shiny)
library(shinydashboard)
header <- dashboardHeader()
sidebar <- dashboardSidebar()
body <- dashboardBody()
ui <- dashboardPage(header,sidebar,body)
server <- function(input, output) {}
shinyApp(ui, server)
```

When you select all the code and run it, a new browser window will open and display a blank dashboard.



When you inspect some shinydashboard code, you will sometimes see a different format in which commands are deeply embedded in other commands. The following code illustrates this approach. I suggest you avoid it because it is harder to debug such code, especially when you are a novice.

```
library(shiny)
library(shinydashboard)
ui <- dashboardPage(
  dashboardHeader(),
  dashboardSidebar(),
  dashboardBody()
)
server <- function(input, output) {}
shinyApp(ui, server)
```

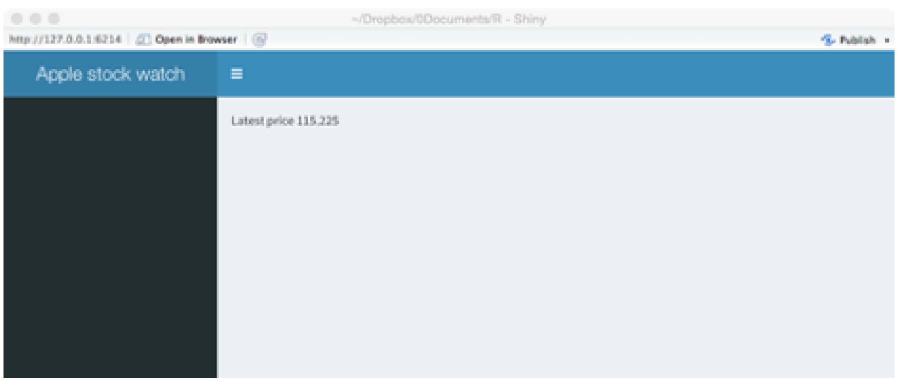
Terminating a dashboard

A dashboard is meant to be a dynamic web page that is updated when refreshed or when some element of the page is clicked on. It remains active until terminated. This means that when you want to test a new version of a dashboard or run another one, you must first stop the current one. You will need to click the stop icon on the console's top left to terminate a dashboard and close its web page.

A header and a body

We now add some content to a basic dashboard by giving it a header and a body. This page reports the share price of Apple, which has the stock exchange symbol of AAPL. The getQuote function[2] of the quantmod package returns the latest price, with about a two hour delay, every time the page is opened or refreshed. Notice the use of paste to concatenate a title and value.

```
library(shiny)
library(shinydashboard)
library(quantmod)
header <- dashboardHeader(title = 'Apple stock watch')
sidebar <- dashboardSidebar()
body <- dashboardBody(paste('Latest price ',getQuote('AAPL')$Last))
ui <- dashboardPage(header,sidebar,body)
server <- function(input, output) {}
shinyApp(ui, server)
```

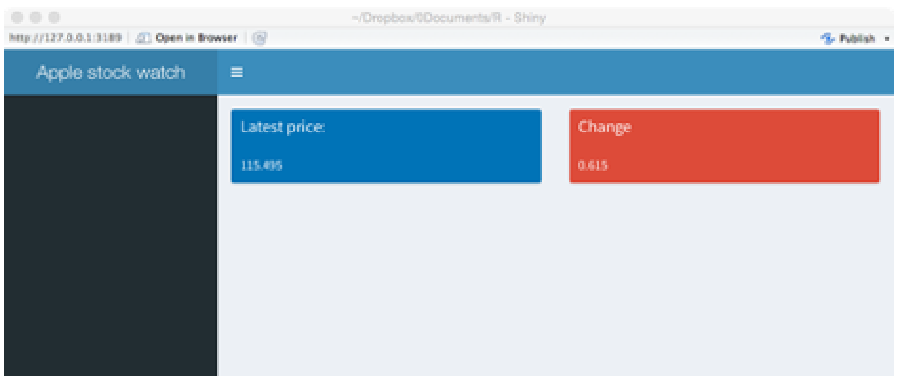


Boxes and rows

Boxes are the building blocks of a dashboard, and they can be assembled into rows or columns. The fluidRow function is used to place boxes into rows and columns. The following code illustrates the use of fluidRow.

[2] getQuote returns a dataframe, containing eight values: Trade Time, Last, Change, %Change, Open, High, Low, Volume. For example, getQuote('AAPL')$%Change returns the percentage change in price since the daily opening price.

```
library(shiny)
library(shinydashboard)
library(quantmod)
header <- dashboardHeader(title = 'Apple stock watch')
sidebar <- dashboardSidebar()
boxLatest <- box(title = 'Latest price: ',
      getQuote('AAPL')$Last, background = 'blue' )
boxChange <-  box(title = 'Change ',
      getQuote('AAPL')$Change, background = 'red' )
row <- fluidRow(boxLatest,boxChange)
body <- dashboardBody(row)
ui <- dashboardPage(header,sidebar,body)
server <- function(input, output) {}
shinyApp(ui, server)
```



☒ *Skill builder*

Add three more boxes (e.g., high price) to the dashboard just created.

Multicolumn layout

Shinydashboard is based on dividing up the breadth of a web page into 12 units, assuming it is wide enough. Thus, a box with width = 6 will take up half a page. The tops of the boxes in each row will be aligned, but the bottoms may not be because of the volume of data they contain. The fluidRows function ensures that a row's elements appear on the same line, if the browser has adequate width.

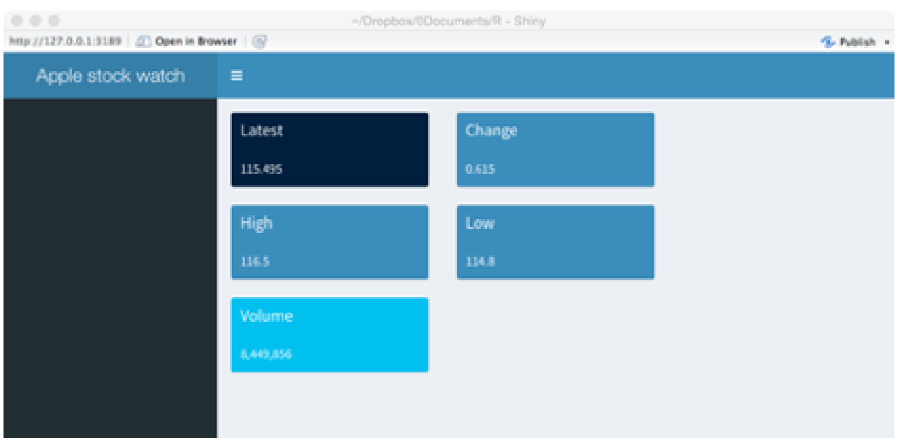
You can also specify that boxes are placed in columns. The column function defines how much horizontal space, within the 12-unit width grid, each element should occupy.

In the following code, note how:

- a background for a box is defined (e.g., background='navy');
- five boxes are organized into two columns (rows <- fluidRow(col1,col2));

- volume of shares traded is formatted with commas (formatC(getQuote(‘AAPL’)$Volume,big.mark=‘,’).

```
library(shiny)
library(shinydashboard)
library(quantmod)
header <- dashboardHeader(title = 'Apple stock watch')
sidebar <- dashboardSidebar()
boxLast <-  box(title = 'Latest', width=NULL,
                getQuote('AAPL')$Last, background='navy')
boxHigh <-  box(title = 'High', width=NULL,
                getQuote('AAPL')$High , background='light-blue')
boxVolume <- box(title = 'Volume', width=NULL,
                 formatC(getQuote('AAPL')$Volume,big.mark=','),
                 background='aqua')
boxChange <-  box(title = 'Change', width=NULL,
                  getQuote('AAPL')$Change, background='light-blue')
boxLow <-  box(title = 'Low', width=NULL,
               getQuote('AAPL')$Low, background='light-blue')
col1 <-  column(width = 4,boxLast,boxHigh,boxVolume)
col2 <-  column(width = 4,boxChange,boxLow)
rows <- fluidRow(col1,col2)
body <- dashboardBody(rows)
ui <- dashboardPage(header,sidebar,body)
server <- function(input, output) {}
shinyApp(ui, server)
```



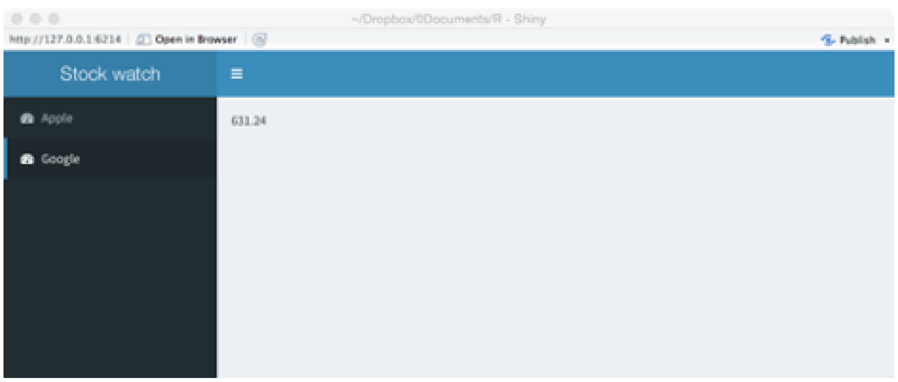
Sidebar

A sidebar is typically used to enable quick navigation of a dashboard’s features. It can contain layers of menus, and by clicking on a menu link or icon, the dashboard can display different content in the body area.

A library of icons is available Font-Awesome and Glyphicons for use in the creation of a dashboard.

```
library(shiny)
library(shinydashboard)
library(quantmod)
header <-  dashboardHeader(title = 'Stock watch')
menuApple <-  menuItem("Apple", tabName = "Apple",
                       icon = icon("dashboard"))
menuGoogle <- menuItem("Google", tabName = "Google",
                       icon = icon("dashboard"))
sidebar <-  dashboardSidebar(sidebarMenu(menuApple, menuGoogle))
tabApple <-  tabItem(tabName = "Apple", getQuote('AAPL')$Last)
tabGoogle <-  tabItem(tabName = "Google", getQuote('GOOG')$Last)
tabs <-  tabItems(tabApple,tabGoogle)
body <-  dashboardBody(tabs)
ui <- dashboardPage(header, sidebar, body)
server <- function(input, output) {}
shinyApp(ui, server)
```

For the following dashboard, by clicking on Apple, you get its latest share price, and similarly for Google.



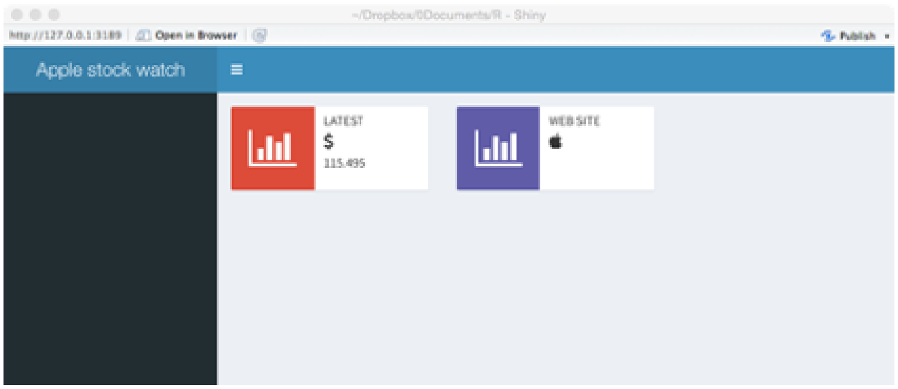
Infobox

An infobox is often used to display a single measure, such as a KPI.

```
library(shiny)
library(shinydashboard)
library(quantmod)
header <- dashboardHeader(title = 'Apple stock watch')
sidebar <- dashboardSidebar()
infoLatest <- infoBox(title = 'Latest', icon('dollar'),
                getQuote('AAPL')$Last, color='red')
```

```
infoChange <- infoBox(title = 'Web site',
                icon('apple'),href='http://investor.apple.com',
                color='purple')
row <- fluidRow(width=4,infoLatest,infoChange)
body <- dashboardBody(row)
ui <- dashboardPage(header,sidebar,body)
server <- function(input, output) {}
shinyApp(ui, server))
```

The following dashboard shows the latest price for Apple's shares. By clicking on the purple infobox, you access Apple investors' web site.



Dynamic dashboards

Dashboards are more useful when they give managers access to determine what is presented. The server function supports dynamic dashboards and executes when a dashboard is opened or refreshed.

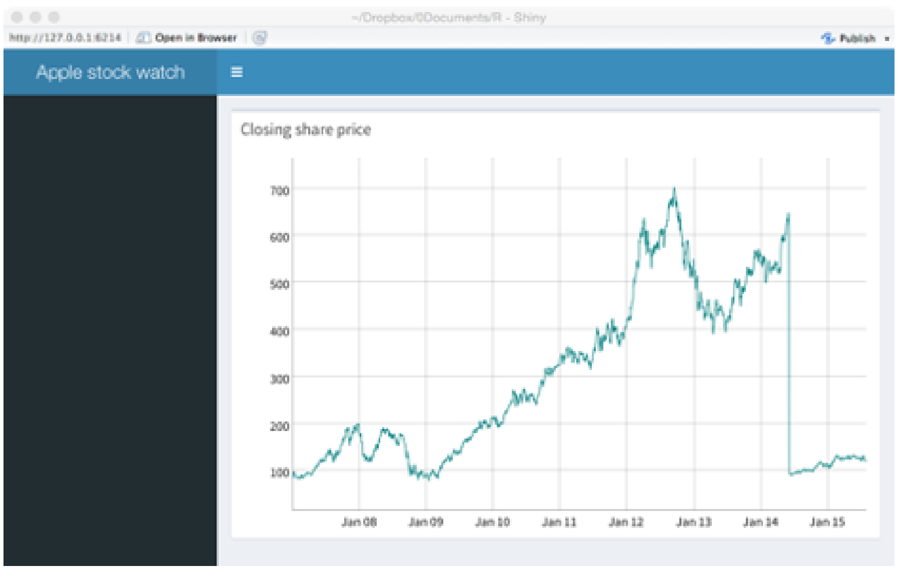
The following basic dashboard illustrates how a server function is specified and how it communicates with the user interface. Using the time series graphing package, dygraphs, it creates a dashboard showing the closing price for Apple. Key points to note:

- The ui function indicates that it wants to create a graph with the code `dygraphOutput('apple')`.
- To produce the graph, the server executes `output$apple <-renderDygraph({dygraph(Cl(get(getSymbols('AAPL'))))})`.
- The linkage between the UI and the server functions is through the highlighted code, as shown in the preceding two bullets and the following code block.
- The text parameter of `dynagraphOutput()` in the UI function must match the text following `output$` in the server function.
- The data to be graphed are retrieved with the Cl function of the quantmod package.[3]

[3] The quantmod function getSymbols('X') returns an time series object named X. The get function retrieves the name of the object and passes it to the Cl function and then the time series is graphed by dygraph. The code is a bit complicated, but necessary to generalize it for use with an interactive dashboard.

```
library(shiny)
library(shinydashboard)
library(quantmod)
library(dygraphs) # graphic package for time series
header <-  dashboardHeader(title = 'Apple stock watch')
sidebar <- dashboardSidebar(NULL)
boxPrice <- box(title='Closing share price',
                width = 12, height = NULL, dygraphOutput('apple'))
body <-   dashboardBody(fluidRow(boxPrice))
ui <- dashboardPage(header, sidebar, body)
server <- function(input, output) {
# quantmod retrieves closing price as a time series
output$apple <- renderDygraph({dygraph(Cl(get(getSymbols('AAPL'))))})
}
shinyApp(ui, server)
```

When you create the dashboard, mouse over the points on the graph and observe the data that are reported.

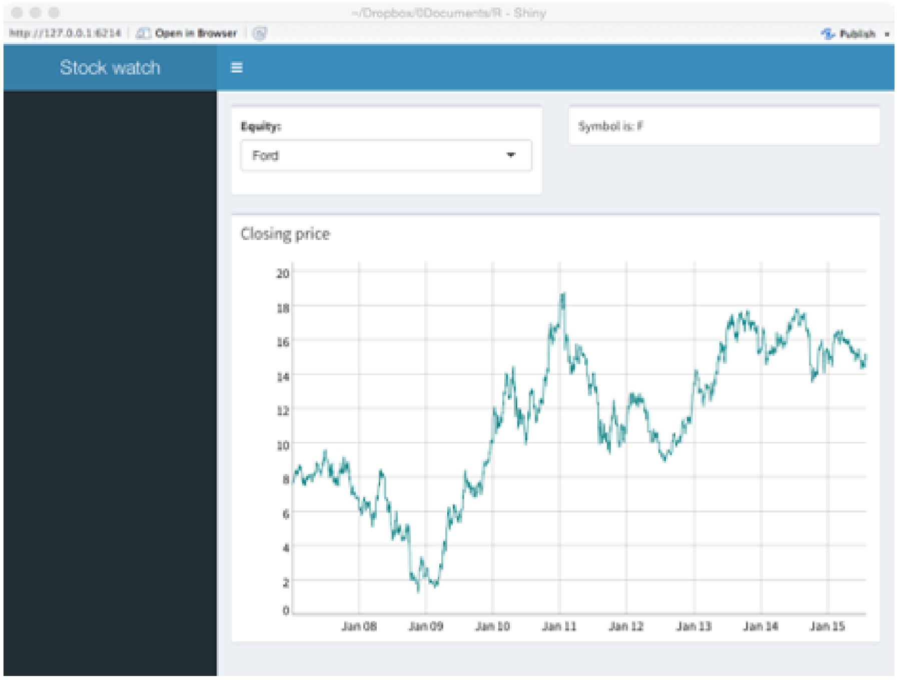


The following code illustrates how to create a dashboard that enables an analyst to graph the closing share price for Apple, Google, or Ford. Important variables in the code have been highlighted so you can easily see the correspondence between the UI and server functions. Note:

- The use of a selection list to pick one of three companies (`selectInput("symbol", "Equity:", choices = c("Apple" = "AAPL", "Ford" = "F", "Google" = "GOOG"))`).
- When an analyst selects one of the three firms, its stock exchange symbol (symbol) is passed to the server function.
- The value of symbol is used to retrieve the time series for the stock and to generate the graphic (chart) for display with `boxSymbol`. The symbol is also inserted into a text string (text) for display with `boxOutput`.

