Designing Relational Databases

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Designing Relational Databases

1 Introduction

1.1 Welcome

The purpose of this guide is to teach you how to successfully design relational databases. While this guide will cover some concepts which are specific to 4th Dimension ("4D"), most of the concepts covered in this guide could be applied to other relational database management systems.

At the conclusion of this guide, you should be able to interview a user who wishes to develop a relational database system, and using the skills obtained from this guide, successfully translate his or her requirements into a workable design.

You should then be able to produce a set of drawings which will communicate to the user (and to any other developer) the nature of your design.

1.2 How the guide works

1.2.1 What you will be doing while working through this guide

Using this guide you will examine the relational database model in detail. In the process, the guide will define lots of technical terms — don't let this throw you. Relational database theory is mostly common sense.

- You are also going to be drawing pictures of database designs while completing the various exercises contained in this guide. There will be lots of exercises. In this guide you will be using a technology known as a pencil and paper. There are a variety of CASE tools on the market, none of which is any better for our purposes than a pencil and paper. The 4D structure editor is sometimes used as a simple CASE tool. This has some disadvantages:
- It is unforgiving (tables and fields cannot be deleted).
- The location of relation lines cannot be controlled.
- Many things, such as primary keys, are not clearly identified.

A pencil and paper, on the other hand, has the following advantages:

- Very portable.
- Highly correctable (the eraser serves this function well).
- Low power requirement.
- Very user-friendly (flat learning curve).

Thus, this guide will not generally be "hands-on" as that term is normally defined (meaning working with computer software). However, it will be very much "hands-on" in the sense that you will be working actively throughout the guide to design databases which

meet real-world demands.

Bear in mind when working these exercises that there may be more than one correct answer. Designing relational databases is as much of an art as a science. Usually, this book will point out when more than one answer is correct. In that case, the book will give one correct answer. If you need confirmation that your answer is correct, check with your tutor.

Towards the end of the guide, you will begin to use 4D more as you translate designs into physical database structures. At the conclusion of the guide, you will look at optimization issues involved in building relational structures in 4D. During this period, you may want to use 4D more extensively.

1.2.2 Guide agenda

You will be taking a look at the theory of the relational database model and defining terms. Later you will begin looking in detail at the rules of database design, using a concept called normalization. While doing so, you will look at some relatively good and bad database designs.

After that, you will begin to examine a way to represent databases in pictures, using a technique called an entity relationship diagram. During this portion of the guide, you will begin to turn to more advanced database design problems.

After that you will begin examining the process of capturing the business rules and constraints which need to be built into the database design. You will also read about the issues of choosing workable names. Then you will cover security as a part of the design process. Issues of performance, and the various "tricks and traps" associated with 4D's implementation of the relational model will be discussed. You will learn when to break or bend the rules in order to gain better performance. Finally, the guide will conclude with a series of exercises which will apply everything you have learned in the guide.

Thus, the guide can be broken up into two areas. The first part is almost entirely concerned with the design phase of database development. Only later will you delve into the areas of construction when you examine optimization and implementation issues. The materials will frequently make this distinction. The statement that you are designing, not programming is your clue that you are covering areas where 4D may cause us to eventually bend or break the rules. However, it is much easier (and safer!) to break the rules after you have created a correct and complete design. Our recommendation will always be to complete the design process first, and then look at areas where the design needs to be adjusted to meet performance objectives.

1.3 Conventions

This guide material will use certain typographic conventions, including:

- The following *italic* font indicates a term that is being defined or explained for the first time.
- The following **normal font** refers to a database object like a table or column
- Characters you type are shown **in this typeface**.
  - Example: Type **Johnson** into the **Name** field.
- Special keys on your keyboard are shown like this: **Enter** and **Return**.
- Choosing an item from a menu is described like this:
  - Choose **File ¬ Open**
  - Explanation: From the **File** menu, choose the **Open** item.
- 4D programming items are shown consistent with the way they are displayed in 4D:

4D Programming Styles

[Customers]State	Field
ALERT	Command
MyProcedure	Procedure

1.4 Phases of software development

This guide does not cover programming details to any significant degree. Rather, this guide is concerned with the design phase of software development.

Software development includes the following six phases:

- System specification
- Requirements analysis
- Design
- Construction (coding)
- Testing
- Maintenance

System specification refers to the process of discovering that a new system is needed, and describing the problem it is designed to solve in broad terms. This is primarily a business issue, and is not covered by this guide.

During requirements analysis the details of what the software is supposed to do is fleshed out. This phase completes the definition of what the software is going to do. The how occurs next. Again, this phase is not covered by this guide.

Design refers to the process of creating a plan for how the software will be built, including where the data is to be stored, the sources of data, and how the data flows through the sys-

tem. It is this phase, particularly with respect to identifying the data, and how it will be stored, which is the primary subject of this guide.

Construction refers to the process of actually building the software. It is this phase that most ACI University training classes address. In addition, you will move into this phase during the last section of this guide.

Testing is the process of evaluating software to confirm that it does, in fact, do what it is supposed to do. The formal testing phase is not covered explicitly in this guide (although testing as a part of construction is certainly covered).

Maintenance is the on-going process of supporting the software while it is in production. Again, this phase is not explicitly covered by this guide.

Each of these phases may occur in a relatively formal or informal way. For example, in the case of a small ad hoc system for the use of a single user (who often happens to be the programmer), the entire process may occur in the programmer's head.

On the other hand, in a large, multi-user client server system for a large enterprise, these phases will probably occur in a much more formal way. In fact, some of the phases may be further broken down, Design might be broken down into architectural design and detailed design, for example.

1.5 Benefits of formal software design

It is a basic principle of computer science that all of these phases occur on the development of any system regardless of whether the system designers are aware of it or not. It has also been proven that some formality in the process of software development generally results in dramatic improvements in the resulting software, as well as reducing the cost of development.

In the case of the small ad hoc system described above, there is relatively little consequence of a major mistake in design. This is simply because the entire program can be completely rewritten with relatively little penalty.

As the size of a software development project grows, the consequences of a basic design error grow exponentially.

The following chart graphically illustrates the problem. What is shown is the relative cost of correcting a problem given when it was introduced in the software development process, and when it was detected.

Phase Introduced

Phase detected	Requirements	Design	Construction
Requirements	1x	-	-

Phase Introduced

Design	2x	1x	-
Construction	15x	5x	1x
Testing	25x	10x	5x

Source: Reference 1

Obviously, a formal design phase will reap huge benefits in a large software development project. Conversely, an informal (and thus incomplete) design phase will virtually doom a large software project to failure.

Applying this principle to 4D, it is obvious that the structure design is a fundamental, architectural decision. (By structure design, we mean, of course, the definition of the tables and fields in the structure editor.) Once the structure is defined, it is difficult to change. Once you are deep into creating forms, procedures and other programming objects, changing the structure becomes even more difficult.

Other benefits of formalizing software design include:

- Scope control. Since the client expects a system which "does everything we need it to," the risk of getting committed (at least in the client's mind) to something much larger than you intended is always present. A detailed design document allows you to get the client's formal commitment that nothing which is not in the design document is in the project. Frequently, this is the only way you have of knowing that you are "done."
- System documentation. Virtually all software of any size will be maintained by someone other than the original programmer. This means that another person has the problem of figuring out what you were thinking when you created the system. While well-commented code and other internal system documentation can certainly help in this regard, it does not provide the "macro" view. Only a detailed design document can give a maintenance programmer the big picture of how the system really works.

Since 4D is becoming a feasible alternative for larger and larger systems, training on the design step of 4D software development is needed. This guide fills that need. It is our hope that this guide will assist you in creating more professional database systems using 4D.

2 Understanding the Relational Database Model

2.1 What is a database?

A database is an organized or structured collection of data. It contains the data necessary for some purpose or purposes. The data is arranged to allow a set of activities to occur, and so that it can be accessed and altered in an efficient manner.

Source: Reference 2

Obviously, this definition does not require that the database be stored on a computer. Some practical examples of databases include:

- Commercial phone book
- Rolodex
- Recipe card box
- School teacher's grade folder

Other examples abound. Can you think of some?

Exercises: Identifying Databases

Exercise 2.1

Frequently it is helpful to understand what something is by understanding what it is not.

Take the following example: A university wants to recruit new students, so it puts up posters on a large number of high school campuses soliciting letters from students. It receives a large number of letters in response. These letters generally contain the student's name, address, city, state and zip code. Some also contain other information such as the student's high school, current grade level, SAT scores and grade point average. When received the letters were placed in a filing cabinet.

- Is this a database? If so, why? If not, why not?
- If the university staff wants to find a particular student's letter, could they do so easily?
- If the university staff wants to sort the letters by state and city, could they do so easily?

Realizing the error of its ways, the university now includes tear-off cards on the posters containing blanks for the student to fill in the following information:

- Last name
- First name
- Street address
- City
- State

- Zip
- Phone
- High School
- Current grade level
- SAT scores
- Grade point average

Again, the university receives a large number of cards in response, all of which it stores in a card filing box.

- Is this a database? If so, why? If not, why not?
- If the university staff wants to find a particular student's card, could they do so easily?
- If the university staff wants to sort the cards by state and city, could they do so easily?

2.2 What is a database management system?

A database management system is software that manages data in an organized or structured way.

Source: Reference 2

This definition follows very logically from the definition of a database given above. Common features offered by most database management systems include:

- A way to define containers (typically tables and columns) to hold data.
- Commands and other features allowing the user to search for and sort the data.
- Commands allowing the user to insert new data, update and delete existing data.
- A GUI builder, or other feature allowing the user to create forms to view the data
- A report generator allowing data to be printed
- Enforcement of relational integrity and business rule constraints
- Management of simultaneous data access among multiple users

Source: Reference 2

Based upon these common features, it is readily apparent that 4D is a database management system. It supports all of these features in some manner. The 4D structure editor satisfies the first condition by allowing users to define tables and fields. Querying for and sorting records in 4D is supported by the following commands (among others):

SEARCH
SEARCH SELECTION
SEARCH BY FORM
SEARCH BY FORMULA

SORT SELECTION
SORT BY FORMULA

Inserting, updating and deleting records is supported in 4D by the following commands (among others):

ADD RECORD
CREATE RECORD
SAVE RECORD
MODIFY RECORD
MODIFY SELECTION
DELETE RECORD
DELETE SELECTION

A GUI builder is provided by the 4D form editor.

Report generation is provided by the 4D form editor for creation of custom reports, as well as the Quick Report, Label and Chart editors.

Enforcement of relational integrity is provided by the various options in the 4D relation dialog as well as the following commands:

RELATE ONE
RELATE MANY
AUTOMATIC RELATIONS

Management of simultaneous data access among multiple users is provided by 4D Server and 4D Client.

2.3 What is a relational database?

Early attempts to create computer databases were closely tied with the physical storage of data on disk. This resulted in onerous requirements on the database developer and user in order to get the desired results. For example, to search for records on disk, it was necessary to write code to sequentially load data using physical disk addresses.

The relational database model was developed to solve that problem. Fundamentally, the relational database model was created to divorce the design and use of databases from the storage of data on disk. This concept is known as data independence.

The relational database model views data in table form. Here is an example:

Part

Part Number	Description
27	Umbrella Stand
32	Spittoon

Part

48	Buggy Whip

In relational terms, this collection of data is known as a table. Thus, the relational database model views data in terms of collections of data in tabular form. A relational database is simply a database in which the user perceives that all data contained within the system is in the form of tables. Notice that the physical storage of records is not relevant. The only relevant view of the data is the user's view. How the data is stored on disk is immaterial for our purposes.

Looking at 4D, the user perceives that the vast majority of data is contained in the form of tables. There are minor exceptions, the principle one being subrecords. Subrecords are a hierarchical concept, and are thus a non-relational feature of 4D. As a practical matter, we will not discuss subrecords in this guide, and we will treat 4D as a relational database management system.

2.4 Basic relational database terminology

The foregoing discussion contained some terms which we will now take the time to define formally.

2.4.1 Table

A table is a two-dimensional collection of data. That is, it consists of columns and rows.

Take a look again at the table shown previously. It looks a lot like a spreadsheet, doesn't it? But there is a unique feature which distinguishes a table from a spreadsheet.

A table is non-positional. This has two aspects. First, this means that the order in which the columns are presented can be switched around at will. Similarly, the order in which rows are displayed can be changed at any time. All of this can be done without changing the table at all. (While this can be done with a spreadsheet, it cannot be done without changing the spreadsheet.)

As an example, take a look at the following table:

Part

Description	Part Number
Spittoon	32
Umbrella Stand	27
Buggy Whip	48

Although the order of both rows and columns has been changed, the relational model

states that this is still the same table.

When you create your 4D structure, you will create one 4D table for each table in your design. In this guide we will use 4D conventions when referring to tables. Thus, the table shown above would be called [Part].

2.4.2 Column

The definition of column follows from that of table given above. A column is simply an item of data which is stored in every row in a table. Columns are sometime called attributes since they contain something about the table which the database is intended to store.

Again, although 4D uses the term field to refer to a column, similar to our treatment of the term table, we will use the term column, not field, to refer to this concept.

- If we are talking about a column in a particular table, we will usually refer to the column by its fully-qualified name. That is to say, we will refer to the column by the combination of the table name and the column name. We will use the 4D convention when we do so.

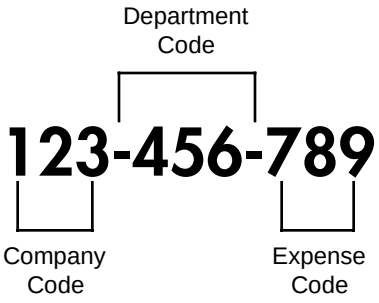
Example: [Table]Column

- Sometimes we will refer to a column separate from its existence in any particular table (as, for example, a column which is contained in more than one table). In that case, we will simply refer to the column by its name.

Example: Column

Columns should contain only one item of data in each row. Stated another way, a column should not contain more than one item of data in a single row. Technically, this is referred to as a composite column. An example of this is a typical accounting code as shown on the following example for a column called Account Number:

Figure 1Account Number



Avoid this type of column in your databases whenever possible. It may make accountants smile, but it makes your databases difficult to work with. Either you have to redundantly store the department code data in another column, or a search to retrieve accounts for a

particular department will require a contains type search. Both of these alternatives are messy.

There are other problems which arise when one of the components of the composite column changes. For example, suppose that an expense code is transferred from one department to another. This would theoretically require that you change the value in the Account Number column as well. That may not be possible, especially if this column is being used to identify each row in the table. (See the section below on primary keys.) The alternative is to leave the data in the composite column unchanged, and update other columns containing the components of the composite column. If you do that, your database is now inconsistent.

A better approach is to split the composite column up into three individual columns, as shown on the following example:

Account

Company Code	Department Code	Expense Code
123	456	7890

Each of these three columns now contains one, and only one, item of data. The quality of a column which contains one, and only one, data value for each row is called atomic. When you design a database, make your columns as atomic as possible.

(You will intentionally create composite columns for performance reasons later in this guide. Don't let that throw you. Right now, you are designing, not programming. Once you have a clean design, it's fine to break the rules, as long as you know you are breaking them. More on this later.)

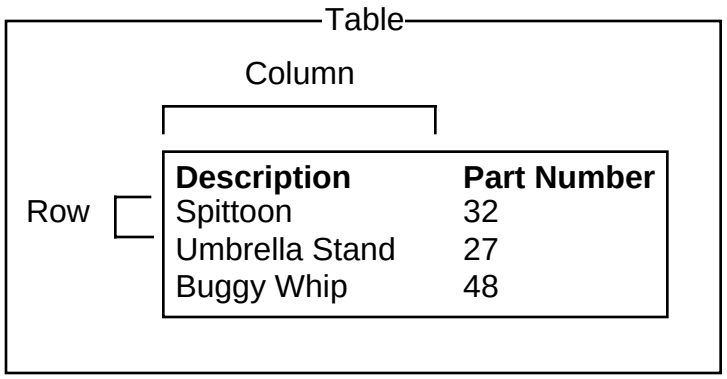
2.4.3 Row

Similar to column, the definition of row follows from the definition of table given above. A row is simply a single instance of whatever is stored in a table. Every row contains every column in the table, even if the value in any given column is undefined.

Again 4D refers to this concept as a record. However, you will use the term most widely used in the relational database design field. Just keep in mind that a record and a row are the same.

The following diagram summarizes what we have discussed on tables, columns and rows:

Figure 2



2.4.4 Primary key

The concept of a primary key is basic to the relational database model. The relational database model states that every row in a table must be unique. Therefore, there must be either a single column or a combination of columns which uniquely identifies each and every row in the table. This column or combination of columns is referred to as the primary key.

Thus the definition of a primary key is the column or combination of columns which can be used to uniquely identify one row from any other row in the table.

Now consider three tables instead of just one:

Part

Part Number	Part Description
27	Umbrella Stand
32	Spittoon
48	Buggy Whip

Warehouse

Warehouse Code	Warehouse City
A	Buffalo
B	Hong Kong
C	New York

Stock

Part Number	Warehouse Code	Stock Quantity
27	A	10

Stock

27	B	15
27	C	7
32	B	25
48	A	8
48	B	12

The primary key of [Part] is [Part]Part Number. This column uniquely identifies each and every row in this table. Similarly, the primary key of [Warehouse] is [Warehouse]Warehouse Code.

When we get to [Stock], the issue is not so obvious. There is not any single column which uniquely identifies each and every row of this table.

The answer is that [Stock] has a multi-column primary key. The primary key of [Stock] consists of two columns: [Stock]Part Number and [Stock]Warehouse Code. A primary key, like [Part]Part Number, which contains only one column is referred to as a simple key. A primary key which contains more than one column, like the combination of [Stock]Part Number and [Stock]Warehouse Code, is referred to as a composite key.

(4D departs slightly from the relational database model by not explicitly supporting composite keys. Do not let that bother you for now. Right now you are designing, not programming. Go ahead and design your database using any necessary composite keys. Later you will show you how to handle composite keys in 4D.)

Another aspect of a primary key is permanence. Permanence indicates that the value in the primary key will never change over the life of a row. Take as an example the following table:

Person

Last Name	First Name	SSN
Williams	Doris	458-38-6214
Worth	Karla	155-78-1648
Vernon	Mark	788-45-3546
Jones	Marc	258-45-3577

While the combination of [Person]Last Name and [Person]First Name uniquely identifies each row in this table, there is a problem with the permanence of these columns. Assume that Mark Vernon and Karla Worth get married, and they decide to hyphenate their last

names. Suddenly the values stored in the table become:

Person

Last Name	First Name	SSN
Williams	Doris	458-38-6214
Worth-Vernon	Karla	155-78-1648
Worth-Vernon	Mark	788-45-3546
Jones	Marc	258-45-3577

That might seem fine, just looking at this table alone, but what if you used these columns to relate to other tables? (See the section below on relations.) Now all of the sudden, you have to change all of the values stored in the related tables. But wait! That might affect other tables related to the related tables. This process can go on endlessly.

This points out another obvious fact. In a composite key, all columns must be unchanging. Any change to any of the columns in the primary key results in a change to the primary key, and that is not allowed.

The obvious solution is to make sure that all columns in the primary key never change during the life of a row. Looking at the [Person] table you might choose the [Person]SSN column as the primary key. (This is very common.)

But there is a problem with this approach as well. Obviously, a primary key must be defined for every row in the table. (That is to say, it must be mandatory.) Assume that Karla and Mark have a baby whom they name Jason. You now wish to enter a row for Jason, but during the first two years of his life, Jason doesn't have a value for [Person]SSN, leading to the following:

Person

Last Name	First Name	SSN
Williams	Doris	458-38-6214
Worth-Vernon	Karla	155-78-1648
Worth-Vernon	Mark	788-45-3546
Jones	Marc	258-45-3577
Worth-Vernon	Jason	

This is unacceptable. There is no way to uniquely identify Jason's row. (By the way, this also implies that every column in a composite key must be mandatory.)

For this reason, you decide to create a unique column to serve as the primary key, as shown:

Person

Last Name	First Name	SSN	Person Number
Williams	Doris	458-38-6214	1
Worth-Vernon	Karla	155-78-1648	2
Worth-Vernon	Mark	788-45-3546	3
Jones	Marc	258-45-3577	4
Worth-Vernon	Jason		5

A primary key (like [Person]SSN if it works) which is already contained in the table, and is mandatory, permanent and uniquely identifies every row is referred to as a natural key. A primary key which you manufacture yourself (such as [Person]Person Number, as shown above) is referred to as a synthetic key.

Natural keys are rare, but they do exist. 4D contains built-in features for creating synthetic keys. In most cases, making your own synthetic key is the way to go.

One other thing about primary keys. All columns in a table which are not in the primary key are called non-key columns. For example, in the above table, [Person]Last Name, [Person]First Name and [Person]SSN are non-key columns.

2.4.5 Relations

Closely related to the concept of primary key is that of a relation. Take another look at the [Stock] table:

Stock

Part Number	Warehouse Code	Quantity
27	A	10
27	B	15
27	C	7
32	B	25
48	A	8
48	B	12

As indicated above, the combination of [Stock]Part Number and [Stock]Warehouse Code is the primary key for this table. Now assume that you wish to see the [Part]Description of each part which is contained in the [Stock] table. By creating a relation you can now produce the following view:

Stock/Part Description View

Part Number	Description from Part	Warehouse Code	Quantity
27	Umbrella Stand	A	10
27	Umbrella Stand	B	15
27	Umbrella Stand	C	7
32	Spittoon	B	25
48	Buggy Whip	A	8
48	Buggy Whip	B	12

Notice that the values for Description are being pulled from the [Part] table. That is to say, you are not redundantly storing the Description in every row in the [Stock] table. You can do this because the values stored in [Stock]Part Number match the values stored in [Part]Part Number. Notice, for example that the value for Umbrella Stand (Part Number 27) matches in both [Stock] and [Part].

This points out several things about the relational database model:

- The relation database model states that links between tables should be performed only by matching data values stored in columns. In the example above, [Stock]Part Number is being used to match to [Part]Part Number.
- This feature allows two tables to be related. A relation is simply the link between two tables both of which contain matching data in columns. (In this guide, we will use the terms related, relation and relationship interchangeably. They all refer to a link between two tables as described in this section.)
- A relation is two-way. You should be able to navigate to the matching row or rows of either table from a row of the other table. For example, you should be able to get the [Part] row for any given [Stock] row, and you should be able to get the matching [Stock] rows for any given [Part] row.
- Relations come in three flavors: many-to-many, one-to-many or one-to-one.
- A one-to-many relation is shown like this: 1:M.
- A many-to-many relation is shown like this: M:M.
- A one-to-one relation is shown like this: 1:1.

- A table on the one side of a 1:M relation is called the one table. A table on the many side of a 1:M relation is called the many table.

M:M relations can be shown during the design phase, but a M:M relation must eventually be resolved into two 1:M relations using a third linking table. (More on this later.)

A foreign key is a column or set of columns which is being used to match values in a relation and is not the primary key of its table. In a correctly designed database, a foreign key will always be on the many side of a 1:M relation. Also, the matching set of columns of the one table will always be the primary key of the one table. If either of these statements is not true, your design is wrong.

Look again at our example using the [Stock] table. The relation between the [Part] table and the [Stock] table is 1:M. That is to say, that a part can be in stock in more than one warehouse, but a [Stock] row can only refer to one part. In this situation, the matching column of the many table, i.e. [Stock]Part Number, is the foreign key of the relation.

Notice that the matching column of the one table, i.e. [Part]Part Number, is the primary key of [Part]. The reason why the matching set of columns on the one side of a 1:M relation is always the primary key of the one table is simple: The primary key is the only way to reliably identify the desired row in the one table. By definition, a primary key is guaranteed to be permanent, mandatory and unique. This means that the primary key is always the best way to identify a row in a table.

Also, notice that [Stock]Part Number is not the primary key of [Stock]. (While Stock]Part Number participates in the primary key of [Stock], it is not by itself the primary key of [Stock].)

If the matching column or set of columns of both tables in a relation are the primary key of their respective tables, the result is a 1:1 relation. The following example illustrates this:

Person I

Last Name	First Name	SSN	Person Number
Williams	Doris	458-38-6214	1
Worth-Vernon	Karla	155-78-1648	2
Worth-Vernon	Mark	788-45-3546	3
Jones	Marc	258-45-3577	4

Person 2

Address	City	State	Person Number
5456 McClintock	Arlington	TX	1
879 Sobrato	Campbell	CA	2
22358 Endres	Orlando	FL	3
4189 Santa Ana	Cocamo	IN	4

Here [Person 1] and [Person 2] are related on the Person Number column. This column is also the primary key for both of these tables. Since the values in both tables for Person Number must be unique, the result is a 1:1 relation. (That is to say, only one row can exist on either side of the relation.)

1:1 relations are not common, but they do occur. When you get into physical creation of a database, you will see that there are valid performance reasons for creating 1:1 relations. In addition, there are valid reasons when designing a database to create 1:1 relations.

2.4.6 Review

- The concepts covered in this section are absolutely critical to your complete understanding of relational database theory. Why don't you go over them again, and think about these concepts for a minute or two?
- The relational database model is based upon all data being stored in tables.
- A table is a two dimensional collection of data. Tables are non-positional. The columns and rows can be rearranged without changing the table. A table is the same concept as a table in 4D.
- A column is a single item of data which is contained in all of the rows in the table. Ideally, a column should contain one, and only one, item of data (atomicity). For example, if the table stores data about persons, Last Name would be a good column in the table. A column is the same concept as a field in 4D.
- A row is a single instance of whatever is stored in the table. For example if the table stores data about persons, then a row refers to one person. A row is the same concept as a record in 4D.
- Every table must have a primary key. A primary key is a column or set of columns which uniquely identifies every row in the table.
- All columns in the primary key must be mandatory. That is, they must all be defined for every row in the table.