```r
library(shiny)
library(shinydashboard)
library(quantmod)
library(dygraphs)
header <-  dashboardHeader(title = 'Stock watch')
sidebar <- dashboardSidebar(NULL)
boxSymbol <-
  box(selectInput("symbol", "Equity:",
      choices = c("Apple" = "AAPL",  "Ford" = "F", "Google" = "GOOG"),
      selected = 'AAPL'))
boxPrice <- box(title='Closing price', width = 12, height = NULL,
                dygraphOutput("chart"))
boxOutput <-  box(textOutput("text"))
body <-   dashboardBody(fluidRow(boxSymbol, boxOutput, boxPrice))
ui <- dashboardPage(header, sidebar, body)
server <- function(input, output) {
  output$text <- renderText({
    paste("Symbol is:",input$symbol)
  })
# Cl in quantmod retrieves closing price as a time series
# graph time series
output$chart <- renderDygraph({dygraph(Cl(get(input$symbol)))})
}
shinyApp(ui, server)
```

The following dashboard shows the pull down list in the top left for selecting an equity. The equity's symbol is then displayed in the top right box, and a time series of its closing price appears in the box occupying the entire second row.



Input options

The preceding example illustrates the use of a selectInput function to select an equity from a list. There are other input options available, and these are listed in the following table.

Function	Purpose
checkboxInput()	Check one or more boxes
checkboxGroupInput()	A group of checkboxes
numericInput()	A spin box for numeric input
radioButtons()	Pick one from a set of options
selectInput()	Select from a drop-down text box
selectSlider()	Select using a slider
textInput()	Input text

☒ *Skill builder*

Using ClassicModels, build a dashboard to report total orders by value and number for a given year and month.

Conclusion

This chapter has introduced you to the basic structure and use of shinydashboard. It has many options, and you will need to consult the online documentation and examples to learn more about creating dashboards.

Summary

A dashboard is a web page or mobile app screen that is designed to present important information in an easy to comprehend and primarily visual format. A dashboard consists of a header, sidebar, and body. Shinydashboard is an R package based on shiny that facilitates the creation of interactive real-time dashboards. It must be used in conjunction with RStudio.

Body	Sidebar
Header	UI function
Server function	User-interface (ui)

References

Few, S. (2006). *Information dashboard design*: O'Reilly.

Exercises

1. Create a dashboard to show the current conditions and temperatures in both Fahrenheit and Celsius at a location. Your will need the rwunderground package and an API key.
2. Revise the dashboard created in the prior exercise to allow someone to select from up to five cities to get the weather details for that city.
3. Extend the previous dashboard. If the temperature is about 30°C (86°F), code the server function to give both temperature boxes a red background, and if it is below 10°C (50°F) give both a blue background. Otherwise the color should be yellow.
4. Use the WDI package to access World Bank Data and create a dashboard for a country of your choosing. Show three or more of the most current measures of the state of the selected country as an information box.
5. Use the WDI package to access World Bank Data for China, India, and the US for three variables, (1) CO2 emissions (metric tons per capita), (2) Electric power consumption (kWh per capita), and (3) forest area (% of land area). The corresponding WDI codes are: EN.ATM.CO2E.PC, EG.USE.ELEC.KH.PC, and AG.LND.FRST.ZS. Set up a dashboard so that a person can select the country from a pull down list and then the data for that country are shown in three infoboxes.
6. Use the WDI package to access World Bank Data for China, India, and the US for three variables, (1) CO2 emissions (metric tons per capita), (2) Electric power consumption (kWh per capita), and (3) forest area (% of land area). The corresponding WDI codes are: EN.ATM.CO2E.PC, EG.USE.ELEC.KH.PC, and AG.LND.FRST.ZS. Set up a dashboard so that a person can select one of the three measures, and then the data for each country are shown in separate infoboxes.

7. Create a dashboard to:
    a. Show the conversion rate between two currencies using the quantmod package to retrieve exchange rates. Let a person select from one of five currencies using a drop down box;
    b. Show the value of input amount when converted one of the selected currencies to the other selected currency;
    c. Show the exchange rate between the two selected currencies over the last 100 days

20 SQL and Java

The vision for Java is to be the concrete and nails that people use to build this incredible network system that is happening all around us.

James Gosling, 2000

Learning objectives

Students completing this chapter will be able to - write Java program to process a parameterized SQL query; - read a CSV file and insert rows into tables; - write a program using HMTL and JavaServer Pages (JSP) to insert data collected by a form data into a relational database; - understand how SQL commands are used for transaction processing.

JAVA

Java is a platform-independent application development language. Its object-oriented nature makes it easy to create and maintain software and prototypes. These features make Java an attractive development language for many applications, including database systems.

This chapter assumes that you have some knowledge of Java programming, can use an integrated development environment (IDE) (e.g., BlueJ, Eclipse, or NetBeans), and know how to use a Java library. It is also requires some HTML skills because JavaServer Pages (JSP) are created by embedding Java code within an HTML document. MySQL is used for all the examples, but the fundamental principles are the same for all relational databases. With a few changes, your program will work with another implementation of the relational model.

JDBC

Java Database Connectivity (JDBC), a Java version of a portable SQL command line interface (CLI), is modeled on Open Database Connectivity (ODBC.) JDBC enables programmers to write Java software that is both operating system and DBMS independent. The JDBC core, which handles 90 percent of database programming, contains seven interfaces and two classes, which are part of the java.sql package. The purpose of each of these is summarized in the following table.

JDBC core interfaces and classes

Interfaces	Description
Connection	Connects an application to a database
Statement	A container for an SQL statement
PreparedStatement	Precompiles an SQL statement and then uses it multiple times
CallableStatement	Executes a stored procedure
ResultSet	The rows returned when a query is executed
ResultSetMetaData	The number, types, and properties of the result set
Classes	
DriverManager	Loads driver objects and creates database connections
DriverPropertyInfo	Used by specialized clients

For each DBMS, implementations of these interfaces are required because they are specific to the DBMS and not part of the Java package. For example, specific drivers are needed for MySQL, DB2, Oracle, and MS SQL. Before using JDBC, you will need to install these interfaces for the DBMS you plan to access. The standard practice appears to be to refer to this set of interfaces as the driver, but the 'driver' also includes implementations of all the interfaces.

Java EE

Java EE (Java Platform Enterprise Edition) is a platform for multi-tiered enterprise applications. In the typical three-tier model, a Java EE application server sits between the client's browser and the database server. A Java EE compliant server, of which there are a variety, is needed to process JSP.

Using SQL within Java

In this section, you will need a Java integrated development environment to execute the sample code. A good option is Eclipse, a widely used open source IDE.

We now examine each of the major steps in processing an SQL query and, in the process, create Java methods to query a database.

Connect to the database

The getConnection method of the DriverManager specifies the URL of the database, the account identifier, and its password. You cannot assume that connecting to the database will be trouble-free. Thus, good coding practice requires that you detect and report any errors using Java's try-catch structure.

You connect to a DBMS by supplying its url and the account name and password.

```
try {
 conn = DriverManager.getConnection(url, account, password);
} catch (SQLException error) {
 System.out.println("Error connecting to database: "
                         + error.toString());
 System.exit(1);
}
```

The format of the url parameter varies with the JDBC driver, and you will need to consult the documentation for the driver. In the case of MySQL, the possible formats are

jdbc:mysql:database

jdbc:mysql://host/database

jdbc:mysql://host:port/database

The default value for host is “localhost” and, for MySQL, the default port is “3306.”

For example:

jdbc:mysql://www.richardtwatson.com:3306/Text will enable connection to the database Text on the host http://www.richardtwatson.com on port 3306.

Create and execute an SQL statement

The prepareStatement method is invoked to produce a Statement object (see the following code). Note that the conn in conn.prepareStatement() refers to the connection created by the getConnection method. Parameters are used in prepareStatement to set execution time values, with each parameter indicated by a question mark (?). Parameters are identified by an integer for the order in which they appear in the SQL statement. In the following sample code, shrdiv is a parameter and is set to indiv by stmt.setInit(1,indiv), where 1 is its identifier (i.e., the first parameter in the SQL statement) and indiv is the parameter. The value of indiv is received as input at run time.

The SQL query is run by the executeQuery() method of the Statement object. The results are returned in a ResultSet object.

Create and execute an SQL statement

```
try {
    stmt = conn.prepareStatement
      ("SELECT shrfirm, shrdiv FROM shr WHERE shrdiv > ?");
    // set the value for shrdiv to indiv
    stmt.setInt(1,indiv);
    rs = stmt.executeQuery();
    }
catch (SQLException error)
    {
        System.out.println("Error reporting from database: "
```

```
            + error.toString());
        System.exit(1);
    }
```

Report a SELECT

The rows in the table containing the results of the query are processed a row at a time using the next method of the ResultSet object (see the following code). Columns are retrieved one at a time using a get method within a loop, where the integer value specified in the method call refers to a column (e.g., rs.getString(1) returns the first column of the result set as a string). The get method used depends on the type of data returned by the query. For example, getString() gets a character string, getInt() gets an integer, and so on.

Reporting a SELECT

```
while (rs.next()) {
    String firm = rs.getString(1);
    int div = rs.getInt(2);
    System.out.println(firm + " " + div);
}
```

Inserting a row

The prepareStatement() is also used for inserting a row in a similar manner, as the following example shows. The executeUpdate() method performs the insert. Notice the use of try and catch to detect and report an error during an insert.

Inserting a row

```
try {
    stmt = conn.prepareStatement
      ("INSERT INTO alien (alnum, alname) VALUES (?,?)");
    stmt.setInt(1,10);
    stmt.setString(2, "ET");
    stmt.executeUpdate();
    }
catch (SQLException error)
{
    System.out.println("Error inserting row into database: "
     + error.toString());
    System.exit(1);
}
```

Release the Statement object

The resources associated with the various objects created are freed as follows:

stmt.close();

rs.close();

conn.close();

To illustrate the use of Java, a pair of programs is available. The first, DataTest.java, creates a database connection and then calls a method to execute and report an SQL. The second program, DatabaseAccess.java, contains the methods called by the first. Both programs are available on the book's web site for examination and use.

❎ *Skill builder*

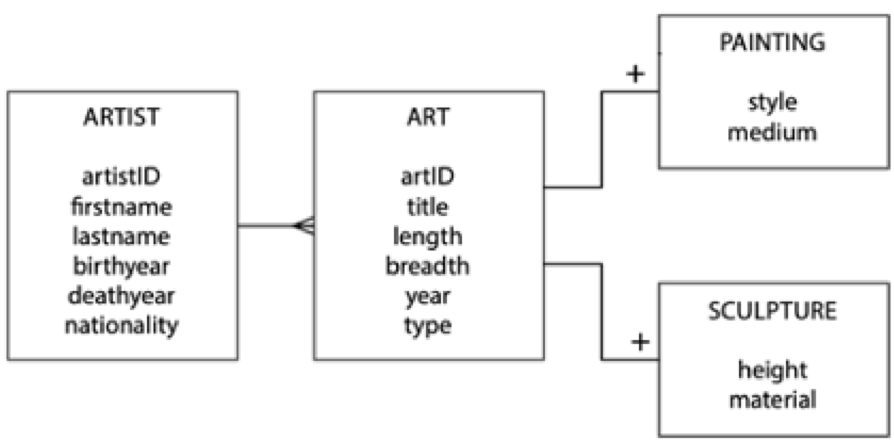
1. Get from this book's supporting Web site the code of DatabaseTest.java and DatabaseAccess.java.
2. Inspect the code to learn how you use SQL from within a Java application.
3. Run DatabaseTest.java with a few different values for indiv.
4. Make modifications to query a different table.

Loading a text file into a database

Java is useful when you have a dataset that you need to load into a database. For example, you might have set up a spreadsheet and later realized that it would be more efficient to use a database. In this case, you can export the spreadsheet and load the data into one or more tables.

We will illustrate loading data from a text file into the ArtCollection database with the following design. Notice that there different tables for different types of art, paintings, and sculptures in this case. The code for creating the database is online

ArtCollection data model



CSV file

A comma-separated values (CSV) file is a common form of text file because most spreadsheet programs offer it as an export option. There are a variety of options available in terms of the separator for fields (usually a comma or tab) and the use of quotation marks to denote text fields. Usually, each record has the same number of fields. Frequently, the first record contains names for each of the fields. Notice in the example file that follows that a record contains details of an artist and one piece of that person's art. As the data model specifies, these two sets of data go into separate tables.

A CSV file

```
firstName,lastName,birthyear,deathyear,nationality,title,
length,breadth,year,style,medium
Edvard,Munch,1863,1944,Norwegian,The Scream,36,29,1893,Cubist,Oil
Claude,Monet,1840,1926,French,Bridge over a Pond of Water
Lilies,36,29,1899,Impressionist,Oil
Toulouse,Lautrec,1864,1901,French,Avril,55,33,1893,Impressionist,Oil
Vincent,Van Gogh,1853,1890,French,The Starry
Night,29,36,1889,Impressionist,Oil
Johannes,Vermeer,1632,1675,Dutch,Girl with a Pearl
Earring,17,15,1665,Impressionist,Oil
Salvador,Dali,1904,1989,Spanish,The Persistence of
Memory,9.5,13,1931,Surreal,Oil
Andrew,Wyeth,1917,2009,American,Christina's World
,32,47,1948,Surreal,Oil
William,Turner,1789,1862,English,The Battle of
Trafalgar,103,145,1822,Surreal,Oil
Tom,Roberts,1856,1931,Australian,Shearing the
Rams,48,72,1890,Surreal,Oil
Paul,Gauguin,1848,1903,French,Spirit of the Dead
Watching,28,36,1892,Surreal,Watercolor
```

Because CSV files are so widely used, there are Java libraries for processing them. We have opted for CsvReader. Here is some code for connecting to a CSV file defined by its URL. You can also connect to text files on your personal computer.

Connecting to a CSV file

```
try {
    csvurl =
      new URL("http://www.richardtwatson.com/data/painting.csv");
} catch (IOException error) {
    System.out.println("Error accessing url: "
                       + error.toString());
    System.exit(1);
}
```

A CSV file is read a record at a time, and the required fields are extracted for further processing. The following code illustrates how a loop is used to read each record in a CSV file and extract some fields. Note the following: - The first record, the header, contains the names of each field and is read before the loop starts. - Field names can be used to extract each field with a get() method. - You often need to convert the input string data to another format, such as integer. - Methods, addArtist, and addArt are included in the loop to add details of an artist to the artist table and a piece of art to the art table.

Processing a CSV file

```
try {
    input = new CsvReader(
        new InputStreamReader(csvurl.openStream()));
    input.readHeaders();
    while (input.readRecord())
    {
    // Artist
        String firstName = input.get("firstName");
        String lastName = input.get("lastName");
        String nationality = input.get("nationality");
        int birthYear
          = Integer.parseInt(input.get("birthyear"));
        int deathYear
          = Integer.parseInt(input.get("deathyear"));
        artistPK
          = addArtist(conn, firstName, lastName,
                      nationality, birthYear, deathYear);
        // Painting
        String title = input.get("title");
        double length
          = Double.parseDouble(input.get("length"));
        double breadth
          = Double.parseDouble(input.get("breadth"));
        int year = Integer.parseInt(input.get("year"));
        addArt(conn, title, length, breadth, year,artistPK);
    }
input.close();
} catch (IOException error) {
    System.out.println("Error reading CSV file: "
                       + error.toString());
    System.exit(1);
}
```

We now need to consider the addArtist method. Its purpose is to add a row to the artist table. The primary key, artistID, is specified as AUTO_INCREMENT, which means it is set by the DBMS. Because of the 1:m relationship between artist and art, we need to know the value of artistID, the primary key of art, to set the foreign key for the corresponding piece of art. We can use the following code to determine the primary key of the last insert.

Determining the value of the primary key of the last insert

```
rs = stmt.executeQuery("SELECT LAST_INSERT_ID()");
    if (rs.next()) {
        autoIncKey = rs.getInt(1);
    }
```

The addArtist method returns the value of the primary key of the most recent insert so that we can then use this value as the foreign key for the related piece of art.

```
artistPK = addArtist(conn, firstName, lastName,
                     nationality, birthYear, deathYear);
```

The call to the addArt method includes the returned value as a parameter. That is, it passes the primary key of artist to be used as foreign key of art.

```
addArt(conn, title, length, breadth, year,artistPK);
```

The Java code for the complete application is available on the book's web site.

❎ Skill builder

1. Add a few sculptors and a piece of sculpture to the CSV file. Also, decide how you will differentiate between a painting and a sculpture.
2. Add a method to ArtCollector.java to insert an artist and that person's sculpture.
3. Run the revised program so that it adds both paintings and sculptures for various artists.

JavaServer Pages (JSP)

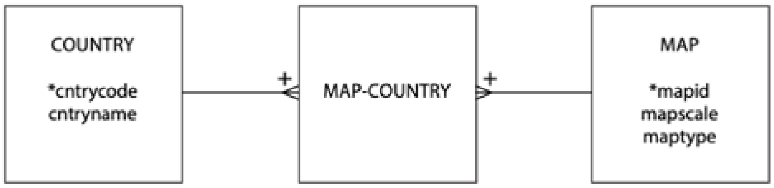
Standard HTML pages are static. They contain text and graphics that don't change unless someone recodes the page. JSP and other technologies, such as PHP and ASP, enable you to create dynamic pages whose content can change based to suit the goals of the person accessing the page, the browser used, or the device on which the page is displayed.

A JSP contains standard HTML code, the static, and JSP elements, the dynamic. When someone requests a JSP, the server combines HTML and JSP elements to deliver a dynamic page. JSP is also useful for server side processing. For example, when someone submits a form, JSP elements can be used to process the form on the server.

Map collection case

An international retailer has added a new product line to meet the needs of its changing clientele. It now stocks a range of maps. The firm's data modeler has created a data model describing the situation . A map has a scale; for example, a scale of 1:1 000 000 means that 1 unit on the map is 1,000,000 units on the ground (or 1 cm is 10 km, and 1 inch is ~16 miles). There are three types of maps: road, rail, and canal. Initially, The retailer decided to stock maps for only a few European countries.

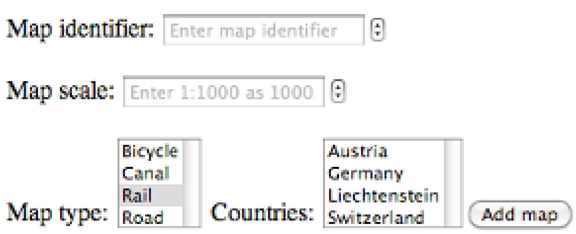
The retailer's map collection data model



Data entry

Once the tables have been defined, we want to insert some records. This could be done using the insertSQL method of the Java code just created, but it would be very tedious, as we would type insert statements for each row (e.g., INSERT INTO map VALUES (1, 1000000, 'Rail');). A better approach is to use a HTML data entry form. An appropriate form and its associated code follow.

Map collection data entry form



Map collection data entry HTML code (index.html)

```
<!DOCTYPE html PUBLIC "-//W3C//DTD HTML 4.01 Transitional//EN"
"http://www.w3.org/TR/html4/loose.dtd">
<html>
<head>
<meta http-equiv="Content-Type"
  content="text/html; charset=ISO-8859-1">
<title>Map collection</title>
</head>
</body>
<form name="MapInsert" action="mapinsert.jsp" method="post">
 <p>
```

```
    <label>Map identifier: <input type="number" required
        pattern="[0-9]{3}" name="mapid" size="24" value=""
        placeholder="Enter map identifier"></label>
<p>
    <label>Map scale: <input type="number" required
        pattern="[0-9]+" min="1000" max="100000" step="1000"
        name="mapscale" size="24" value=""
        placeholder="Enter 1:1000 as 1000"></label>
<p>
    <label>Map type: <select name="maptype" size="3"
        laceholder="Select type of map"></label>
</p>
    <option value="Bicycle">Bicycle</option>
    <option value="Canal">Canal</option>
    <option value="Rail" selected>Rail</option>
    <option value="Road">Road</option>
    </select> <label>Countries:
          <select name="countries" size="4" multiple
        placeholder="Select countries"></label>
    <option value="at">Austria</option>
    <option value="de">Germany</option>
    <option value="li">Liechtenstein</option>
    <option value="ch">Switzerland</option>
    <input type="submit" name="submitbutton" value="Add map">
</form>
</body>
</html>
```

The data entry form captures a map's identifier, scale, type, and the number of countries covered by the map. A map identifier is of the form M001 to M999, and a regular expression is used to validate the input.[A map scale must be numeric with a minimum of 1000 and maximum of 100000 in increments of 1000. The type of map is selected from the list, which is defined so that only one type can be selected. Multiple countries can be selected by holding down an appropriate key combination when selected from the displayed list of countries. When the "Add map" button is clicked, the page mapinsert.jsp is called, which is specified in the first line of the HTML body code.

Passing data from a form to a JSP

In a form, the various entry fields are each identified by a name specification (e.g., name="mapid" and name="mapscale"). In the corresponding JSP, which is the one defined in the form's action statement (i.e., action="mapinsert.jsp") these same fields are accessed using the getParameter method when there is a single value or getParameterValues when there are multiple values. The following chunks of code show corresponding form and JSP code for maptype.

```
<label>Map type: <select name="maptype" size="3"
            placeholder="Select type of map"></label>
```

```
maptype = request.getParameter("maptype");
```

Transaction processing

A transaction is a logical unit of work. In the case of adding a map, it means inserting a row in map for the map and inserting one row in mapCountry for each country on the map. All of these inserts must be executed without failure for the entire transaction to be processed. SQL has two commands for supporting transaction processing: COMMIT and ROLLBACK. If no errors are detected, then the various changes made by a transaction can be *committed*. In the event of any errors during the processing of a transaction, the database should be *rolled back* to the state prior to the transaction.

20.0.0.0.1 * Autocommit

Before processing a transaction, you need to turn off autocommit to avoid committing each database change separately before the entire transaction is complete. It is a good idea to set the value for autocommit immediately after a successful database connection, which is what you will see when you inspect the code for mapinsert.jsp. The following code sets autocommit to false in the case where conn is the connection object.

```
conn.setAutoCommit(false);
```

20.0.0.0.2 * Commit

The COMMIT command is executed when all parts of a transaction have been successfully executed. It makes the changes to the database permanent.

```
conn.commit(); // all inserts successful
```

20.0.0.0.3 * Rollback

The ROLLBACK command is executed when any part of a transaction fails. All changes to the database since the beginning of the transaction are reversed, and the database is restored to its state before the transaction commenced.