- In addition, all columns in the primary key must be permanent. That means, they must all be unchanging during the life of a row in the table.
- The columns in a table which are not part of the primary key are called non-key columns.
- Relations are links between tables based upon matching data values in columns.
- A relation is based upon a column or set of columns which contain identical values in the two related tables.
- Relations can be many-to-many (M:M), one-to-many (1:M), or one-to-one (1:1).
- Eventually, a M:M relation must be resolved into two 1:M relations.
- The matching set of columns of the many table in a 1:M relation is a called foreign key.
- The matching key of the one table in 1:M relation is always (in a correctly designed database) the primary key of the one table.

A relation in which both matching keys are the primary key of their respective table is a 1:1 relation.

Exercises: Identifying tables, columns and keys

Exercise 2.2

Assume that data is stored on disk using the following data structure (Note: this is the way the data is stored, not just a report.).

Part

Part Number	Part Description	Warehouse Code	Quantity
27	Umbrella Stand		
		A	10
		B	15
		C	7
32	Spittoon		
		B	25
48	Buggy Whip		
		A	8
		B	12

Is this a table in the relational sense? (Hint: is this structure two-dimensional?)

How would you design a search for all parts stored in warehouse B? Would it be easy?

Sort the parts by total quantity stored. Can you do this easily?

Is this structure efficient in terms of storage space?

Exercise 2.3

Consider the following tables:

Item

Item Number	Item Description	Price
123	Pontoon Cover	$100.00
124	Potato Peeler	$5.00
125	Pimento Polisher	$55.00
126	Pig Preener	$25.00
127	Pain Preventer	$7.50
128	Pretty Parrot	$87.50

Order

Order Number	Item Number	Quantity
1234	123	1
1235	126	12
1236	128	7
1237	124	65
1238	123	2
1239	128	3

Identify the primary keys of both tables.

- Are there any natural keys?
- Are there any synthetic keys?
- Are the tables related?
    - If so, what is the nature of the relation (1:M, 1:1, or M:M)?
- What is the one table?
- What is the many table?

- What is the matching column or set of columns?

Which column or set of columns is the foreign key?

Exercise 2.4

Now slightly rearrange things:

Item

Item Number	Item Description	Price
123	Pontoon Cover	$100.00
124	Potato Peeler	$5.00
125	Pimento Polisher	$55.00
126	Pig Preener	$25.00
127	Pain Preventer	$7.50
128	Pretty Parrot	$87.50

Order

Order Number	Customer Number	Order Date
1234	8015	12/8/94
1235	0478	4/1/94
1236	9678	5/6/94

Order Item

Order Number	Item Number	Quantity
1234	123	1
1234	126	12
1234	128	7
1235	124	65
1236	123	2
1236	128	3

Basically the same questions apply to this example as the last one. That is:

Identify the primary keys of all three tables.

Are there any natural keys?

- Are there any synthetic keys?
- Are any of the tables related?
- If so, describe the nature of each relation (1:M, 1:1, or M:M).
- What is the one table in each relation?
- What is the many table in each relation?
- What is the matching key in each relation?
- Which table is the many table, if any, in each relation?
- Which key is the foreign key in each relation?

Exercise 2.5

Consider the following table:

Person

Name	SSN	Address	City/State/Zip
Doris Williams	458-38-6214	5456 McClintock	Arlington, TX 75012
Karla Worth	155-78-1648	879 Sobrato	Campbell, CA 95008
Mark Vernon	788-45-3546	22358 Endres	Orlando, FL 14033
Marc Jones	258-45-3577	4189 Santa Ana	Cocamo, IN 35701

→ What problems exist with this table structure? (Hint: look for composite columns.)

→ Try to find the person rows where the last name is greater than "K". Can you do this?

→ Try to sort by the person's last name. Can you do this?

→ Try to search for all rows where the person lives in the state of Texas. Is this possible?

Try to sort the rows by zip code. Can you do this at all?

3 What is a relational database good for?

There will be times when you will be offered the opportunity to do a system, and you will not be sure whether 4D is the right tool for the job. The purpose of this section is to help you answer that question.

- As you have seen, 4D is a relational database management system. Generally, systems which can be created in a relational database management system can be created in 4D. (There are issues concerning performance and capacity which are beyond the scope of this guide. However, with 4D's increasing capabilities, the vast majority of relational database applications being written today could be written in 4D.) Thus, you can focus on what types of systems can (or should) be created in a relational database management system. To do this, you will use the old three rules of thumb:
  - Rows are cheap
  - Columns are expensive
  - Tables are priceless

What this means is simple. It is easy to add rows to tables. On the other hand, adding columns to a table is a fairly major undertaking. And adding entirely new tables is the equivalent of heart surgery.

Thus, the structure of the proposed system must be capable of being described thoroughly and completely. (Teaching you how to describe the structure is what this guide is all about.)

In addition, you must be able to completely describe the data structure in terms of relational tables. In order for the structure to be described, it has to be stable (i.e. unchanging) over time. If any part of the data structure is likely to change frequently during the course of the system (i.e. at runtime), the system probably cannot be created with a relational database alone. The quality of any part of a data structure which changes frequently is called volatile. There may be parts of a data structure which can be described, and parts which cannot. (Thus, there may be stable parts of the data structure, and volatile parts.)

Don't talk yourself out of a job here. Notice we said the job cannot be done with a relational database alone. If may be needed is a spreadsheet or a word processor to store the volatile data, that can be accomplished with 4D Calc or 4D Write.

- Here is an example a system that could not be accomplished by means of a relational database alone:
- The client is a large integrated oil company wishes to build a system to do long-term financial planning on the company's projects. A project is a distinct unit of work (e.g. drilling a set of wells, etc.) with a fixed life. The performance of a project is modeled

in financial variables which are displayed over a period of years. Operators are applied to financial variables to calculate other financial variables. Eventually, this models what the real-world behavior of the project would be, assuming conditions are similar to what is stored in the financial variables.

- The client cannot tell you what financial variables will be used at any given time, because they are constantly updating their financial planning methodology and adding new financial variables. In addition, the financial variables and their operators are constantly changing because the client likes to do "what if" analysis on the projects to see what the results would be in any given situation.

Further, the client cannot tell you what period of years will be applied to a particular project, since the life of each project is different from any other project.

Most of what is being described here is, of course, a spreadsheet. However, there is a part of the system (i.e. the concept of a project) which is quite stable. A project table could, for example, contain the name of the project, its region, the personnel responsible for planning the project, etc.

It is when you get to the financial variables that you get into trouble. One alternative would be create an very wide table with the number of columns equal to the maximum number of years the client thinks he or she is likely to need, as shown below:

Financial Variable

Name	Year 1	Year	...	Year N
Year	1995	1996	...	NNNN
Capital Investment	$1,000,000	$500,000	...	$0
Operating Expense	$0	$10,000	...	$300,000
Salvage Expense	$0	$0	...	$250,000

This approach will result in terrible performance and lots of wasted space. In addition, you will have to figure out how to store the operators and apply them to each financial variable in each year. Since the client can use any operator on any financial variable, your code will have to be very complex. And since the client will constantly be coming up with new rules, you will have a maintenance nightmare.

While you may find this example to be ridiculous, it was seriously proposed in the halls of a major publicly-traded oil company not too long ago.

The solution did, in fact, end up using a relational database for storage, but not in the way shown above. Instead, the financial variables were stored in 4D Calc spreadsheets, and these spreadsheets were stored in rows in a table, using 4D's built-in BLOB feature.

What is a relational database good for?

By having spreadsheets explicitly associated with their various projects and making them readily available in a multi-user relational database system, the client achieved significant performance gains in its financial planning department. Thus, the system was successful. It would not have been successful if the only tool used was the relational database management system.

There is a saying: "If the only tool you have is a hammer, pretty soon every problem begins to look like a nail." There are some things relational databases are not good for. Get the right tool for the job. With the 4D environment, there are some additional capabilities beyond that of a traditional relational database management system. This makes it possible to use 4D for storage of volatile data, as long as you remember the issues involved.

4 Formal representation of tables

In this guide we are going to be looking at tables in a variety of ways. The first form of representing a table which you need to learn about is called the entity/attribute listing. Don't let the terminology throw you. This is simply a listing of all the columns in the table, showing their types, and their participation in the primary and foreign keys. Here is an example of a the entity/attribute listing of a table we have been working with in this guide:

Stock

Column Names	Data Types	Keys
Part Number	Longint	PK1 FK1
Warehouse Code	String (2)	PK2 FK2
Quantity	Real	

The column names and data types are self-explanatory. Keys requires some explanation:

- PK indicates that the column participates in the primary key. If more than one column is included in the primary key (as in this case), the columns are numbered, as shown above. Otherwise, it is simply shown as PK.

FK indicates a foreign key. Foreign keys are always numbered, as shown above, even if there is only one of them in the table (in which case it is shown as FK1, of course). If there is more than one column in a foreign key, they are shown like this: FK1.1, FK1.2, etc.

Exercises: Drawing entity/attribute views

Exercise 4.1

Draw the entity/attribute views for the following tables:

Item

Item Number	Item Description	Price
123	Pontoon Privy	$100.00
124	Potato Peeler	$5.00
125	Pimento Polisher	$55.00
126	Pig Preener	$25.00
127	Pain Preventer	$7.50
128	Pretty Parrot	$87.50

Order

Order Number	Customer Number	Order Date
1234	8015	12/8/94
1235	0478	4/1/94
1236	9678	5/6/94

Order Item

Order Number	Item Number	Quantity
1234	123	1
1234	126	12
1234	128	7
1235	124	65
1236	123	2
1236	128	3

These are the same tables used in the last exercise.

→ How does the entity/attribute listing assist you in your understanding of the tables?

If the tables were more complex, would the tables be capable of being understood any other way?

5 Normalization

Normalization is an important part of relational database design. It is possible to explain normalization very concisely. However learning a definition and understanding how to apply it are two very different things. For this reason, we will provide lots of examples and explanation in this section.

5.1 What is normalization?

Normalization is the process of deciding what columns belong in what tables. One of the basic principles of normalization to that you want to minimize redundant or duplicated data. Another basic concept is that you want to group related columns together in a table because there is a clear and logical relationship among them. Source: Reference 2

The result of normalization is a logical database design. That is, normalization results in a design which clearly and consistently captures the true nature of the data.

The result of the normalization process is called a normal form. Normalization is a step-by-step process in which various normal forms are achieved. Thus, there is the first normal form, the second normal form, and so forth. Each normal form is more logically correct than the one before it. Each normal form also includes the ones before it. Thus, a table which is in second normal form is also in first normal form, and so on.

The rules of normalization are based upon common sense. It is very possible that you would intuitively follow them. The advantage of having the rules of normalization stated explicitly is that you can then consciously make sure that you follow all of them.

Some will certainly argue that a normalized database design is not the most optimized. We will say it again. Remember, you are designing, not programming. Once you have created a correct, normalized design you will address the performance issues and make appropriate adjustments in your design to meet those issues. The process of backing off of a perfectly normalized structure for performance reasons is called denormalization, and you will be doing lots of that on the third day.

5.2 Why normalize?

There are many reasons to normalize. Here are a few of them:

- A normalized database design organizes data according to its meaning.
- A normalized database design will be robust and will not be susceptible to a variety of problems. Also, a normalized database design will be easy to change if modifications become necessary. This is because normalization reduces redundancy or duplication of data.

The process of normalization forces the designer to fully understand each element of the

data. This last benefit may be the most important.

5.3 Functional dependency

Key to understanding normalization is understanding the concept of functional dependency. This is a subtle concept. We say that Column A is functionally dependent on Column B if, and only if, there must be a single value in Column B for every value in Column A.

Source: Reference 2

A practical example will help. Suppose you have a database which tracks the stock market. That database contains a table called [Common Stock]. Included in the [Common Stock] table are the columns Name and Price, as follows:

Common Stock

Name	Price
Ford	25 3/8
GM	44 1/4
Chrysler	64 5/8
IBM	100 3/4
Apple	54 7/8
Microsoft	102 5/8

Now you can say that Price is functionally dependent upon Name because there must be one, and only one, value for Price for any given Name. By the way, the process works the other way, as well. Thus Name is not functionally dependent upon Price because there does not have to be a single value of Name for any given Price.

- A functional dependency is written this way:

  Name –> Price

This says that Price is functionally dependent on Name. Notice that it is perfectly legitimate to say that a column is functionally dependent upon a set of columns. Borrow from an example used earlier:

Stock

Part Number	Warehouse Code	Quantity
27	A	10
27	B	15

Stock

27	C	7
32	B	25
48	A	8
48	B	12

The Quantity column is functionally dependent upon the combination of the columns Part Number and Warehouse Code.

- This functional dependency is written this way:

  Part Number + Warehouse Code –> Quantity

Notice that these two columns also happen to be the primary key of this table, a broad hint as to where you are headed next.

Exercises: Recognizing Functional Dependencies

Exercise 5.1

Consider the following tables used by a pet store database:

Inventory

Inventory Number	Species	Breed	Acquired
2002	Canine	Bulldog	1/30/95
2003	Canine	Fox Terrier	2/4/95
2004	Canine	Spaniel	2/14/95
2005	Feline	Persian	2/17/95
2006	Feline	Manx	3/2/95
2007	Feline	Persian	3/14/95
2008	Canine	Spaniel	3/19/95
2009	Feline	Siamese	5/2/95

Feeding Plan

Breed	Species	Feed	Quantity
Bulldog	Canine	Bulemia Dog Chow	16 Oz.
Fox Terrier	Canine	Bulemia Dog Chow	24 Oz.
Spaniel	Canine	Bulemia Cat Chow	18 Oz.

Feeding Plan

Siamese	Feline	Bulemia Cat Chow	10 Oz.
Persian	Feline	Bulemia Dog Chow	14 Oz.
Manx	Feline	Bulemia Cat Chow	10 Oz.

- Identify all functional dependencies.
- What columns are dependent upon a single column?
- What columns are dependent upon more than one column?

5.4 First Normal Form

The first normal form is easy. It is also a bit different from all of the other normal forms. It simply requires that any table that you design conform to the correct definition of a table.

Suppose you want to track employees and the projects they are currently working on, so you create a table which looks like this:

Employee

Column Names	Data Types	Keys
Employee Number	Longint	PK
Last Name	String (45)	
First Name	String (45)	
Project Name 1	String (20)	
Start Date 1	Date	
End Date 1	Date	
Project Name 2	String (20)	
Start Date 2	Date	
End Date 2	Date	
Project Name 3	String (20)	
Start Date 3	Date	
End Date 3	Date	

This type of structure is common in flat file databases. It is also the reason why relational databases work much better than flat file databases. The technical definition for the group of columns representing the project name, start date and end date is a repeating group.

Flat files use lots of repeating groups for the simple reason that flat file databases can only work with one table at a time. Therefore you don't have a choice if you use this type of database.

- Look at the effect of a repeating group structure like the one shown. First assume that you want to search for all of the employees who are working on the GIS project. The only way to do this would be to do something like the following:

  [Employee]Project Name 1 = "GIS" Or
  [Employee]Project Name 2 = "GIS" Or
  [Employee]Project Name 3 = "GIS"

Now you realize that you have a go-getter who is working on four projects at once. All of the sudden you have to add another element to the repeating group. Then any code that you have written to support this search has to be rewritten to allow for the new column. Also, you have to redo your forms, and so on.

Repeating groups are inherently volatile. That is one reason why they are bad. A repeating group is a maintenance nightmare, because it will never be big enough.

Another problem. Suppose you want to create a project report showing the employees working on each project. You want the listing by project.

Can you do that? Not without an enormous amount of programming. And, again, if you add another element to the repeating group, your report is now broken and has to be rewritten.

So, you see that the rule for first normal form is as follows:

A table is in first normal form if it has no repeating groups.

Source: Reference 2

(That's really the formal definition of the first normal form.)

The first normal form is written this way: 1NF.

Exercises: First Normal Form

Exercise 5.2

Your client has asked you to design a database which will be used for tracking a doctor's patient records. She hands you a rather typical patient record form, which she simply wants to be converted into database storage. This patient record form has the following blanks (we have converted them to columns for you.).

Personnel Evaluation

Column Names	Data Types	Keys
Patient ID	Longint	PK
Patient Last Name	String (45)	
Patient First Name	String (45)	
Appointment 1 Date	Date	
Appointment 1 Time	Time	
Appointment 2 Date	Date	
Appointment 2 Time	Time	
Appointment 3 Date	Date	
Appointment 3 Time	Time	
Appointment 4 Date	Date	
Appointment 4 Time	Time	
Last Appointment Date	Date	
Symptom 1	String (80)	
Symptom 2	String (80)	
Symptom 3	String (80)	
Symptom 4	String (80)	
Symptom 5	String (80)	
Diagnosis 1	String (80)	
Diagnosis 2	String (80)	
Diagnosis 3	String (80)	
Diagnosis 4	String (80)	
Diagnosis 5	String (80)	
Measles	Boolean	
Measles Diagnosis Date	Date	
Chickenpox	Boolean	
Chickenpox Diagnosis Date	Date	
DPT Shot	Boolean	

Personnel Evaluation

DPT Shot Date	Date	
Small Pox Vaccination	Boolean	
Small Pox Vaccination Date	Date	
Flu Shot	Boolean	
Flu Shot Date	Date	
Mumps	Boolean	
Mumps Diagnosis Date	Date	
Asthma	Boolean	
Asthma Diagnosis Date	Date	
Mold Allergy	Boolean	
Mold Allergy Diagnosis Date	Date	

Identify all of the repeating groups. Come up with a set of tables which are in 1NF.

- Now, explain to your client why her idea of automating the patient record form is a bad idea, and why your normalized database design is better.

Exercise 5.3

Your financial planning manager would like to be able to chart the company's performance on a monthly, quarterly, and annual basis. It is important to be able to track total sales during the period, and a 1-year rolling average sales figure (monthly and quarterly only). Being a finance person, he is very familiar with spreadsheets. Therefore, he proposes the following structure.

Monthly Data

Column Names	Data Types	Keys
Year	Integer	PK
January Total Sales	Real	
January Avg Sales	Real	
February Total Sales	Real	
February Avg Sales	Real	
March Total Sales	Real	
March Avg Sales	Real	
April Total Sales	Real	

Monthly Data

April Avg Sales	Real	
May Total Sales	Real	
May Avg Sales	Real	
June Total Sales	Real	
June Avg Sales	Real	
July Total Sales	Real	
July Avg Sales	Real	
August Total Sales	Real	
August Avg Sales	Real	
September Total Sales	Real	
September Avg Sales	Real	
October Total Sales	Real	
October Avg Sales	Real	
November Total Sales	Real	
November Avg Sales	Real	
December Total Sales	Real	
December Avg Sales	Real	

Quarterly Data

Column Names	Data Types	Keys
Year	Integer	PK
Q1 Total Sales	Real	
Q1 Avg Sales	Real	
Q2 Total Sales	Real	
Q2 Avg Sales	Real	
Q3 Total Sales	Real	
Q3 Avg Sales	Real	
Q4 Total Sales	Real	
Q4 Avg Sales	Real	

Annual Data

Column Names	Data Types	Keys
Year	Integer	PK
Annual Total Sales	Real	

He thinks this is a really great data structure, and will work well. (Obviously, he hasn't read this guide!)

Come up with a data structure which meets the 1NF, and sell him on the idea.

5.5 Second Normal Form

Second normal form involves the idea of whether or not all of the columns in the table are functionally dependent upon the primary key of the table. Look at some sample data:

Employee ID

Employee ID	Name	Project ID	Project Name	Start Date	Completion Date
123	Harry	XYZ	Space Shuttle	7/7/91	8/8/91
123	Harry	ZYX	Place Scuttle	8/9/91	12/24/91
231	Mary	XYZ	Space Shuttle	7/12/91	12/24/91
231	Mary	XYX	Face Shuttle	12/26/91	3/18/92
312	Larry	ZYX	Place Scuttle	7/27/91	3/3/92

Now, suppose that you have identified the following functional dependencies:

Employee ID –> Name
Project ID –> Project Name
Employee ID + Project ID –> Start Date
Employee ID + Project ID –> Completion Date

You stored the fact that Employee ID 123 is Harry twice. You've also stored the fact that Project ID XYZ is Space Shuttle twice. If you ever need to alter either of these facts, you must be sure to alter all occurrences. The data will be inconsistent if you do not.

Similarly, when you enter data about a new employee, you must either assign a project to the employee or leave the project data blank. In addition, if you enter a new project, you must leave the employee blank or assign an employee to the project.

Should you decide to delete the data regarding the only employee in a project, you will delete the project data as well. Should you delete the data regarding the only project assigned to an employee, you will delete the employee data as well.

How can you eliminate these problems? Begin by observing that no single column in this table is an appropriate primary key. It must be possible for a given primary key to uniquely identify every row in the table.

- By looking at your functional dependencies, you can also see that you are concerned with three different kinds of relationships:

  Name is functionally dependent upon Employee ID
  (Employee ID –> Name).
- Project Name is functionally dependent upon Project ID

  (Project ID –> Project Name).

Start Date and Completion Date are functionally dependent upon the combination of Employee ID and Project ID (Employee ID + Project ID –> Start Date and Employee ID + Project ID –> Completion Date).

- You have combined several different kinds of data or relationships into one table. You can resolve these problems by following the rule for the second normal form:

A table is in second normal form if it is already in 1NF, and all non-key columns are functionally dependent upon the entire primary key. Source: Reference 2

By applying this rule to your data, you come up with the following table structure:

Employee

Column Names	Data Types	Keys
Employee ID	Longint	PK
Name	String (45)	

Project

Column Names	Data Types	Keys
Project ID	Longint	PK
Project Name	String (45)	

Assignment

Column Names	Data Types	Keys
Employee ID	Longint	PK1 FK1
Project ID	Longint	PK2 FK2
Start Date	Date	
Completion Date	Date	

with the following sample data:

Employee

Employee ID	Name
123	Harry
231	Mary
312	Larry

Project

Project ID	Project Name
XYZ	Space Shuttle
ZYX	Place Scuttle
XYX	Face Shuttle

Assignment

Employee ID	Project ID	Start Date	Completion Date
123	XYZ	7/7/91	8/8/91
123	ZYX	8/9/91	12/24/91
231	XYZ	7/12/91	12/24/91
231	XYX	12/26/91	3/18/92
312	ZYX	7/27/91	3/3/92

It might appear that a redundancy has been introduced. The opposite is true. Each kind of data has been stored but once. The matching of data values is the way that the relations are linked. The problems mentioned above have been completely eliminated.

The second normal form is written in this way: 2NF.

Exercises: Second normal form

Exercise 5.4

An insurance company has a database system which you have been asked to review. The

main table in the system is called [Policy], and it has the following structure:

Policy

Column Names	Data Types	Keys
Carrier ID	Longint	PK1 FK1
Carrier Name	String (45)	
Policy Number	String (10)	PK2
Customer ID	Longint	FK2
Customer Last Name	String (45)	
Customer First Name	String (45)	

- Identify all functional dependencies in this table.
- Create a set of tables which comply with 2NF. Write the entity/attribute views for these tables, clearly identifying all primary and foreign keys.

5.6 Third Normal Form

- The third normal form is very similar to 2NF. In fact, you probably normalized the exercise above to the third normal form without knowing it. The rule simply states:

A table is in third normal form if it is already in 2NF and no non-key column is functionally dependent upon any other non-key column. This rule comes into play in situations like the following:

Employee

Employee ID	Department	Building
26622	Sales	West Block
41156	Accounting	Headquarters
33897	R&D	North Lab
88644	Sales	West Block
91214	Marketing	Headquarters

This table is in 1NF. It does not have a composite key since Employee ID uniquely identifies every row in the table. Therefore it is automatically in 2NF. (Remember that 2NF had to do with columns being functionally dependent upon the entire primary key. Here the primary key is one column.)

The rule for the third normal form asks for you to look for second-hand functional

dependencies. That would be a situation where one column is functionally dependent upon another column, which is in turn functionally dependent upon a third column. Technically, this is called a transitive dependency.

Is there a functional dependency between the non-key columns Department and Building?

Well, it depends. If it is a business rule of this enterprise that every department is housed in one building, then if you know the department, you automatically know the building.

- In this case, the dependency between Building and Employee ID is second-hand. While it is true that Building is functionally dependent upon Employee ID (that is, if you know the value for Employee ID, you can determine the value for Building), this functional dependency is indirect. That makes it a transitive dependency, and this is written this way:

  Employee ID –> Department –> Building

When there is a transitive dependency, the table is not in third normal form, and should be split into two tables:

Employee

Column Names	Data Types	Keys
Employee ID	Longint	PK
Department	String (20)	FK1

Department

Column Names	Data Types	Keys
Department	String (20)	PK
Building	String (20)	

If, on the other hand, the employees work all over, wherever space can be found, then the building is a fact about the employee, not about the department, and the original table is in third normal form.

By the way, there is another issue here concerning inferring business rules from the data. In this case it happens that the employees of any given department are all working in the same building. If there is nothing in the business rules which states that an employee could not work in any other building, then you are better off sticking with the one-table design shown above. Take care about making inferences about how the business works from the data. The patterns which you see in the data may be correct, but you must probe further to confirm them.

Take a look at another example to reinforce what you have learned already.

Consider the following table structure for an art museum:

Work

Column Names	Data Types	Keys
Work ID	Longint	PK
Title	String (45)	
Artist Last Name	String (45)	
Artist First Name	String (45)	
Artist DOB	Integer	

With the following sample data:

Work

Work ID	Title	Artist First Name	Artist Last Name	Artist DOB
001	Snowstorm	Joseph	Turner	1775
002	The Night Watch	Rembrandt	van Rijn	1606
003	Brighton Beach	John	Constable	1776
004	Howl of the Weather	Frederick	Remington	1861
005	The Haywain	John	Constable	1776

There are no repeating groups. Therefore, the table is in 1NF.

Work ID is the only column in the primary key. Therefore, the table is in 2NF.

- When you take a look at the non-key columns, you notice that the Artist DOB is functionally dependent upon the combination of Artist Last Name and Artist First Name. Thus, you have identified a transitive dependency, which you would write like this:

  Work ID –> Artist Last Name + Artist First Name –> Artist DOB

Therefore, the table is not in third normal form, and needs to be split into two tables. (In the structure that follows, you have also addressed the issue that there is not a natural key for the new table.)

Work

Column Names	Data Types	Keys

Work

Work ID	Longint	PK
Title	String (45)	
Artist ID	Longint	FK1

Artist

Column Names	Data Types	Keys
Artist ID	Longint	PK
Artist First Name	String (45)	
Artist Last Name	String (45)	
Artist DOB	Integer	

And here is the new sample data:

Work

Work ID	Title	Artist ID
001	Snowstorm	1001
002	The Night Watch	1002
003	Brighton Beach	1003
004	Howl of the Weather	1004
005	The Haywain	1003

Artist

Artist ID	Artist First Name	Artist Last Name	Artist DOB
1001	Joseph	Turner	1775
1002	Rembrandt	van Rijn	1606
1003	John	Constable	1776
1004	Frederick	Remington	1861

These tables are now in third normal form.

The third normal form is written in this way: 3NF.

Exercises: Third normal form

Exercise 5.5

Consider the following data structure:

Employee

Column Names	Data Types	Keys
Employee ID	Longint	PK
Employee Name	String (45)	
Department ID	String (3)	
Department Name	String (20)	

- Is the table in 1NF?
- Is the table in 2NF?
- Is the table in 3NF? (Hint: identify all functional dependencies. Are any non-key columns functionally dependent upon any other non-key columns?)
- How would you correct any problems you see? Create any necessary tables, and write an entity/attribute listing on each one of them.

5.7 Further normalization

There are either five or six normal forms, depending on whose book you read. The normal forms above 3NF have to do with issues which are reminiscent of the medieval debate over how many angels can dance on the head of a pin.

You are not likely to run into a situation where you need to normalize above 3NF. If you become proficient at normalizing to this level, you will do well.

5.8 Review

Go over what you have learned in this chapter one more time to reinforce the concepts:

- Normalization is the process of deciding what columns belong in what tables.
- The result of normalization is a logical database design which clearly and consistently captures the true nature of the data.
- Normalization is based upon the concept of functional dependency, which is where the value in one column can be determined from the value in the other column.
- A functional dependency is written this way:

  Common Stock Name –> Common Stock Price.

- This statement says that Common Stock Price is functionally dependent upon Common Stock Name.
- A table is in first normal form if it has no repeating groups. The first normal form is written 1NF.
- A table is in second normal form if it is already in 1NF, and all non-key columns are functionally dependent upon the entire primary key. The second normal form is written 2NF.
- A table is in third normal form if it is already in 2NF and no non-key column is functionally dependent upon any other non-key column. The third normal form is written 3NF.

Another definition of 3NF is that transitive dependencies are not allowed. A transitive dependency is one which is indirect. That is, one column is functionally dependent upon a second column, which is functionally dependent upon a third column.

Exercises: Normalization

Exercise 5.6

Assume the following functional dependencies:

Bee ID –> Bee Name
Bee ID –> Hive ID (Bee resides in hive)
Hive ID –> Hive Capacity
Hive ID –> Hive Phone Number
Flower ID –> Flower Type
Flower ID –> Color
Person ID –> Person Name
Bee ID + Person ID –> Number of Stings
Bee ID + Pollination Date + Pollination Time -> Flower ID

Ignore any composite columns in this example. This makes the problem simpler.

Assume further that a bee can sting any number of people, and that a bee can pollinate any number of flowers. Similarly, a person can be stung by any number of bees, and a flower can be pollinated by any number of bees.

Is the following table normalized?

Bee

Column Names	Data Types	Keys
Bee ID	Longint	PK
Name	String (20)	

Bee

Hive ID	Longint	FK1
Hive Capacity	Longint	

If not, which normal form is violated? Provide and explain the correct normalization.

Is the following table normalized?

Sting

Column Names	Data Types	Keys
Bee ID	Longint	PK1
Person ID	Longint	PK2
Number of Stings	Integer	
Person Name	String (45)	

If not, which normal form is violated? Provide and explain the correct normalization.

➔ Develop a complete set of normalized tables for the above scenario. Explain in detail why your relations are normalized.

Exercise 5.7

Identify all functional dependencies and develop a set of normalized tables for the following scenario. Draw the entity/attribute listing for each table. Explain in detail why your design is normalized.

- Sheep are cared for by shepherds and live in pens. Each shepherd has a unique ID (Shepherd ID) as well as a name (Shepherd Name) and a shirt size (Shepherd Size).
- A shepherd may look after several pens. A given pen is controlled by one shepherd only. Each pen is identified by a unique Pen ID. Each pen also has a value (Pen Value) and a capacity.
- A given sheep lives in one and only one pen. Each sheep is assigned a Sheep ID and has a weight (Sheep Weight) and a value (Sheep Value).

Exercise 5.8

Identify all functional dependencies and develop a set of normalized tables for the following scenario. Draw the entity/attribute listing for each table. Explain in detail why your design is normalized.

- Magicians are identified by IDs (Magician ID). They have names (Magician Name) and daily rates which they charge for their magic tricks (Magician Rate).

- Magicians belong to Magic Clubs. A magician may belong to more than one club. And more than one magician may belong to a club.
- Each club is identified by a unique club name (Club Name). However, once in a while a club changes its name. Each club has a mailing address (Club Address) and a phone number (Club Phone).
- The tricks that magicians can show are described in the master trick catalog. Each trick has its own unique trick ID (Trick ID), a descriptive name (Trick Name), and a rating in terms of how amazing it is (Trick Amazing).
- Most magicians are capable of performing many different tricks. It is possible for several magicians to perform the same trick. Each magician has a magic trick competency rating (Trick Competency) for each trick which he or she is capable of performing.

Exercise 5.9

Identify all functional dependencies and develop a set of normalized tables for the following scenario. Draw the entity/attribute listing for each table. Explain in detail why your design is normalized.

- Horses are cared for by trainers and live in horse barns.
- Each trainer has a unique ID (Trainer ID) as well as a name (Trainer Name) and a shoe size (Trainer Size).
- A given horse lives in one and only one horse barn. Each horse is assigned a horse ID (Horse ID) and has a weight (Horse Weight) and a value (Horse Value).
- A trainer may operate several horse barns. A given horse barn is operated by but one trainer. Each horse barn is identified by a unique horse barn identifying number (Horse Barn ID). Each horse barn also has a capacity (Horse Barn Capacity) and a value (Horse Barn Value). A given trainer cares for all of the horses kept in any barn he or she owns. Thus you can tell the trainer for any given horse if you know the barn the horse lives in.

Exercise 5.10

Identify all functional dependencies and develop a set of normalized tables for the following scenario. Draw the entity/attribute listing for each table. Explain in detail why your design is normalized.

- Painters are identified by unique IDs (Painter ID). They have names (Painter Name) and daily rates which they charge for their commissions (Painter Rate).
- Painters belong to clubs. A given painter may belong to more than one club. More than one painter can belong to any particular club. Each club is identified by a unique

name (Club Name). Once in a while a club changes its name. Each club has a mailing address (Club Address) and a phone number (Club Phone).

- The painting mediums that the painter can paint in are described in the master medium catalog. Each type of medium (watercolor, oil, gouache etc.) has its own unique medium identifier (Medium ID), a descriptive name (Medium Name), and a rating in terms of how skilled it is (Medium Skill).
- Most painters are capable of painting in many different types of medium. It is also possible for several different painters to work in the same medium. Each painter has a painter competency rating (Medium Competency) for each type of medium that he or she is capable of working in.

6 Modeling the database

In this chapter you are going to begin to produce one of the main deliverables of the design process: the entity/relationship diagram ("ERD").

6.1 What is an entity/relationship diagram?

Simply stated, an entity/relationship diagram is a picture which illustrates the tables which are to be included in the system and the relationships among the tables. Source: Reference 2

In relational database parlance, an entity is a object about which you intend to store data. For the purposes of this guide, you are going to treat an entity as equivalent to a table. (Despite the dark warnings in some textbooks, that is generally how it ends up being applied.)

Similarly, a relationship is a connection or association between or among entities. For our purpose you are going to treat a relation and a relationship as the same thing.

Finally, in database terms, an attribute is a characteristic of interest about an entity. For our purposes, you will treat an attribute and a column as representing basically the same concept.

6.2 Why diagram?

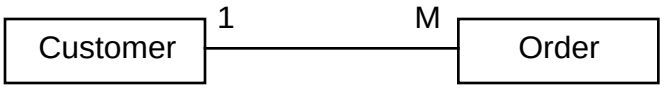
There are at least three good reasons to introduce this technique.

- It is not possible to successfully design a system without a complete understanding of the entities involved.
- While normalization is a useful technique, it is not always easy to identify the functional dependencies involved. Why, you ask, does one decide that color of part is functionally dependent upon part number? Isn't it because you mentally attach both to the idea of a real-world thing called a part? Why not recognize this and employ the technique formally. You find when you do so that functional dependencies become much easier to see.
- Grasping the overall physical design of a database using an ERD is easier than looking at tables in entity/attribute listings, as you will see.

6.3 Technique

Many different diagramming styles have been proposed. It is quite possible that one is as good as the other. Our style is illustrated by the following diagram:

Figure 3



Relationships are shown as lines. A 1 indicates which end of the line is connected to the one entity, and an M indicates which end is connected to the many entity.

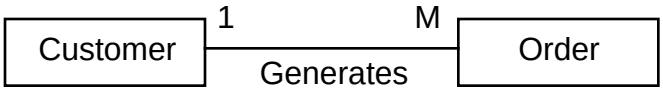
To document what attribute or attributes are being used for the relationship, you can display the attribute name or names, as shown below:

Figure 4

However, this is really unnecessary. As indicated in Chapter 4, there is no meaningful choice as to what column or columns are used to create a relation. On the one side, it is the primary key. On the many side, it is the foreign key (consisting of the same columns as the primary key on the one side). Thus, you only show the attribute name or names in the diagram in the rare case where there is some ambiguity.

Here is a better way to document relationships. Since relationships represent associations between entities, there will almost always be possible relationship names which are verbs. In your [Customer] and [Order] situation, you could have labeled the relationship as follows:

Figure 5

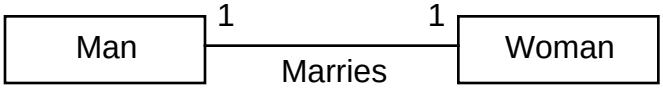


This statement says "Customer generates order," which is about as simple and straightforward as documentation can get.

6.4 Why entities and relationships?

Take a look at some real-world problems to illustrate this technique. Consider the following diagram illustrating the relationship between a man and a woman in marriage:

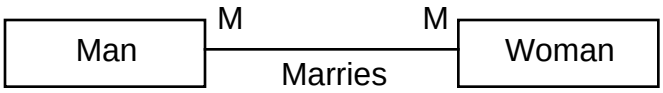
Figure 6



In the American cultural norm one man is married to one woman at a time. (Notice that this is not the case in all cultures.) The American cultural norm also states that a marriage involves individuals of the opposite sex. Suppose that you model only the two entities

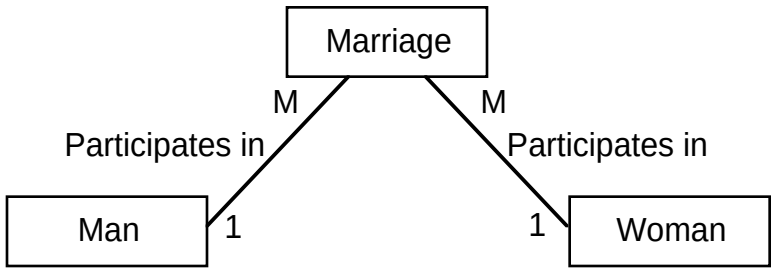
[Man] and [Woman] on the diagram. However, you recognize that the American culture allows serial polygamy (i.e. multiple spouses over time). Thus, you intend to track all of the marriages in which individuals are involved. This would lead to the following diagram:

Figure 7



From a physical design standpoint, you know that it is not possible to have a M:M relation in a relational database. Thus, you need to split this M:M relation into two 1:M relations. This is done by adding a third linking entity between the two base entities, as shown in the following diagram:

Figure 8

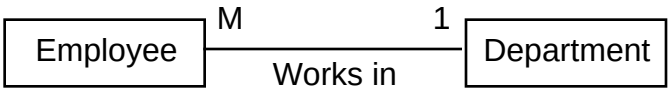


The first step in developing an entity relationship diagram is to identify the things that are to be stored in your database. The name of an entity will almost always be a noun. Each entity will have some type of identifier (the primary key) plus other attributes (i.e. columns). The specific value of the identifier must lead us to one and only one instance the entity.

6.5 Examples

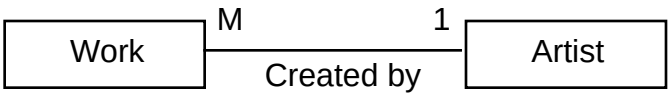
Here is the diagram for the first structure discussed in Section 5.6, illustrating the application of 3NF:

Figure 9



And here is the diagram for the second structure discussed in Section 5.6, also illustrating the application of 3NF:

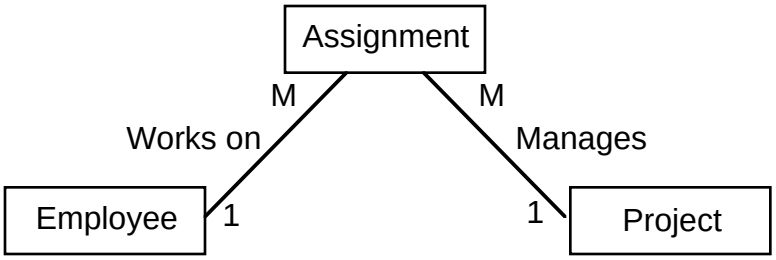
Figure 10



These diagrams are natural and obvious.

This is the diagram for the example used in Section 5.5 (illustrating the use of the 2NF):

Figure 11



There should be little resistance to this diagram. [Employee] and [Project] are certainly real world objects which you are interested in tracking. In addition, the concept of [Assignment] is natural and obvious. The relationships between these entities are clear. This is also a good example of a many to many relationship and its appropriate diagram. Note the [Assignment] table serves as the linking table between [Employee] and [Project].

6.6 Review

Review the concepts of an entity/relationship diagram before going on.

- An entity is a real-world person, place, thing or concept which the system is intended to track. For our purposes, you are treating an entity and a table as the same concept.
- An attribute is something about an entity which you wish to store. Again, you are considering an attribute and a column to represent two sides of the same coin.
- A relationship is an association between or among entities. A relationship can almost always be labeled as a verb. You consider a relationship and a relation to be equivalent.

An entity/relationship diagram is a picture of the real world things which the system is intended to track, and the relationships among them.

Exercises: Creating entity/relationship diagrams

Exercise 6.1

➔ Refer to Exercise 5.1. Create an ERD representing the structure used in that exercise.

Exercise 6.2

➔ Refer to Exercise 5.2. Create an ERD representing the normalized structure you cre-

ated in that exercise.

Exercise 6.3

→ Refer to Exercise 5.4. Create an ERD representing the normalized structure you created in that exercise.

Exercise 6.5

→ Refer to Exercise 5.6. Create an ERD representing the normalized structure you created in that exercise.

Exercise 6.6

→ Refer to Exercise 5.7. Create an ERD representing the normalized structure you created in that exercise.

Exercise 6.7

→ Refer to Exercise 5.8. Create an ERD representing the normalized structure you created in that exercise.

Exercise 6.8

→ Refer to Exercise 5.9. Create an ERD representing the normalized structure you created in that exercise.

Exercise 6.9

→ Refer to Exercise 5.10. Create an ERD representing the normalized structure you created in that exercise.

Exercise 6.10

Consider the following scenario.

This database will be used by the Central Pirate Registry located in the Lower Bermuda Triangle. (No doubt the 4D system used will be unregistered pirated software!)

- Pirates are identified by unique pirate nicknames regulated by the Central Pirate Registry. Pirates are never allowed to change their nicknames. In addition, each pirate is given a Christian name, a ferocity rating, and a date of first piracy.
- Pirate ships are also identified by unique pirate ship names. These are also regulated by the Central Pirate Registry. Important information about a pirate ship includes the number of masts, number of cannon and date commissioned.
- Merchant vessels are identified by unique merchant ship names regulated by the Potential Victims Association of London, England. Important characteristics of merchant vessels include weight and number of masts. The Pirate Registry keeps track of merchant vessels that have actually been plundered or sunk.

- A given pirate is a crew member for a specific pirate ship at any given time. A pirate may also be unemployed at some times. One and only one pirate is Captain of one and only one pirate ship at any given time. (Assume that the history of past employment is not material.)
- The Pirate Registry keeps track of each incident of plundering. The record identifies the pirate ship, the merchant vessel, and the date of plundering, whether or not the merchant vessel was sunk, and how many innocent seamen were forced to walk the plank. It is possible for the same pirate ship to plunder the same merchant ship more than once.

→ Identify all functional dependencies.

→ Develop a normalized database structure.

→ Create a complete entity/attribute listing for all tables in the structure.

→ Create an entity/relationship diagram for the structure.

7 Discovering entities, attributes and relationships

This chapter contains a simple cookbook approach for determining what entities, attributes and relationships are included in the system.

7.1 A client interview process

Discovering entities consists of interviewing the client and asking the question: "What types of things does this system intend to track?" The answer to this question will inevitably consist of lots of nouns and adjectives.

Generally, the nouns will be entities and attributes and the adjectives will be (or will imply) attributes.

Looking at our example above, if you ask this question of your client, he or she might reply: "We need to track men and women and the marriages they are involved in." (This is a remarkably clear answer, and you will not normally get anything so easy as this.) You have three nouns in this sentence, so you can propose three candidate entities: [Man], [Woman] and [Marriage].

It is sometimes difficult to tell whether something is an entity or attribute. This can be resolved by considering the purpose of the design activity. You think of something as an entity if it is something about which you want to store data. Also, if something has an attribute, it is an entity. Attributes can't have attributes.

Once you have finished the process of recording and analyzing the client's response, you ask the next question: "What is it about entity name that you wish to track?" Again, you will get a statement with a lot of nouns and adjectives. Almost all of these will be attributes, but you may discover another entity or two in the process. You then need to add this to your list of entities and go on.

Returning to your example, let us assume that you ask:

"What is it about [Man] that you wish to track?"

and the client replies:

"We need to know the man's last name, first name, middle initial, address, city, state, zip code, age, ethnic group and religious preference."

Again, an unrealistically clean response. Based upon that, you can make the following entity/attribute listing for [Man]:

MAN

Column Names	Data Types	Keys
Man ID	Longint	PK

MAN

Last Name	String (45)	
First Name	String (45)	
MI	String (45)	
Address	String (80)	
City	String (30)	
State	String (2)	
Zip Code	String (9)	
Ethnic Group	String (20)	
Religious Preference	String (20)	

If you can't decide whether a noun is an attribute or an entity, make it an entity. It will fall out later in the design process.

In terms of discovering the relationships, ask your client this question for every entity pair in your list:

"Is there a relationship between entity A and entity B?"

For those pairs of entities which the client answers "Yes" ask the following two questions:

"Can there be many entity As for each entity B?"

and

"Can there be many entity Bs for each entity A?"

If the answer leads to a 1:M relationship, you can model it accordingly. If the answer leads to a M:M relationship, you know that you have a hidden entity, and you need to probe further to determine the details of the linking entity.

Returning to your example, let us assume that you ask:

"Can there be many men for each woman?"

and the client replies:

"The American cultural norm does not allow polygamy. However, since it does allow multiple marriages over time, I would say, yes, there can be many men for each woman."

Then you ask:

"Can there be many women for each man?"

and the client replies:

"Again, I would say, yes, there can be many women for each man."

In this way, you discover the M:M relationship between man and woman. You then ask:

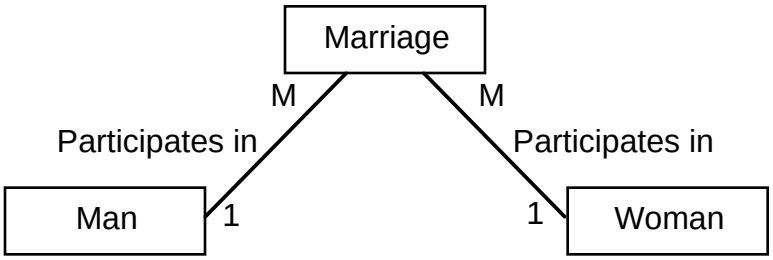
"Apparently there is something else which needs to be tracked. Since there are many men associated with a woman, and many women associated with a man, that means that there is something linking them together. Can you tell me what that could be?"

The client replies:

"Well, marriage of course is the thing which joins them together."

Suddenly, you remember that the client told you about this entity to begin with. Feeling slightly foolish, you note the 1:M relationships between [Man] and [Marriage] and between [Woman] and [Marriage].

The process leads to the ERD shown below (also included in the previous chapter):



This method may seem ridiculously mechanical, given our example. However, when you are dealing with a client who works in the widget manufacturing industry, and you wouldn't know widget if it hit you on the head, you will find that it works pretty well. The advantage is that you don't have to know anything about the client's

business in order to begin to discover the nature of the system he or she wants. Inevitably, you will learn lots about the client's business in the process.

7.2 Differing users' views

So far, you have emphasized a top-down approach which involves discovering entities and relationships from the nature of the problem using the client interview process described above. Often it is possible to proceed in this matter, but not always. This is true for several reasons:

- Individual users will frequently describe their particular views of the system when asked for help.
- The situation may be so complex that the entities and relationships are not readily apparent. The larger the project, the more likely this is to be the case.

You really need to make sure that all of the important details are captured.

- The alternative is to recognize and document the individual users' views. These will often be embodied in reports, paper forms, or screens of the existing system. This is often called a bottom-up approach. Here is the procedure:
- Document each user's view using the interview process shown above.
- List and define all data elements (entities, attributes and relationships).
- Identify all functional dependencies for each view.
- Develop an ERD for each view.
- Normalize the contents of each view.
- Examine all of the views.
- Look for entities with the same key. It should usually be possible to combine them into one entity.
- Look for entities or relationships with attributes which are keys or parts of keys of other relationships or entities. These will usually be foreign keys, and are indicative of other relationships.

Be very careful to avoid duplication of entities, relationships and attributes.

The following section will point out some of these problems.

7.3 Naming conflicts

The first area of concern is naming conflicts. Here you run into synonyms and homonyms

Two words are synonyms when they have the same or nearly identical meaning. We use the word in a special way. In a database, two names are synonyms if they represent the same concept.

Two words are homonyms if they sound the same or are spelled the same but have different meanings. In a database, one word which is used for two distinct concepts is a homonym.

Both of these items are things to avoid in designing a database. Unfortunately, they crop up all too often.

Assume that you have a client with several personnel involved in the database design process. One individual, a Mr. Smith, is the sales and marketing guy. The other person, Ms. Jones, is the accountant.

When you interview Mr. Smith he tells us the system needs to keep track of Product Sales Slips. When you interview Ms. Jones, she says the system must keep track of Purchase Orders.

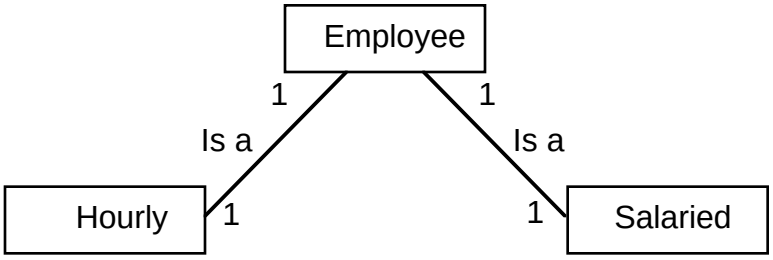
You think you have two distinct entities here. The opposite is true. After probing, you

find that a Product Sales Slip is simply the salmon colored copy of a Purchase Order. (The client has re-labeled this particular copy at the request of the sales and marketing folks.)

You have just been bitten by a synonym. The result of a synonym is that you will have extraneous entities that need to be combined.

A homonym is similar. Assume that you are developing an application for tracking personnel matters. One of your entities is [Employee]. After probing, you find that there are two types of employees, hourly and salaried. The characteristics of these two types of employees are totally different. Hourly employees have different benefits, and so on.

This is an example of an is a relationship. A salaried employee is a member of the class of employee. Likewise, an hourly employee is a member of the class of employee. Nonetheless, the attributes of these entities are so different that you must recognize them formally, which you do as follows:



This is an example of a 1:1 relationship. (Whether you implement this 1:1 relationship is another matter. Remember, you are designing, not programming.)

The homonym was employee. By considering this as a single entity, you were missing a basic aspect of the system. Thus a homonym will disguise multiple entities as a single entity.