```
conn.rollback(); // at least one insert failed
```

20.0.0.0.4 * Completing the transaction

The final task, to commit or roll back the transaction depending on whether errors were detected during any of the inserts, is determined by examining transOK, which is a boolean variable set to false when any errors are detected during a transaction.

Completing the transaction

```
if (transOK) {
    conn.commit(); // all inserts successful
} else {
    conn.rollback(); // at least one insert failed
}
conn.close(); // close database
```

Putting it all together

You have now seen some of the key pieces for the event handler that processes a transaction to add a map and the countries on that map. The code can be downloaded from the book's Web site.

mapinsert.jsp

```
<%@ page language="java"
  contentType="text/html; charset=ISO-8859-1"
    pageEncoding="ISO-8859-1"%>
<!DOCTYPE html PUBLIC "-//W3C//DTD HTML 4.01 Transitional//EN"
    "http://www.w3.org/TR/html4/loose.dtd">
<%@ page import="java.util.*"%>
<%@ page import="java.lang.*"%>
<%@ page import="java.sql.*"%>
<html>
<head>
<meta http-equiv="Content-Type" content="text/html;
    charset=ISO-8859-1">
<title>Map insert page</title>
</head>
<body>
    <%
    String url;
    String jdbc = "jdbc:mysql:";
    String database = "//localhost:3306/MapCollection";
    String username = "student", password = "student";
    String mapid, maptype, countries;
    String[] country;
    int mapscale = 0;
    boolean transOK = true;
    PreparedStatement insertMap;
```

```
    PreparedStatement insertMapCountry;
    Connection conn = null;
    // make connection
    url = jdbc + database;
    try {
        conn = DriverManager.getConnection(url, username, password);
    } catch (SQLException error) {
        System.out.println("Error connecting to database: "
                    + error.toString());
        System.exit(1);
    }
    try {
        conn.setAutoCommit(false);
    } catch (SQLException error) {
        System.out.println("Error turning off autocommit"
                    + error.toString());
        System.exit(2);
    }
    //form data
    mapid = request.getParameter("mapid");
    mapscale = Integer.parseInt(request.getParameter("mapscale"));
    maptype = request.getParameter("maptype");
    country = request.getParameterValues("countries");
    transOK = true;
    // insert the map
 try {
        insertMap = conn.prepareStatement
        ("INSERT INTO map (mapid, mapscale, maptype) VALUES (?,?,?)");
        insertMap.setString(1, mapid);
        insertMap.setInt(2, mapscale);
        insertMap.setString(3, maptype);
        System.out.println(insertMap);
        insertMap.executeUpdate();
        // insert the countries
 for (int loopInx = 0; loopInx < country.length; loopInx++) {
    insertMapCountry = conn.prepareStatement
    ("INSERT INTO mapCountry (mapid ,cntrycode ) VALUES (?,?)");
    insertMapCountry.setString(1, mapid);
    insertMapCountry.setString(2, country[loopInx]);
    System.out.println(insertMapCountry);
    insertMapCountry.executeUpdate();
        }
    } catch (SQLException error) {
        System.out.println("Error inserting row: "
                           + error.toString());
        transOK = false;
    }
    if (transOK) {
```

```
        conn.commit(); // all inserts successful
        System.out.println("Transaction commit");
    } else {
        conn.rollback(); // at least one insert failed
        System.out.println("Transaction rollback");
    }
    conn.close();
    System.out.println("Database close"); // close database
    %>
</body>
</html>
```

The code in mapinsert.jsp does the following:

1. Creates a connection to a database
2. Gets the data from the map entry form
3. Inserts a row for a new map
4. Uses a loop to insert a row for each country on the map
5. Shows how to handle a transaction failure.

Conclusion

Java is a widely used object-oriented programming language for developing distributed multi-tier applications. JDBC is a key technology in this environment because it enables a Java application to interact with various implementations of the relational database model (e.g., Oracle, SQL Server, MySQL). As this chapter has demonstrated, with the help of a few examples, JDBC can be readily understood and applied.

Summary

Java is a platform-independent application development language. JDBC enables programs that are DBMS independent. SQL statements can be embedded within Java programs. JSP is used to support server side processing. COMMIT and ROLLBACK are used for transaction processing.

Key terms and concepts

Autocommit	Java Database Connectivity (JDBC)
Comma-separated values	Java Server Pages (JSP)
COMMIT	ROLLBACK
IDE	Transaction processing
Java	

References and additional readings

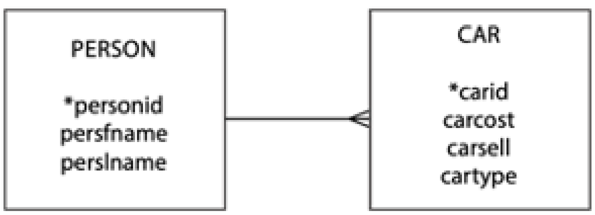
Barnes, D. J., and M. Kölling. 2005. *Objects first with Java : a practical introduction using Blue J*. 2nd ed. Upper Saddle River, NJ: Prentice Hall.

Exercises

1. Write a Java program to run a parameterized query against the ClassicModels database. For example, you might report the sum of payments for a given customer's name.

Extend ArtCollection.java so that it can handle inserting rows for multiple pieces of art for a single artist. You will have to rethink the structure of the CSV file and how to record multiple pieces of art from a single artist.

2. Write a JSP application to maintain the database defined by the following data model. The database keeps track of the cars sold by a salesperson in an automotive dealership. Your application should be able to add a person and the cars a person has sold. These should be separate transactions.



Section 4 Managing Organizational Memory

> *Every one complains of his memory, none of his judgment.*
>
> François Duc de La Rochefoucauld "Sentences et Maximes," Morales No. 89 1678

In order to manage data, you need a database architecture, a design for the storage and processing of data. Organizations strive to find an architecture that simultaneously achieves multiple goals:

1. Responds in a timely manner.
2. Minimizes the cost of
   a. processing data,
   b. storing data,
   c. data delivery,
   d. application development.
3. Highly secure.

The section deals with the approaches that can be used to achieve these goals. It covers database structure and storage alternatives. It provides the knowledge necessary to determine an appropriate data storage structure and device for a given situation. It also addresses the fundamental questions of where to store the data and where they should be processed.

As you now realize, organizational memory is an important resource requiring management. An inaccurate memory can result in bad decisions and poor customer service. Some aspects of organizational memory (e.g., chemical formulae, marketing strategy, and R&D plans) are critical to the well-being of an organization. The financial consequences can be extremely significant if these memories are lost or fall into the hands of competitors. Consequently, organizations must develop and implement procedures for maintaining data integrity. They need policies to protect the existence of data, maintain its quality, and ensure its confidentiality. Some of these procedures may be embedded in organizational memory technology, and others may be performed by data management staff. Data integrity is also addressed in this section.

21 Data Structure and Storage

The modern age has a false sense of superiority because it relies on the mass of knowledge that it can use, but what is important is the extent to which knowledge is organized and mastered.

Goethe, 1810

Learning objectives

Students completing this chapter will, for a given situation, be able to:

- understand the implications of the data deluge;
- recommend a data storage structure;
- recommend a storage device.

The data deluge

With petabytes of new data being created daily, and the volume continuing to grow, many IS departments and storage vendors struggle to handle this data flood. "Big Data," as the deluge is colloquially known, arises from the flow of data created by Internet searches, Web site visits, social networking activity, streaming of videos, electronic health care records, sensor networks, large-scale simulations, and a host of other activities that are part of everyday business in today's world. The deluge requires a continuing investment in the management and storage of data.

A byte size table

Abbreviation	Prefix	Factor	Equivalent to
k	kilo	10^3	
M	mega	10^6	
G	giga	10^9	A digital audio recording of a symphony
T	tera	10^{12}	
P	peta	10^{15}	50 percent of all books in U.S. academic libraries
E	exa	10^{18}	5 times all the world's printed material

Abbreviation	Prefix	Factor	Equivalent to
Z	zetta	10^{21}	
Y	yotta	10^{24}	Around 2030, the world will generate a yottabyte of data per year
R	ronna	10^{27}	
Q	quetta	10^{30}	

The following pages explore territory that is not normally the concern of application programmers or database users. Fortunately, the relational model keeps data structures and data access methods hidden. Nevertheless, an overview of what happens under the hood is part of a well-rounded education in data management and will equip you to work on some of the problems of the data deluge.

Data structures and access methods are the province of the person responsible for physically designing the database so that it responds in a timely manner to both queries and maintenance operations. Of course, there may be installations where application programmers have such responsibilities, and in these situations you will need to know physical database design.

Data structures

An in-depth consideration of the internals of database architecture provides an understanding of the basic structures and access mechanisms underlying the technology. As you will see, the overriding concern of the internal level is to minimize disk access. In dealing with this level, we will speak in terms of files, records, and fields rather than the relational database terms of tables, rows, and columns. We do this because the discussion extends beyond the relational model to file structures in general.

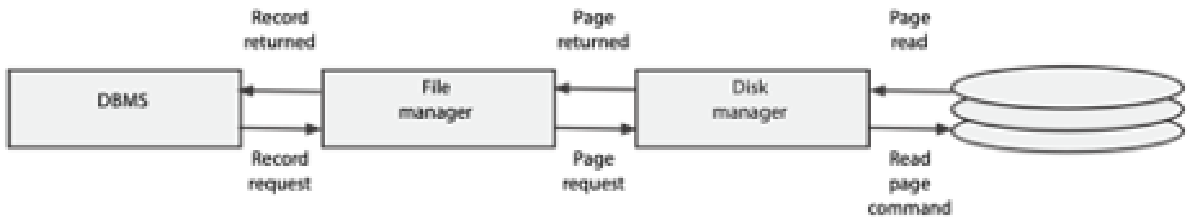
The time required to access data on a magnetic disk, the storage device for many databases, is relatively long compared to that for main memory. Disk access times are measured in milliseconds (10^3), and main memory access times are referred to in nanoseconds (10^9). There are generally around five orders of magnitude difference between disk and main memory access—it takes about 10^5 times longer. This distinction is more meaningful if placed in an everyday context; it is like asking someone a question by phone or writing them a letter. The phone response takes seconds, and the written response takes days.

For many business applications, slow disk drives are a bottleneck. The computer often must wait for a disk to retrieve data before it can continue processing a request for information. This delay means that customers are also kept waiting. Appropriate selection of data structures and data access methods can considerably reduce delays. Database designers have two options: decrease disk read/write head movement or reduce disk accesses. Before considering these options, we need a general model of database access.

Database access

A three-layer model provides a framework for thinking about minimization of data access. This is a generic model, and a particular DBMS may implement the approach using a different number of layers. For simplicity, the discussion is based on retrieving a single record in a file, although the principles also apply to the retrieval of multiple records or an entire file.

Database access layers



1. The DBMS determines which record is required and passes a request to the file manager to retrieve a particular record in a file.
2. The file manager converts this request into the address of the unit of storage (usually called a page) containing the specified record. A page is the minimum amount of storage accessed at one time and is typically around 1-4 kbytes. A page will often contain several short records (e.g., 200 bytes), but a long record (e.g., 10 kbytes) might be spread over several pages. In this example, we assume that records are shorter than a page.
3. The disk manager determines the physical location of the page, issues the retrieval instructions, and passes the page to the file manager.
4. The file manager extracts the requested record from the page and passes it to the DBMS.

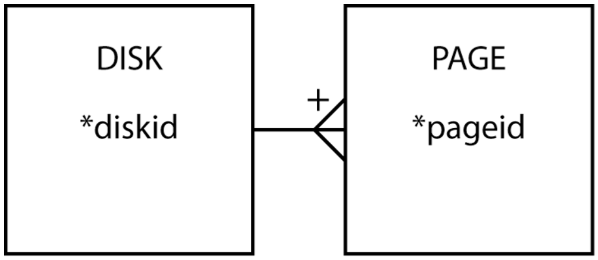
The disk manager

The disk manager is that part of the operating system responsible for physical input and output (I/O). It maintains a directory of the location of each page on the disk with all pages identified by a unique page number. The disk manager's main functions are to retrieve pages, replace pages, and keep track of free pages.

Page retrieval requires the disk manager to convert the page number to a physical address and issue the command to read the physical location. Since a page can contain multiple records, when a record is updated, the disk manager must retrieve the relevant page, update the appropriate portion containing the record, and then replace the page without changing any of the other data on it.

The disk manager thinks of the disk as a collection of uniquely numbered pages. Some of these pages are allocated to the storage of data, and others are unused. When additional storage space is required, the disk manager allocates a page address from the set of unused page addresses. When a page becomes free because a file or some records are deleted, the disk manager moves that page's address to the unallocated set. Note, it does not erase the data, but simply indicates the page is available to be overwritten. This means that it is sometimes possible to read portions of a deleted file. If you want to ensure that an old file is truly deleted, you need to use an erase program that writes random data to the deleted page.

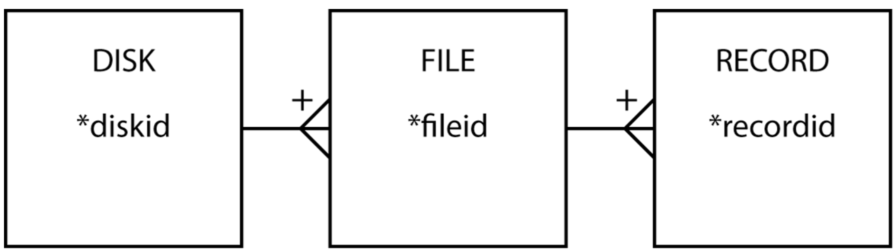
Disk manager's view of the world



The file manager

The file manager, a level above the disk manager, is concerned with the storage of files. It thinks of the disk as a set of stored files. Each file has a unique file identifier, and each record within a file has a record identifier that is unique within that file.

File manager's view of the world



The file manager can

- Create a file
- Delete a file
- Retrieve a record from a file
- Update a record in a file
- Add a new record to a file
- Delete a record from a file

Techniques for reducing head movement

All disk storage devices have some common features. They have one or more recording surfaces. Typically, a magnetic disk drive has multiple recording surfaces, with data stored on tracks on each surface.

The key characteristics of disk storage devices that affect database access are rotational speed and access arm speed. The rotational speed of a magnetic disk is in the range of 3,000 to 15,000 rpm. Reading or writing a page to disk requires moving the read/write head to the destination track and waiting for the storage address to come under the head. Because moving the head usually takes more time (e.g., about 9 msec) than waiting for the storage address to appear under it (e.g., about 4 msec), data access times can be reduced by minimizing the movement of the read/write head or by rotating the disk faster. Since rotational speed is set by the disk manufacturer, minimizing read/write head movement is the only option available to database designers.

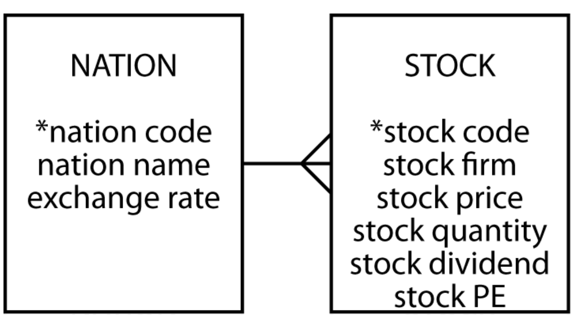
Cylinders

Head movement is reduced by storing data that are likely to be accessed at the same time, such as records in a file, on the same track on a single surface. When a file is too large to fit on one track, then it can be stored on the same track on different surfaces (i.e., one directly above or below the current track); such a collection of tracks is called a cylinder. The advantage of cylinder storage is that all tracks can be accessed without moving the read/write head. When a cylinder is full, remaining data are stored on adjacent cylinders. Adjacent cylinders are ideal for sequential file storage because the record retrieval pattern is predefined—the first record is read, then the second, and so on.

Clustering

Cylinder storage can also be used when the record retrieval pattern has some degree of regularity to it. Consider the following familiar data model of the following figure. Converting this data model to a relational database creates two tables. Conceptually, we may think of the data in each of the tables as being stored in adjacent cylinders. If, however, you frequently need to retrieve one row of nation and all the corresponding rows of stock, then nation and stock rows should be intermingled to minimize access time.

Data model for nation and stock



The term clustering denotes the concept that records that are frequently used together should be physically close together on a disk. Some DBMSs permit the database designer to specify clustering of different files to tune the database to reduce average access times. If usage patterns change, clustering specifications should be altered. Of course, clustering should be totally transparent to application programs and clients.

Techniques for reducing disk accesses

Several techniques are used to accelerate retrieval by reducing disk accesses. The ideal situation is when the required record is obtained with a single disk access. In special circumstances, it may be possible to create a file where the primary key can convert directly to a unique disk address (e.g., the record with primary key 1 is stored at address 1001, the record with primary key 2 is stored at address 1002, and so on). If possible, this method of direct addressing should be used because it is the fastest form of data access; however, it is most unusual to find such a direct mapping between the primary key and a disk address. For example, it would not be feasible to use direct addressing with a personnel file that has a Social Security number as the primary key because so many disk addresses would be wasted. Furthermore, direct addressing can work only for the primary key. What happens if there is a need for rapid retrieval on another field?

In most cases, database designers use features such as indexing, hashing, and linked lists. Indexing, a flexible and commonly used method of reducing disk accesses when searching for data, centers on the creation of a compact file containing the index field and the address of its corresponding record. The B-tree is a particular form of index structure that is widely used as the storage structure of relational DBMSs. Hashing is a direct access method based on using an arithmetic function to compute a disk address from a field within a file. A linked list is a data structure that accelerates data access by using pointers to show relationships existing between records.

Indexing

Consider the item file partially shown in the following table. Let's assume that this file has 10,000 records and each record requires 1 kbyte, which is a page on the particular disk system used. Suppose a common query is to request all the items of a particular type. Such a query might be

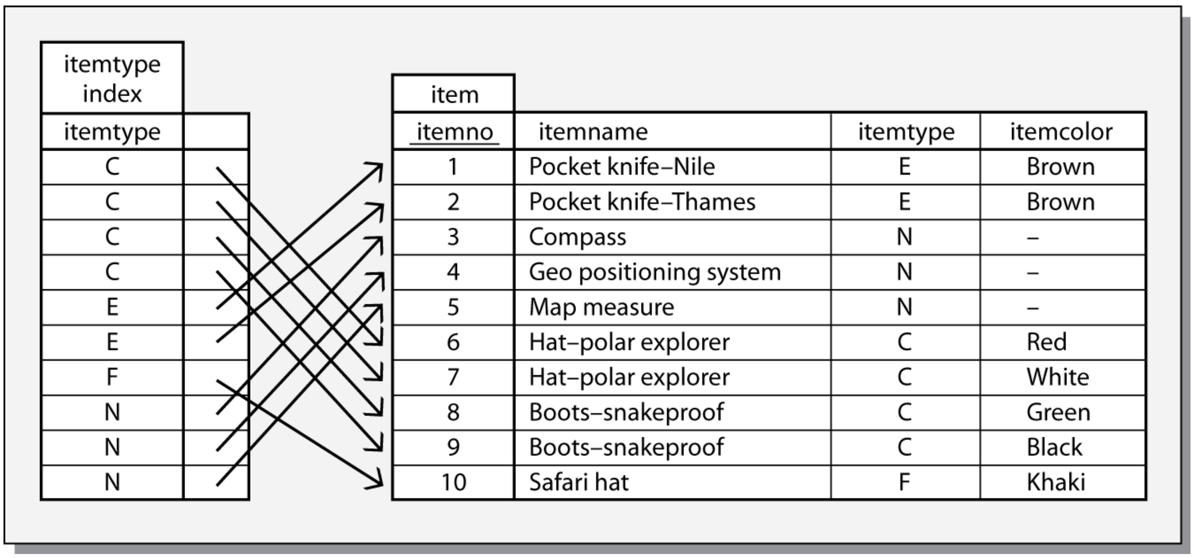
Find all items of type E.

Regardless of the number of records with ITEMTYPE = 'E', this query will require 10,000 disk accesses. Every record has to be retrieved and examined to determine the value of `itemtype`. For instance, if 20 percent of the items are of type E, then 8,000 of the disk accesses are wasted because they retrieve a record that is not required. The ideal situation would be to retrieve only those 2,000 records that contain an item of type E. We get closer to this ideal situation by creating a small file containing just the value of `itemtype` for each record and the address of the full record. This small file is called an index.

Portion of a 10,000 Record File

*itemno	itemname	itemtype	itemcolor
1	Pocket knife—Nile	E	Brown
2	Pocket knife—Thames	E	Brown
3	Compass	N	—
4	Geopositioning system	N	—
5	Map measure	N	—
6	Hat—polar explorer	C	Red
7	Hat—polar explorer	C	White
8	Boots—snake proof	C	Green
9	Boots—snake proof	C	Black
10	Safari chair	F	Khaki

Part of the itemtype index



The `itemtype` index is a file. It contains 10,000 records and two fields. There is one record in the index for each record in `item`. The first columns contains a value of `itemtype` and the second contains a pointer, an address, to the matching record of item. Notice that the index is in `itemtype` sequence. Storing the index in a particular order is another means of reducing disk accesses, as we will see shortly. The index is quite small. One byte is required for `itemtype` and four bytes for the pointer. So the total size of the index is 50 kbytes, which in this case is 50 pages of disk space.

Now consider finding all records with an item type of E. One approach is to read the entire index into memory, search it for type E items, and then use the pointers to retrieve the required records from `item`. This method requires 2,050 disk accesses—50 to load the index and 2,000 accesses of `item`, as there are 2,000 items of type E. Creating an index for item results in substantial savings in disk accesses for this example. Here, we assume that 20 percent of the records in item contained `itemtype =` 'E'. The number of disk accesses saved varies with the proportion of records meeting the query's criteria. If there are no records meeting the criteria, 9,950 disk accesses are avoided.

At the other extreme, when all records meet the criteria, it takes 50 extra disk accesses to load the index.

The SQL for creating the index is