Exercises: Client interview process

Exercise 7.1

The law office of Dewey, Cheatham and Howe, Esq. has asked you to design a system for keeping track of case information, and helping the firm to fully automate their practice of ambulance-chasing personal injury law.

Your client contact is Hugh Louis Dewey (known to his friends as Huey Louie Dewey), the senior partner of the firm. Huey is an aggressive, hotshot young lawyer, and he knows it. Unfortunately, he thinks he knows as much about database design as you do.

One of Huey's main objectives is to track the effectiveness of his yellow pages, print, radio and television advertising. For this reason, he wants to be able to track the clients who come to him as the result of any particular advertisement. By doing so, Huey hopes to be able to focus his advertising dollars on the most effective advertisers and ads.

Also, Huey receives referrals from doctors who work with him on cases. (He refers business to them as well, a classic example of a good-old-boy, "you scratch my back and I'll scratch yours" relationship.) He wants to track which doctors are sending him the most business, so that he can return the favor.

When you arrive, you find that Huey has already designed the database structure for you. He simply wants you to implement it, and because he has saved you all this work, he wants a discount. Here is a part of his structure:

Client

Column Names	Data Types	Keys
Client Last Name	String (45)	PK1
Client First Name	String (45)	PK2
Client MI	String (45)	PK3
Client Address	Text	
Client CSZ	String (45)	
Work Phone	String (10)	
Home Phone	String (10)	
Ad Result	Boolean	
Advertiser Name	String (30)	FK1.1
Advertiser Phone	String (10)	
Ad Date	Date	FK1.2
Physician Referral	Boolean	
Physician Name	String (80)	
Physician Specialty	String (20)	

Case

Column Names	Data Types	Keys
Case Number	Longint	PK
Client Last Name	String (45)	FK1.1
Client First Name	String (45)	FK1.2
Work Phone	String (10)	
Home Phone	String (10)	
Defendant Name	String (45)	

Case

Case Amount	Real	
Defendant Address	Text	
Defendant CSZ	String (45)	
Opposing Atty Name	String (80)	
Opposing Atty Phone	String (10)	
Ad Result	Boolean	
Advertiser Name	String (30)	FK2.1
Advertiser Phone	String (10)	
Ad Date	Date	FK2.2
Physician Referral	Boolean	
Physician Name	String (80)	
Physician Specialty	String (20)	

Ad

Column Names	Data Types	Keys
Advertiser	String (30)	PK1 FK1
Ad Date	Date	PK2

- Some of these tables contain composite columns. Eliminate them and replace them with atomic columns.
- Some of Huey's choices for primary keys are suspect. Correct them. Create synthetic keys where necessary.
- Identify all functional dependencies.
- Normalize these tables to 3NF.
- There are some missing tables in this structure. Add them.
- Create an entity/attribute listing for each normalized table identifying the primary and foreign keys.
- Create an ERD representing the normalized structure.
- You are a hungry database designer. You don't particularly like this person, but you need the money. On the other hand, you realize that he would just as soon sue you as look at you. Explain to Huey why your structure will be better than his for the ongo-

ing automation of his practice.

Exercise 7.2

Your client is American Press International ("API"), a news service used by various newspapers and other media nationwide.

The name of your contact is Dave. He is the general manager of API's New York office. You proceed to interview Dave as shown in the following dialog:

You: "Dave, can you tell me what types of things the system should keep track of?"

Dave: "Well, we have various newspapers, magazines and other publishers. They file stories. Stories are written by reporters working for these publishers. We need to know the publishers of any story, as well as the reporter who wrote the story. It's frequently handy to know who a reporter has worked for as well.

"Anyway, we get requests for stories having to do with particular subjects. We track subjects as single words. For example, we could have a customer who asks for stories with the words 'Persian,' 'Gulf,' 'War,' 'Desert' or 'Storm'. Also we need to be able to ask for stories which include all of a set of subjects, or don't include subjects, or any combination of these. So it can get pretty complicated.

"That's basically how it works."

Dave now gets called away to an urgent meeting, and that's all you have go on. Before running off, Dave asks you to put together something "quick and dirty" showing him what you think the system would look like.

- Identify all of the entities to be included in the system.
- See if you can figure out the attributes as well. (Guess if you have to.)
- Identify the functional dependencies between the attributes.
- Create an entity/attribute listing for each entity.
- Try to create an ERD based upon the above.

8 More advanced modeling concepts

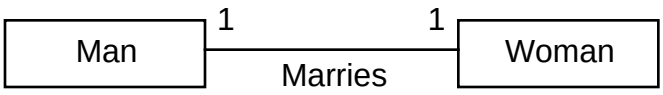
This chapter continues the discussion of entity relationship modeling. Here you will deal with some of the trickier problems and introduce some advanced data modeling concepts which will help resolve them.

8.1 Storing historical data

- You have already been storing historical data while not formally recognizing the process. Typically, data will take one of two forms with respect to time:
- The database will store a single instance of the data, indicating the current state of the data, and ignoring history.

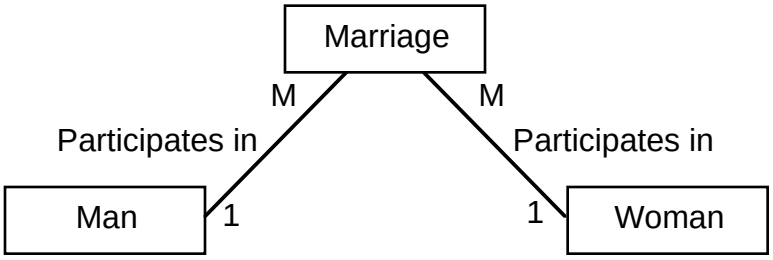
The database will store multiple instances of the data, representing historical changes over time. Typically, the most recent instance will represent the current state of the data.

Remember your example using marriage? Originally, you modeled the database in the first way:



This simply stores the fact that a man is married to one woman at a time, and visa versa.

However, you then became interested in storing the changes in marital state over time, which led to this structure:



Thus, you see that storing historical data involves taking the attributes to be stored over time, and turning them into a new entity with an 1:M relation between the old entity and the new one. You can apply this process anytime you need to store historical data.

Broadly speaking, there are at least two ways that historical data can be tracked. One is that shown above, where you are tracking marriages. Since a person can be either married or single at any given time, it is necessary to store the start date and the end date of the

event, as shown in the following entity/attribute listing:

Marriage

Column Names	Data Types	Keys
Man ID	Longint	PK1 FK1
Woman ID	Longint	PK2 FK2
Date Married	Date	PK3
Date Divorced	Date	

Notice that it is necessary to include Date Married in the primary key, since two people can be married more than once.

The other way is best illustrated by an example you used earlier of [Parts]. Assume that you want to track the changes in the price of any given part. Obviously, a part always has a price. Thus, it is not necessary to store the end date of a price. You simply infer that the end date of one price is equal to the start date of the next price. This leads the following structure:

Part Price

Column Names	Data Types	Keys
Part ID	Longint	PK1
Start Date	Date	PK2
Price	Real	

Again, you must include Start Date in the primary key, since a part can have the same price more than once.

8.2 Relating an entity to itself (bill of materials)

Another classic problem of relational design is called the bill of materials problem. This concerns the situation where a part is included in an assembly, which is also itself a part. This is known as a recursive relationship. The relationship is recursive because it loops back upon itself.

You know you have a recursive relationship if an entity relates to instances of itself. The example of a bill of materials is apt because a part can include a part.

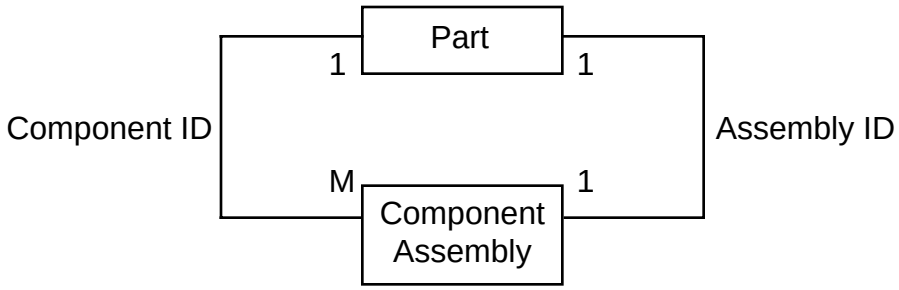
The structure to implement this relationship is typically something like the following:

Part

Column Names	Data Types	Keys
Part ID	Longint	PK
Description	String (80)	

Component Assembly

Column Names	Data Types	Keys
Component ID	Longint	PK1
Assembly ID	Longint	PK2



Notice that the relationship goes full circle. That is the mark of a recursive relationship. Also notice that the relationship is 1:M on one side and 1:1 on the other. Thus, a part can be a component of many assemblies, but an assembly is a part.

There is a problem with this approach which cannot be solved with relational database design. Take a look at the following sample data:

Component Assembly

Component ID	Assembly ID
123	456
123	567
123	678
456	777
456	778
567	887

Component Assembly

567	888
678	222
678	223
678	224
222	123

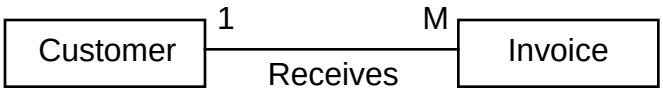
123 is shown containing 678 which is shown containing 222 which is shown containing 123 which is shown containing 678 which…

Clearly, there is something wrong here. Someone has entered incorrect data. The result is that your retrieval will be in an endless loop. The program must check each row as it is entered to make sure the where used regression is valid. This issue becomes part of the implementation of the database, and is beyond the scope of this class. For the time being, it is enough for you to know that the issue exists.

8.3 Storing derived data

An issue frequently arises in database design concerning whether to store derived data, that is data which consists of calculations from other data. Examples include storing the year-to-date sales by department, or the average invoice total per customer.

One issue you need to deal with right away is normalization with respect to derived data. The examples which follow all deal with the following simple data structure:



Consider the following entity/attribute listing for the [Customer] table:

Customer

Column Names	Data Types	Keys
Customer ID	Longint	PK
Customer Phone	String (10)	
Customer Address	String (80)	
Customer City	String (35)	
Customer State	String (2)	
Customer Zip	String (9)	

Customer

Average Invoice Amount	Real	

You define the Average Invoice Amount as the average of all Invoice Totals for a customer. Thus, if you knew all of the Invoice Totals for a customer, you could calculate the Average Invoice Amount. You would then argue that Average Invoice Amount is functionally dependent upon Invoice Number, not Customer ID. The opposite is true. Remember the definition of functional dependency from Chapter 5:

You say that Column A is functionally dependent on Column B if, and only if, there must be a single value in Column B for every value in Column A. Source: Reference 2

Now, there is not a single value of Average Invoice Amount for every value in Invoice Number. In fact, you know that this is not true. Thus, Average Invoice Amount is not functionally dependent upon Invoice Number. And you can further conclude that this column is not a violation of the any normal forms that you have seen.

However, lets take another example. Consider the following entity/attribute listing:

Invoice

Column Names	Data Types	Keys
Invoice Number	Longint	PK
Customer ID	Longint	FK1
Invoice Total	Real	
Invoice Tax	Real	
Invoice Grand Total	Real	

Here you are storing Invoice Grand Total which consists of the sum of Invoice Total and Invoice Tax. Since Invoice Grand Total is functionally dependent upon the combination of Invoice Total and Invoice Tax, this violates 3NF.

There is a third possibility. Look at one more scenario. This time you will include both the [Customer] and [Invoice] tables:

Customer

Column Names	Data Types	Keys
Customer ID	Longint	PK
Customer Phone	String (10)	
Customer Address	String (80)	

Customer

Customer City	String (35)	
Customer State	String (2)	
Customer Zip	String (9)	
Discount Rate	Real	

Invoice

Column Names	Data Types	Keys
Invoice Number	Longint	PK
Customer ID	Longint	FK1
Invoice Gross Total	Real	
Discount Amount	Real	
Invoice Net Total	Real	

Notice that [Invoice]Discount Amount is a calculated column, consisting of [Invoice]Invoice Gross Total multiplied by [Customer]Discount Rate. Since the [Invoice]Discount Amount is clearly functionally dependent upon the combination of [Invoice]Invoice Gross Total and [Customer]Discount Rate 3NF is obviously violated.

Thus, there are three types of derived data. The first type is summary derived data which is calculated with respect to a one table by calculating values from a many table. In our first example, the Average Invoice Amount is summary derived data because the [Customer] table is the one table in a 1:M relationship with [Invoice].

The second type is detail derived data which is calculated from the columns within a single table and stored in that table. In your second example, the Invoice Grand Total is detail derived data.

The third type is cross-table derived data which is calculated from columns of both tables, but stored on the many side of a 1:M relationship. In your third example, [Invoice]Discount Amount is an example of cross-table derived data. ([Invoice]Invoice Net Total is detail derived data, since it is calculated from columns entirely within the [Invoice] table.)

There is only one type of derived data which is normalized. That is summary derived data, or data which is calculated from the columns in a many table and stored in a column in the one table. Modeling of derived data other than summary derived data should be avoided. (However, you may end up storing other types of derived data anyway. Remember, you are designing, not programming.)

Even with respect to summary derived data, there is an issue of redundancy. Since the

derived data is calculated from other data, the data is in a sense redundant. You could calculate it anytime you like, and this makes storage of this data unnecessary. However, clearly this is not a major issue. Since the data is being stored on the one side of the 1:M relationship, by definition summary derived data will take up much less space than either of the other types of derived data.

In addition, you must always recalculate the data whenever any of the underlying data changes, which creates a relational integrity issue. Isn't this what normalization is designed to avoid? This is a serious issue, but is somewhat mitigated by the mechanism of posting, which is explained below.

Finally, there is an issue concerning performance. Returning to your original example:

Customer

Column Names	Data Types	Keys
Customer ID	Longint	PK
Customer Phone	String (10)	
Customer Address	String (80)	
Customer City	String (35)	
Customer State	String (2)	
Customer Zip	String (9)	
Average Invoice Amount	Real	

Now assume that you add an invoice for a given customer. Calculating Average Invoice Amount is going to require that you perform the following steps:

- Enter the invoice as you normally would.
- Select all of the invoices ever created for this customer, including the new one.
- Add up all of [Invoice]Invoice Totals for all of the invoices returned in the previous step.
- Divide the resulting sum by the number of invoices ever created for this customer, including the new one.

Save the result into the [Customer]Average Invoice Amount column.

That's certainly a lot of trouble just to enter a single invoice. The process is going to be slow. Worse, for your best customers, the ones with the most invoices, it is going to become continuously slower.

In order to eliminate or reduce the issues of relational integrity and performance, judgment must be applied to the problem of storing derived data. In order to understand how

to apply this judgment, you must further categorize the derived data. Consider the following alternate design of the [Customer] table:

Customer

Column Names	Data Types	Keys
Customer ID	Longint	PK
Customer Phone	String (10)	
Customer Address	String (80)	
Customer City	String (35)	
Customer State	String (2)	
Customer Zip	String (9)	
Total Purchases	Real	
Total Number of Invoices	Longint	

Here, you have split the Average Invoice Amount column into two columns, Total Purchases and Total Number of Invoices. Note that these are the components of the Average Invoice Amount using the calculation process detailed above. What you have done is to split up Average Invoice Amount into its component parts. You are not going to store Average Invoice Amount because you know that doing so would now violate 3NF. (It would then be detail derived data.) Thus, you will simply calculate Average Invoice Amount when you need it.

- Also, when you look at the process of entering a new invoice you find that all you need to do is the following:
- Enter the invoice as you normally would
- Increment the [Customer]Total Purchases column by the amount stored in [Invoice]Invoice Total. (Note that you already have the [Customer] row loaded, so there is no database impact whatsoever.)
- Increment the [Customer]Total Number of Invoices column by one. (Again, no database impact whatsoever.)

You have eliminated all but a trivial amount of the overhead associated with storing this derived data. Also, you will be able to calculate the Average Invoice Amount whenever you need it.

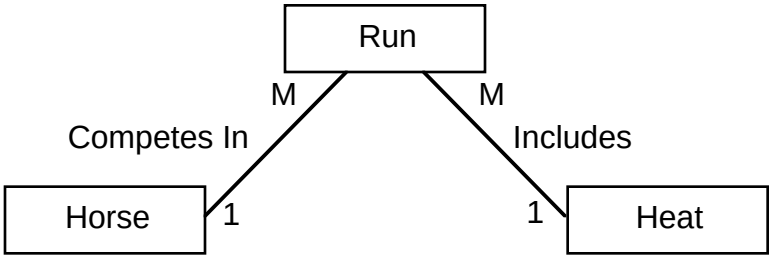
So, you conclude that by splitting the [Customer]Average Invoice Amount column into simpler parts you were able to create a better design. The first type of derived data, represented by the [Customer]Average Invoice Amount column in your original design, is called second order derived data. The quality which distinguishes second order derived

data is that it is derived from other derived data.

The second type of data, represented by the [Customer]Total Purchases and [Customer]Total Number of Invoices columns, is called first order derived data. The characteristic which distinguishes first order derived data is that it is only derived from base (i.e. non-derived) data. Thus, you see that both [Customer]Total Purchases and [Customer]Total Number of Invoices are calculated only from base data in the [Invoice] table.

The thing which is nice about first order derived data is that it can be calculated by posting. The process of posting involves adding or subtracting values stored in a column in the one table based upon values in one or more columns in a single row in the many table. If posting is performed as each of the many table rows are inserted, updated or deleted, the overhead involved is trivial. Once you have a posting system in place it will maintain itself. Look at one more example to reinforce these concepts.

Assume you have a system for keeping track of the performance of race horses. Each race horse participates in many heats. A single horse competing in a heat is called a run. You wish to keep track of the average time for each horse. The following is a partial structure for this database:



Here are the entity/attribute listings.

Horse

Column Names	Data Types	Keys
Horse ID	Longint	PK
Horse Name	String (80)	
Trainer	String (80)	
Breed	String (35)	
Male	Boolean	
Total Run Time	Real	
Total Runs	Integer	

Run

Column Names	Data Types	Keys
Horse ID	Longint	PK1 FK1
Heat ID	Longint	PK2 FK2
Run Time	Real	

Heat

Column Names	Data Types	Keys
Heat ID	Longint	PK1
Track	String (80)	PK2 FK1
Date	Date	

It seems strange to store the Total Run Time for a horse. Surely, the amount of time that a horse spends in the track is of only slight interest. The same is true of Total Runs. What you are really interested in is the average run time so that you can rate horses and compare them.

However, you arrived at this structure by decomposing the average run time calculation into first order derived data. By doing so, you can simply post the Run Time for each horse into the [Horse]Total Run Time column. Then you increment the [Horse]Total Runs column by one. That gives us a quick and easy way to calculate the average run time for any horse, or to sort [Horse] by the resulting calculation.

Exercises: Advanced Modeling Concepts

Exercise 8.1

Refer back to Exercise 6.10. You now wish to track the historical data with respect to a pirate's career.

- Show all changes in functional dependencies.
- Create any modifications to the entity/attribute listings.
- Create a new entity/relationship diagram showing the changes.

Exercise 8.2

You wish to create a database to track the genealogical records of individuals. Included in the database should be the birth, marriage, divorce and death of the persons tracked in the database.

Create the database design to do this, including an entity/attribute listing for each entity

and an ERD showing all entities.

Exercise 8.3

The American Baseball League has hired you as a database consultant to design a database to track team and player performance. Since baseball is a very statistical game, they want all sorts of statistics on players, including:

- Batting average (by season)
- Batting average (lifetime)
- Attendance (by season)
- Attendance (lifetime)
- Average errors per game (by season)
- Average errors per game (lifetime)
- Runs (by season)
- Runs (lifetime)
- Home runs (by season)
- Home runs (lifetime)

You also need to calculate the following statistics on teams:

- Total runs (by season)
- Average runs per game (by season)
- Games won (by season)
- Games lost (by season)
- Games tied (by season)

It is also helpful to be able to see the statistics for teams in past seasons, for comparison.

For those unfamiliar with the game of baseball, a single playing year is called a season. A player's batting average is determined by dividing the number of hits by the number of times at bat. (Ignore walks for the moment.) Also, it is enough to know that a player can commit one or more errors during a game. Obviously, attendance consists of a player participating in a game.

A run is simply the event of a player crossing home plate. A game is won by the team with the most runs.

→ Design an appropriate database for this purpose, including an entity/attribute listing for each entity and an ERD showing all entities.

9 Completing a Database Design Specification

This chapter completes our discussion of the design phase of software construction. In this chapter, you will complete a document called the database design specification ("DDS") which will form your basic design document.

9.1 Definitions

You need complete definitions of all entities, relationships and attributes in the design. The model is not complete without definitions which assure that the next programmer will understand your design as well as you do. An ERD alone is not enough.

9.1.1 Entity definitions

An entity definition must describe the entity clearly enough to make it possible to determine whether or not a specific thing or concept is an occurrence of the entity in question. The definition must also tell us why this entity is of interest to the database.

9.1.2 Attribute definitions

An attribute definition must describe the thing or concept clearly enough to make it possible to determine what aspect or characteristic of the entity is being described. The definition must also tell us why this attribute is of interest to the database. The data type of the attribute should also be shown.

9.1.3 Relationship definitions

It is very helpful to define the nature of the relationships between the entities. As stated above, this will normally consist of a verb. Again, the definition must be clear enough for us to tell if an event is an instance of the relationship. The attributes used to establish the relationship should be shown here.

The end result of this process is a data dictionary. The following is an example of a data dictionary for the database first described in Section 2.4:

Data dictionary:

Entities:

- [Part]
  - A [Part] is a type of item which is sold by the company through its normal sales process. Thus, this concept does not refer to the individual items themselves, but the types of items which can exist. Examples include Umbrella Stand, Spittoon, Buggy Whip.
- [Warehouse]

- A [Warehouse] is a location where items sold by the company are stored prior to sale. Examples would include Warehouse A in Buffalo, Warehouse B in Hong Kong, and so forth.

- [Stock]
  - A [Stock] is an individual set of items which are stored in a warehouse prior to sale by the company's normal sales process. All items in a [Stock] are of the same type, that is, they are all the same [Part]. All [Part] items of a particular [Part] which are stored in a [Warehouse] are contained within a single [Stock]. Examples include 20 Umbrellas which are stored in Warehouse A, 100 Spittoons stored in Warehouse B, etc.

Attributes:

- Part Number
  - Uniquely identifies an individual [Part]. Stored as a Longint.
- Part Description
  - The textual description on an individual [Part]. Stored as a String (80). All Part Description entries must be unique within [Part].
- Warehouse Code
  - Uniquely identifies an individual [Warehouse]. Stored as a String (2).
- Warehouse City
  - The location of an individual [Warehouse]. Stored as a String (30).

Relationships:

- References
  - An instance of an individual [Stock] referencing a [Part]. Based on Part Number.
- Stores
  - An instance of an individual [Warehouse] storing a [Stock] item. Based on Warehouse Code.

As you can see, a data dictionary is an enormously useful item to have around, both during construction and afterwards.

9.2 Naming conventions

Naming and the selection of naming conventions is often very controversial and divisive. The following naming conventions are based upon common sense, and may be useful to you. If not create your own:

- Use common nouns and verbs to describe data elements. Avoid computer terminology. You need something which is useful to the user, as well as to the programmer.
- Spaces should be used in names in the design document (as they have in this guide). They can be excluded when the program is implemented, if desired.
- Make the names as long as necessary when in the design phase. Later on, you can come up with shorter names which fit within 4D's limits. It is often helpful to create a cross-reference listing showing the design names and the implementation names. However, the names in the design document and in 4D should not differ substantially.

All names should be unique in the design document. Do not reuse names. Thus, do not name an attribute Last Name. Instead, name it Customer Last Name. That way you can have another completely different attribute called Employee Last Name. This practice will make your data dictionary much more meaningful. When you implement the database you can change this decision if necessary. Then you can simply use the fully-qualified name of a field to reference an attribute in your design.

9.3 Identifying data storage and transaction requirements

You must determine how much data will be stored in each table, and how many additions, modifications and deletions to rows will occur over a regular period (normally one year). You also need to know if there is any peak period during which the transaction load will be unusually heavy.

This part of the client interview process occurs after the initial design has been developed. You simply ask the client the following questions with respect to each entity in the design:

- "How many rows are you currently storing on entity name?"
- "During any given 12 month period how many rows do you think will be added to entity name?"
- "During any given 12 month period how many rows do you think will be deleted from entity name?"
- "During any given 12 month period how many rows do you think will be modified in entity name?"
- "Is there any particular period during which the number of rows added, deleted or modified in entity name will be unusually high?"

Take the example used in Section 5.6 concerning a museum database. You are interviewing Ms. Simons who is the museum's curator:

You: "Ms. Simons, we have identified two tables we are going to store data in, [Work] and [Artist]. How many works do you have in the museum pres-

ently?"

Simons: "The museum has approximately 30,000 different objects on display, on loan and in storage."

You: "Do you have any idea how many artists are represented in all of these works?"

Simons: "I would guess about 5,000."

You: "How many new works are acquired each year?"

Simons: "This year we acquired 4,500 new works. Last year the number was somewhat higher, about 5,500."

You: "Is the ratio of works to artists about the same for new works as those already on hand, that is about six-to-one?"

Simons: "I would guess that is about right."

You: "When you sell a work, I assume you delete it from the database?"

Simons: "Of course."

You: "Is there a time when you might delete an artist from the database?"

Simons: "Yes. If we have no more works by that artist, he or she is no longer of interest to us."

You: "How many works to you sell each year?"

Simons: "We attempt to balance the museum's acquisitions and dispositions each year. Thus the number of additions and deletions is about the same."

You: "Is there any type of event which would cause you to modify the data on a work?"

Simons: "Yes. If we loan out a work, or place it in storage, or remove it from storage, we change the status of the work."

You: "How many works are affected by this each year?"

Simons: "I would guess about ten percent per year."

You: "Is there any type of event which would cause you to modify the data on an artist?"

Simons: "That would be extremely rare. Since we only collect works up to the late nineteenth century, none of your artists are still alive. Thus, we would not modify the data unless there was a mistake in typing."

You: "Is there any particular time of the year when the business of the museum is more busy than any other time?"

Simons: "Yes there is. Almost all of the activity occurs at the annual auctions at Sotheby's and Christie's. These auctions occur in June."

Notice we did not follow precisely the form of the questions shown above, but you got the information you needed. It is fine to rephrase the questions in a language more appropriate to your client.

This conversation would lead to the following table load listings:

Work

Current Storage	30,000
Add	5,000
Delete	5,000
Net Storage Change	0
Modify	3,000
Peak Monthly Transactions	10,000

Artist

Current Storage	5,000
Add	833
Delete	833
Net Storage Change	0
Modify	0
Peak Monthly Transactions	1,666

Now the practical use for this process is apparent. You know the number of rows in each table. By examining the data structure, you can determine the total storage requirements for the database. You also know the future growth for planning purposes. More important, you have found out that the database will have to be able to absorb over 11,000 transactions in a single month. That's an important piece of information for us to have in order to successfully design this database.

9.4 Identifying business rules and other constraints

For each attribute you must determine what the business rules and constraints are. Thus, if a Salary attribute must be between $15,000 and $150,000, that should be documented. Also, you should document any default values. Similarly, you should document any choice lists which will be applied to attributes.

This leads to a table constraint listing as follows:

Part Price

Column Names	Minimum	Maximum	Default	Choice List
Part ID				
Price Start Date			Current Date	
Part Price	0	1,500		
Price Change Type				Price Change Type List

Sample data for choice lists can be documented as follows:

Price Change Type List

Temporary Discount
Permanent
New Supplier
Clearance

9.5 Frequent search and sort parameters

- You must identify the columns which the client will frequently use to search and sort rows in the database. This is critical for at least two reasons:
- This process will help establish the columns which must be indexed.

Cross-table searching and sorting requires certain strategies in order to achieve acceptable performance. Knowing the columns affected will help you better plan this, and thus reduce the modifications to the database which will be needed as a result of testing.

- To determine the frequent search and sort parameters, simply ask the client at the end of the design process which columns or sets of columns he or she intends to search or sort on frequently for any given table. You will always include the primary key columns of the table in question in both the search and sort lists. Pay particular attention when the client wants to search or sort one table on the columns of another table. Cross-relational searching and sorting is inherently slow. (This is not unique to 4D. It is inherently slow in any database management system.) Also, pay attention to searches and sorts on multiple columns. This is another performance issue. It is also necessary to determine the frequency that the client intends to sort or search by a particular column or set of columns. The optimization strategies will vary considerably depending upon the frequency of each operation. Frequency is shown like this:

- Daily + indicates that the client intends to perform the operation on an almost constant basis.
- Daily indicates that the client intends to the perform the operation at least once per day.
- Weekly indicates that the client intends to perform the operation at least once per week.
- Monthly indicates that the client intends to perform the operation at least once per month.
- Rarely indicates that the client intends to perform the operation less frequently than once per month. Unless the table is very large or the operation is extremely time consuming, rare operations do not have to be shown.

Once you establish the frequent search and sort columns, document them in a search/sort listing, as follows:

Part

Search Columns	Frequency
Part ID	Daily +
Part Description	Daily +
Sort Columns	**Frequency**
Part ID	Daily +
Part Description	Daily +

Warehouse

Search Columns	Frequency
Warehouse Code	Daily +
City	Daily +
Sort Columns	**Frequency**
Warehouse Code	Daily +
City	Daily +

Stock

Search Columns	Frequency
Part ID + Warehouse Code	Daily +

Stock

Part ID	Daily
Warehouse Code	Daily
Sort Columns	**Frequency**
Part ID	Weekly
Warehouse Code + Part ID	Weekly
Part ID + Stock Quantity	Weekly
Warehouse Code + Stock Quantity	Monthly

9.6 Security

You should explicitly deal with the issue of security during the design phase. This is a political hot potato, and you may have to force your client's top management to solve the issues for you. Postponing this issue until implementation is a bad idea. Get them on the table early.

For each entity, the questions you need to ask the client are:

- Who should be allowed to read the data?
- Who should be allowed to add data
- Who should be allowed to modify data?
- Who should be allowed to delete data?

For any given security setup it can be proven that all security requirements can be decomposed into a distinct set of groups. A group is any set of users who have the same security access privileges.

Groups can be hierarchical. That is, a group can be nested within a group. The top-level group is normally Design, which consists of the developer only (assuming a single developer). The Design group is normally nested within all groups, thus giving the developer access to all functions of the program.

Other groups may include Accounting, Sales, Executive, Marketing, etc. It is typical for groups to be established along functional lines. Often, the group definitions are included within the data dictionary.

By getting these questions answered, you can develop a set of groups which implements the security requirements. Typically, your client will establish the groups for you and give them to you with little or no effort on your part (once you force them to confront the issue). These groups and their privileges can then be documented in a security listing, as follows:

Work

Access	Group
Read	All
Add	Acquisitions
Modify	Acquisitions
Delete	Curator

Artist

Access	Group
Read	All
Add	Acquisitions
Modify	Curator
Delete	Curator

9.7 Finalizing the Database Design Specification

The DDS consists of all of the various items which you have been creating throughout this class. These include:

- ERD
- Data dictionary
- Entity/attribute listings
- Table load listings
- Table constraint listings
- Search/sort listings
- Security listings

Note that you did not include functional dependencies in the list. Functional dependency lists are very useful during normalization. Once you have a normalized structure, their usefulness is somewhat reduced, as the functional dependencies are then self-evident. You may end up making a list of functional dependencies for design purposes, but will probably not include this document in the final DDS.

Exercises: Finalizing the database design specification

Exercise 9.1

Huey caved. (Refer to Exercise 7.1.) You now have the design authority you need to do the project.

In the final interview stage of the process, you determine the following facts:

- Huey immediately agreed, once you raised the issue, that there can be multiple parties related to case, and multiple attorneys related to a party. In fact, he pointed out that there can also be multiple clients in a case. In addition, some of the plaintiffs in a case are not clients of the firm, and they have attorneys as well.
- The Law Office of Dewey, Cheatham & Howe, Esq. ("DCH") is currently handling 5,000 cases for 3,500 clients.
- DCH takes on approximately 1,500 cases per year, and settles about 1,000. Cases which are settled must still be stored in the database for a period of three years, after which the data can be archived and purged from the database. Cases are settled continuously throughout the year. Purging and archiving data occurs once per year at year end.
- The ratio of new cases to new clients is approximately the same as that stated above, i.e. 5:3.5.
- DCH never deletes data about a former client. They continue to send marketing material to former clients indefinitely.
- The active case data is modified frequently. Every row is modified at least once per month. Client data is modified to reflect changes in address information, phone numbers, etc. About 1,000 client rows are modified each year.
- DCH places ads in 35 different advertisers. DCH might try a new advertiser once a year. At least 5 new ads are placed each month. DCH seldom modifies the data on advertisers, but does add new advertisers once in a while. Data on individual advertisements is almost never modified. DCH almost never deletes data on an advertiser. Data on ads more than one year old is archived and purged.
- DCH works with 18 individual physicians. Physician data is seldom modified. No physician is ever deleted from the database. One physician might be added per year, if that.
- Every individual case has at least one party other than the client, but sometimes parties are involved in more than one case. Huey says that a party being involved in more than one case is pretty rare. Huey also guesses that almost all clients are involved in only one case. Parties are added as the cases involving them are added. They are only deleted if the case or cases they are involved in are archived and purged. Most of the time, parties get modified about once a year. Since new cases come in all the time, there is never any time when parties are added

- Although every party has at least one attorney, there are only about 100 attorneys in this area, and thus the parties tend to pick among these. Once in awhile, Huey sees a new attorney show up, but not often. Attorneys are always changing their office (due to firm splits and other factors) so each attorney gets modified about once a year. He guesses there might be ten new attorneys a year. DCH never deletes data on attorneys, since they might crop up again later, and it's helpful to know what cases they worked on before. It is very rare for a party to have more than one attorney, but it does happen. Since attorneys are being entered and modified all the time, there is never any time when this is done more than any other time.
- DCH never takes a case where the amount which the firm believes can be recovered is less than $100,000.
- It will be necessary to search for clients by both last name and first name. This will be done often, more than once per day. Sorting will either be by client number, or by the combination of last name and first name. Again, this will be done whenever client data is examined, more than once per day. To facilitate direct mail at reduced rates, it is also necessary to sort by zip code. However, this only happens once per month. Further, to examine the clients who were brought in by advertising, you need to be able to search for clients who were the result of advertising, and sort by their ads and advertisers. Again, this report is run at the end of the month. Also, you need to be able to search for clients which were referred to DCH by physicians. This should be based upon the physician's last name or first name, and will be performed weekly. For running reports, you must be able to sort the clients by the combination of the physician's last name and first name. These reports are also done at the end of the month.
- DCH prioritizes cases based upon dollar amount. Thus, the most important fact about a case is the amount involved. However, you also need to be able to search for cases involving individual clients by either the client last name or client first name, or the combination of both of these, more than once per day. Also, you need to be able to run reports which sort the cases based upon the combination of the client's last name and first name about once per week.
- DCH needs to be able to search and sort advertisers by name more than once per day. Also, DCH needs to be able to run reports showing the advertisements run by the various advertisers, which is sorted by the advertisers' names followed by the ad date. These reports are run at the end of the month.
- DCH needs to be able to sort and search for parties and their participation in cases based upon the first name, last name, or combination of the first name and last name. The same is true for attorneys. This will be done more than once per day.

- DCH needs to be able to sort and search for physicians based upon the first name, last name, or combination of the first name and last name. This will be done more than once per day.
- Huey, as the senior partner, is the only person in the firm who is allowed to add or delete clients and participation of clients in cases, advertisers, or physicians as well as delete cases or attorneys. Any other personnel is allowed to add cases and participation of clients in cases, parties and participation of parties in cases, attorneys, and ads, as well as to modify clients, advertisers, physicians, cases and participation of clients in cases, parties and participation of parties in cases, or attorneys and participation of attorneys in cases.

➔ Combining what you did before, complete the database design specification for this database. Make appropriate modifications to your previous design to take the new information into account.

10 Optimizing the database design

The performance issues involved in creating a 4D database are covered extensively in other ACI classes. This section concerns specifically the issues you will want to be aware of when designing the database structure.

Normalization eliminates redundancy and arranges a collection of data by a logical structure. This process helps achieve a complete understanding of the data. Completely normalizing a database is a step which cannot be skipped. However, a completely normalized database may not be a completely optimized database. There is significant overhead involved in the continual joining or searching of relations.

The table load listing and search/sort listing are the critical documents which you will use to optimize your structure. The search/sort listing will tell you what operations the client will tend to perform most frequently, and the tables and fields affected by these operations. The table load listing will identify the tables where there will be a large number of records stored in the database. The intersection of these two listings, i.e. where there are search and sort operations on tables with large record counts, is where the performance issues will occur.

10.1 Trade-offs in performance

There is a trade off in performance between single record processing (load, insert, update and delete) and multiple record processing (search and sort). Performance in searching and sorting will tend to be improved by indexing fields, denormalization and storing derived data. Unfortunately, these same operations will degrade performance when a single record is edited.

For example, the larger the number of indexes, the more indexes must be updated every time a row is inserted, updated or deleted. Similarly, if a table is denormalized this will increase the amount of data stored in each record, which will make the record slower to load and save. Finally, storing derived data will cause more posting operations to run. While individual posting operations may create only minor overhead, a large number of them can cause a performance problem.

Also, bear in mind that all of these optimization techniques will increase the size of the data file stored on disk.

That is why it is always best to leave a table in a fully normalized structure, and index the minimum number of fields possible, as long as there is not a performance issue. The performance issues are indicated by the existence of a relatively large number of records in the table, and the need to do an operation frequently.

The question is: what is a large number of records? The answer must always be “it depends.” You must make that judgment call depending on this client’s particular situa-

tion. If you are automating a live television show, performance of less than a second will be absolutely critical. In that case, more than one hundred records might be considered large. If you are automating a warehouse, a couple of seconds might be considered perfectly acceptable response time, and more than a few thousand records might be considered large.

You must determine from your client what is an acceptable response time for any given operation. Make sure the client is aware that improved performance is not free, and that trade-offs are involved.

10.2 Performance issues

This section further details the issues involved in building a 4D database structure.

10.2.1 Storage considerations

Each index effectively doubles the space required to store any particular field. For example if a table has 20,000 records and a field in that table is of the type Alpha (10), the space required to store the field without an index is a maximum of 200 Kb. (That is not precisely correct, but it is close enough.) However, if the same field is indexed, the maximum storage required becomes 400 Kb.

Denormalizing, redundantly storing concatenated values, and storing derived data all increase the number of fields in tables. As the field count increases, the space required to store that table's data grows accordingly.

10.2.2 Loading records

4D effectively stores two copies of any given record when it is loaded into memory. Also, the entire record is loaded into memory when a record is edited, not just the fields which are displayed. This means that increasing the number of fields in a table increases the amount of memory required to hold the record by twice the size of the field. Also, the amount of time required to load the record from disk increases.

Since you are only talking about a single record, the amount of data for each field is small (say, 20 Bytes for the example discussed above). However, if your table has hundreds of fields, and many of them are indexed, you could create a performance issue. (Normally, if your tables which look like that, you should be examining your structure anyway.)

Another issue on loading records concerns the size of the data stored in the fields. If there are some very large data items, such as pictures or text fields containing lots of text, you may want to consider splitting the table in two by creating a 1:1 relationship. This technique is discussed further below.

10.2.3 Inserting, updating and deleting records

Whenever a record is inserted, updated or deleted in a table, all indexes in the table must be updated. This takes time. Increasing the number of indexes will therefore affect the

performance when saving or deleting records. Again, the amount of time required to update each index is not great, but if the number of indexes is very large, it could become perceptible.

10.2.4 Searching and sorting (single-field)

Indexing dramatically improves the performance of sorting and searching on a single field. If a common operation involves searching and sorting on a single field in a large table, indexing that field is the quickest and simplest performance win.

Bear in mind the trade-offs involved: Indexing will increase the storage space required for the table, and there is some overhead involved with updating the indexes when records are inserted, updated or deleted.

10.2.5 Querying and sorting (multi-field)

When searching on multiple fields, 4D has an optimizer which attempts to figure out the most efficient path to perform the search. For example, if one of the search fields is indexed, 4D will perform the search on that field first, and then perform the rest of the search on the non-indexed fields. While this helps some, multi-field searches are always slower than single-field searches.

In the case of sorting, there is no way for 4D to optimize the operation. Therefore any sort which includes at least one non-indexed field is entirely non-indexed. Even if all fields are indexed, a multi-field sort is always slower than one on a single indexed field.

If you have a common operation involving searching or sorting on a set of multiple fields, and the table is large, you will want to consider redundantly storing the data in a concatenated field, and indexing that field. This technique is discussed further below.

10.2.6 Querying and sorting (cross-table)

Searching and sorting operations which include fields from more than one table are always non-indexed, and are therefore slow. Anytime you have a common cross-table search or sort operation on a large table, you will want to consider denormalizing the data. This takes the fields in the one table and redundantly stores them in fields the many table. Then, the search or sort can be performed on the many table, which is faster. The denormalizing technique is discussed further below.

10.2.7 Searching and sorting (calculated data)

The slowest operation of all involves searching or sorting using a formula (4D's **SEARCH BY FORMULA**, **SEARCH SELECTION BY FORMULA** and **SORT SELECTION BY FORMULA** commands). If you have a common operation on a large table which involves searching or sorting by using a formula, you will want to consider storing the calculated data in an indexed field. This will dramatically improve the performance on this operation. See below for a discussion of this.

10.3 The results of indexing

Indexing drastically improves the ability to search and find records. An index is nothing more than an additional copy of the data, sorted and attached to each unique entry in the index is the address or record number of a record which matches that value in the index. A index which existed long before computers was the card catalog in a library.

Because the index is presorted the values can be examined quickly and then go look up the appropriate records based upon the information found in the index. It is possible to create more than one index on the table thereby providing additional rapid search and sort avenues.

However, it is not practical to index on every field in the database. Indexes take up large amounts of space. For completely unique values the index is actually larger than the original data. Indexes must be changed whenever the data is changed. Each index must be revised on every new record or modified value in each indexed field. On a large table with frequent changes, even if that table has only a few fields this will slow down the performance of the database because it must continually spend time updating the indexes.

Multiple indexes may not always be helpful. 4D is only capable of using one index per search. Although searching in 4D is optimized to be as efficient as possible, searching after the initial group of records is found must be sequential on all subsequent fields to arrive at the final solution.

There are several guidelines on when to index and when not to index.

- 4D will automatically index all fields which are directly involved in relations.
- Index any field which is frequently used as a search argument or access path.
- Avoid indexing any field which is frequently updated.
- Avoid indexing long character valued attributes.
- Be very stingy with indexes to a table which is frequently updated via adding and deleting records. Be generous with indexes to a table which is rarely updated.

Indexes are unnecessary overhead for very small tables.

10.4 Denormalizing 1:M relationships

This is a very controversial issue. On the one hand normalization eliminates redundancy. On the other frequent joins are very expensive in terms of performance. It may be necessary to denormalize in order to eliminate repetitive joins. Particularly if the joins involve very large tables or those involving joins across several tables.

Denormalization is the process of taking field data from one table and duplicating it in another. For example storing the product name in the line items table for an invoice. If you denormalize you want to be sure that it is truly beneficial and that there is no better

alternative. You want to be sure that some other important transaction is not severely degraded or rendered impossible. For example changing the product name and having that name change reflect across all open invoices.

Denormalized tables will almost always be created by duplicating information in one table in another. The resulting table will have more fields and data to store and perhaps even index. Each time the record is accessed it will require that more data be handled. This will take longer. More memory will be required, etc., etc. It, therefore, should be carefully explored before it is considered.

Denormalized tables are much more expensive to update. Data which is frequently updated should not be replicated without an extremely good reason. Record locking in multi-user or multi-process databases can render data updating impossible.

Another issue to consider is speed. Performance in searching can be dramatically reduce through denormalization. If there are specific queries or updates which occur frequently and/or have a strict performance requirement, there may be no choice but to denormalize in their favor. This is likely to be true only for extremely demanding performance requirements, such as when the data in the database is needed to control real time events.

10.5 When you should create a 1:1 relationship

10.5.1 The "Fat" table.

Unless you are in a list form using **DISPLAY SELECTION** or **MODIFY SELECTION** each time you use a field on a form the entire record all its fields and all their data is loaded into memory. In the case of 4D Server it is even brought across the network to the Client.

Pictures, BLOBs and large text blocks potentially make up a large amount of data.

Take for example a High School student database which lists every student, their home address, phone, parents name, extra curricular activities, and includes a picture of each student. In a completely normalized structure the picture would be stored in the [Student] table. This would mean that every time someone wanted to look up the student's phone number, print a roster for the drama club or pep club each student's picture would be found on the disk, loaded into memory and sent to the Client. If only the phone number or student name is needed this is a huge waste of resources and time.

Another example is the employee database which has a large text field for comments about the employee from their manager. This is a free flowing area which the manager can keep adding additional comments and browse the past entries quickly. If this is stored in the [Employee's] table as would be called for in a normalized database, every time the employee record is accessed this would be loaded into memory and moved across the network. Again wasting a lot of time and resources. Not to mention security issues.

This solution to both of the above is simple. Make a separate table called [Fat] which as

three fields in the table

Fat Table

Column Names	Data Types	Keys
Fat ID	Longint	PK
Picture	Picture	
Text	Text	
Blob	BLOB	

Any time in the database you need either a picture, BLOB or a large text item you create a foreign key in the table where you need the data.

Students

Column Names	Data Types	Keys
Student ID	Longint	PK
First Name	String(20)	
Last Name	String(25)	
…	…	…
Picture ID	Longint	FK1

You can actually have multiple links to the same fat table simply getting different data items with each reference.

Employees

Column Names	Data Types	Keys
Employee ID	Longint	PK
First Name	String(20)	
Last Name	String(25)	
…	…	…
Manager Comments Fat ID	Longint	FK1
Employee Photo ID	Longint	FK2
Employee Self Eval ID	Longint	FK3

Make the relationship between the main table and the [Fat] table a manual relationship

with the [Fat] table being the many table. This manual relationship will insure that the data only loads when it is actually needed. Any time the information is needed it can be easily found by using the **RELATE MANY** command on the field in the main table. Even though this is technically a 1:1 relationship 1:M must actually be used. The actual data will only represent a 1:1 relationship because for each Fat ID used in the main table only one record will exist in the [Fat] table. If more than one record is being accessed in the [Fat] table for different fields in the main table variables must be used to display and temporarily store the data.

10.5.2 Large amounts of seldom used data.

In some databases the normalization process places hundreds of fields in one table, many actually get filled in with data but the data is rarely used. This is frequently the case in research databases. In the case where you have this type situation it is perfectly acceptable to place these fields in a separate table and create a manual relationship between the two tables. This means the main table can be used without loading all this rarely used information. Note: if you only have a few fields (<40) that are small in size you will gain no significant speed advantage from this technique.

10.6 Storing derived data (reprise)

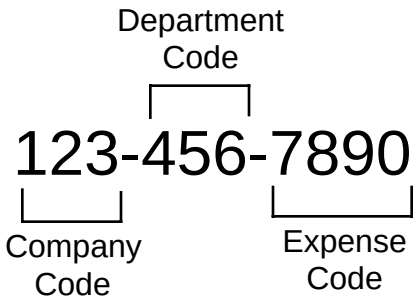
There is a rule of thumb in database design that says "Never store anything you can calculate!" Derived data breaks that rule completely. Frequent searching or sorting on calculated data will render your database useless. It may be necessary to pre-calculate these values and save them in the data in order to make the database usable.

A prime example is regarding an invoice. An invoice total is nothing more than the sum of each product quantity times its appropriate price. However, if you wanted to sort the invoices by the highest invoice total for the month the amount of math and work the database would have to perform is substantial. It is often beneficial to calculate these frequently used values and save them in the database. In this particular example it would be considered normal to actually have two denormalized values present. One which would be in the [Line Items] table which was the total for that individual line item Quantity times Price. In addition it would be helpful to have the total amount for the invoice calculated and saved in the [Invoice] table.

Also special consideration should be given to your databases which are using 4D Server. If any of your reports or calculations make calls to any of the … "**BY FORMULA**" commands you might benefit from looking at the data. Using any of the … "**BY FORMULA**" commands causes all data to be loaded and moved across the network. If the values used by the formula is constant and the data is constant (or at least can be recalculated when changed), you would substantially increase performance by saving these calculations before they are needed.

10.7 Storing concatenated fields

Again looking at the Search and Sort Listings you might identify two or more fields from one or more tables which will be frequently needed (Daily+). Since searching and sorting on multiple fields takes additional time (see indexing discussion above) you might consider combining these fields into one concatenated field. Lets go back to our first composite column example:



When designing we pointed out that a composite field like this should be avoided. Searching or sorting on Department Code is almost impossible. On the other hand reports and searches are often done on the combination of all three fields will take considerable time. One possible solution is save both. In this example have four fields, Company Code, Department Code, Expense Code and Accounting Code.

10.8 Repeating Fields

The first normal form states that “Thou shall not have repeating fields!” That's great but what about those multiple line addresses. There are two possible solutions.

- Make the field a text block. Now there is no problem 1 line, 2 line, 3 line or more. However, exporting that data to an outside source or IBM system becomes almost impossible. Text fields allow carriage returns. Since most other systems require carriage returns at the end of records importing the data with carriage returns present could be a problem.

Therefore, you might consider the other option.

- Use repeating fields. Address1; Address2; Address3.

10.9 Empty first table

4D has one additional unique property. When 4D or 4D Client launches it loads the address table of the first table of the database in interpreted mode. The “first table” is the first table created when the database was brand new, it cannot be changed to another table. If the address table for the first table is the largest table in your database it will pause

while it loads the address table of the whole table in memory. If on the other hand there has never been any records saved in this table the address table has never been created and, therefore, there is nothing to load into memory. The result is no time or memory wasted. The difference between a table which has never had even one record saved and a table which has had one record saved but deleted is 32K.

Exercises: Optimizing the database design

Exercise 10.1

A wholesale distributor ACI Video, has asked you to design a database for their company. They want to track their Product, Customer and Invoice information.

Products, which are the movie titles they sell, are identified by a unique Part Number. This part number is assigned by the ACI Video company and does not reflect any manufacturer's part number. Also of interest about each video is its title, wholesale price, the year the movie was released and a general category or genre in which the movie fits.

Customers are identified by a unique Company Name. ACI Video assures us that no company name could ever possibly change. If it did they would create a new company. Items of importance about the company are the contact person's name, address information and phone number.

Invoices are identified by a unique Invoice number. The date of the invoice, who it was for, whether the invoice is paid and how was it paid are of prime concern.

ACI Video would like to be able to search and sort by its best Invoices, and further identify all customers who have purchased over $2000 in sales.

Product prices change from time to time in relation to supply and demand, age of the release, and other factors such as inventory levels when the boss walks around the warehouse and sees too many of a particular video in stock.