```
CREATE INDEX itemtypeindx ON item (itemtype);
```

The entire index need not be read into memory. As you will see when we discuss tree structures, we can take advantage of an index's ordering to reduce disk accesses further. Nevertheless, the clear advantage of an index is evident: it speeds up retrieval by reducing disk accesses. Like many aspects of database management, however, indexes have a drawback. Adding a record to a file without an index requires a single disk write. Adding a record to an indexed file requires at least two, and maybe more, disk writes, because an entry has to be added to both the file and its index. The trade-off is between faster retrievals and slower updates. If there are many retrievals and few updates, then opt for an index, especially if the indexed field can have a wide variety of values. If the file is very volatile and updates are frequent and retrievals few, then an index may cost more disk accesses than it saves.

Indexes can be used for both sequential and direct access. Sequential access means that records are retrieved in the sequence defined by the values in the index. In our example, this means retrieving records in `itemtype` sequence with a range query such as

Find all items with a type code in the range E through K.

Direct access means records are retrieved according to one or more specified values. A sample query requiring direct access would be

Find all items with a type code of E or N.

Indexes are also handy for existence testing. Remember, the EXISTS clause of SQL returns *true* or *false* and not a value. An index can be searched to check whether the indexed field takes a particular value, but there is no need to access the file because no data are returned. The following query can be answered by an index search:

Are there any items with a code of R?

Multiple indexes

Multiple indexes can be created for a file. The `item` file could have an index defined on `itemcolor` or any other field. Multiple indexes may be used independently, as in this query:

List red items.

or jointly, with a query such as

Find red items of type C.

The preceding query can be solved by using the indexes for `itemtype` and `itemcolor`.

Indexes for fields itemtype and itemcolor itemtype index

itemtype	Disk address
C	d6
C	d7
C	d8
C	d9
E	d1
E	d2
F	d10
N	d3
N	d4
N	d5

itemcolor index

itemcolor	Disk address
Black	d9
Brown	d1
Brown	d2
Green	d8
Khaki	d10
Red	d6
White	d7
–	d3
–	d4
–	d5

Examination of the `itemtype` index indicates that items of type C are stored at addresses d6, d7, d8, and d9. The only red item recorded in the `itemcolor` index is stored at address d6, and since it is the only record satisfying the query, it is the only record that needs to be retrieved.

Multiple indexes, as you would expect, involve a trade-off. Whenever a record is added or updated, each index must also be updated. Savings in disk accesses for retrieval are exchanged for additional disk accesses in maintenance. Again, you must consider the balance between retrieval and maintenance operations.

Indexes are not restricted to a single field. It is possible to specify an index that is a combination of several fields. For instance, if item type and color queries were very common, then an index based on the concatenation of both fields could be created. As a result, such queries could be answered with a search of a single index rather than scanning two indexes as in the preceding example. The SQL for creating the combined index is

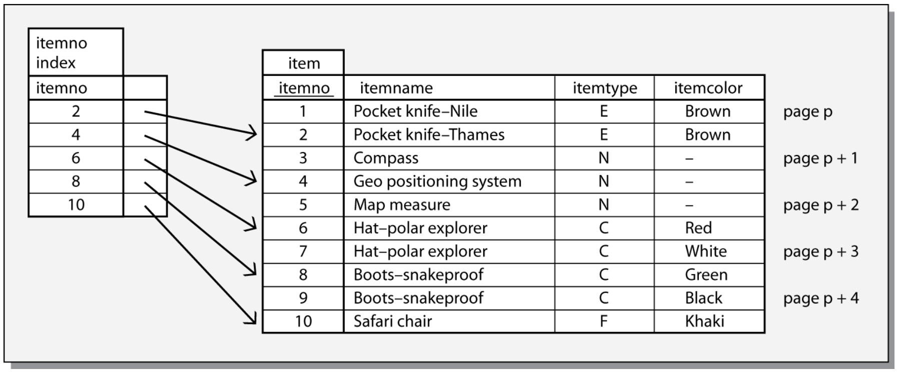
```
CREATE INDEX typecolorindx ON item (itemtype, itemcolor);
```

Sparse indexes

Indexes are used to reduce disk accesses to accelerate retrieval. The simple model of an index introduced earlier suggests that the index contains an entry for each record of the file. If we can shrink the index to eliminate an entry for each record, we can save more disk accesses. Indeed, if an index is small enough, it, or key parts of it, can be retained continuously in primary memory.

There is a physical sequence to the records in a file. Records within a page are in a physical sequence, and pages on a disk are in a physical sequence. A file can also have a logical sequence, the ordering of the file on some field within a record. For instance, the item file could be ordered on itemno. Making the physical and logical sequences correspond is a way to save disk accesses. Remember that the item file was assumed to have a record size of 1,024 bytes, the same size as a page, and one record was stored per page. If we now assume the record size is 512 bytes, then two records are stored per page. Furthermore, suppose that item is physically stored in `itemno` sequence. The index can be compressed by storing `itemno` for the second record on each page and that page's address.

A sparse index for item



Consider the process of finding the record with ITEMNO = 7. First, the index is scanned to find the first value for `itemno` that is greater than or equal to 7, the entry for ITEMNO = 8. Second, the page on which this record is stored (page p + 3) is loaded into memory. Third, the required record is extracted from the page.

Indexes that take advantage of the physical sequencing of a file are known as sparse or non-dense because they do not contain an entry for every value of the indexed field. (A dense index is one that contains an entry for every value of the indexed field.)

As you would expect, a sparse index has pros and cons. One major advantage is that it takes less storage space and so requires fewer disk accesses for reading. One disadvantage is that it can no longer be used for existence tests because it does not contain a value for every record in the file.

A file can have only one sparse index because it can have only one physical sequence. This field on which a sparse index is based is often called the primary key. Other indexes, which must be dense, are called secondary indexes.

In SQL, a sparse index is created using the CLUSTER option. For example, to define a sparse index on item the command is

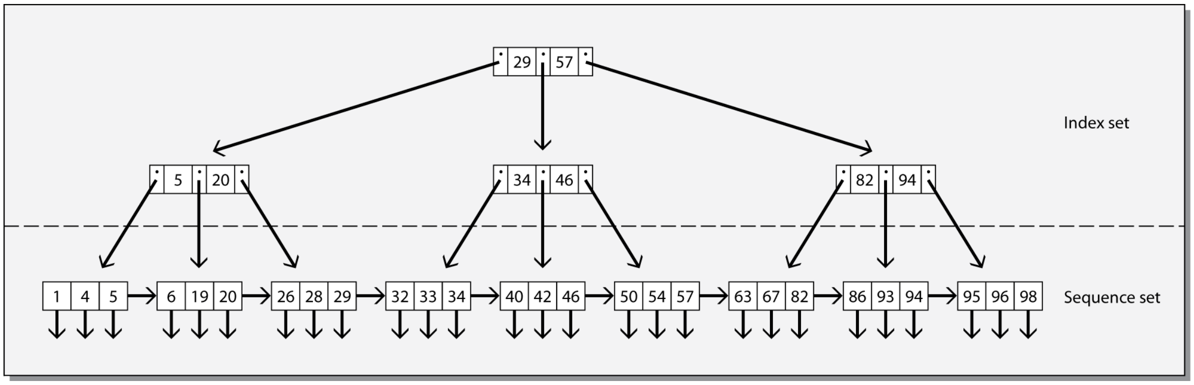
```
CREATE INDEX itemnoindx ON item (itemno) CLUSTER;
```

B-trees

The B-tree is a particular form of index structure that is frequently the main storage structure for relational systems. It is also the basis for IBM's VSAM (Virtual Storage Access Method), the file structure underlying DB2, IBM's relational database. A B-tree is an efficient structure for both sequential and direct accessing of a file. It consists of two parts: the sequence set and the index set.

The sequence set is a single-level index to the file with pointers to the records (the vertical arrows in the lower part of the following figure). It can be sparse or dense, but is normally dense. Entries in the sequence set are grouped into pages, and these pages are linked together (the horizontal arrows) so that the logical ordering of the sequence set is the physical ordering of the file. Thus, the file can be processed sequentially by processing the records pointed to by the first page (records with identifiers 1, 4, and 5), the records pointed to by the next logical page (6, 19, and 20), and so on.

Structure of a simple B-tree



The index set is a tree-structured index to the sequence set. The top of the index set is a single node called the root. In this example, it contains two values (29 and 57) and three pointers. Records with an identifier less than or equal to 29 are found in the left branch, records with an identifier greater than 29 and less than or equal to 57 are found in the middle branch, and records with an identifier greater than 57 are found in the right branch. The three pointers are the page numbers of the left, middle, and right branches. The nodes at the next level have similar interpretations. The pointer to a particular record is found by moving down the tree until a node entry points to a value in the sequence set; this value can be used to retrieve the record. Thus, the index set provides direct access to the sequence set and then the data.

The index set is a B-tree. The combination of index set and sequence set is generally known as a B+ tree (B-plus tree). The B-tree simplifies the concept in two ways. *First*, the number of data values and pointers for any given node is not restricted to 2 and 3, respectively. In its general form, a B-tree of order *n* can have at least *n* and no more than *2n* data values. If it has *k* values, the B-tree will have *k+1* pointers (in the example tree, nodes have two data values, *k* = 2, and there are three, *k+1* = 3, pointers). *Second*, B-trees typically have free space to permit rapid insertion of data values and possible updating of pointers when a new record is added.

As usual, there is a trade-off with B-trees. Retrieval will be fastest when each node occupies one page and is packed with data values and pointers. This lack of free space will slow down the addition of new records, however. Most implementations of the B+ tree permit a specified portion of free space to be defined for both the index and sequence set.

Hashing

Hashing reduces disk accesses by allowing direct access to a file. As you know, direct accessing via an index requires at least two or more accesses. The index must be loaded and searched, and then the record retrieved. For some applications, direct accessing via an index is too slow. Hashing can reduce the number of accesses to almost one by using the value in some field (the hash field, which is usually the primary key) to compute a record's address. A hash function converts the hash field into a hash address.

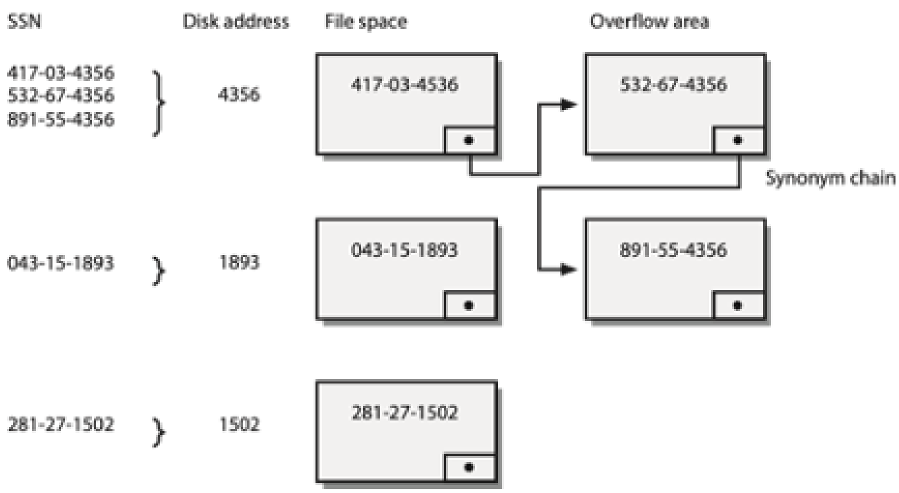
Consider the case of an organization that uses the nine-digit Social Security number (SSN) as the personnel key. If the organization has 10,000 students, it could simply use the last four digits of the SSN as the address. In effect, the file space is broken up into 10,000 slots with one personnel record in each slot. For example, the data for the person with SSN 417-03-4356 would be stored at address 4356. In this case, the hash field is SSN, and the hash function is

hash address = remainder after dividing SSN by 10,000.

What about the person with SSN 532-67-4356? Unfortunately, the hashing function will give the same address because most hashing schemes cannot guarantee a unique hash address for every record. When two hash fields have the same address, they are called synonyms, and a collision is said to have occurred.

There are techniques for handling synonyms. Essentially, you store the colliding record in an overflow area and point to it from the hash address. Of course, more than two records can have the same hash address, which in turn creates a synonym chain. The following figure shows an example of hashing with a synonym chain. Three SSNs hash to the same address. The first record (417-03-4356) is stored at the hash address. The second record (532-67-4356) is stored in the overflow area and is connected by a pointer to the first record. The third record (891-55-4356) is also stored in the overflow area and connected by a pointer from the second record. Because each record contains the full key (SSN in this case), during retrieval the system can determine whether it has the correct record or should follow the chain to the next record.

An example of hashing



If there are no synonyms, hashing gives very fast direct retrieval, taking only one disk access to retrieve a record. Even with a small percentage of synonyms, retrieval via hashing is very fast. Access time degrades, however, if there are long synonym chains.

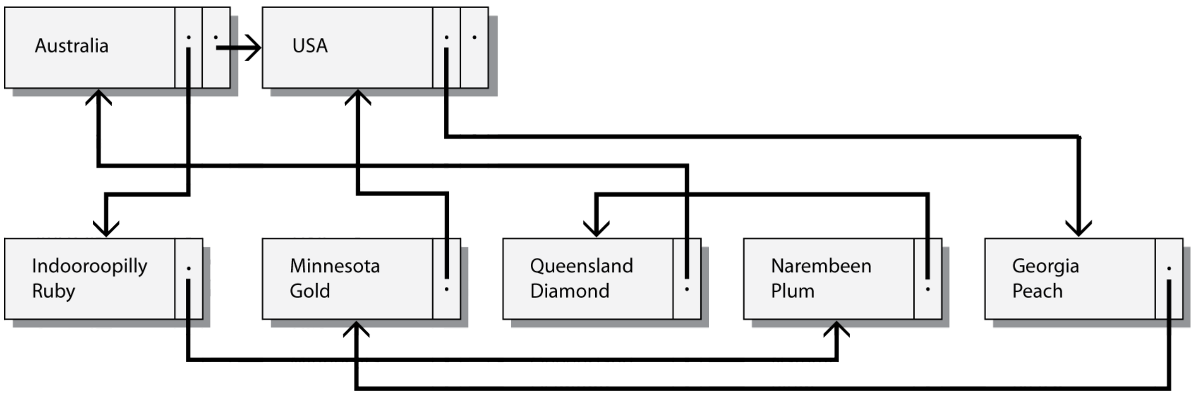
There are a number of different approaches to defining hashing functions. The most common method is to divide by a prime and use the remainder as the address. Before adopting a particular hashing function, test several functions on a representative sample of the hash field. Compute the percentage of synonyms and the length of synonym chains for each potential hashing function and compare the results.

Of course, hashing has trade-offs. There can be only one hashing field. In contrast, a file can have many indexed fields. The file can no longer be processed sequentially because its physical sequence loses any logical meaning if the records are not in primary key sequence or are sequenced on any other field.

Linked lists

A linked list is a useful data structure for interfile clustering. Suppose that the query, *Find all stocks of country X*, is a frequent request. Disk accesses can be reduced by storing a nation and its corresponding stocks together in a linked list.

A linked list



In this example, we have two files: `nation` and `stock`. Records in `nation` are connected by pointers (e.g., the horizontal arrow between Australia and USA). The pointers are used to maintain the nation file in logical sequence (by nation, in this case). Each record in `nation` is linked to its `stock` records by a forward-pointing chain. The `nation` record for Australia points to the first `stock` record (Indooroopilly Ruby), which points to the next (Narembeen Plum), which points to the final record in the chain (Queensland Diamond). Notice that the last record in this `stock` chain points to the `nation` record to which the chain belongs (i.e., Australia). Similarly, there is a chain for the two USA stocks. In any chain, the records are maintained in logical sequence (by firm name, in this case).

This linked-list structure is also known as a parent/child structure. (The parent in this case is `nation` and the child is `stock`.) Although it is a suitable structure for representing a one-to-many (1:m) relationship, it is possible to depict more than one parent/child relationship. For example, stocks could be grouped into classes (e.g., high, medium, and low risk). A second chain linking all stocks of the same risk class can run through the file. Interfile clustering of a nation and its corresponding stocks will speed up access; so, the record for the parent Australia and its three children should be stored on one page. Similarly, all American stocks could be clustered with the USA record and so on for all other nations.

Of course, you expect some trade-offs. What happens with a query such as *Find the country in which Minnesota Gold is listed?* There is no quick way to find Minnesota Gold except by sequentially searching the `stock` file until the record is found and then following the chain to the parent nation record. This could take many disk accesses. One way to circumvent this is to build an index or hashing scheme for `stock` so that any record can be found directly. Building an index for the parent, `nation`, will speed up access as well.

Linked lists come in a variety of flavors:

- Lists that have two-way pointers, both forward and backward, speed up deletion.

- For some lists, every child record has a parent pointer. This helps prevent chain traversal when the query is concerned with finding the parent of a particular child.

Bitmap index

A bitmap index uses a single bit, rather than multiple bytes, to indicate the specific value of a field. For example, instead of using three bytes to represent *red* as an item's color, the color red is represented by a single bit. The relative position of the bit within a string of bits is then mapped to a record address.

Conceptually, you can think of a bitmap as a matrix. The following figure shows a bitmap containing details of an item's color and code. An item can have three possible colors; so, three bits are required, and two bits are needed for the two codes for the item. Thus, you can see that, in general, *n* bits are required if a field can have *n* possible values.

A bitmap index

itemcode	color			code		Disk address
	Red	Green	Blue	A	N	
1001	0	0	1	0	1	d1
1002	1	0	0	1	0	d2
1003	1	0	0	1	0	d3
1004	0	1	0	1	0	d4

When an item has a large number of values (i.e., *n* is large), the bitmap for that field will be very sparse, containing a large number of zeros. Thus, a bitmap is typically useful when the value of *n* is relatively small. When is *n* small or large? There is no simple answer; rather, database designers have to simulate alternative designs and evaluate the trade-offs.

In some situations, the bit string for a field can have multiple bits set to *on* (set to 1). A location field, for instance, may have two bits *on* to represent an item that can be found in Atlanta and New York.

The advantage of a bitmap is that it usually requires little storage. For example, we can recast the bitmap index as a conventional index. The core of the bitmap in the previous figure (i.e., the cells storing data about the color and code) requires 5 bits for each record, but the core of the traditional index requires 9 bytes, or 72 bits, for each record.

An index

itemcode	color	code	Disk address
	char(8)	char(1)	
1001	Blue	N	d1
1002	Red	A	d2
1003	Red	A	d3
1004	Green	A	d4

Bitmaps can accelerate query time for complex queries.

Join index

Many RDBMS queries frequently require two or more tables to be joined. Indeed, some people refer to the RDBMS as a join machine. A join index can be used to improve the execution speed of joins by creating indexes based on the matching columns of tables that are highly likely to be joined. For example, `natcode` is the common column used to join nation and stock, and each of these tables can be indexed on `natcode`.

Indexes on natcode for nation and stock

nation index	
natcode	Disk address
UK	d1
USA	d2

stock index	
natcode	Disk address
UK	d101
UK	d102
UK	d103
USA	d104
USA	d105

A join index is a list of the disk addresses of the rows for matching columns. All indexes, including the join index, must be updated whenever a row is inserted into or deleted from the `nation` or `stock` tables. When a join of the two tables on the matching column is made, the join index is used to retrieve only those records that will be joined. This example demonstrates the advantage of a join index. If you think of a join as a product with a WHERE clause, then without a join index, 10 (2*5) rows have to be retrieved, but with the join index only 5 rows are retrieved. Join indexes can also be created for joins involving several tables. As usual, there is a trade-off. Joins will be faster, but insertions and deletions will be slower because of the need to update the indexes.

Join Index

join index	
nation disk address	stock disk address
d1	d101
d1	d102
d1	d103
d2	d104
d2	d105

Data coding standards

The successful exchange of data between two computers requires agreement on how information is coded. The American Standard Code for Information Interchange (ASCII) and Unicode are two widely used data coding standards.

ASCII

ASCII is the most common format for digital text files. In an ASCII file, each alphabetic, numeric, or special character is represented by a 7-bit code. Thus, 128 (2^7) possible characters are defined. Because most computers process data in eight-bit bytes or multiples thereof, an ASCII code usually occupies one byte.

Unicode

Unicode, officially the Unicode Worldwide Character Standard, is a system for the interchange, processing, and display of the written texts of the diverse languages of the modern world. Unicode provides a unique binary code for every character, no matter what the platform, program, or language. The Unicode standard currently contains around 145,000 distinct coded characters derived from 159 supported language scripts. These characters cover the principal written languages of the world.

Unicode provides for two encoding forms: a default 16-bit form, and a byte (8-bit) form called UTF-8 that has been designed for ease of use with existing ASCII-based systems. As the default encoding of HTML and XML, Unicode is required for Internet protocols. It is implemented in all modern operating systems and computer languages such as Java. Unicode is the basis of software that must function globally.

Data storage devices

Many corporations double the amount of data they need to store every two to three years. Thus, the selection of data storage devices is a key consideration for data managers. When evaluating data storage options, data managers need to consider possible uses, which include:

1. Online data
2. Backup files
3. Archival storage

Many systems require data to be online—continually available. Here the prime concerns are usually access speed and capacity, because many firms require rapid response to large volumes of data. Backup files are required to provide security against data loss. Ideally, backup storage is high volume capacity at low cost. Archived data may need to be stored for many years; so the archival medium should be highly reliable, with no data decay over extended periods, and low-cost.

In deciding what data will be stored where, database designers need to consider a number of variables:

1. Volume of data
2. Volatility of data
3. Required speed of access to data
4. Cost of data storage
5. Reliability of the data storage medium
6. Legal standing of stored data

The design options are discussed and considered in terms of the variables just identified. First, we review some of the options.

Magnetic technology

Over USD 80 billion is spent annually on magnetic storage devices.[1] A significant proportion of many units IS hardware budgets is consumed by magnetic storage. Magnetic technology, the backbone of data storage for five decades, is based on magnetization and demagnetization of spots on a magnetic recording surface. The same spot can be magnetized and demagnetized repeatedly. Magnetic recording materials may be coated on rigid platters (hard disks), thin ribbons of material (magnetic tapes), or rectangular sheets (magnetic cards).

The main advantages of magnetic technology are its relative maturity, widespread use, and declining costs. A major disadvantage is susceptibility to strong magnetic fields, which can corrupt data stored on a disk. Another shortcoming is data storage life; magnetization decays with time.

As organizations continue to convert paper to images, they need a very long-term, unalterable storage medium for documents that could be demanded in legal proceedings (e.g., a customer's handwritten insurance claim or a client's completed form for a mutual fund investment). Because data resident on magnetic media can be readily changed and decay with time, magnetic storage is not an ideal medium for storing archival data or legal documents.

Fixed magnetic disk

A fixed magnetic disk, also known as a hard disk drive (HDD), containing one or more recording surfaces is permanently mounted in the disk drive and cannot be removed. The recording surfaces and access mechanism are assembled in a clean room and then sealed to eliminate contaminants, making the device more reliable and permitting higher recording density and transfer rates. Access time is typically between 4 and 10 ms, and transfer rates can be as high as 1,300 Mbytes per second. Disk unit capacities range from gigabytes to terabytes. Magnetic disk units are sometimes called direct-access storage devices or DASD (pronounced *dasdee*).

[1] Physics World

Fixed disk is the medium of choice for most systems, from personal computers to supercomputers. It gives rapid, direct access to large volumes of data and is ideal for highly volatile files. The major disadvantage of magnetic disk is the possibility of a head crash, which destroys the disk surface and data. With the read/write head of a disk just 15 millionths of an inch (40 millionths of a centimeter) above the surface of the disk, there is little margin for error. Hence, it is crucial to make backup copies of fixed disk files regularly.

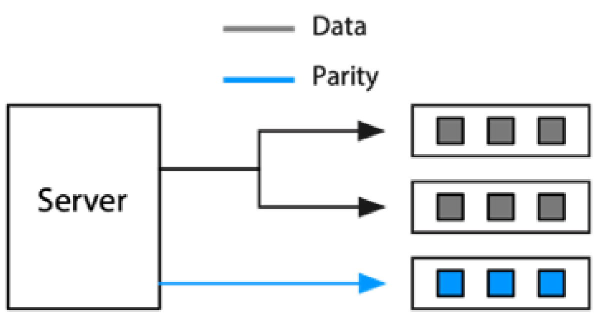
RAID

RAID (redundant array of independent, or inexpensive, disks) takes advantage of the economies of scale in manufacturing disks for the personal computing market. The cost of drives increases with their capacity and speed. RAIDs use several cheaper drives whose total cost is less than one high-capacity drive but have the same capacity. In addition to lower cost, RAID offers greater data security. All RAID levels (except level 0) can reconstruct the data on any single disk from the data stored on the remaining disks in the array in a manner that is quite transparent to the user.

RAID uses a combination of mirroring and striping to provide greater data protection. When a file is written to a mirrored array, the disk controller writes identical copies of each record to each drive in the array. When a file is read from a mirrored array, the controller reads alternate pages simultaneously from each of the drives. It then puts these pages together in the correct sequence before delivering them to the computer. Mirroring reduces data access time by approximately the number of drives in the array because it interleaves the reading of records. During the time a conventional disk drive takes to read one page, a RAID system can read two or more pages (one from each drive). It is simply a case of moving from sequential to parallel retrieval of pages. Access times are halved for a two-drive array, quartered for a four-drive array, and so on.

If a read error occurs on a particular disk, the controller can always read the required page from another drive in the array because each drive has a full copy of the file. Mirroring, which requires at least two drives, improves response time and data security; however, it does take considerably more space to store a file because multiple copies are created.

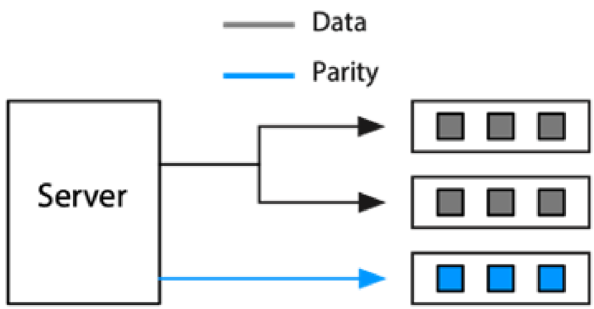
Mirroring



When a file is written to a striping array of three drives, for instance, one half of the file is written to the first drive and the second half to the second drive. The third drive is used for error correction. A parity bit is constructed for each corresponding pair of bits written to drives one and two, and this parity bit is written to the third drive. A parity bit is a bit added to a chunk of data (e.g., a byte) to ensure that the number of bits in the chunk with a value of one is even or odd. Parity bits can be checked when a file is read to detect data errors, and in many cases the data errors can be corrected. Parity bits demonstrate how redundancy supports recovery.

When a file is read by a striping array, portions are retrieved from each drive and assembled in the correct sequence by the controller. If a read error occurs, the lost bits can be reconstructed by using the parity data on the third drive. If a drive fails, it can be replaced and the missing data restored on the new drive. Striping requires at least three drives. Normally, data are written to every drive but one, and that remaining drive is used for the parity bit. Striping gives added data security without requiring considerably more storage, but it does not have the same response time increase as mirroring.

Striping



RAID subsystems are divided into seven levels, labeled 0 through 6. All RAID levels, except level 0, have common features:

- There is a set of physical disk drives viewed by the operating system as a single, logical drive.
- Data are distributed across corresponding physical drives.
- Parity bits are used to recover data in the event of a disk failure.

Level 0 has been in use for many years. Data are broken into blocks that are interleaved or *striped* across disks. By spreading data over multiple drives, read and write operations can occur in parallel. As a result, I/O rates are higher, which makes level 0 ideal for I/O intensive applications such as recording video. There is no additional parity information and thus no data recovery when a drive failure occurs.

Level 1 implements *mirroring*, as described previously. This is possibly the most popular form of RAID because of its effectiveness for critical nonstop applications, although high levels of data availability and I/O rates are counteracted by higher storage costs. Another disadvantage is that every write command must be executed twice (assuming a two-drive array), and thus level 1 is inappropriate for applications that have a high ratio of writes to reads.

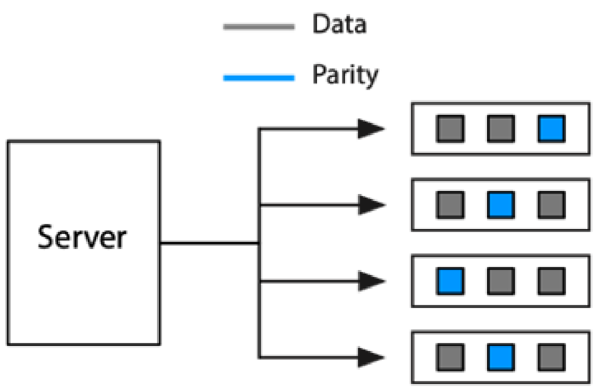
Level 2 implements *striping by interleaving* blocks of data on each disk and maintaining parity on the check disk. This is a poor choice when an application has frequent, short random disk accesses, because every disk in the array is accessed for each read operation. However, RAID 2 provides excellent data transfer rates for large sequential data requests. It is therefore suitable for computer-aided drafting and computer-aided manufacturing (CAD/CAM) and multimedia applications, which typically use large sequential files. RAID 2 is rarely used, however, because the same effect can be achieved with level 3 at a lower cost.

Level 3 utilizes *striping at the bit or byte level*, so only one I/O operation can be executed at a time. Compared to level 1, RAID level 3 gives lower-cost data storage at lower I/O rates and tends to be most useful for the storage of large amounts of data, common with CAD/CAM and imaging applications.

Level 4 uses *sector-level striping*; thus, only a single disk needs to be accessed for a read request. Write requests are slower, however, because there is only one parity drive.

Level 5, *a variation of striping*, reads and writes data to separate disks independently and permits simultaneous reading and writing of data. Data and parity are written on the same drive. Spreading parity data evenly across several drives avoids the bottleneck that can occur when there is only one parity drive. RAID 5 is well designed for the high I/O rates required by transaction processing systems and servers, particularly e-mail servers. It is the most balanced implementation of the RAID concept in terms of price, reliability, and performance. It requires less capacity than mirroring with level 1 and higher I/O rates than striping with level 3, although performance can decrease with update-intensive operations. RAID 5 is frequently found in local-area network (LAN) environments.

RAID level 5



RAID 6 takes fault tolerance to another level by enabling a RAID system to still function when two drives fail. Using a method called *double parity*, it distributes parity information across multiple drives so that, on the fly, a disk array can be rebuild even if another drive fails before the rebuild is complete.

RAID does have drawbacks. It often lowers a system's performance in return for greater reliability and increased protection against data loss. Extra disk space is required to store parity information. Extra disk accesses are required to access and update parity information. You should remember that RAID is not a replacement for standard backup procedures; it is a technology for increasing the fault tolerance of critical online systems. RAID systems offer terabytes of storage.

Removable magnetic disk

Removable drives can be plugged into a system as required. The disk's removability is its primary advantage, making it ideal for backup and transport. For example, you might plug in a removable drive to the USB port of your laptop once a day to backup its hard drive. Removable disk is also useful when applications need not be continuously online. For instance, the monthly payroll system might be stored on a removable drive and mounted as required. Removable drives cost about USD 100 per terabyte.

Magnetic tape

A magnetic tape is a thin ribbon of plastic coated with ferric oxide. The once commonly used nine-track 2,400-foot (730 m) tape has a capacity of about 160 Mbytes and a data transfer rate of 2 Mbytes per second. The designation nine-track means nine bits are stored across the tape (8 bits plus one parity bit). Magnetic tape was used extensively for archiving and backup in early database systems; however, its limited capacity and sequential nature have resulted in its replacement by other media, such as magnetic tape cartridge.

Magnetic tape cartridges

Tape cartridges, with a capacity measured in Gbytes and transfer rates of up to 6 Mbytes per second, have replaced magnetic tape. They are the most cost effective (from a purchase price USD/GB perspective) magnetic recording device. Furthermore, a tape cartridge does not consume any power when unmounted and stored in a library. Thus, the operating costs for a tape storage archival system are much lower than an equivalent hard disk storage system, though hard disks provide faster access to archived data.

Mass storage

There exists a variety of mass storage devices that automate labor-intensive tape and cartridge handling. The storage medium, with a capacity of terabytes, is typically located and mounted by a robotic arm. Mass storage devices can currently handle hundreds of petabytes of data. They have slow access time because of the mechanical loading of tape storage, and it might take several minutes to load a file.

Solid-state memory

A solid-state disk (SSD) connects to a computer in the same way as regular magnetic disk drives do, but they store data on arrays of memory chips. SSDs require lower power consumption (longer battery life) and come in smaller sizes (smaller and lighter devices). As well, SSDs have faster access times. However, they cost around six times as much as equivalent size HDDs, but they declining in prices rapidly, and might be as little as twice as costly by 2021. SSD is common for laptops.

A flash drive, also known as a keydrive or jump drive, is a small, removable storage device with a Universal Serial Bus (USB) connector. It contains solid-state memory and is useful for transporting small amounts of data. Capacity is in the range 1 to 128 Gbytes. The price for low capacity drives is about about USD 1–2 per Gbytes.

Optical technology

Optical technology is a more recent development than magnetic. Its advantages are high-storage densities, low-cost media, and direct access. Optical storage systems work by reflecting beams of laser light off a rotating disk with a minutely pitted surface. As the disk rotates, the amount of light reflected back to a sensor varies, generating a stream of ones and zeros. A tiny change in the wavelength of the laser translates into as much as a tenfold increase in the amount of information that can be stored. Optical technology is highly reliable because it is not susceptible to head crashes.

There are three storage media based on optical technology: CD-ROM, DVD, and Blu-ray. Most optical disks can reliably store records for at least 10 years under prescribed conditions of humidity and temperature. Actual storage life may be in the region of 30 to 50 years. Optical media are compact medium for the storage of permanent data. Measuring 12 cm (~ 4.75 inches) in diameter, the size consistency often means later generation optical readers can read earlier generation media.

Optical technology

Medium	Introduced	Capacity
Compact disc (CD)	1982	.65 Gbytes
Digital versatile disc (DVD)	1995	1.5–17 Gbytes
Blu-ray disc (BD)	2006	25–50 Gbytes

Optical media options

Format	Description
ROM	Read-only
R	Recordable or write-once
RW	Read/write or re-recordable

Data stored on read-only or write-once optical media are generally reckoned to have the highest legal standing of any of the forms discussed because, once written, the data cannot be altered. Thus, they are ideal for storage of documents that potentially may be used in court. Consequently, we are likely to see archival storage emerge as the major use for optical technology.

Storage-area networks

A storage-area network (SAN) is a high-speed network for connecting and sharing different kinds of storage devices, such as tape libraries and disk arrays. In the typical LAN, the storage device (usually a disk) is closely coupled to a server and communicates through a bus connection. Communication among storage devices occurs through servers and over the LAN, which can lead to network congestion.

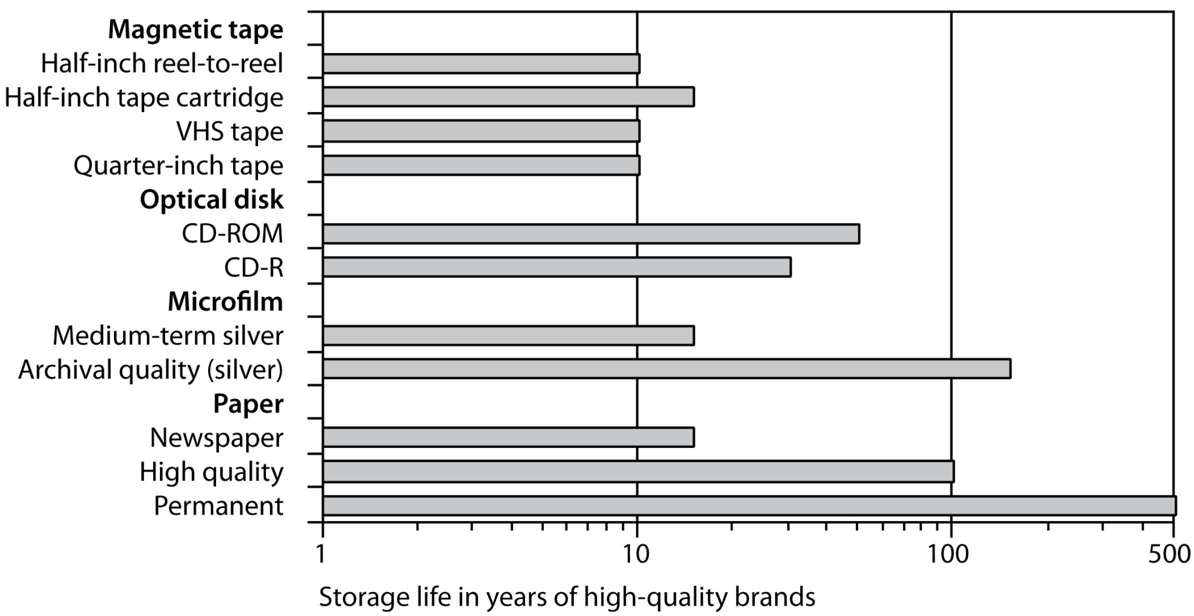
SANs support disk mirroring, backup and restore, archival and retrieval of archived data, data migration from one storage device to another, and the sharing of data among different servers in a network. Typically, a SAN is part of the overall network of computing resources for an enterprise. SANs are likely to be a critical element for supporting e-commerce and applications requiring large volumes of data. As Storage Area Networks (SANs) have become increasingly affordable, their use in enterprises and even smaller businesses has become widespread.

Long-term storage

Long-term data storage has always been of concern to societies and organizations. Some data, such as the location of toxic-waste sites, must be stored for thousands of years. Increasingly, governments are converting their records to electronic format. Unlike paper, magnetic media do not show degradation until it is too late to recover the data. Magnetic tapes can become so brittle that the magnetic coating separates from the backing. In addition, computer hardware and software rapidly become obsolete. The medium may be readable, but there could be no hardware to read it and no software to decode it.

Paper, it seems, is still the best medium for long-term storage, and research is being conducted to create extra-long-life paper that can store information for hundreds of years. This paper, resistant to damage from heat, cold, and magnetism, will store data in a highly compact format but, obviously, nowhere near optical disk densities.

The life expectancy of various media at 20°C (68°F) and 40 percent relative humidity (source: National Media Lab)



Data compression

Data compression is a method for encoding digital data so that they require less storage space and thus less communication bandwidth. There are two basic types of compression: lossless methods, in which no data are lost when the files are restored to their original format, and lossy methods, in which some data are lost when the files are decompressed.

Lossless compression

During lossless compression, the data-compression software searches for redundant or repetitive data and encodes it. For example, a string of 100 asterisks (*) can be stored more compactly by a compression system that records the repeated character (i.e.,*) and the length of the repetition (i.e., 100). The same principle can be applied to a photo that contains a string of horizontal pixels of the same color. Clearly, you want to use lossless compression with text files (e.g., a business report or spreadsheet).

Lossy compression

Lossy compression is used for graphics, video, and audio files because humans are often unable to detect minor data losses in these formats. Audio files can often be compressed to 10 percent of their original size (e.g., an MP3 version of a CD recording).

> ☒ *Skill builder*
>
> An IS department in a major public university records the lectures for 10 of its classes for video streaming to its partner universities in India and China. Each twice-weekly lecture runs for 1.25 hours and a semester is 15 weeks long. A video streaming expert estimates that one minute of digital video requires 6.5 Mbytes using MPEG-4 and Apple's QuickTime software. What is MPEG-4? Calculate how much storage space will be required and recommend a storage device for the department.

Details of the various storage devices are summarized in the following table. A simple three-star rating system has been used for each device—the more stars, the better. In regard to access speed, RAID gets more stars than DVD-RAM because it retrieves a stored record more quickly. Similarly, optical rates three stars because it costs less per megabyte to store data on a magneto-optical disk than on a fixed disk. The scoring system is relative. The fact that removable disk gets two stars for reliability does not mean it is an unreliable storage medium; it simply means that it is not as reliable as some other media.

Relative merits of data storage devices

Device	Access speed	Volume	Volatility	Cost per megabyte	Reliability	Legal standing
Solid state	***	*	***	*	***	*
Fixed disk	***	***	***	***	**	*
RAID	***	***	***	***	***	*

Device	Access speed	Volume	Volatility	Cost per megabyte	Reliability	Legal standing
Removable disk	**	**	***	**	**	*
Flash memory	**	*	***	*	***	*
Tape	*	**	*	***	**	*
Cartridge	**	***	*	***	**	*
Mass Storage	**	***	*	***	**	*
SAN	***	***	***	***	***	*
Optical-ROM	*	***	*	***	***	***
Optical-R	*	***	*	***	***	**
Optical-RW	*	***	**	***	***	*

Legend

Characteristic	More stars mean ...
Access speed	Faster access to data
Volume	Device more suitable for large files
Volatility	Device more suitable for files that change frequently
Cost per megabyte	Less costly form of storage
Reliability	Device less susceptible to an unrecoverable read error
Legal standing	Media more acceptable as evidence in court

Conclusion

The internal and physical aspects of database design are a key determinant of system performance. Selection of appropriate data structures can substantially curtail disk access and reduce response times. In making data structure decisions, the database administrator needs to weigh the pros and cons of each choice. Similarly, in selecting data storage devices, the designer needs to be aware of the trade-offs. Various devices and media have both strengths and weaknesses, and these need to be considered.

Summary

The data deluge is increasing the importance of data management for organizations. It takes considerably longer to retrieve data from a hard disk than from main memory. Appropriate selection of data structures and data access methods can considerably reduce delays by reducing disk accesses. The key characteristics of disk storage devices that affect database access are rotational speed and access arm speed. Access arm movement can be minimized by storing frequently used data on the same track on a single surface or on the same track on different surfaces. Records that are frequently used together should be clustered together. Intrafile clustering applies to the records within a single file. Interfile clustering applies to multiple files. The disk manager, the part of the operating system responsible for physical I/O, maintains a directory of pages. The file manager, a level above the disk manager, contains a directory of files.

Indexes are used to speed up retrieval by reducing disk accesses. An index is a file containing the value of the index field and the address of its full record. The use of indexes involves a trade-off between faster retrievals and slower updates. Indexes can be used for both sequential and direct access. A file can have multiple indexes. A sparse index does not contain an entry for every value of the indexed field. The B-tree, a particular form of index structure, consists of two parts: the sequence set and the index set. Hashing is a technique for reducing disk accesses that allows direct access to a file. There can be only one hashing field. A hashed file can no longer be processed sequentially because its physical sequence has lost any logical meaning. A linked list is a useful data structure for interfile clustering. It is a suitable structure for representing a 1:m relationship. Pointers between records are used to maintain a logical sequence. Lists can have forward, backward, and parent pointers.

Systems designers have to decide what data storage devices will be used for online data, backup files, and archival storage. In making this decision, they must consider the volume of data, volatility of data, required speed of access to data, cost of data storage, reliability of the data storage medium, and the legal standing of the stored data. Magnetic technology, the backbone of data storage for six decades, is based on magnetization and demagnetization of spots on a magnetic recording surface. Fixed disk, removable disk, magnetic tape, tape cartridge, and mass storage are examples of magnetic technology. RAID uses several cheaper drives whose total cost is less than one high-capacity drive. RAID uses a combination of mirroring or striping to provide greater data protection. RAID subsystems are divided into six levels labeled 0 through 6. A storage-area network (SAN) is a high-speed network for connecting and sharing different kinds of storage devices, such as tape libraries and disk arrays.

Optical disks can reliably store records for at least 10 years and possibly up to 30 years. Optical technology is not susceptible to head crashes.

Data compression techniques reduce the need for storage capacity and bandwidth. Lossless methods result in no data loss, whereas with lossy techniques, some data are lost during compression.

Key terms and concepts

Access time	Index set
Archival file	Interfile clustering
ASCII	Internal schema
B-tree	Intrafile clustering
Backup file	Join index
Bitmap index	Linked list
Blue-ray disc (BD)	Lossless compression
Compact disc (CD)	Lossy compression
Clustering	Magnetic disk
Conceptual schema	Magnetic tape

Cylinder	Mass storage
Data compression	Mirroring
Data deluge	Page
Data storage device	Parity
Database architecture	Pointer
Digital versatile disc (DVD)	Redundant arrays of inexpensive or independent drives (RAID)
Disk manager	Sequence set
External schema	Solid-state disk (SSD)
File manager	Sparse index
Hash address	Storage-area network (SAN)
Hash field	Striping
Hash function	Track
Hashing	Unicode
Index	VSAM

Exercises

1. Why is a disk drive considered a bottleneck?
2. What is the difference between a record and a page?
3. Describe the two types of delay that can occur prior to reading a record from a disk. What can be done to reduce these delays?
4. What is clustering? What is the difference between intrafile and interfile clustering?
5. Describe the differences between a file manager and a disk manager.
6. What is an index?
7. What are the advantages and disadvantages of indexing?
8. Write the SQL to create an index on the column natcode in the nation table.
9. A Paris insurance firm keeps paper records of all policies and claims made on it. The firm now has a vault containing 100 filing cabinets full of forms. Because Paris rental costs are so high, the CEO has asked you to recommend a more compact medium for long-term storage of these documents. Because some insurance claims are contested, she is very concerned with ensuring that documents, once stored, cannot be altered. What would you recommend and why?
10. A video producer has asked for your advice on a data storage device. She has specified that she must be able to record video at 5 to 7 Mbytes per second. What would you recommend and why?
11. A German consumer research company collects scanning data from supermarkets throughout central Europe. The scanned data include product code identifier, price, quantity purchased, time, date, supermarket location, and supermarket name, and in some cases where the supermarket has a frequent buyer plan, it collects a consumer identification code. It has

also created a table containing details of the manufacturer of each product. The database contains over 500 Tbytes of data. The data are used by market researchers in consumer product companies. A researcher will typically request access to a slice of the database (e.g., sales of all detergents) and analyze these data for trends and patterns. The consumer research company promises rapid access to its data. Its goal is to give clients access to requested data within one to two minutes. Once clients have access to the data, they expect very rapid response to queries. What data storage and retrieval strategy would you recommend?

12. A magazine subscription service has a Web site for customers to place orders, inquire about existing orders, or check subscription rates. All customers are uniquely identified by an 11-digit numeric code. All magazines are identified by a 2- to 4-character code. The company has approximately 10 million customers who subscribe to an average of four magazines. Subscriptions are available to 126 magazines. Draw a data model for this situation. Decide what data structures you would recommend for the storage of the data. The management of the company prides itself on its customer service and strives to answer customer queries as rapidly as possible.
13. A firm offers a satellite-based digital radio service to the continental U.S. market. It broadcasts music, sports, and talk-radio programs from a library of 1.5 million digital audio files, which are sent to a satellite uplink and then beamed to car radios equipped to accept the service. Consumers pay $9.95 per month to access 100 channels.
    a. Assuming the average size of a digital audio file is 5 Mbytes (~4 minutes of music), how much storage space is required?
    b. What storage technology would you recommend?
14. Is MP3 a lossless or lossy compression standard?
15. What is the data deluge? What are the implications for data management?
16. Apple's music subscription service offers around 50 million songs in the iTunes store. What storage technology might be a good choice for this library?

22 Data Integrity

Integrity without knowledge is weak and useless, and knowledge without integrity is dangerous and dreadful.

Samuel Johnson, Rasselas, 1759

Learning objectives

After completing this chapter, you will - understand the three major data integrity outcomes; - understand the strategies for achieving each of the data integrity outcomes; - understand the possible threats to data integrity and how to deal with them; - understand the principles of transaction management; - realize that successful data management requires making data available and maintaining data integrity.

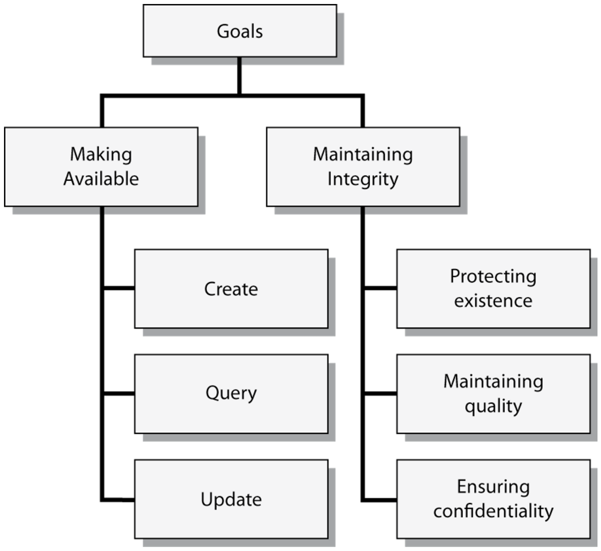
Introduction

The management of data is driven by two goals: availability and integrity. Availability deals with making data available to whomever needs it, whenever and wherever he or she needs it, and in a meaningful form. As illustrated in following figure, availability concerns the creation, interrogation, and update of data stores. Although most of the book, thus far, has dealt with making data available, a database is of little use to anyone unless it has integrity. Maintaining data integrity implies three goals:[1]

1. Protecting existence: Data are available when needed.
2. Maintaining quality: Data are accurate, complete, and current.
3. Ensuring confidentiality: Data are accessed only by those authorized to do so.

Goals of managing organizational memory

[1]To the author's knowledge, Gordon C. Everest was the first to define data integrity in terms of these three goals. See Everest, G. (1986). *Database management: objectives, systems functions, and administration*. New York, NY: McGraw-Hill.



This chapter considers the three types of strategies for maintaining data integrity:

1. Legal strategies are externally imposed laws, rules, and regulations. Privacy laws are an example.
2. Administrative strategies are organizational policies and procedures. An example is a standard operating procedure of storing all backup files in a locked vault.
3. Technical strategies are those incorporated in the computer system (e.g., database management system, application program, or operating system). An example is the inclusion of validation rules (e.g., NOT NULL) in a database definition that are used to ensure data quality when a database is updated.

A consistent database is one in which all data integrity constraints are satisfied.

Our focus is on data stored in multiuser computer databases and technical and administrative strategies for maintaining integrity in computer system environments., commonly referred to as database integrity. More and more, organizational memories are being captured in computerized databases. From an integrity perspective, this is a very positive development. Computers offer some excellent mechanisms for controlling data integrity, but this does not eliminate the need for administrative strategies. Both administrative and technical strategies are still needed.

Who is responsible for database integrity? Some would say the data owners, others the database administrator. Both groups are right; database integrity is a shared responsibility, and the way it is managed may differ across organizations. Our focus is on the tools and strategies for maintaining data integrity, regardless of who is responsible.

The strategies for achieving the three integrity outcomes are summarized in the following table. We will cover procedures for protecting existence, followed by those for maintaining integrity, and finally those used to ensure confidentiality. Before considering each of these goals, we need to examine the general issue of transaction management.

Strategies for maintaining database integrity

Database integrity outcome	Strategies for achieving the outcome
Protecting existence	Isolation (preventive)
	Database backup and recovery (curative)
Maintaining quality	Update authorization
	Integrity constraints/data validation
	Concurrent update control
Ensuring confidentiality	Access control
	Encryption

Transaction management

Transaction management focuses on ensuring that transactions are correctly recorded in the database. The transaction manager is the element of a DBMS that processes transactions. A transaction is a series of actions to be taken on the database such that they must be entirely completed or entirely aborted. A transaction is a logical unit of work. All its elements must be processed; otherwise, the database will be incorrect. For example, with a sale of a product, the transaction consists of at least two parts: an update to the inventory on hand, and an update to the customer information for the items sold in order to bill the customer later. Updating only the inventory or only the customer information would create a database without integrity and an inconsistent database.

Transaction managers are designed to accomplish the ACID (atomicity, consistency, isolation, and durability) concept. These attributes are:

1. Atomicity: If a transaction has two or more discrete pieces of information, either all of the pieces are committed or none are.
2. Consistency: Either a transaction creates a valid new database state or, if any failure occurs, the transaction manager returns the database to its prior state.
3. Isolation: A transaction in process and not yet committed must remain isolated from any other transaction.
4. Durability: Committed data are saved by the DBMS so that, in the event of a failure and system recovery, these data are available in their correct state.

Transaction atomicity requires that all transactions are processed on an all-or-nothing basis and that any collection of transactions is serializable. When a transaction is executed, either all its changes to the database are completed or none of the changes are performed. In other words, the entire unit of work must be completed. If a transaction is terminated before it is completed, the transaction manager must undo the executed actions to restore the database to its state before the transaction commenced (the consistency concept). Once a transaction is successfully completed, it does not need to be undone. For efficiency reasons, transactions should be no larger than necessary to ensure the integrity of the database. For example, in an accounting system, a debit and credit would be an appropriate transaction, because this is the minimum amount of work needed to keep the books in balance.

Serializability relates to the execution of a set of transactions. An interleaved execution schedule (i.e., the elements of different transactions are intermixed) is serializable if its outcome is equivalent to a non-interleaved (i.e., serial) schedule. Interleaved operations are often used to increase the efficiency of computing resources, so it is not unusual for the components of multiple transactions to be interleaved. Interleaved transactions cause problems when they interfere with each other and, as a result, compromise the correctness of the database.

The ACID concept is critical to concurrent update control and recovery after a transaction failure.

Concurrent update control

When updating a database, most applications implicitly assume that their actions do not interfere with any other's actions. If the DBMS is a single-user system, then a lack of interference is guaranteed. Most DBMSs, however, are multiuser systems, where many analysts and applications can be accessing a given database at the same time. When two or more transactions are allowed to update a database concurrently, the integrity of the database is threatened. For example, multiple agents selling airline tickets should not be able to sell the same seat twice. Similarly, inconsistent results can be obtained by a retrieval transaction when retrievals are being made simultaneously with updates. This gives the appearance of a loss of database integrity. We will first discuss the integrity problems caused by concurrent updates and then show how to control them to ensure database quality.

Lost update

Uncontrolled concurrent updates can result in the lost-update or phantom-record problem. To illustrate the lost-update problem, suppose two concurrent update transactions simultaneously want to update the same record in an inventory file. Both want to update the quantity-on-hand field (quantity). Assume quantity has a current value of 40. One update transaction wants to add 80 units (a delivery) to quantity, while the other transaction wants to subtract 20 units (a sale).

Suppose the transactions have concurrent access to the record; that is, each transaction is able to read the record from the database before a previous transaction has been committed. This sequence is depicted in the following figure. Note that the first transaction, A, has not updated the database when the second transaction, B, reads the same record. Thus, both A and B read in a value of 40 for quantity. Both make their calculations, then A writes the value of 120 to disk, followed by B promptly overwriting the 120 with 20. The result is that the delivery of 80 units, transaction A, is lost during the update process.

Lost update when concurrent accessing is allowed

Time	Action		Database record	
			Part#	Quantity
			P10	40
T1	App A receives message for delivery of 80 units of P10			
T2	App A reads the record for P10	←	P10	40
T3	App B receives message for sale of 20 units of P10			
T4	App B reads the record for P10	←	P10	40

Time	Action		Database record	
T5	App A processes delivery (40 + 80 = 120)			
T6	App A updates the record for P10	→	P10	120
T7	App B processes the sale of (40 - 20 = 20)			
T8	App B updates the record P10	→	P10	20

Inconsistent retrievals occur when a transaction calculates some aggregate function (e.g., sum) over a set of data while other transactions are updating the same data. The problem is that the retrieval may read some data before they are changed and other data after they are changed, thereby yielding inconsistent results.

The solution: locking

To prevent lost updates and inconsistent retrieval results, the DBMS must incorporate a resource lock, a basic tool of transaction management to ensure correct transaction behavior. Any data retrieved by one application with the intent of updating must be locked out or denied access by other applications until the update is completed (or aborted).

There are two types of locks: Slocks (shared or read locks) and Xlocks (exclusive or write locks). Here are some key points to understand about these types of locks:

1. When a transaction has a Slock on a database item, other transactions can issue Slocks on the same item, but there can be no Xlocks on that item.
2. Before a transaction can read a database item, it must be granted a Slock or Xlock on that item.
3. When a transaction has an Xlock on a database item, no other transaction can issue either a Slock or Xlock on that item.
4. Before a transaction can write to a database item, it must be granted an Xlock on that item.

Consider the example used previously. When A accesses the record for update, the DBMS must refuse all further accesses to that record until transaction A is complete (i.e., an Xlock). As the following figure shows, B's first attempt to access the record is denied until transaction A is finished. As a result, database integrity is maintained. Unless the DBMS controls concurrent access, a multiuser database environment can create both data and retrieval integrity problems.

Valid update when concurrent accessing is not allowed

Time	Action		Database record	
			Part#	Quantity
			P10	40
T1	App A receives message for delivery of 80 units of P10			
T2	App A reads the record for P10	←	P10	40
T3	App B receives message for sale of 20 units of P10			
T4	App B attempts to read the record for P10	deny	P10	40
T5	App A process delivery (40 + 80 = 120)			

Time	Action		Database record	
T6	App A updates the record for P10	→	P10	120
T7	App B reads the record for P10	←	P10	120
T8	App B processes the sale of (120 - 20 = 100)			
T9	App B updates the record P10	→	P10	100

To administer locking procedures, a DBMS requires two pieces of information: 1. Whether a particular transaction will update the database; 2. Where the transaction begins and ends.

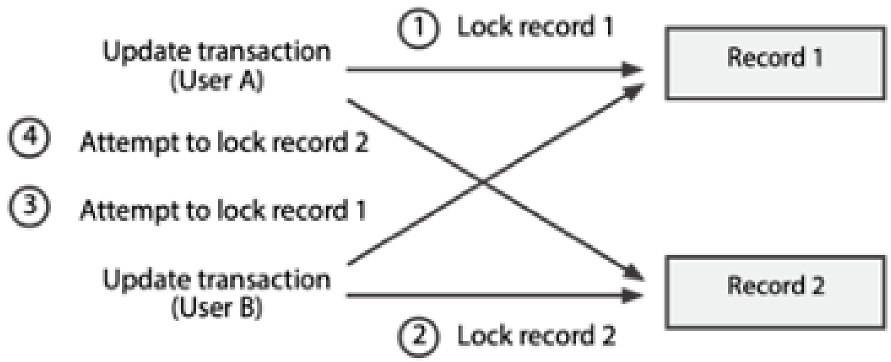
Usually, the data required by an update transaction are locked when the transaction begins and then released when the transaction is completed (i.e., committed to the database) or aborted. Locking mechanisms can operate at different levels of locking granularity: database, table, page, row, or data element. At the most precise level, a DBMS can lock individual data elements so that different update transactions can update different items in the same record concurrently. This approach increases processing overhead but provides the fewest resource conflicts. At the other end of the continuum, the DBMS can lock the entire database for each update. If there were many update transactions to process, this would be very unacceptable because of the long waiting times. Locking at the record level is the most common approach taken by DBMSs.

In most situations, applications are not concerned with locking, because it is handled entirely by the DBMS. But in some DBMSs, choices are provided to the programmer. These are primarily limited to programming language interfaces.

Resource locking solves some data and retrieval integrity problems, but it may lead to another problem, referred to as deadlock or the deadly embrace. Deadlock is an impasse that occurs because two applications lock certain resources, then request resources locked by each other. The following figure illustrates a deadlock situation. Both transactions require records 1 and 2. Transaction A first accesses record 1 and locks it. Then transaction B accesses record 2 and locks it. Next, B's attempt to access record 1 is denied, so the application waits for the record to be released. Finally, A's attempt to access record 2 is denied, so the application waits for the record to be released. Thus, application A's update transaction is waiting for record 2 (locked by application B), and application B is waiting for record 1 (locked by application A). Unless the DBMS intervenes, both applications will wait indefinitely.

There are two ways to resolve deadlock: prevention and resolution. Deadlock prevention requires applications to lock in advance all records they will require. Application B would have to lock both records 1 and 2 before processing the transaction. If these records are locked, B would have to wait.

An example of deadlock



The two-phase locking protocol is a simple approach to preventing deadlocks. It operates on the notion that a transaction has a growing phase followed by a shrinking phase. During the growing phase, locks can be requested. The shrinking phase is initiated by a release statement, which means no additional locks can be requested. A release statement enables the program to signal to the DBMS the transition from requesting locks to releasing locks.

Another approach to deadlock prevention is deadlock resolution, whereby the DBMS detects and breaks deadlocks. The DBMS usually keeps a resource usage matrix, which instantly reflects which applications (e.g., update transactions) are using which resources (e.g., rows). By scanning the matrix, the DBMS can detect deadlocks as they occur. The DBMS then resolves the deadlock by backing out one of the deadlocked transactions. For example, the DBMS might release application A's lock on record 1, thus allowing application B to proceed. Any changes made by application A up to that time (e.g., updates to record 1) would be rolled back. Application A's transaction would be restarted when the required resources became available.

Transaction failure and recovery

When a transaction fails, there is the danger of an inconsistent database. Transactions can fail for a variety of reasons, including

- Program error (e.g., a logic error in the code)
- Action by the transaction manager (e.g., resolution of a deadlock)
- Self-abort (e.g., an error in the transaction data means it cannot be completed)
- System failure (e.g., an operating-system bug)

If a transaction fails for any reason, then the DBMS must be able to restore the database to a correct state. To do this, two statements are required: an end of transaction (EOT) and commit. EOT indicates the physical end of the transaction, the last statement. Commit, an explicit statement, must occur in the transaction code before the EOT statement. The only statements that should occur between commit and EOT are database writes and lock releases.

When a transaction issues a commit, the transaction manager checks that all the necessary write-record locks for statements following the commit have been established. If these locks are not in place, the transaction is terminated; otherwise, the transaction is committed, and it proceeds to execute the database writes and release locks. Once a transaction is committed, a system problem is the only failure to which it is susceptible.

When a transaction fails, the transaction manager must take one of two corrective actions:

- If the transaction has not been committed, the transaction manager must return the database to its state prior to the transaction. That is, it must perform a rollback of the database to its most recent valid state.
- If the transaction has been committed, the transaction manager must ensure that the database is established at the correct post-transaction state. It must check that all write statements executed by the transaction and those appearing between commit and EOT have been applied. The DBMS may have to redo some writes.

Protecting existence

One of the three database integrity outcomes is protecting the existence of the database—ensuring data are available when needed. Two strategies for protecting existence are isolation and database backup and recovery. Isolation is a preventive strategy that involves administrative procedures to insulate the physical database from destruction. Some mechanisms for doing this are keeping data in safe places, such as in vaults or underground; having multiple installations; or having security systems. For example, one organization keeps backup copies of important databases on removable magnetic disks. These are stored in a vault that is always guarded. To gain access to the vault, employees need a badge with an encoded personal voice print. Many companies have total-backup computer centers, which contain duplicate databases and documentation for system operation. If something should happen at the main center (e.g., a flood), they can be up and running at their backup center in a few hours, or even minutes in some highly critical situations. What isolation strategies do you use to protect the backup medium of your personal computer? Do you make backup files?

A study of 429 disaster declarations reported to a major international provider of disaster recovery services provides some insights as to the frequency and effects of different IT disasters. These data cover the period 1981–2000 and identify the most frequent disasters and statistics on the length of the disruption.[2]

Most frequent IT disasters

Category	Description
Disruptive act	Strikes and other intentional human acts, such as bombs or civil unrest, that are designed to interrupt normal organizational processes
Fire	Electrical or natural fires
IT failure	Hardware, software, or network problems
IT move/upgrade	Data center moves and CPU upgrades
Natural event	Earthquakes, hurricanes, severe weather

[2] Source: Lewis Jr, W., Watson, R. T., & Pickren, A. (2003). An empirical assessment of IT disaster probabilities. Communications of the ACM, 46(9), 201-206.

Category	Description
Power outage	Loss of power
Water leakage	Unintended escape of contained water (e.g., pipe leaks, main breaks)

Days of disruption per year

Category	Number	Minimum	Maximum	Mean
Natural event	122	0	85	6.38
IT failure	98	1	61	6.89
Power outage	67	1	20	4.94
Disruptive act	29	1	97	23.93
Water leakage	28	0	17	6.07
Fire	22	1	124	13.31
IT move/upgrade	14	1	204	20.93
Environmental	6	1	183	65.67
Miscellaneous	5	1	416	92.8
IT capacity	2	4	8	6
Theft	2	1	3	2
Construction	1	2	2	2
Flood	1	13	13	13
IT user error	1	1	1	1

Backup and recovery

Database backup and recovery is a curative strategy to protect the existence of a physical database and to recreate or recover the data whenever loss or destruction occurs. The possibility of loss always exists. The use of, and choice among, backup and recovery procedures depends upon an assessment of the risk of loss and the cost of applying recovery procedures. The procedures in this case are carried out by the computer system, usually the DBMS. Data loss and damage should be anticipated. No matter how small the probability of such events, there should be a detailed plan for data recovery.

There are several possible causes for data loss or damage, which can be grouped into three categories.

Storage-medium destruction

In this situation, a portion or all of the database is unreadable as a result of catastrophes such as power or air-conditioning failure, fire, flood, theft, sabotage, and the overwriting of disks or tapes by mistake. A more frequent cause is a disk failure. Some of the disk blocks may be unreadable as a consequence of a read or write malfunction, such as a head crash.

Abnormal termination of an update transaction

In this case, a transaction fails part way through execution, leaving the database partially updated. The database will be inconsistent because it does not accurately reflect the current state of the business. The primary causes of an abnormal termination are a transaction error or system failure. Some operation within transaction processing, such as division by zero, may cause it to fail. A hardware or software failure will usually result in one or more active programs being aborted. If these programs were updating the database, integrity problems could result.

Incorrect data discovered

In this situation, an update program or transaction incorrectly updated the database. This usually happens because a logic error was not detected during program testing.

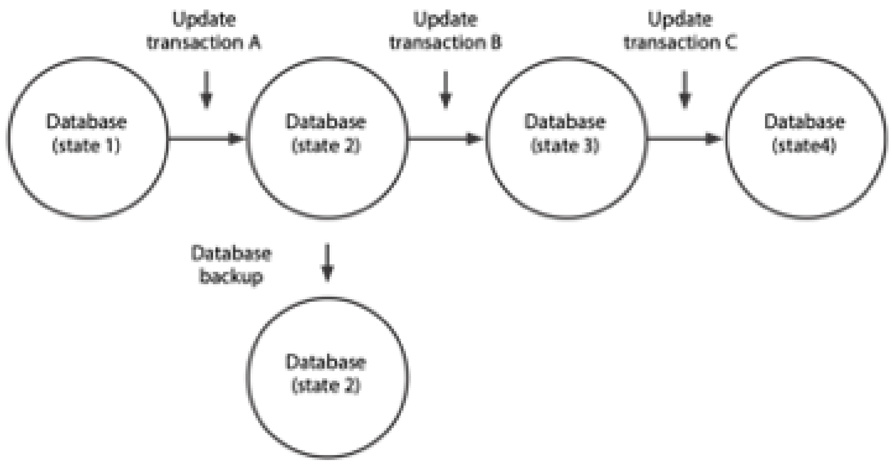
Because most organizations rely heavily on their databases, a DBMS must provide the following three mechanisms for restoring a database quickly and accurately after loss or damage:

1. Backup facilities, which create duplicate copies of the database
2. Journaling facilities, which provide backup copies or an audit trail of transactions or database changes
3. A recovery facility within the DBMS that restores the database to a consistent state and restarts the processing of transactions

Before discussing each of these mechanisms in more depth, let us review the steps involved in updating a database and how backup and journaling facilities might be integrated into this process.

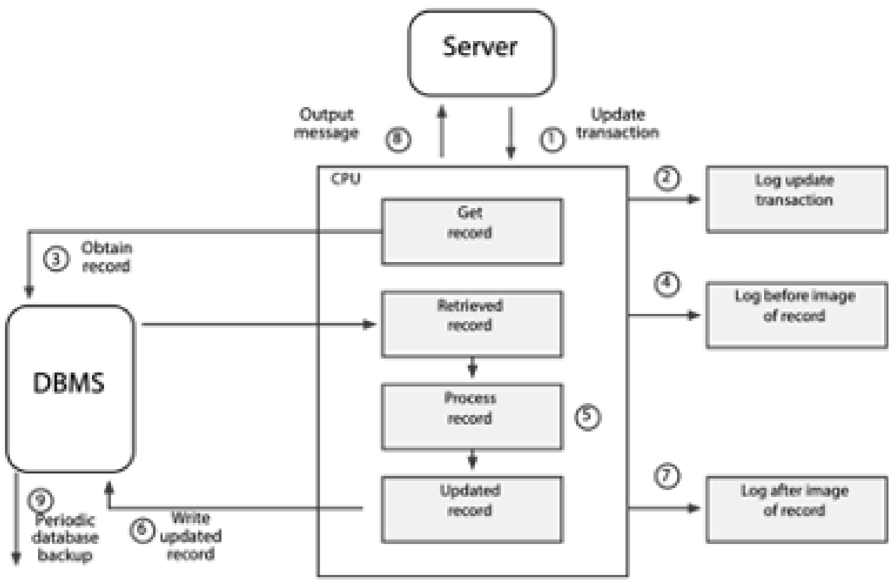
An overview of the database update process is captured in the following figure. The process can be viewed as a series of database state changes. The initial database, state 1, is modified by an update transaction, such as deleting customer Jones, creating a new state (state 2). State 1 reflects the state of the organization with Jones as a customer, while state 2 reflects the organization without this customer. Each update transaction changes the state of the database to reflect changes in organizational data. Periodically, the database is copied or backed up, possibly onto a different storage medium and stored in a secure location. The backup is made when the database is in state 2.

Database state changes as transactions are processed



A more detailed illustration of database update procedures and the incorporation of backup facilities is shown in the following figure.

Possible procedures for a database update



The updating of a single record is described below.

1. The client submits an update transaction from a workstation.
2. The transaction is edited and validated by an application program or the DBMS. If it is valid, it is logged or stored in the transaction log or journal. A journal or log is a special database or file that stores information for backup and recovery.
3. The DBMS obtains the record to be updated.
4. A copy of the retrieved record is logged to the journal file. This copy is referred to as the *before image*, because it is a copy of the database record before the transaction changes it.

5. The transaction is processed by changing the affected data items in the record.
6. The DBMS writes the updated record to the database.
7. A copy of the updated record is written to the journal. This copy is referred to as the *after image*, because it is a copy of the database record after the transaction has updated it.
8. An output message tells the application that the update has been successfully completed.
9. The database is copied periodically. This backup copy reflects all updates to the database up to the time when the copy was made. An alternative strategy to periodic copying is to maintain multiple (usually two) complete copies of the database online and update them simultaneously. This technique, known as *mirroring*, is discussed in Chapter 11.

In order to recover from data loss or damage, it is necessary to store backup data, such as a complete copy of the database or the necessary data to restore the accuracy of a database. Preferably, backup data should be stored on another medium and kept separate from the primary database. As the description of the update process indicates, there are several options for backup data, depending on the objective of the backup procedure.

Backup option

Objective	Action
Complete copy of database	Dual recording of data (mirroring)
Past states of the database (also backup known as database dumps)	Database backup
Changes to the database	Before-image log or journal After-image log or journal
Transactions that caused a change in the state of the database	Transaction log or journal

Data stored for backup and recovery are generally some combination of periodic database backups, transaction logs, and before- and after-image logs. Different recovery strategies use different combinations of backup data to recover a database.

The recovery method is highly dependent on the backup strategy. The database administrator selects a strategy based on a trade-off between ease of recovery from data loss or damage and the cost of performing backup operations. For example, keeping a mirror database is more expensive then keeping periodic database backups, but a mirroring strategy is useful when recovery is needed very quickly, say in seconds or minutes. An airline reservations system could use mirroring to ensure fast and reliable recovery. In general, the cost of keeping backup data is measured in terms of interruption of database availability (e.g., time the system is out of operation when a database is being restored), storage of redundant data, and degradation of update efficiency (e.g., extra time taken in update processing to save before or after images).

Recovery strategies

The type of recovery strategy or procedure used in a given situation depends on the nature of the data loss, the type of backup data available, and the sophistication of the DBMS's recovery facilities. The following discussion outlines four major recovery strategies: switch to a duplicate database, backward recovery or rollback, forward recovery or roll forward, and reprocessing transactions.

The recovery procedure of switching to a duplicate database requires the maintenance of the mirror copy. The other three strategies assume a periodic dumping or backing up of the database. Periodic dumps may be made on a regular schedule, triggered automatically by the DBMS, or triggered externally by personnel. The schedule may be determined by time (hourly, daily, weekly) or by event (the number of transactions since the last backup).

Switching to a duplicate database

This recovery procedure requires maintaining at least two copies of the database and updating both simultaneously. When there is a problem with one database, access is switched to the duplicate. This strategy is particularly useful when recovery must be accomplished in seconds or minutes. This procedure offers good protection against certain storage-medium destruction problems, such as disk failures, but none against events that damage or make both databases unavailable, such as a power failure or a faulty update program. This strategy entails additional costs in terms of doubling online storage capacity. It can also be implemented with dual computer processors, where each computer updates its copy of the database. This duplexed configuration offers greater backup protection at a greater cost.

Backward recovery or rollback

Backward recovery (also called rollback or rolling back) is used to back out or undo unwanted changes to the database. For example, the database update procedures figure shows three updates (A, B, and C) to a database. Let's say that update B terminated abnormally, leaving the database, now in state 3, inconsistent. What we need to do is return the database to state 2 by applying the before images to the database. Thus, we would perform a rollback by changing the database to state 2 with the before images of the records updated by transaction B.

Backward recovery reverses the changes made when a transaction abnormally terminates or produces erroneous results. To illustrate the need for rollback, consider the example of a budget transfer of $1,000 between two departments.

1. The program reads the account record for Department X and subtracts $1,000 from the account balance and updates the database.
2. The program then reads the record for Department Y and adds $1,000 to the account balance, but while attempting to update the database, the program encounters a disk error and cannot write the record.

Now the database is inconsistent. Department X has been updated, but Department Y has not. Thus, the transaction must be aborted and the database recovered. The DBMS would apply the before image to Department X to restore the account balance to its original value. The DBMS may then restart the transaction and make another attempt to update the database.

Forward recovery or roll forward

Forward recovery (also called roll forward or bringing forward) involves recreating a database using a prior database state. Returning to the example in the database update procedures figure, suppose that state 4 of the database was destroyed and that we need to recover it. We would take the last database dump or backup (state 2) and then apply the after-image records created by update transactions B and C. This would return the database to state 4. Thus, roll forward starts with an earlier copy of the database, and by applying after images (the results of good transactions), the backup copy of the database is moved forward to a later state.

Reprocessing transactions

Although similar to forward recovery, this procedure uses update transactions instead of after images. Taking the same example shown above, assume the database is destroyed in state 4. We would take the last database backup (state 2) and then reprocess update transactions B and C to return the database to state 4. The main advantage of using this method is its simplicity. The DBMS does not need to create an after-image journal, and there are no special restart procedures. The one major disadvantage, however, is the length of time to reprocess transactions. Depending on the frequency of database backups and the time needed to get transactions into the identical sequence as previous updates, several hours of reprocessing may be required. Processing new transactions must be delayed until the database recovery is complete.

The following table reviews the three types of data losses and the corresponding recovery strategies one could use. The major problem is to recreate a database using a backup copy, a previous state of organizational memory. Recovery is done through forward recovery, reprocessing, or switching to a duplicate database if one is available. With abnormal termination or incorrect data, the preferred strategy is backward recovery, but other procedures could be used.

What to do when data loss occurs

Problem	Recovery procedures
Storage medium destruction (database is unreadable)	*Switch to a duplicate database—this can be transparent with RAID Forward recovery Reprocessing transactions
Abnormal termination of an update transaction (transaction recovery error or system failure)	*Backward recovery
	Forward recovery or reprocessing transactions—bring forward to the state just before termination of the transaction

Problem	Recovery procedures
Incorrect data detected (database has been incorrectly updated)	*Backward recovery
	Reprocessing transactions has been (excluding those from the update program that created the incorrect data)

- Preferred strategy

Use of recovery procedures

Usually the person doing a query or an update is not concerned with backup and recovery. Database administration personnel often implement strategies that are automatically carried out by the DBMS. ANSI has defined standards governing SQL processing of database transactions that relate to recovery. Transaction support is provided through the use of the two SQL statements COMMIT and ROLLBACK. These commands are employed when a procedural programming language such as Java is used to update a database. They are illustrated in the chapter on SQL and Java.

> ☒ *Skill builder*
>
> An Internet bank with more than 10 million customers has asked for your advice on developing procedures for protecting the existence of its data. What would you recommend?

Maintaining data quality

The second integrity goal is to maintain data quality, which typically means keeping data accurate, complete, and current. *Data are high-quality if they fit their intended uses in operations, decision making, and planning. They are fit for use if they are free of defects and possess desired features*.[3] The preceding definition implicitly recognizes that data quality is determined by the customer. It also implies that data quality is relative to a task. Data could be high-quality for one task and low-quality for another. The data provided by a flight-tracking system are very useful when you are planning to meet someone at the airport, but not particularly helpful for selecting a vacation spot. Defect-free data are accessible, accurate, timely, complete, and consistent with other sources. Desirable features include relevance, comprehensiveness, appropriate level of detail, easy-to-navigate source, high readability, and absence of ambiguity.

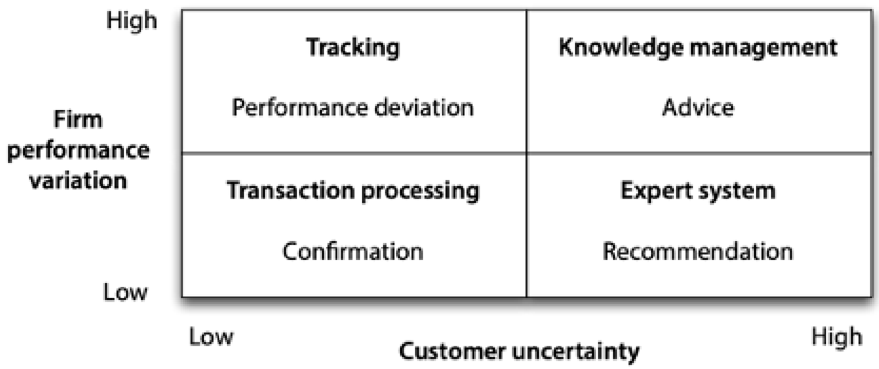
Poor-quality data have several detrimental effects. Customer service decreases when there is dissatisfaction with poor and inaccurate information or a lack of appropriate information. For many customers, information is the heart of customer service, and they lose confidence in firms that can't or don't provide relevant information. Bad data interrupt information processing

[3] Redman, T. C. (2001). *Data quality : the field guide*. Boston: Digital Press.

because they need to be corrected before processing can continue. Poor-quality data can lead to a wrong decision because inaccurate inferences and conclusions are made.

As we have stated previously, data quality varies with circumstances, and the model in the following figure will help you to understand this linkage. By considering variations in a customer's uncertainty about a firm's products and a firm's ability to deliver consistently, we arrive at four fundamental strategies for customer-oriented data quality.

Customer-oriented data quality strategies



Transaction processing: When customers know what they want and firms can deliver consistently, customers simply want fast and accurate transactions and data confirming details of the transaction. Most banking services fall into this category. Customers know they can withdraw and deposit money, and banks can perform reliably.

Expert system: In some circumstances, customers are uncertain of their needs. For instance, Vanguard offers personal investors a choice from more than 150 mutual funds. Most prospective investors are confused by such a range of choices, and Vanguard, by asking a series of questions, helps prospective investors narrow their choices and recommends a small subset of its funds. A firm's recommendation will vary little over time because the characteristics of a mutual fund (e.g., intermediate tax-exempt bond) do not change.

Tracking: Some firms operate in environments where they don't have a lot of control over all the factors that affect performance. One of the busiest airports in the world, Atlanta's Hartsfield Airport becomes congested when bad weather, such as a summer thunderstorm, slows down operations. Passengers clearly know what they want—data on flight delays and their consequences. They assess data quality in terms of how well data tracks delays and notifies them of alternative travel arrangements.

Knowledge management: When customers are uncertain about their needs for products delivered by firms that don't perform consistently, they seek advice from knowledgeable people and organizations. Data quality is judged by the soundness of the advice received. Thus, a woman wanting a custom-built house would likely seek the advice of an architect to select the site, design the house, and supervise its construction, because architects are skilled in eliciting clients' needs and knowledgeable about the building industry.

An organization's first step toward improving data quality is to determine in which quadrant it operates so it can identify the critical information customers expect. Of course, data quality in many situations will be a mix of expectations. The mutual fund will be expected to confirm fund addition and deletion transactions. However, a firm must meet its dominant goal to attract and retain customers.

A firm will also need to consider its dominant data quality strategy for its internal customers, and the same general principles illustrated by the preceding figure can be applied. In the case of internal customers, there can be varying degrees of uncertainty as to what other organizational units can do for them, and these units will vary in their ability to perform consistently for internal customers. For example, consulting firms develop centers of excellence as repositories of knowledge on a particular topic to provide their employees with a source of expertise. These are the internal equivalent of knowledge centers for external customers.

Once they have settled on a dominant data quality strategy, organizations need a corporate-wide approach to data quality, just like product and service quality. There are three generations of data quality: - First generation: Errors in existing data stores are found and corrected. This data cleansing is necessary when much of the data is captured by manual systems. - Second generation: Errors are prevented at the source. Procedures are put in place to capture high-quality data so that there is no need to cleanse it later. As more data are born digital, this approach becomes more feasible. Thus, when customers enter their own data or barcodes are scanned, the data should be higher-quality than when entered by a data-processing operator. - Third generation: Defects are highly unlikely. Data capture systems meet six-sigma standards (3.4 defects per million), and data quality is no longer an issue.

> ☒ *Skill builder*
>
> 1. A consumer electronics company with a well-respected brand offers a wide range of products. For example, it offers nine world-band radios and seven televisions. What data quality strategy would you recommend?
> 2. What data quality focus would you recommend for a regulated natural gas utility?
> 3. A telephone company has problems in estimating how long it takes to install DSL in homes. Sometimes it takes less than an hour and other times much longer. Customers are given a scheduled appointment and many have to make special arrangements so that they are home when the installation person arrives. What data might these customers
> expect from the telephone company, and how would they judge data quality?

Dimensions

The many writers on quality all agree on one thing—quality is multidimensional. Data quality also has many facets, and these are presented in the following table. The list also provides data managers with a checklist for evaluating overall high-quality data. Organizations should aim for a balanced performance across all dimensions because failure in one area is likely to diminish overall data quality.

The dimensions of data quality

Dimension	Conditions for high-quality data
Accuracy	Data values agree with known correct values.

Dimension	Conditions for high-quality data
Completeness	Values for all reasonably expected attributes are available.
Representation consistency	Values for a particular attribute have the same representation across all tables (e.g., dates).
Organizational consistency	There is one organization wide table for each entity and one organization wide domain for each attribute.
Row consistency	The values in a row are internally consistent (e.g., a home phone number's area code is consistent with a city's location).
Timeliness	A value's recentness matches the needs of the most time-critical application requiring it.
Stewardship	Responsibility has been assigned for managing data.
Sharing	Data sharing is widespread across organizational units.
Fitness	The format and presentation of data fit each task for which they are required.
Interpretation	Clients correctly interpret the meaning of data elements.
Flexibility	The content and format of presentations can be readily altered to meet changing circumstances.
Precision	Data values can be conveniently formatted to the required degree of accuracy.
International	Data values can be displayed in the measurement unit of choice (e.g., kilometers or miles).
Accessibility	Authorized users can readily access data values through a variety of devices from a variety of locations.
Security and privacy	Data are appropriately protected from unauthorized access.
Continuity	The organization continues to operate in spite of major disruptive events.
Granularity	Data are represented at the lowest level necessary to support all uses (e.g., hourly sales).
Metadata	There is ready access to accurate data about

☒ *Skill builder*

1. What level of granularity of sales data would you recommend for an online retailer?
2. What level of data quality completeness might you expect for a university's student DBMS?

DBMS and data quality

To assist data quality, functions are needed within the DBMS to ensure that update and insert actions are performed by authorized persons in accordance with stated rules or integrity constraints, and that the results are properly recorded. These functions are accomplished by update authorization, data validation using integrity constraints, and concurrent update control. Each of these functions is discussed in turn.

Update authorization

Without proper controls, update transactions can diminish the quality of a database. Unauthorized users could sabotage a database by entering erroneous values. The first step is to ensure that anyone who wants to update a database is authorized to do so. Some responsible person—usually the database owner or database administrator—must tell the DBMS who is permitted to initiate particular database operations. The DBMS must then check every transaction to ensure that it is authorized. Unauthorized access to a database exposes an organization to many risks, including fraud and sabotage.

Update authorization is accomplished through the same access mechanism used to protect confidentiality. We will discuss access control more thoroughly later in this chapter. In SQL, access control is implemented through GRANT, which gives a user a privilege, and REVOKE, which removes a privilege. (These commands are discussed in Chapter 10.) A control mechanism may lump all update actions into a single privilege or separate them for greater control. In SQL, they are separated as follows:

- UPDATE (privilege to change field values using UPDATE; this can be column specific)
- DELETE (privilege to delete records from a table)
- INSERT (privilege to insert records into a table)

Separate privileges for each of the update commands allow tighter controls on certain update actions, such as updating a salary field or deleting records.

Data validation using integrity constraints

Once the update process has been authorized, the DBMS must ensure that a database is accurate and complete before any updates are applied. Consequently, the DBMS needs to be aware of any integrity constraints or rules that apply to the data. For example, the `qdel` table in the relational database described previously would have constraints such as

- Delivery number (`delno`) must be unique, numeric, and in the range 1–99999.
- Delivered quantity (`delqty`) must be nonzero.
- Item name (`itemname`) must appear in the `qitem` table.
- Supplier code (`splno`) must appear in the `qspl` table.

Once integrity constraints are specified, the DBMS must monitor or validate all insert and update operations to ensure that they do not violate any of the constraints or rules.

The key to updating data validation is a clear definition of valid and invalid data. Data validation cannot be performed without integrity constraints or rules. A person or the DBMS must know acceptable data format, valid values, and procedures to invoke to determine validity. All data validation is based on a prior expression of integrity constraints.

Data validation may not always produce error-free data, however. Sometimes integrity constraints are unknown or are not well defined. In other cases, the DBMS does provide a convenient means for expressing and performing validation checks.

Based on how integrity constraints have been defined, data validation can be performed outside the DBMS by people or within the DBMS itself. External validation is usually done by reviewing input documents before they are entered into the system and by checking system outputs to ensure that the database was updated correctly. Maintaining data quality is of paramount importance, and data validation preferably should be handled by the DBMS as much as possible rather than by the application, which should handle the exceptions and respond to any failed data validation checks.

Integrity constraints are usually specified as part of the database definition supplied to the DBMS. For example, the primary-key uniqueness and referential integrity constraints can be specified within the SQL CREATE statement. DBMSs generally permit some constraints to be stored as part of the database schema and are used by the DBMS to monitor all update operations and perform appropriate data validation checks. Any given database is likely to be subject to a very large number of constraints, but not all of these can be automatically enforced by the DBMS. Some will need to be handled by application programs.

The general types of constraints applied to a data item are outlined in the following table. Not all of these necessarily would be supported by a DBMS, and a particular database may not use all types.

Types of data items in integrity constraint

Type of integrity constraint	Explanation	Example
type	Validating a data item value against a specified data type	Supplier number is numeric.
size	Defining and validating the minimum and maximum size of a data item	Delivery number must be at least 3 digits, and at most 5.
values	Providing a list of acceptable values for a data item	Item colors must match the list provided.
range	Providing one or more ranges within which the data item must lie	Employee numbers must be in the range 1–100.
pattern	Providing a pattern of allowable characters that define permissible formats for data values	Department phone number must be of the form 542-nnnn (stands for exactly four decimal digits).

Type of integrity constraint	Explanation	Example
procedure	Providing a procedure to be invoked to validate data items	A delivery must have valid item name, department, and supplier values before it can be added to the database (tables are checked for valid entries).
Conditional	Providing one or more conditions to apply against data values	If item type is “Y,” then color is null.
Not null (mandatory)	Indicating whether the data item value is mandatory (not null) or optional; the not-null option is required for primary keys	Employee number is mandatory.
Unique	Indicating whether stored values for this data item must be compared to other values of the item within the same table	Supplier number is unique.

As mentioned, integrity constraints are usually specified as part of the database definition supplied to the DBMS. The following example contains typical specifications of integrity constraints for a relational DBMS.

Example