➔ Design an appropriate database for ACI Video, including a denormalized entity/attribute listing for each entity and an ERD showing all entities.

Exercise 10.2

You are a freelance 4D consultant. Fred's Hardware Palace has approached you to design a database. New to the world of relational databases, Fred is asking you to be creative in designing fields, tables, and features for this database.

Fred's Hardware Palace would like to track the following types of information:

- Customer information for doing mailings
- Billing information in the form of invoices.

- Product information in the form of Part Number, Description, Current selling price, Current inventory, Cost or product, etc.
- Vendor information in the form of Name, Address, Phone, etc.

Many of the products that Fred's Hardware Palace sells are generic. For example, Fred's can purchase 1 inch nails from several different vendors. The customer is not concerned with who produced the nails. Hence, Fred's has only one part number for 1 inch nails. Fred's would like to track what the different vendors charge for these generic items.

This information will help Fred's reorder products. Fred's would like to keep track of the vendors' par numbers so that reordering products can be more efficient. Also, Fred's would like to keep notes on the quality of the different products that the different vendors sell.

➔ Design an appropriate database for Fred's, including a denormalized entity/attribute listing for each entity and an ERD showing all entities.

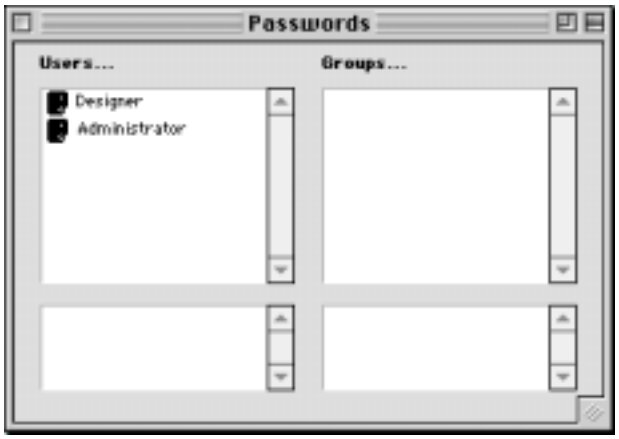
11 Creating the physical database structure

Once you have completed your DDS, you will find that construction is simple.

11.1 Creating groups

The first step of the construction phase is to create the groups which are implied in your security listings. You will need one group for each security level contained in your design.

Using the example of the previous chapter, you would need two groups: Curator and Acquisitions. Creating a group is easy. While in the design environment, choose **Tools ¬ Passwords**. This will open the Password Access editor, as shown below:

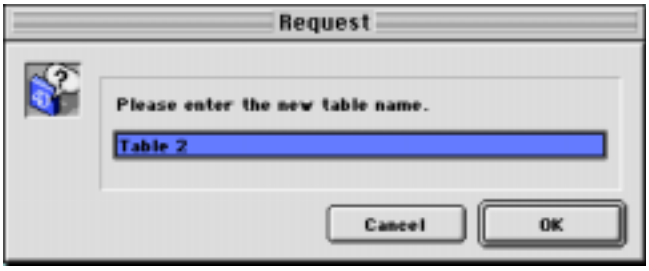


Now choose **Passwords ¬ New Group...**. This will open the **Group Definition** dialog, which is shown below:

Using this dialog, name the group. That's all you need to do at this point.

11.2 Converting entities to tables

The next step is to create your tables. Doing so is simple. Choose **Structure ¬ New Table...** while in the structure window. A dialog will appear:



- Give your table a name and associate the security privileges with the appropriate group. When you do so, you can use the following map:
  - Load = Read
  - Save = Modify
  - Add = Add
  - Delete = Delete

Unless you intend to do multi-programmer development with 4D Server, you can ignore Table Definition Access.

11.3 Adding fields

Adding fields to your tables is also simple. After clicking on a table choose **Structure ¬ New Field...** or double-click on the body of the table. This will open the **Field Properties** dialog:

11.3.1 Creating primary key fields

By convention, a table's primary keys are always the first fields in the table. If the table has only one field in its primary key, then the operation is simple. Simple add the primary key as the first field and give it the attributes indexed, mandatory, unique and can't modify. If the field is a synthetic key which the system will generate, you might want to add display only. (Note: there is no overhead involved in any of these attributes except for indexed and mandatory. Since a primary key must be mandatory, and since it must be indexed to be unique, go ahead and choose all of them.) The following shows a primary key field being defined:

The one non-intuitive aspect of creating the fields in your 4D tables will be the case of composite primary keys. 4D does not explicitly support composite primary keys. In order to enforce the uniqueness, you will need to create an additional field to redundantly store the primary key data. This field can be made invisible, if desired, since the user will not normally see this field. The following is an example of a field for storing a composite primary key redundantly:

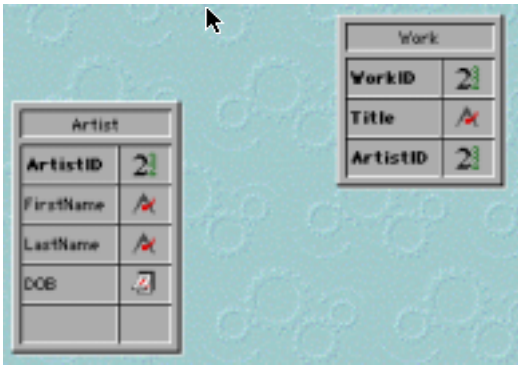
Note that the unique attribute has been applied to this field. That's the whole idea. 4D

has to have a single field to evaluate the uniqueness of a value. The fields which are the components of the primary key would have the attributes mandatory, can't modify and indexed.

In this case, the value stored in the PartIDWarhsCode field would be something like "123-A" where "123" represents the string equivalent of the PartID and "A" represents the Warehouse Code.

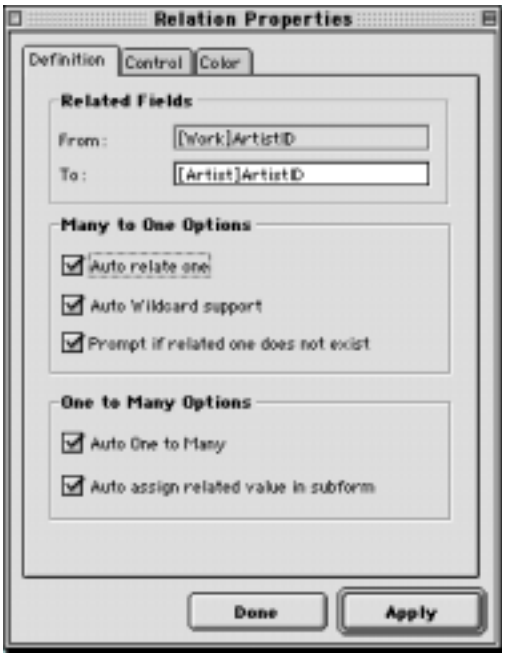
11.3.2 Entering non-key fields

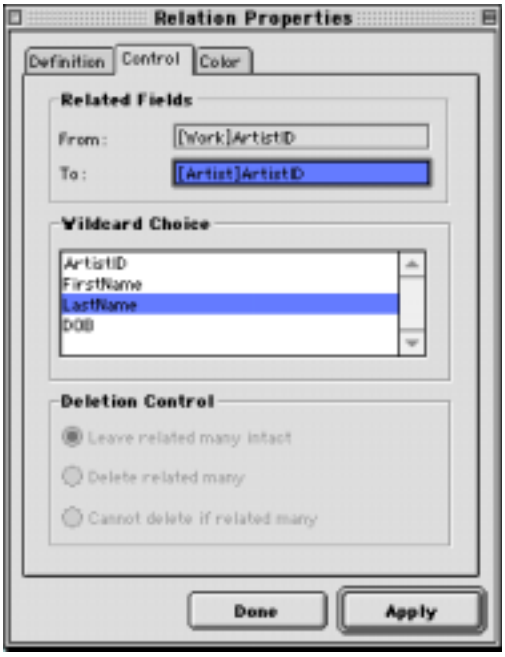
Entering the other fields into the structure present no special problem. Simply follow your design and enter a matching field for each column, making appropriate adjustments for field name length limitations. The following is the structure for the art museum database described earlier.



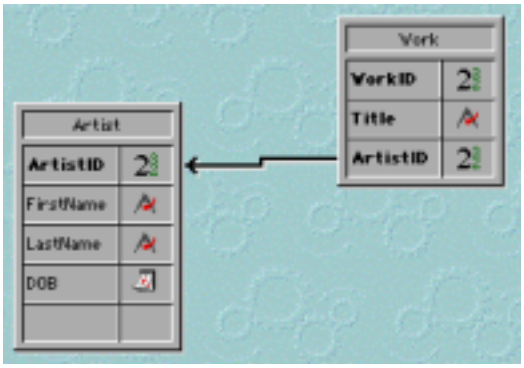
11.3.3 Establishing relations

4D contains a feature which allows for the automatic maintenance of relations between tables. This feature requires that the relations be established in the structure editor. Doing this is simple. Click on the foreign key field of the many table and drag to the primary key of the one table. This operation opens the relation dialog, as follows:





After the relation is established, 4D displays the following relation line:



This indicates that the relation will be automatically maintained by 4D.

Exercises: Creating the physical database structure

Exercise 11.1

- Refer to Exercises 5.8 and 6.6. Create a physical database structure representing this database. Ignore issues of security.

Exercise 11.2

- Refer to Exercises 5.9 and 6.7. Create a physical database structure representing this database. Ignore issues of security.

Exercise 11.3

- Refer to Exercises 5.10 and 6.8. Create a physical database structure representing this database. Ignore issues of security.

Exercise 11.4

- Refer to Exercises 5.11 and 6.9. Create a physical database structure representing this database. Ignore issues of security.

12 Final Exercise

12.1 Moscow State

You have been hired to design the Moscow State Computer System for handling class registration and related data.

Moscow State would like to track the following types of information:

- Student information for keeping track of where students are located, their majors and minors, grades, degree, class
- Class information in the form of descriptions, multiple offerings, instructors, pre-requisites, books needed, locations for class, equipment needed to teach the class, student materials required
- Department information, department chairmen, faculty in department, and the departmental weekly meeting
- Faculty information for doing mailings, tracking their degrees, etc.

The following is an excerpt from their letter to us requesting your services.

- "Moscow Stare has approximately 50,000 students and offers about 2,000 courses in 20 different departments, with 45 different degrees awarded. We are very concerned about storage requirements because computer systems are still hard to come by here. We would like to eventually add our class history to the system consisting of data going back to the downfall of the czar. We have been promised by our government a 6 user 4th Dimension Server and 7 computers to devote to this project. The server computer has a 2 G Hard Disk.

Data to be Stored

Students	Classes	Departments	Faculty
Name	Name	Name	Name
Address	Credits	Head	Address
Phone	Dates	Faculty	Department
Grades	Times	Meeting Date	Degrees
Credits	Department	Meeting Time	Office Location
Department	Instructors	Meeting Location	Office Phone
Majors	Books	Classes	Office Hrs.
Minors	Location		Home Phone
Degree`	Prerequisites		Classes

Final Exercise

Data to be Stored

Students	Classes	Departments	Faculty
Class (Fr,So,Jr,Sr)	Teaching Equipment		Publications
Books Needed	Student Materials		
Materials Needed			

Designing Relational Databases

Appendix A References

Reference 1

Code Complete, a Practical Handbook of Software Construction, by Steve McConnell (Microsoft Press, 1993)

This book is the most complete book on software construction which we have found. It is required reading by all programmers at Microsoft. It contains some useful tips on software design as well, oriented primarily towards helping the programmer know if the design has been done properly.

Reference 2

Relational Database Design, a Practitioner's Guide, by Charles J. Wertz (CRC Press 1993)

This book is a good intermediate textbook on relational database design using conventional structured analysis. It is fairly technical. This guide draws heavily from the material in this book.

Reference 3

An Introduction to Database Systems, Volume I, by C.J. Date (Addison Wesley 1990)

This book is probably the most widely used college textbook on relational database theory. It is oriented primarily towards people who are design relational database management systems, not those who are designing relational databases. However, it does include a section on database design. It is written at a very high technical level. Definitely not for the faint of heart.

Reference 4

An Introduction to Database Systems, Volume II, by C.J. Date (Addison Wesley 1983)

This book completes Date's seminal work on relational database theory. Like Volume 1, it is at a very high level.

Reference 5

Rapid System Development Using Structured Analysis and Relational Technology, by Chris Gane (Prentice Hall 1989)

Gane is the originator of the RAD (Rapid Application Development) approach to systems development. This book contains his methodology, which borrows heavily from JAD (Joint Application Development). His book also contains a very good introductory level treatment of relational database design. If you are a student seeking a way to get familiar with relational concepts quickly and easily, this is probably the best book for you. This guide also borrow heavily from the material in this book.

Reference 6

The Relational Model for Database Management, Version 2, by E.F. Codd (Addison Wesley 1990)

Codd is the originator of the relational model of database management. In his work at IBM during the 1970's Codd was responsible for designing the system which became known as DB2. His contribution to our industry is immense. Unfortunately, his book is almost completely unreadable unless you have a Ph.D. is computer science. Unless you are very technical, stick with one of the other references shown above.

Appendix B Solutions to exercises

Chapter 2 exercises

Exercise 2.1

The university's collection of letters is not a database because it is not structured. In order for a collection of data to be a database it must be organized or structured in some way.

The university staff cannot find a letter for any particular student easily because the data is not structured. To find any particular student's letter would require reading all letters one by one until the desired letter is found.

Similarly, the university staff could not sort the letters by state and city without examining the entirety of every letter.

The university's collection of tear-off cards is a database because it is organized into logical fields or columns.

The university staff can now more easily find a particular student's card by simply scanning the cards and looking in the one blank for student name. (Having the cards in a 4D database would make this easier, of course.)

The university staff can also now more easily sort the cards, by simply ordering them by the data in any given blank, or set of blanks.

Exercise 2.2

The data structure shown is not a table. It is three-dimensional. Tables are only two-dimensional

A search for all parts stored in warehouse B would require a sequential scan of every record on disk (assuming of course that there is not some sort of an index structure to support this).

Sorting the parts by total quantity stored would require a lot of programming. Basically you would have to go to every [Part] record one at a time and add up the total quantity stored. Then you would have to save that information into another structure, which could then be sorted.

Notice also the large amount of wasted space the data occupies on disk. This is technically known as a sparse matrix.

These problems were typical in network and hierarchical databases which preceded the relational database model.

Exercise 2.3

The primary key of the [Item] table is [Item]Item Number.

The primary key of the [Order] table is [Order]Order Number.

There is a candidate natural key in the [Item] which is [Item]Item Description. If this column did not change (i.e. was permanent), it would work as a primary key.

Both of the primary keys of these tables are synthetic.

The tables are related on the [Item]Item Number column. The relation is 1:M. That is, there can be many orders for an item, but only one item for an order. The latter limitation is a defect which is corrected in the second version of the tables shown in the following exercise.

The foreign key is [Order]Item Number.

Exercise 2.4

The primary key of the [Item] table is [Item]Item Number.

The primary key of the [Order] table is [Order]Order Number.

The primary key of the [Order Item] table is [Order Item]Order Number + [Order Item]Item Number. This is a composite key.

There is a candidate natural key in the [Item] which is [Item]Item Description. If this column did not change (i.e. was permanent), it would work as a primary key. Also, the primary key of [Order Item] is a natural key.

There are now two 1:M relations which implement a single M:M relation.

The [Order Item] table is related to the [Order] table on the column Order Number. This relation is 1:M with [Order] being the one table and [Order Item] being the many table.

The [Order Item] table is also related to the [Item] table on the column Item Number. This relation is 1:M with [Item] being the one table and [Order Item] being the many table.

[Order Item] is therefore a linking table for a M:M relation between [Order] and [Item].

There are two foreign keys: [Order Item]Order Number and [Order Item]Item Number.

Exercise 2.5

There are two composite columns: [Person]Name and [Person]CSZ. These columns need to be broken up into atomic columns.

[Person]Name should be broken up into [Person]First Name and [Person]Last Name (and possibly [Person]MI).

[Person]CSZ should be broken up into [Person]City, [Person]State and [Person]Zip

Code.

You cannot look for persons with a specific last name, because you cannot identify the location of the last name in the [Person]Name column. There is no solution for this problem (other than reorganizing the structure, of course). Trying to locate the last name in the data by string parsing will be unreliable.

You cannot sort the data last name, because you cannot identify the location of the last name in the [Person]Name column. There is no solution for this problem (other than reorganizing the structure, of course). Trying to locate the last name in the data by string parsing will be unreliable.

You cannot look for persons with who live in Texas, because you cannot identify the location of the state in the [Person]CSZ column. There is no feasible solution for this problem (other than reorganizing the structure, of course). Trying to locate the state in the data by string parsing will be unreliable.

You cannot sort by zip code, because you cannot identify the location of the zip code in the [Person]CSZ column. There is no solution for this problem (other than reorganizing the structure, of course). Trying to locate the zip code in the data by string parsing will be unreliable.

Chapter 4 exercises

Exercise 4.1

Item

Column Names	Data Types	Keys
Item Number	Longint	PK
Item Description	String (80)	
Price	Real	

Order

Column Names	Data Types	Keys
Order Number	Longint	PK
Customer Number	Longint	
Order Date	Date	

Order Item

Column Names	Data Types	Keys
Order Number	Longint	PK1 FK1
Item Number	Longint	PK2 FK2
Quantity	Real	

You are more clearly able to see the relationships between the tables, as well as the relationships between the columns and the primary keys in each table.

Once tables become fairly complex (say above ten columns) the sample data view becomes unmanageable, and you have to use an entity/attribute view to grasp the table as a whole.

Chapter 5 exercises

Exercise 5.1

Here are all of the functional dependencies:

[Inventory]Inventory Number –> [Inventory]Species
[Inventory]Inventory Number –> [Inventory]Breed
[Inventory]Inventory Number –> [Inventory]Acquired
[Inventory]Breed –> [Inventory]Species

[Feeding Plan]Breed –> [Feeding Plan]Species
[Feeding Plan]Breed –> [Feeding Plan]Feed
[Feeding Plan]Breed –> [Feeding Plan]Quantity

The second question is a hint. These tables are not normalized. They violate 3NF. You will learn more about this later in the chapter.

Notice that you can determine the species from the breed in both tables. Thus:

[Inventory]Breed –> [Inventory]Species

and

[Feeding Plan]Breed –> [Feeding Plan]Species

That means that the tables violate 3NF. The [Inventory]Species and [Feeding Plan]Species columns are both dependent upon two columns.

Exercise 5.2

There are four repeating groups in this structure:

Appointments Date
Appointments Time
Symptoms
Diagnosis

The combination of multiple Boolean and text columns for things like Measles, Mumps, Chicken pox, EPT shot etc., constitutes another repeating group. (This one was subtle.)

There is more than one correct solution for this problem. The following describes a correct solution.

The Appointments Date and Appointments Time group should be removed to another table called [Appointments] which stores data concerning the specific office visit. By doing so, the limitation on the number of appointments stored is removed.

Unless there is a need to search on specific symptom, the Symptom group can be replaced by a text column. Since the symptom is most likely related to a specific office visit the data can be accommodated in this table. Otherwise, this group should be replaced with a related table.

Unless there is a need to search on a specific diagnosis, the Diagnosis group can be replaced by a text column. Since the diagnosis most likely related to a specific office visit the data can be accommodated in this table. An individual diagnosis may not necessarily be related to symptoms reported. Otherwise, this group should be replaced with a related table.

The combination of multiple Boolean and date columns for things like Measles, Mumps. Chicken pox, DPT shot we will refer to as the Patient History group. This is the “big win”

in correcting this structure. By moving this data into a related table, we make it possible to reorganize and update the health history at any time. Storing information about a disease, vaccination or other significant health history item is no needed. Plus in the event it becomes important to store a new disease in the patient history such as Malaria it can be easily added to the health history without redesigning the database. Also the absence of the data from the record indicates that the patient has never had this disease or vaccination.

Here is the new structure:

Patient Record

Column Names	Data Types	Keys
Patient ID	Longint	PK
Patient Last Name	String (45)	
Patient First Name	String (45)	
Patient Birth Date	Text	
Allergies	Text	

Appointments

Column Names	Data Types	Keys
Patient ID	Longint	PK1 FK1
Appointment Date	Date	PK2
Appointment Time	Time	
Symptoms	Text	
Diagnosis	Text	

Health History

Column Names	Data Types	Keys
Patient ID	Longint	PK1 FK1
Item Name	String (45)	PK2
Item Date	Date	PK3

A system such as that shown above is called data driven. This is one of the most powerful aspects of relational database technology.

This exercise points out the dangers of automating a paper process. While your doctor is

very comfortable with the paper form process which is currently in place, she must understand (or be made to understand) that a paper system and a computerized system are two fundamentally different things. Simply automating a paper system can result in a disastrous failure. (On the other hand, paper forms supply vital information on the nature of the data, as we will see when we get to data modeling.)

Exercise 5.3

There are two repeating groups in the proposed data structure.

- The first is the combination of Total Sales and Avg Sales on a monthly basis in the [Monthly Data] table.
- The second is the combination of Total Sales and Avg Sales on a monthly basis in the [Quarterly Data] table.

This type of error is extremely common among people who are familiar with spreadsheets and who attempt to cross over into relational database design.

There is more than one correct solution to this problem. The following describes a correct solution.

We combine all three tables into one table which performs the calculations on the basis of a start date and an end date. Then, by simply entering the appropriate data, a financial analyst can perform the calculations on any period he or she likes.

Here is the normalized structure:

Periodic Data

Column Names	Data Types	Keys
Start Date	Date	PK1
End Date	Date	PK2
Total Sales	Real	
Avg Sales	Real	

One question you are probably asking is how we are going to do an annual rolling average based upon any given period. The answer is simple.

If the period is less than six months, we will divide the last year into any number of equal periods ending with this one. (If this cannot be done evenly, we will generate an error and leave the [Periodic Data]Avg Sales column blank.)

We will then calculate [Periodic Data]Avg Sales based upon these periods.

If the period is more than six months, we will leave the [Periodic Data]Avg Sales column blank.

This is another example of data driven programming.

Exercise 5.4

Whoever the insurance company's developer was, he or she did not understand normalization.

Here are the functional dependencies:

Carrier ID –> Carrier Name
Carrier ID + Policy Number –> Customer ID
Carrier ID + Policy Number –> Customer Last Name
Carrier ID + Policy Number –> Customer First Name
Carrier ID + Policy Number –> Customer First Name
Customer ID –> Customer Last Name
Customer ID –> Customer First Name

Thus, we see that there is a violation of 2NF. Carrier Name is dependent on Carrier ID only. This is not the entire primary key of [Policy]. Thus the table is not in 2NF.

By the way, there is also a violation of 3NF. If you caught that you are catching on. Customer Last Name and Customer First Name are dependent on the entire primary key of [Policy], but this is a transitive dependency. That is, this dependency is second-hand, by way of Customer ID. That means the table is not in 3NF either.

Here are the correctly normalized tables:

Policy

Column Names	Data Types	Keys
Carrier ID	Longint	PK1 FK1
Policy Number	String (10)	PK2
Customer ID	Longint	FK2

Carrier

Column Names	Data Types	Keys
Carrier ID	Longint	PK
Carrier Name	String (45)	

Customer

Column Names	Data Types	Keys
Customer ID	Longint	PK

Customer

Customer Last Name	String (45)	
Customer First Name	String (45)	

Exercise 5.5

- The table is in 1NF. There are no repeating groups.
- The table is in 2NF. There is only one column in the primary key. Therefore, all columns are dependent upon the entire primary key.

Here are the functional dependencies:

Employee ID –> Employee Name
Employee ID –> Department ID
Employee ID –> Department Name
Department ID –> Department Name

Since Department Name is functionally dependent on Department ID, 3NF is violated. (The rule for 3NF states that no non-key column can be functionally dependent upon any other non-key column.)

Moving the Department Name column into another table solves the problem. Here is a normalized structure:

Employee

Column Names	Data Types	Keys
Employee ID	Longint	PK
Employee Name	String (45)	
Department ID	String (3)	FK1

Department

Column Names	Data Types	Keys
Department ID	String (3)	PK
Department Name	String (20)	

Exercise 5.6

The first table shown violates 3NF. Hive Capacity is functionally dependent upon Hive

ID and therefore does not belong in the table. The correct structure is:

Bee

Column Names	Data Types	Keys
Bee ID	Longint	PK
Name	String (20)	
Hive ID	Longint	FK1

The second table shown violates 2NF. Person Name is functionally dependent upon Person ID only and therefore does not belong in the table. The correct structure is:

Sting

Column Names	Data Types	Keys
Bee ID	Longint	PK1
Person ID	Longint	PK2
Number of Stings	Integer	

Here are the only additional tables necessary for completely normalized structure:

Hive

Column Names	Data Types	Keys
Hive ID	Longint	PK
Hive Capacity	Longint	
Hive Phone Number	String (10)	

Flower

Column Names	Data Types	Keys
Flower ID	Longint	PK
Flower Type	String (45)	
Color	String (10)	

Pollination

Column Names	Data Types	Keys
Bee ID	Longint	PK1 FK1

Pollination

Pollination Date	Date	PK2
Pollination Time	Time	PK3
Flower ID	Longint	FK2

Person

Column Names	Data Types	Keys
Person ID	Longint	PK
Person Name	String (80)	

These tables, along with the ones shown above, constitute a completely normalized structure because all functional dependencies are implemented and none of the rules of normalization are violated.