```
CREATE TABLE stock (
    stkcode CHAR(3),
    …,
    natcode CHAR(3),
        PRIMARY KEY(stkcode),
        CONSTRAINT fk_stock_nation
            FOREIGN KEY(natcode)
                REFERENCES nation(natcode)
                    ON DELETE RESTRICT);
```

> *Explanation*
>
> Column stkcode must always have 3 or fewer alphanumeric characters, and stkcode must be unique because it is a primary key.
>
> Column natcode must be assigned a value of 3 or less alphanumeric characters and must exist as the primary key of the nation.
>
> Do not allow the deletion of a row in nation while there still exist rows in stock containing the corresponding value of natcode.

Data quality control does not end with the application of integrity constraints. Whenever an error or unusual situation is detected by the DBMS, some form of response is required. Response rules need to be given to the DBMS along with the integrity constraints. The responses can take many different forms, such as abort the entire program, reject entire update transaction, display a message and continue processing, or let the DBMS attempt to correct the error. The response may vary depending on the type of integrity constraint violated. If the DBMS does not allow the specification of response rules, then it must take a default action when an error is detected. For example, if alphabetic data are entered in a numeric field, most DBMSs will have a default response and message (e.g., nonnumeric data entered in numeric field). In the case of application programs, an error code is passed to the program from the DBMS. The program would then use this error code to execute an error-handling procedure.

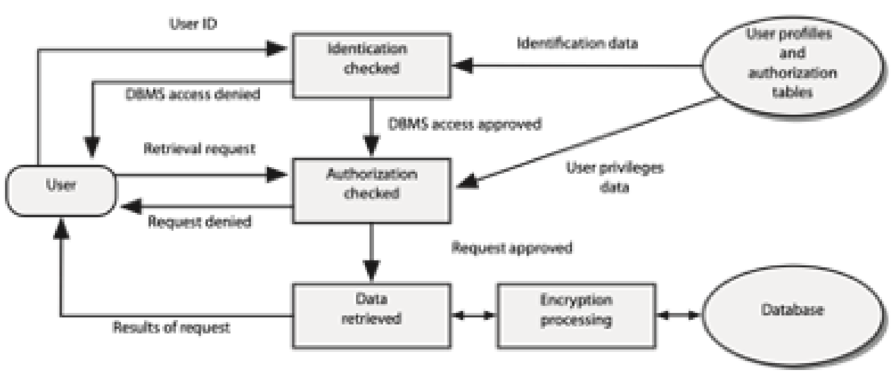
Ensuring confidentiality

Thus far, we have discussed how the first two goals of data integrity can be accomplished: Data are available when needed (protecting existence); data are accurate, complete, and current (maintaining quality). This section deals with the final goal: ensuring confidentiality or data security. Two DBMS functions—access control and encryption—are the primary means of ensuring that the data are accessed only by those authorized to do so. We begin by discussing an overall model of data security.

General model of data security

The following figure depicts the two functions for ensuring data confidentiality: access control and encryption. Access control consists of two basic steps—identification and authorization. Once past access control, the user is permitted to access the database. Access control is applied only to the established avenues of entry to a database. Clever people, however, may be able to circumvent the controls and gain unauthorized access. To counteract this possibility, it is often desirable to hide the meaning of stored data by encrypting them, so that it is impossible to interpret their meaning. Encrypted data are stored in a transformed or coded format that can be decrypted and read only by those with the appropriate key.

A general model of data security



Now let us walk through the figure in detail.

1. A client must be identified and provide additional information required to authenticate this identification (e.g., an account name and password). Client profile information (e.g., a password or a voice print) is used to verify or authenticate a connection.
2. Having authenticated the client, the authorization step is initiated by a request (retrieve or update database). The previously stored client authorization rules (what data each client can access and the authorized actions on those data) are checked to determine whether the client has the right or privilege to access the requested data. (The previously stored client's privileges are created and maintained by an authorized person, database owner, or administrator.) A decision is made to permit or deny the execution of the request. If access is permitted, the transaction is processed against the database.
3. Data are encrypted before storage, and retrieved data are decrypted before presentation.

Data access control

Data access control begins with identification of an organizational entity that can access the database. Examples are individuals, departments, groups of people, transactions, terminals, and application programs. Valid combinations may be required, for example, a particular person entering a certain transaction at a particular terminal. A user identification (often called userid) is the first piece of data the DBMS receives from the subject. It may be a name or number. The user identification enables the DBMS to locate the corresponding entry in the stored user profiles and authorization tables (see preceding figure).

Taking this information, the DBMS goes through the process of authentication. The system attempts to match additional information supplied by the client with the information previously stored in the client's profile. The system may perform multiple matches to ensure the identity of the client (see the following table for the different types). If all tests are successful, the DBMS assumes that the subject is an authenticated client.

Authenticating mechanisms[1]

Class	Examples
Something a person knows: remembered information	Name, account number, password
Something the person has: possessed object	Badge, plastic card, key
Something the person is: personal characteristic	Fingerprint, voiceprint, signature, hand size

Many systems use remembered information to control access. The problem with such information is that it does not positively identify the client. Passwords have been the most widely used form of access control. If used correctly, they can be very effective. Unfortunately, people leave them around where others can pick them up, allowing unauthorized people to gain access to databases.

To deal with this problem, organizations are moving toward using personal characteristics and combinations of authenticating mechanisms to protect sensitive data. Collectively, these mechanisms can provide even greater security. For example, access to a large firm's very valuable marketing database requires a smart card and a fingerprint, a combination of personal characteristic and a possessed object. The database can be accessed through only a few terminals in specific locations, an isolation strategy. Once the smart card test is passed, the DBMS requests entry of other remembered information—password and account number—before granting access.

Data access authorization is the process of permitting clients whose identity has been authenticated to perform certain operations on certain data objects in a shared database. The authorization process is driven by rules incorporated into the DBMS. Authorization rules are in a table that includes subjects, objects, actions, and constraints for a given database. An example of such a table is shown in the following table. Each row of the table indicates that a particular subject is authorized to take a certain action on a database object, perhaps depending on some constraint. For example, the last entry of the table indicates that Brier is authorized to delete supplier records with no restrictions.

Sample authorization table

Subject/Client	Action	Object	Constraint
Accounting department	Insert	Supplier table	None
Purchase department clerk	Insert	Supplier table	If quantity < 200
Purchase department supervisor	Insert	Delivery table	If quantity >= 200
Production department	Read	Delivery table	None
Todd	Modify	Item table	Type and color only
Order-processing program	Modify	Sale table	None
Brier	Delete	Supplier table	None

We have already discussed subjects, but not objects, actions, and constraints. Objects are database entities protected by the DBMS. Examples are databases, views, files, tables, and data items. In the preceding table, the objects are all tables. A view is another form of security. It restricts the client's access to a database. Any data not included in a view are unknown to the client. Although views promote security, several persons may share a view or unauthorized persons may gain access. Thus, a view is another object to be included in the authorization process. Typical actions on objects are shown in the table: read, insert, modify, and delete. Constraints are particular rules that apply to a subject-action-object relationship.

Implementing authorization rules

Most contemporary DBMSs do not implement the complete authorization table shown in the table. Usually, they implement a simplified version. The most common form is an authorization table for subjects with limited applications of the constraint column. Let us take the granting of table privileges, which are needed in order to authorize subjects to perform operations on both tables and views.

Authorization commands

SQL Command	Result
SELECT	Permission to retrieve data

SQL Command	Result
UPDATE	Permission to change data; can be column specific
DELETE	Permission to delete records or tables
INSERT	Permission to add records or tables

The GRANT and REVOKE SQL commands discussed in Chapter 10 are used to define and delete authorization rules. Some examples:

```
GRANT SELECT ON qspl TO vikki;
GRANT SELECT, UPDATE (splname) ON qspl TO huang;
GRANT ALL PRIVILEGES ON qitem TO vikki;
GRANT SELECT ON qitem TO huang;
```

The GRANT commands have essentially created two authorization tables, one for Huang and the other for Vikki. These tables illustrate how most current systems create authorization tables for subjects using a limited set of objects (e.g., tables) and constraints.

A sample authorization table

Client	Object (table)	Action	Constraint
vikki	qspl	SELECT	None
vikki	qitem	UPDATE	None
vikki	qitem	INSERT	None
vikki	qitem	DELETE	None
vikki	qitem	SELECT	None
huang	qspl	SELECT	None
huang	qspl	UPDATE	splname only
huang	qitem	SELECT	None

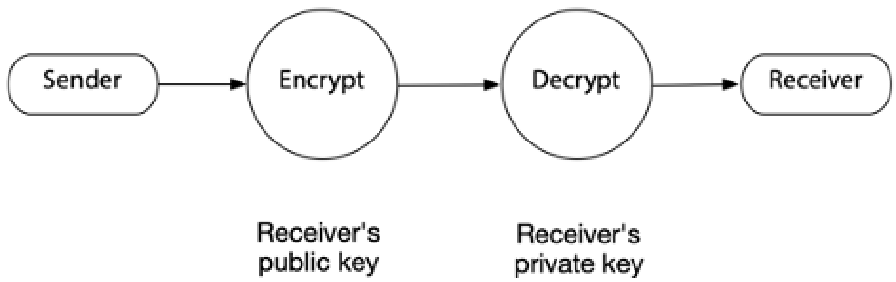
Because authorization tables contain highly sensitive data, they must be protected by stringent security rules and encryption. Normally, only selected persons in data administration have authority to access and modify them.

Encryption

Encryption techniques complement access control. As the preceding figure illustrates, access control applies only to established avenues of access to a database. There is always the possibility that people will circumvent these controls and gain unauthorized access to a database. To counteract this possibility, encryption can be used to obscure or hide the meaning of data. Encrypted data cannot be read by an intruder unless that person knows the method of encryption and has the key. Encryption is any transformation applied to data that makes it difficult to extract meaning. Encryption transforms data into cipher text or disguised information, and decryption reconstructs the original data from cipher text.

Public-key encryption is based on a pair of private and public keys. A person's public key can be freely distributed because it is quite separate from his or her private key. To send and receive messages, communicators first need to create private and public keys and then exchange their public keys. The sender encodes a message with the intended receiver's public key, and upon receiving the message, the receiver applies her private key. The receiver's private key, the only one that can decode the message, must be kept secret to provide secure message exchanging.

Public-key encryption



In a DBMS environment, encryption techniques can be applied to transmitted data sent over communication lines to and from devices, or between computers, and to all highly sensitive stored data in active databases or their backup versions. Some DBMS products include routines that automatically encrypt sensitive data when they are stored or transmitted over communication channels. Other DBMS products provide exits that allow users to code their own encryption routines. Encrypted data may also take less storage space because they are often compressed.

> ❎*Skill builder*
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> A university has decided that it will e-mail students their results at the end of each semester. What procedures would you establish to ensure that only the designated student opened and viewed the e-mail?

Monitoring activity

Sometimes no single activity will be detected as an example of misuse of a system. However, examination of a pattern of behavior may reveal undesirable behavior (e.g., persistent attempts to log into a system with a variety of userids and passwords). Many systems now monitor all activity using audit trail analysis. A time- and date-stamped audit trail of all system actions (e.g., database accesses) is maintained. This audit log is dynamically analyzed to detect unusual behavior patterns and alert security personnel to possible misuse.

A form of misuse can occur when an authorized user violates privacy rules by using a series of authorized queries to gain access to private data. For example, some systems aim to protect individual privacy by restricting authorized queries to aggregate functions (e.g., AVG and COUNT). Since it is impossible to do non-aggregate queries, this approach should prevent access to individual-level data, which it does at the single-query level. However, multiple queries can be constructed to circumvent this restriction.

Assume we know that a professor in the IS department is aged 40 to 50, is single, and attended the University of Minnesota. Consider the results of the following set of queries.[4]