Exercise 5.7

Here are the functional dependencies:

Shepherd ID –> Shepherd Name
Shepherd ID –> Shepherd Size
Pen ID –> Pen Value
Pen ID –> Pen Capacity
Pen ID –> Shepherd ID
Sheep ID –> Pen ID
Sheep ID –> Sheep Weight
Sheep ID –> Sheep Value

Here is the normalized data structure:

Shepherd

Column Names	Data Types	Keys
Shepherd ID	Longint	PK
Shepherd Name	String (80)	
Shepherd Size	Integer	

Pen

Column Names	Data Types	Keys
Pen ID	Longint	PK
Pen Value	Real	

Pen

Pen Capacity	Real	
Shepherd ID	Longint	FK1

Sheep

Column Names	Data Types	Keys
Sheep ID	Longint	PK
Sheep Value	Real	
Sheep Weight	Real	
Pen ID	Longint	FK1

These tables constitute a completely normalized structure because all functional dependencies are implemented and none of the rules of normalization are violated.

Exercise 5.8

Here are the functional dependencies:

Magician ID –> Magician Name
Magician ID –> Magician Rate
Club Name –> Club Address
Club Name –> Club Phone
Trick ID –> Trick Name
Trick ID –> Trick Amazing
Trick ID + Magician ID –> Trick Competency

There are some other issues in this problem. Due to the fact that Club Name can change, it doesn't work as a primary key. We also need to implement a M:M relationship between [Magician] and [Club].

Here is the normalized data structure:

Wizard

Column Names	Data Types	Keys
Magician ID	Longint	PK
Magician Name	String (80)	
Magician Rate	Real	

Club

Column Names	Data Types	Keys

Club

Club ID	Longint	PK
Club Name	String (80)	
Club Address	String (80)	
Club Phone	String (10)	

Spell

Column Names	Data Types	Keys
Trick ID	Longint	PK
Trick Name	String (80)	
Trick Amazing	Integer	

Magician Club

Column Names	Data Types	Keys
Magician ID	Longint	PK1 FK1
Club ID	Longint	PK2 FK2

Magician Spell

Column Names	Data Types	Keys
Magician ID	Longint	PK1 FK1
Trick ID	Longint	PK2 FK2
Trick Competency	Integer	

These tables constitute a completely normalized structure because all functional dependencies are implemented and none of the rules of normalization are violated.

Exercise 5.9

Here are the functional dependencies:

Trainer ID –> Trainer Name
Trainer ID –> Trainer Size
Horse Barn ID –> Horse Barn Value
Horse Barn ID –> Horse Barn Capacity
Horse Barn ID –> Trainer ID
Horse ID –> Horse Barn ID
Horse ID –> Horse Weight

Horse ID –> Horse Value

Here is the normalized data structure:

Trainer

Column Names	Data Types	Keys
Trainer ID	Longint	PK
Trainer Name	String (80)	
Trainer Size	Integer	

Horse Barn

Column Names	Data Types	Keys
Horse Barn ID	Longint	PK
Horse Barn Value	Real	
Horse Barn Capacity	Real	
Trainer ID	Longint	FK1

Horse

Column Names	Data Types	Keys
Horse ID	Longint	PK
Horse Value	Real	
Horse Weight	Real	
Horse Barn ID	Longint	FK1

These tables constitute a completely normalized structure because all functional dependencies are implemented and none of the rules of normalization are violated.

Exercise 5.10

Here are the functional dependencies:

Painter ID –> Painter Name
Painter ID –> Painter Rate
Club Name –> Club Address
Club Name –> Club Phone
Painter ID –> Medium Name
Medium ID –> Medium Skill
Medium ID + Painter ID –> Medium Competency

There are some other issues in this problem. Due to the fact that Club Name can change, it doesn't work as a primary key. We also need to implement a M:M relationship between [Painter] and [Club]. Here is the normalized data structure:

Painter

Column Names	Data Types	Keys
Painter ID	Longint	PK
Painter Name	String (80)	
Painter Rate	Real	

Club

Column Names	Data Types	Keys
Club ID	Longint	PK
Club Name	String (80)	
Club Address	String (80)	
Club Phone	String (10)	

Medium

Column Names	Data Types	Keys
Medium ID	Longint	PK
Medium Name	String (80)	
Medium Skill	Integer	

Painter Club

Column Names	Data Types	Keys
Painter ID	Longint	PK1 FK1
Club ID	Longint	PK2 FK2

Painter Medium

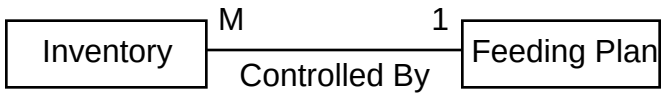
Column Names	Data Types	Keys
Painter ID	Longint	PK1 FK1
Medium ID	Longint	PK2 FK2
Medium Competency	Integer	

These tables constitute a completely normalized structure because all functional dependencies are implemented and none of the rules of normalization are violated.

Chapter 6 exercises

Exercise 6.1

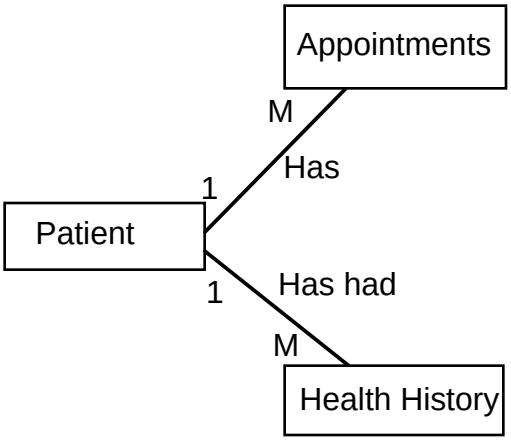
Here is the ERD:



Remember that this data structure is not correctly normalized. See the solution to Exercise 5.1 for details.

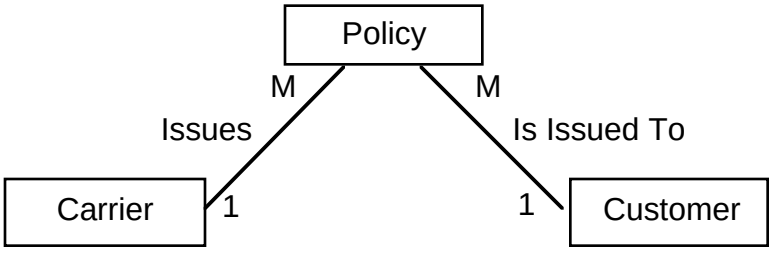
Exercise 6.2

Here is the ERD:



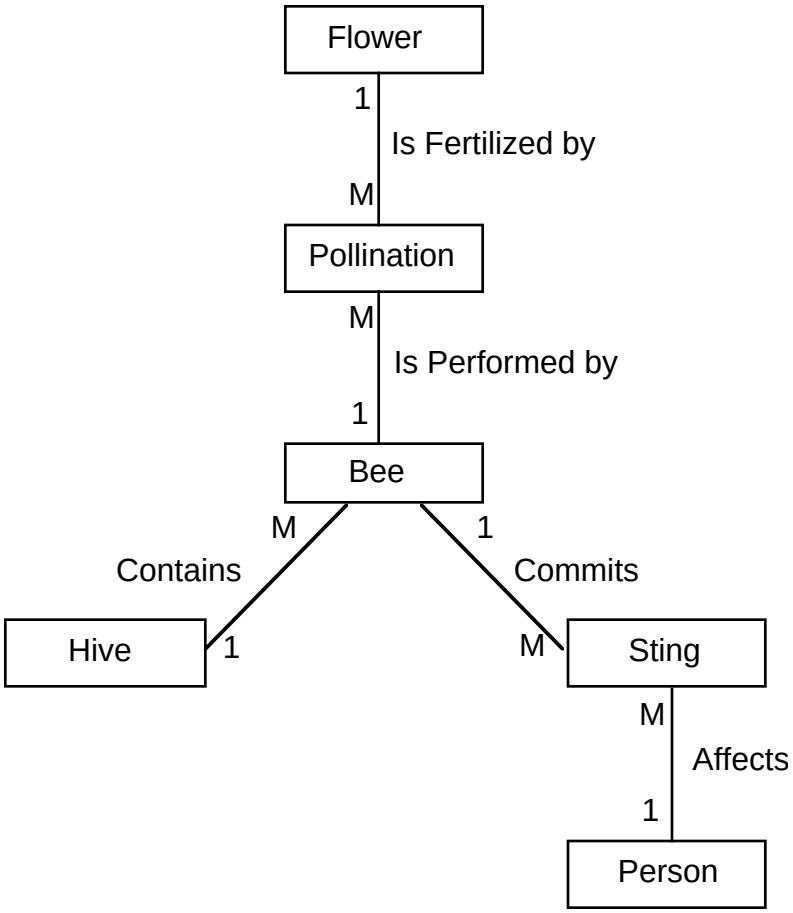
Exercise 6.3

Here is the ERD:



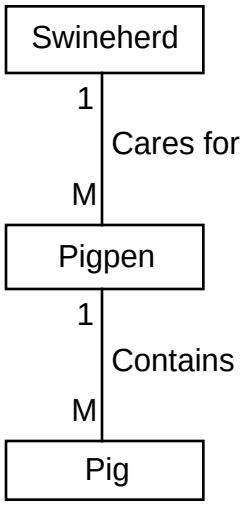
Exercise 6.5

Here is the ERD:



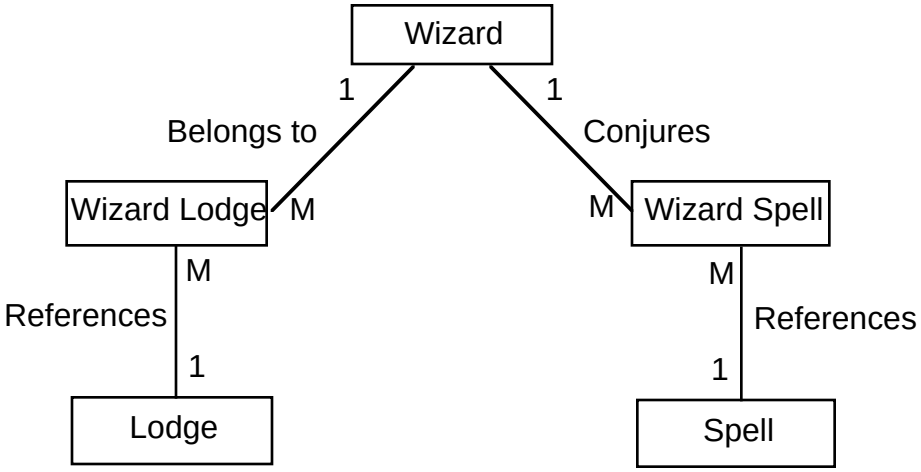
Exercise 6.6

Here is the ERD:



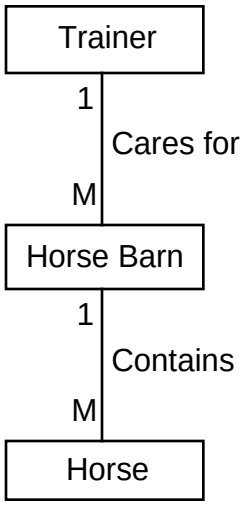
Exercise 6.7

Here is the ERD:



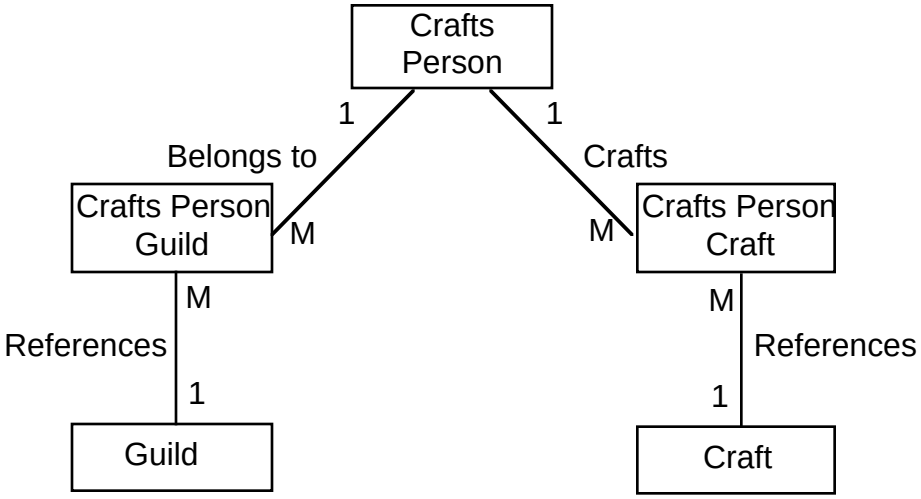
Exercise 6.8

Here is the ERD:



Exercise 6.9

Here is the ERD:



Exercise 6.10

Here are the functional dependencies:

Pirate Nickname –> Pirate Christian Name
Pirate Nickname –> Pirate Ferocity Rating
Pirate Nickname –> Pirate Date of First Piracy
Pirate Nickname –> Pirate Ship Name
Pirate Ship Name –> Pirate Ship Number of Masts
Pirate Ship Name –> Pirate Ship Number of Cannon

Pirate Ship Name –> Pirate Ship Date Commissioned

Pirate Ship Name –> Pirate Ship Captain

Merchant Ship Name –> Merchant Ship Weight

Merchant Ship Name –> Merchant Ship Number of Masts

Merchant Ship Name + Pirate Ship Name + Plundering Date –> Merchant Ship Sunk

Merchant Ship Name + Pirate Ship Name + Plundering Date –> Plundering Walked the Plank

Here is the normalized data structure:

Pirate

Column Names	Data Types	Keys
Pirate Name	String (80)	PK
Pirate Christian Name	String (80)	
Pirate Ferocity Rating	Integer	
Pirate Date of First Piracy	Date	
Pirate Ship Name	String (80)	FK1

Pirate Ship

Column Names	Data Types	Keys
Pirate Ship Name	String (80)	PK
Pirate Ship Number of Masts	Integer	
Pirate Ship Number of Cannon	Integer	
Pirate Ship Date Commissioned	Date	
Pirate Ship Captain	String (80)	FK1

Merchant Ship

Column Names	Data Types	Keys
Merchant Ship Name	String (80)	PK
Merchant Ship Number of Masts	Integer	

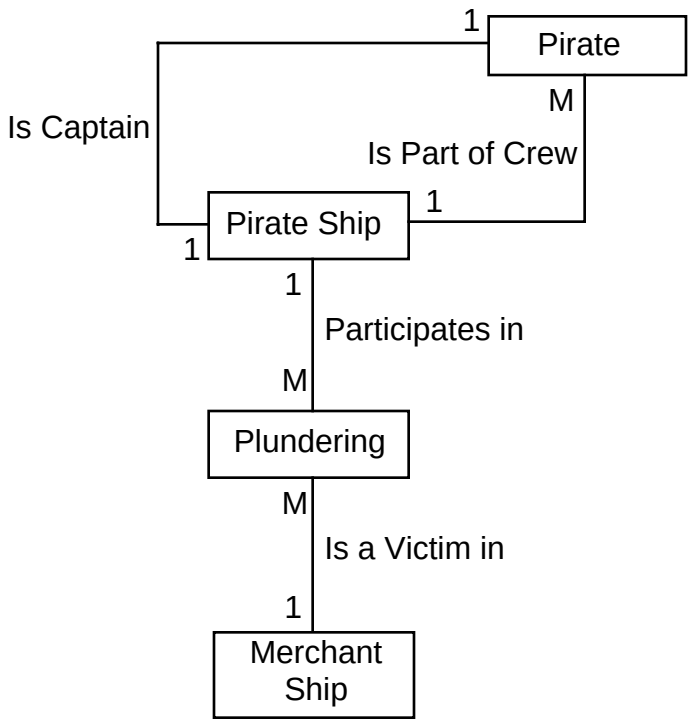
Plundering

Column Names	Data Types	Keys
Merchant Ship Name	String (80)	PK1 FK1
Pirate Ship Name	String (80)	PK2 FK2

Plundering

Plundering Date	Date	PK3
Plundering Merchant Ship Sunk	Boolean	
Plundering Walked the Plank	Integer	

And here is the ERD:



Chapter 7 exercises

Exercise 7.1

There is more than one solution to this problem. The following describes a correct solution.

Huey may be a smart lawyer, but he's a wash-up as a relational database designer. (Of course, you can't tell him that.)

Here are the composite columns (this one was pretty easy):

Client CSZ
Defendant Name
Defendant CSZ
Opposing Atty Name

Physician Name

Obviously, these composite columns need to be replaced with atomic columns containing the same data. Here are the new columns:

Client City
Client State
Client Zip Code
Defendant Last Name
Defendant First Name
Defendant MI
Defendant City
Defendant State
Defendant Zip Code
Opposing Atty Last Name
Opposing Atty First Name
Opposing Atty MI
Physician Last Name
Physician First Name
Physician MI

Remember the rules for choosing a primary key:

- The primary key must uniquely identify every row in the table
- The primary key must be permanent (i.e. unchanging) over the life of the row
- The primary key must be mandatory (i.e. defined in every row).

Huey has some problems with the second and third rules.

Take [Client] for example. The choice of a primary key consisting of the combination of Client Last Name, Client First Name and Client MI is poor. Many people do not use a middle initial. (Indeed, some people don't even use a last name, e.g. Prince, Sting and Madonna.) Thus, all of these columns cannot be made mandatory.

Also, we have seen that people tend to change their names. Thus, Huey's choice of primary key for this table is not permanent. We need to create a synthetic key for the [Client] table. We will call this key Client ID.

The same problem exists with the primary key for the [Ad] table. How many times do newspapers change their names? The Chicago Tribune used to be the Chicago Star, the Dallas Times Herald was bought out by the Dallas Morning News, and so on.

The problem here is that we do not have a table to store [Advertiser] and we need one. In order to create a primary key which works for the [Ad] table, we need a synthetic key for

[Advertiser]. We have to have a table in order to store this synthetic key. Here is the table:

Advertiser

Column Names	Data Types	Keys
Advertiser ID	Longint	PK
Advertiser Name	String (30)	
Advertiser Phone	String (10)	

After making those corrections, here are the functional dependencies:

Client ID –> Client Last Name
Client ID –> Client First Name
Client ID –> Client MI
Client ID –> Address
Client ID –> City
Client ID –> State
Client ID –> Zip Code
Client ID –> Work Phone
Client ID –> Home Phone
Client ID –> Ad Result
Client ID –> Advertiser ID
Client ID –> Advertiser Name
Client ID –> Advertiser Phone
Client ID –> Ad Date
Client ID –> Physician Referral
Client ID –> Physician Last Name
Client ID –> Physician First Name
Client ID –> Physician MI
Client ID –> Physician Specialty
Advertiser ID –> Advertiser Name
Advertiser ID –> Advertiser Phone
Physician Last Name + Physician First Name + Physician MI –> Physician Specialty
Case Number –> Client ID
Case Number –> Client Last Name
Case Number –> Client First Name
Case Number –> Client MI
Case Number –> Work Phone
Case Number –> Home Phone
Case Number –> Case Amount
Case Number –> Defendant Last Name

Case Number –> Defendant First Name
Case Number –> Defendant MI
Case Number –> Defendant Address
Case Number –> Defendant City
Case Number –> Defendant State
Case Number –> Defendant Zip Code
Defendant Last Name + Defendant First Name + Defendant MI –> Defendant Address
Defendant Last Name + Defendant First Name + Defendant MI –> Defendant City
Defendant Last Name + Defendant First Name + Defendant MI –> Defendant State
Defendant Last Name + Defendant First Name + Defendant MI –> Defendant Zip Code
Defendant Last Name + Defendant First Name + Defendant MI –> Opposing Atty Last Name
Defendant Last Name + Defendant First Name + Defendant MI –> Opposing Atty First Name
Defendant Last Name + Defendant First Name + Defendant MI –> Opposing Atty MI
Defendant Last Name + Defendant First Name + Defendant MI –> Opposing Atty Phone
Case Number –> Opposing Atty Last Name
Case Number –> Opposing Atty First Name
Case Number –> Opposing Atty MI
Case Number –> Opposing Atty Phone
Opposing Atty Last Name + Opposing Atty First Name + Opposing Atty MI –> Opposing Atty Phone
Case Number –> Ad Result
Case Number –> Advertiser ID
Case Number –> Advertiser Name
Case Number –> Ad Date
Case Number –> Physician Referral
Case Number –> Physician Last Name
Case Number –> Physician First Name
Case Number –> Physician MI
Case Number –> Physician Specialty

There are at least 22 violations of 3NF in this example. (Unfortunately, this is a pathetically real world example of database design by untrained personnel. Avoiding this type of design is the purpose of this guide.)

Here is a complete list of all of the 3NF violations we can see:

- Advertiser Name does not belong in [Client]. It is functionally dependent on Advertiser ID. (Admittedly, we introduced this ourselves when we corrected the primary key problems.)
- Advertiser Phone does not belong in [Client]. It is functionally dependent on Advertiser ID.

- Physician Specialty is functionally dependent upon the combination of Physician Last Name, Physician First Name and Physician MI. Therefore it does not belong in [Client].
- Client Last Name is functionally dependent upon Client ID. Therefore it does not belong in [Case]. Ditto for Client First Name, Client MI, Work Phone and Home Phone.
- Defendant Address is functionally dependent upon the combination of Defendant Last Name, Defendant First Name and Defendant MI. Therefore it does not belong in [Case]. Ditto for Defendant City, Defendant State and Defendant Zip Code.
- Opposing Atty Last Name is functionally dependent upon the combination of Defendant Last Name, Defendant First Name and Defendant MI. Therefore it does not belong in [Case]. Ditto for Opposing Atty First Name, Opposing Atty MI and Opposing Atty Phone.
- Opposing Atty Phone is functionally dependent upon the combination of Opposing Atty Last Name, Opposing Atty First Name and Opposing Atty MI. Therefore it does not belong in [Case].
- Ad Result is functionally dependent upon Client ID. Therefore it does not belong in [Case]. Ditto for Advertiser ID and Ad Date.
- Advertiser Name is functionally dependent upon Advertiser ID. Therefore it does not belong in [Case].

After removing all of the 3NF violations by creating new tables and moving the offending columns into them, and then adding the appropriate synthetic keys to the new tables, the following is a correctly normalized database structure:

Client

Column Names	Data Types	Keys
Client ID	Longint	PK
Client Last Name	String (45)	
Client First Name	String (45)	
Client MI	String (45)	
Client Address	Text	
Client City	String (45)	
Client State	String (2)	
Client Zip Code	String (9)	

Client

Work Phone	String (10)	
Home Phone	String (10)	
Ad Result	Boolean	
Advertiser ID	String (30)	FK1.1
Ad Date	Date	FK1.2
Physician Referral	Boolean	
Physician ID	Longint	FK2

Case

Column Names	Data Types	Keys
Case Number	Longint	PK
Client ID	Longint	FK1
Defendant ID	String (45)	FK2
Opposing Atty ID	String (80)	FK3
Case Amount	Real	

Advertiser

Column Names	Data Types	Keys
Advertiser ID	Longint	PK
Advertiser Name	String (30)	
Advertiser Phone	String (10)	

Ad

Column Names	Data Types	Keys
Advertiser ID	Longint	PK1 FK1
Ad Date	Date	PK2

Physician

Column Names	Data Types	Keys
Physician ID	Longint	PK
Physician Last Name	String (45)	

Physician

Physician First Name	String (45)	
Physician MI	String (2)	
Physician Specialty	String (45)	

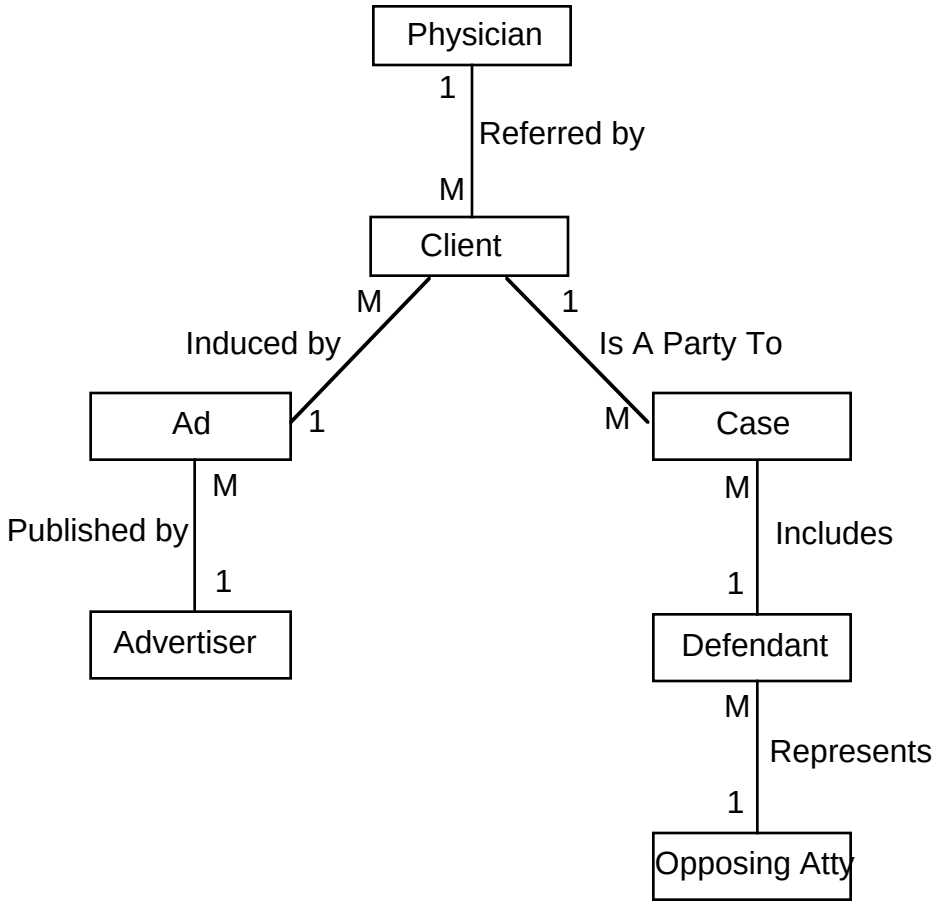
Defendant

Column Names	Data Types	Keys
Defendant ID	Longint	PK
Defendant Last Name	String (45)	
Defendant First Name	String (45)	
Defendant MI	String (45)	
Opposing Atty ID	Longint	FK1

Opposing Atty

Column Names	Data Types	Keys
Opposing Atty ID	Longint	PK
Opposing Atty Last Name	String (45)	
Opposing Atty First Name	String (45)	
Opposing Atty MI	String (45)	
Opposing Atty Phone	String (10)	

Here is the ERD:



This structure does not take into account the fact that there might be multiple defendants in a case, or that a defendant might have multiple attorneys, both of which were ignored by Huey. If either of both of these are the case, then further normalization is needed.