```
SELECT COUNT(*) from faculty
    WHERE dept = 'MIS'
    AND age >= 40 AND age <= 50;
```

10

```
SELECT COUNT(*) FROM faculty
    WHERE dept = 'MIS'
    AND age >= 40 AND age <= 50
    AND degree_from = 'Minnesota';
```

2

```
SELECT COUNT(*) FROM faculty
    WHERE = 'MIS'
    AND age >= 40 AND age <= 50;
    AND degree_from = 'Minnesota'
    AND marital_status = 'S';
```

1

```
SELECT AVG(salary) FROM faculty
    WHERE dept = 'MIS'
    AND age >= 40 AND age <= 50
    AND degree_from = 'Minnesota'
    AND marital_status = 'S';
```

85000

The preceding set of queries, while all at the aggregate level, enables one to deduce the salary of the professor. This is an invasion of privacy and counter to the spirit of the restriction queries to aggregate functions. An audit trail should detect such tracker queries, one or more authorized queries that collectively violate privacy. One approach to preventing tracker queries is to set a lower bound on the number of rows on which a query can report.

[4] Adapted from Helman, P. (1994). *The science of database management*. Burr Ridge, IL: Richard D. Irwin, Inc. p. 434

Summary

The management of organizational data is driven by the joint goals of availability and integrity. Availability deals with making data available to whoever needs them, whenever and wherever they need them, and in a meaningful form. Maintaining integrity implies protecting existence, maintaining quality, and ensuring confidentiality. There are three strategies for maintaining data integrity: legal, administrative, and technical. A consistent database is one in which all data integrity constraints are satisfied.

A transaction must be entirely completed or aborted before there is any effect on the database. Transactions are processed as logical units of work to ensure data integrity. The transaction manager is responsible for ensuring that transactions are correctly recorded.

Concurrent update control focuses on making sure updated results are correctly recorded in a database. To prevent loss of updates and inconsistent retrieval results, a DBMS must incorporate a resource-locking mechanism. Deadlock is an impasse that occurs because two users lock certain resources, then request resources locked by each other. Deadlock prevention requires applications to lock all required records at the beginning of the transaction. Deadlock resolution uses the DBMS to detect and break deadlocks.

Isolation is a preventive strategy that involves administrative procedures to insulate the physical database from destruction. Database backup and recovery is a curative strategy that protects an existing database and recreates or recovers the data whenever loss or destruction occurs. A DBMS needs to provide backup, journaling, and recovery facilities to restore a database to a consistent state and restart the processing of transactions. A journal or log is a special database or file that stores information for backup and recovery. A before image is a copy of a database record before a transaction changes the record. An after image is a copy of a database record after a transaction has updated the record.

In order to recover from data loss or damage, it is necessary to store redundant, backup data. The recovery method is highly dependent on the backup strategy. The cost of keeping backup data is measured in terms of interruption of database availability, storage of redundant data, and degradation of update efficiency. The four major recovery strategies are switching to a duplicate database, backward recovery or rollback, forward recovery or roll forward, and reprocessing transactions. Database administration personnel often implement recovery strategies automatically carried out by the DBMS. The SQL statements COMMIT and ROLLBACK are used with a procedural programming language for implementing recovery procedures.

Maintaining quality implies keeping data accurate, complete, and current. The first step is to ensure that anyone wanting to update a database is required to have authorization. In SQL, access control is implemented through GRANT and REVOKE. Data validation cannot be performed without integrity constraints or rules. Data validation can be performed external to the DBMS by personnel or within the DBMS based on defined integrity constraints. Because maintaining data quality is of paramount importance, it is desirable that the DBMS handles data validation rather than the application. Error response rules need to be given to the DBMS along with the integrity constraints.

Two DBMS functions, access control and encryption, are the primary mechanisms for ensuring that the data are accessed only by authorized persons. Access control consists of identification and authorization. Data access authorization is the process of permitting users whose identities have been authenticated to perform certain operations on certain data objects. Encrypted data cannot be read by an intruder unless that person knows the method of encryption and has the key. In a DBMS environment, encryption can be applied to data sent over communication lines between computers and data storage devices.

Database activity is monitored to detect patterns of activity indicating misuse of the system. An audit trail is maintained of all system actions. A tracker query is a series of aggregate function queries designed to reveal individual-level data.

Key terms and concepts

ACID	Integrity constraint
Administrative strategies	Isolation
After image	Journal
All-or-nothing rule	Legal strategies
Atomicity	Locking
Audit trail analysis	Maintaining quality
Authentication	Private key
Authorization	Protecting existence
Backup	Public-key encryption
Before image	Recovery
COMMIT	Reprocessing
Concurrent update control	REVOKE
Consistency	Roll forward
Data access control	ROLLBACK
Data availability	Rollback
Data quality	Serializability
Data security	Slock
Database integrity	Technical strategies
Deadlock prevention	Tracker query
Deadlock resolution	Transaction
Deadly embrace	Transaction atomicity
Decryption	Transaction manager
Durability	Two-phase locking protocol
Encryption	Validation
Ensuring confidentiality	Xlock
GRANT	

Exercises

1. What are the three goals of maintaining organizational memory integrity?
2. What strategies are available for maintaining data integrity?
3. A large corporation needs to operate its computer system continuously to remain viable. It currently has data centers in Miami and San Francisco. Do you have any advice for the CIO?

4. An investment company operates out of a single office in Boston. Its business is based on many years of high-quality service, honesty, and reliability. The CEO is concerned that the firm has become too dependent on its computer system. If some disaster should occur and the firm's databases were lost, its reputation for reliability would disappear overnight and so would many of its customers in this highly competitive business. What should the firm do?
5. What mechanisms should a DBMS provide to support backup and recovery?
6. What is the difference between a before image and an after image?
7. A large organization has asked you to advise on backup and recovery procedures for its weekly, batch payroll system. They want reliable recovery at the lowest cost. What would you recommend?
8. An online information service operates globally and prides itself on its uptime of 99.98 percent. What sort of backup and recovery scheme is this firm likely to use? Describe some of the levels of redundancy you would expect to find.
9. The information systems manager of a small manufacturing company is considering the backup strategy for a new production planning database. The database is used every evening to create a plan for the next day's production. As long as the production plan is prepared before 6 a.m. the next day, there is no impact upon plant efficiency. The database is currently 200 Mbytes and growing about 2 percent per year. What backup strategy would you recommend and why?
10. How do backward recovery and forward recovery differ?
11. What are the advantages and disadvantages of reprocessing transactions?
12. When would you use ROLLBACK in an application program?
13. When would you use COMMIT in an application program?
14. Give three examples of data integrity constraints.
15. What is the purpose of locking?
16. What is the likely effect on performance between locking at a row compared to locking at a page?
17. What is a deadly embrace? How can it be avoided?
18. What are three types of authenticating mechanisms?
19. Assume that you want to discover the grade point average of a fellow student. You know the following details of this person. She is a Norwegian citizen who is majoring in IS and minoring in philosophy. Write one or more aggregate queries that should enable you to determine her GPA.
20. What is encryption?
21. What are the disadvantages of the data encryption standard (DES)?
22. What are the advantages of public-key encryption?

23. A national stock exchange requires listed companies to transmit quarterly reports to its computer center electronically. Recently, a hacker intercepted some of the transmissions and made several hundred thousand dollars because of advance knowledge of one firm's unexpectedly high quarterly profits. How could the stock exchange reduce the likelihood of this event?