Given your client's personality problems, convincing him that he's wrong and you're right is going to be a little tough. A better approach might be to talk to him about how he might improve "his" design. Then point out each defect one by one. Emphasize the fact that performance will be better and storage space less on each item. That will appeal to his sense of cheapness. Hopefully, each change will eventually become his idea. After about ten defects, he may get the idea and voluntarily "deep six" his design in favor of one you come up with. Otherwise, you will have to go through each of the defects one-by-one in this manner.

If this is too much trouble, you're not hungry enough. Better get yourself another client.

Exercise 7.2

There is more than one correct solution to this problem. The following describes a correct solution.

Here are the candidate entities:

[Publisher]
[Story]
[Reporter]
[Job]
[Subject]

Here are the attributes:

Publisher ID
Publisher Name
Story ID
Story Name
Reporter ID
Reporter Last Name
Reporter First Name
Job Start Date
Job End Date
Subject Key Word

Here are the functional dependencies:

Publisher ID –> Publisher Name
Story ID –> Story Name
Story ID –> Publisher ID
Story ID –> Reporter ID
Reporter ID –> Reporter Last Name
Reporter ID –> Reporter First Name
Reporter ID + Publisher ID + Job Start Date –> Job End Date

In addition, we can see that there is a M:M relationship between [Story] and [Subject] which we have implemented through another entity, [Subject Reference].

Here are the entity/attribute listings:

Publisher

Column Names	Data Types	Keys
Publisher ID	Longint	PK
Publisher Name	String (30)	

Reporter

Column Names	Data Types	Keys

Reporter

Reporter ID	Longint	PK
Reporter Last Name	String (80)	
Reporter First Name		

Story

Column Names	Data Types	Keys
Story ID	Longint	PK
Publisher ID	Longint	FK1
Reporter ID	Longint	FK2
Story Name	String (80)	

Subject

Column Names	Data Types	Keys
Subject Key Word	String (80)	PK

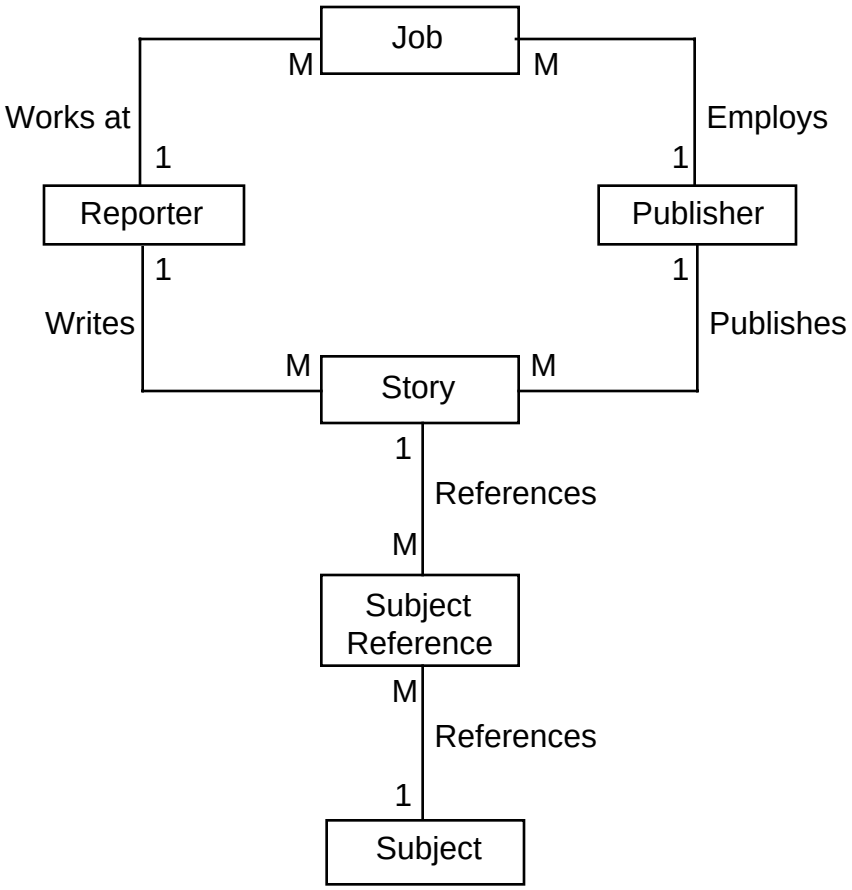
Subject Reference

Column Names	Data Types	Keys
Subject Key Word	String (80)	PK1 FK1
Story ID	Longint	PK2 FK2

Job

Column Names	Data Types	Keys
Publisher ID	Longint	PK1 FK1
Reporter ID	Longint	PK2 FK2
Job Start Date	Date	PK3
Job End Date		

Here is the ERD:



Chapter 8 exercises

Exercise 8.1

There is more than one correct solution to this problem. The following describes a correct solution.

Solving this problem requires adding a new entity which we call [Job].

Here are the new functional dependencies:

Pirate Nickname + Pirate Ship Name + Job Start Date –> Job End Date
Pirate Nickname + Pirate Ship Name + Job Start Date –> Pirate Ship Captain

The latter functional dependency replaces the following one shown in the prior solution:

Pirate Nickname –> Pirate Ship Captain

Since we are now tracking a pirate's career, and since a pirate can be captain multiple times, we now have a 1:M relationship between a pirate ship and its captain.

Here is the new entity:

Job

Column Names	Data Types	Keys
Pirate Name	String (80)	PK1 FK1
Pirate Ship Name	String (80)	PK2 FK2
Job Start Date	Date	PK3
Job End Date	Date	
Pirate Ship Captain	Boolean	

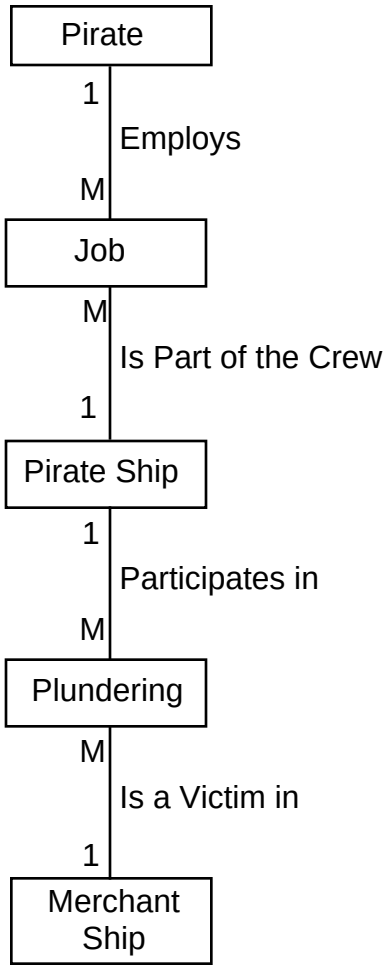
Here is the changed [Pirate Ship] entity:

Pirate Ship

Column Names	Data Types	Keys
Pirate Ship Name	String (80)	PK
Pirate Ship Number of Masts	Integer	
Pirate Ship Number of Cannon	Integer	
Pirate Ship Date Commissioned	Date	

Notice that Pirate Ship Captain has been converted from a string to a Boolean.

Here is the new ERD:



This is an extremely common modification to a database. Clients frequently discover that they need to store historical data rather than just current data. You must design your database with this in mind. If your database follows the rules of normalization, this type of change will be simple and easy. Otherwise, it may be difficult.

Exercise 8.2

This database requires a recursive approach. This is because individuals create offspring who are in turn individuals. There are several correct solutions to this problem. The following describes a correct solution.

Here are the entity/attribute listings:

Person

Column Names	Data Types	Keys
Person ID	Longint	PK

Person

Person Last Name	String (80)	
Person First Name	String (80)	
Date of Birth	Date	
Date of Death		

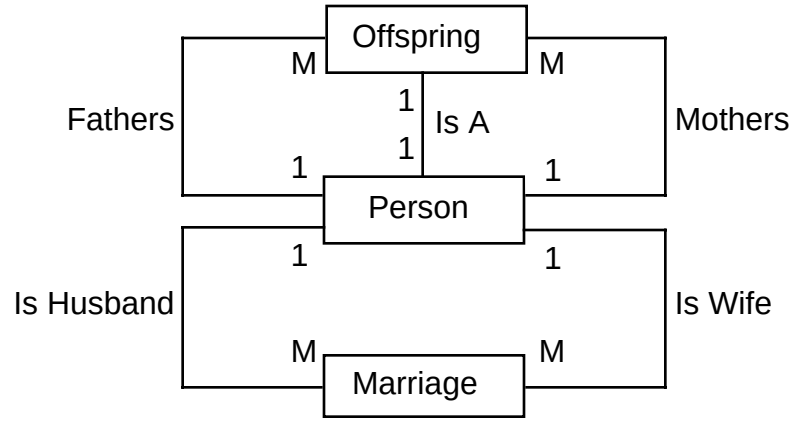
Marriage

Column Names	Data Types	Keys
Man ID	Longint	PK1
Woman ID	Longint	PK2
Marriage Date	Date	PK3
Divorce Date	Date	

Offspring

Column Names	Data Types	Keys
Offspring ID	Longint	PK
Father ID	Longint	FK1
Woman ID	Longint	FK2

And here is the ERD:

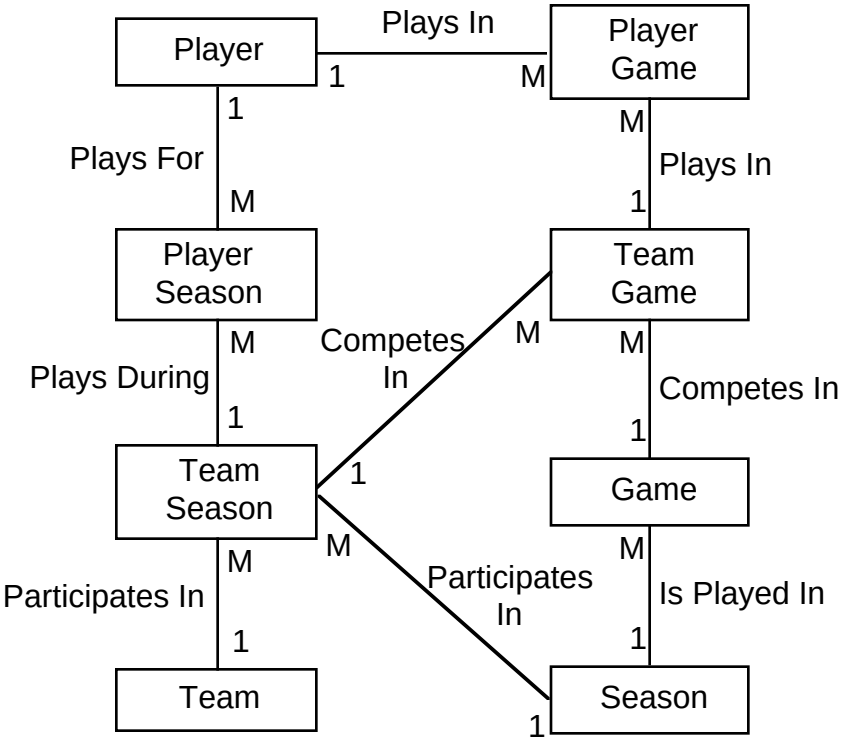


Notice some subtle things about this design. First, it recognizes the practical fact that not all births occur within marriage. Thus, an offspring is related to its father and mother, not to a marriage.

Also, there is a three-way relationship between [Person], and [Offspring]. We consider Date of Birth to be an attribute of the [Person], not the [Offspring], but since this is a 1:1 relationship, that is a matter of taste.

Exercise 8.3

There is more than one correct solution to this problem. The following describes a correct solution. Here is the ERD:



Here are the entity/attribute listings:

Player

Column Names	Data Types	Keys
Player ID	Longint	PK
Player Last Name	String (80)	
Player First Name	String (80)	
Player Total Hits	Integer	
Player Total Times at Bat	Integer	
Player Total Attendance	Integer	

Player

Player Total Errors	Integer	
Player Total Home Runs	Integer	
Player Total Runs	Integer	

Team

Column Names	Data Types	Keys
Team ID	Longint	PK
Team Name	String (80)	
Location	String (80)	

Season

Column Names	Data Types	Keys
Season Start Date	Date	PK
Season End Date	Date	

Team Season

Column Names	Data Types	Keys
Team ID	Longint	PK1 FK1
Season Start Date	Date	PK2 FK2
Total Runs	Integer	
Total Games	Integer	
Total Games Won	Integer	
Total Games Lost	Integer	
Total Games Tied	Integer	

Player Season

Column Names	Data Types	Keys
Player ID	Longint	PK1 FK1
Team ID	Longint	PK2 FK2.1
Season Start Date	Date	PK3 FK2.2
Player Season Total Hits	Integer	

Player Season

Player Season Total Times at Bat	Integer	
Player Season Total Attendance	Integer	
Player Season Total Errors	Integer	
Player Season Total Runs	Integer	
Player Season Total Home Runs	Integer	

Game

Column Names	Data Types	Keys
Game ID	Longint	PK
Game Date	Date	
Game Time	Time	
Location	String (80)	

Team Game

Column Names	Data Types	Keys
Team ID	Longint	PK1 FK1
Game ID	Longint	PK2 FK2
Start	Boolean	
Runs	Integer	

Player Game

Column Names	Data Types	Keys
Player ID	Longint	PK1 FK1
Ball Club ID	Longint	PK2 FK2.1
Game ID	Longint	PK3 FK2.2
Times at Bat	Integer	
Hits	Integer	
Errors	Integer	
Runs	Integer	
Home Runs	Integer	

Let's take a look at how we satisfy each of the requirements of the exercise:

Player statistics

- Batting average (by season)
  - Player Season Total Hits divided by Player Season Total Times at Bat.
  - Player Season Total Hits is posted from [Player Game]Hits.
  - Player Season Total Times at Bat is posted from [Player Game]Times at Bat.
- Batting average (lifetime)
  - Player Total Hits divided by Player Total Times at Bat.
  - Player Total Hits is posted from [Player Game]Hits.
  - Player Total Times at Bat is posted from [Player Game]Times at Bat.
- Attendance (by season)
  - Player Season Total Attendance is posted from [Player Game] (simply the number of rows in [Player Game] for a given season).
- Attendance (lifetime)
  - Player Total Attendance is posted from [Player Game] (simply the number of rows in [Player Game]).
- Average errors per game (by season)
  - Player Season Total Errors divided by Player Season Total Attendance.
  - Player Season Total Errors is posted from [Player Game]Errors.
- Average errors per game (lifetime)
  - Player Total Errors divided by Player Total Attendance.
  - Player Total Errors is posted from [Player Game]Errors.
- Runs (by season)
  - Player Season Total Runs is posted from [Player Game]Runs.
- Runs (lifetime)
  - Player Total Runs is posted from [Player Game]Runs.
- Home runs (by season)
  - Player Season Total Home Runs is posted from [Player Game]Home Runs.
- Home runs (lifetime)
  - Player Total Home Runs is posted from [Player Game]Home Runs.

Team statistics

- Total runs (by season)
- [Team Game]Runs is posted from [Player Game]Runs.

- [Team Season]Total Runs is posted from [Team Game]Runs.
- Average runs per game (by season)
- [Team Season]Total Runs divided by [Team Season]Total Games.
- [Team Season]Total Games is posted from [Team Game] (simply the number of rows in [Team Game] for a given season).
- Games won (by season)
- Of the two rows in [Team Game] related to any given [Game], the one with the most runs (the highest value in [Team Game]Runs) is the winner. For that row, increment the Total Games Won column by one.
- Games lost (by season)
- Of the two rows in [Team Game] related to any given [Game], the one with the least runs (the lowest value in [Team Game]Runs) is the loser. For that row, increment the Total Games Lost column by one.
- Games tied (by season)

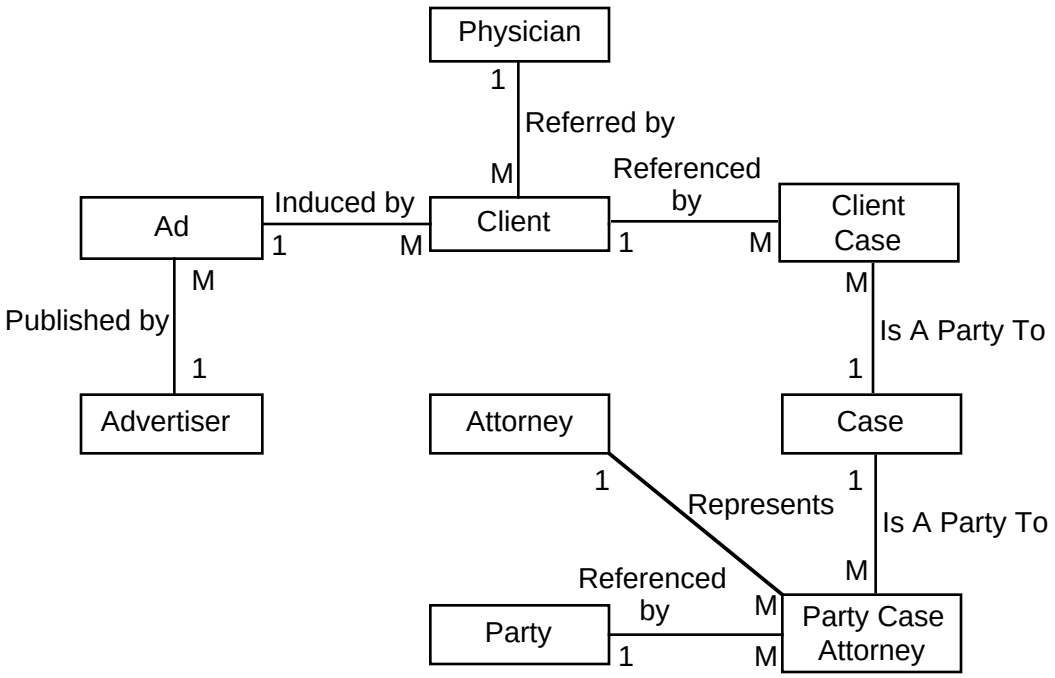
If the two rows in [Team Game] related to any given [Game] have the same number of runs (identical values in [Team Game]Runs) there is a tie. Increment the Total Games Tied column by one for both teams.

Chapter 9 exercises

Exercise 9.1

There is more than one correct solution to this problem. The following describes a correct solution.

Entity/relationship diagram:



Data dictionary:

Entities:

[Client]

An individual who is either now or was at one time represented by the firm in a case.

[Case]

A single matter which has either been or is intended to be filed as a lawsuit in court. The firm represents the plaintiff in the case, and the opposing party is the defendant.

[Client]

An individual who is either now or was at one time represented by the firm in a case.

[Client Case]

The participation of a client in a case. This is the linking table for supporting the M:M relationship between [Client] and [Case].

[Ad]

A single unit of advertising run on a single day. An ad may be run more than once on that day (as in radio or television ads). However, as a simplifying assumption, the firm only tracks ads on a per-day basis.

[Physician]

A medical, osteopathic or chiropractic practitioner who is referring, or at one time

referred, clients to the firm.

[Party]

An individual who is not a client, and who is intended to be, or presently is, a participant in one or more lawsuits being handled by the firm. Parties come in two types: defendants and plaintiffs.

[Attorney]

An attorney who is representing a party.

[Party Case Attorney]

The representation of a party by an attorney in a case. This is the linking table for supporting a three-way M:M relationship between [Party], [Attorney] and [Case].

Attributes:

Client ID

The unique identifier of [Client]. Stored as Longint.

Client Last Name

The last name of a client. Stored as String (45).

Client First Name

The first name of a client. Stored as String (45).

Client MI

The middle initial of a client. Stored as String (45).

Client Address

The street address of a client. Stored as Text.

Client City

The city of a client. Stored as String (45).

Client State

The state of a client. Stored as String (2).

Client Zip Code

The zip code of a client. Stored as String (9).

Client Zip Code

The zip code of a client. Stored as String (9).

Client Work Phone

The phone number where a client can be reached during normal business hours. Stored as String (10).

Client Home Phone

The phone number where a client can be reached during other than normal business hours. Stored as String (10).

Ad Result

True if the client came into the office originally as the result of an ad. False otherwise. Stored as a Boolean.

Physician Referral

True if the client came into the office originally as the result of a referral from a physician. False otherwise. Stored as a Boolean.

Case Number

The unique identifier of [Case]. Stored as Longint.

Case Amount

The amount, expressed in dollars, which the firm estimates can be recovered on behalf of a client in a case. Not necessarily the same as the amount which will be claimed in a lawsuit. Stored as a Real.

Advertiser ID

The unique identifier of [Advertiser]. Stored as Longint.

Advertiser Name

The name of a publisher of advertising. If the advertiser is a newspaper or magazine, this is the name of the newspaper or magazine. If the advertiser is a radio or television statement, this is the call sign of the station. If the advertiser is a phone company (in the case of yellow pages advertising) this is the name of the telephone company, qualified by the region (example: Southwestern Bell Dallas). Stored as a String (30).

Advertiser Phone

The phone number where the advertising office of an advertiser can be reached during normal business hours. Stored as String (10).

Ad Date

A the date upon which single unit of advertising is run. An ad may be run more than once on that day (as in radio or television ads). However, as a simplifying assumption, the firm only tracks ads on a per-day basis. Stored as Date.

Physician ID

The unique identifier of [Physician]. Stored as Longint.

Physician Last Name

The last name of a physician. Stored as String (45).

Physician First Name

The first name of a physician. Stored as String (45).

Physician MI

The middle initial of a physician. Stored as String (45).

Party ID

The unique identifier of [Party]. Stored as Longint.

Party Last Name

The last name of a party. Stored as String (45).

Party First Name

The first name of a party. Stored as String (45).

Party MI

The middle initial of a party. Stored as String (45).

Attorney ID

The unique identifier of [Attorney]. Stored as Longint.

Attorney Last Name

The last name of an attorney. Stored as String (45).

Attorney First Name

The first name of an attorney. Stored as String (45).

Attorney MI

The middle initial of an attorney. Stored as String (45).

Defendant

True if a party is a defendant. False otherwise. Stored as Boolean.

Relationships:

Referred By

The event of a physician referring a client to the firm. Based upon Physician ID.

Induced By

The event of a client coming to the firm as a result of an ad. Based upon Advertiser ID and Ad Date.

Is A Party To

The event of a client or party participating in a case. The relationship name is reused because the relationship between a client to a case and a party to a case is identical. In the

case of [Client], the relationship is based upon Client ID. In the case of [Party], the relationship is based upon Party ID.

Referenced By

The event of a client or party being referenced by a [Client Case] or [Party Case Attorney] row. This is strictly a linking relationship. The relationship name is reused because the relationship between a client to a case and a party to a case is identical. In the case of [Client], the relationship is based upon Client ID. In the case of [Party], the relationship is based upon Party ID.

Represents

The event of an attorney representing a party in a case. based upon Attorney ID.

Entity/attribute listings:

Client

Column Names	Data Types	Keys
Client ID	Longint	PK
Client Last Name	String (45)	
Client First Name	String (45)	
Client MI	String (45)	
Client Address	Text	
Client City	String (45)	
Client State	String (2)	
Client Zip Code	String (9)	
Work Phone	String (10)	
Home Phone	String (10)	
Ad Result	Boolean	
Advertiser ID	String (30)	FK1.1
Ad Date	Date	FK1.2
Physician Referral	Boolean	
Physician ID	Longint	FK2

Case

Column Names	Data Types	Keys
Case Number	Longint	PK

Case

Case Amount	Real	

Client Case

Column Names	Data Types	Keys
Client ID	Longint	PK1 FK1
Case Number	Longint	PK2 FK2

Advertiser

Column Names	Data Types	Keys
Advertiser ID	Longint	PK
Advertiser Name	String (30)	
Advertiser Phone	String (10)	

Ad

Column Names	Data Types	Keys
Advertiser ID	Longint	PK1 FK1
Ad Date	Date	PK2

Physician

Column Names	Data Types	Keys
Physician ID	Longint	PK
Physician Last Name	String (45)	
Physician First Name	String (45)	
Physician MI	String (45)	

Party

Column Names	Data Types	Keys
Party ID	Longint	PK
Party Last Name	String (45)	
Party First Name	String (45)	
Party MI	String (45)	

Attorney

Column Names	Data Types	Keys
Attorney ID	Longint	PK
Attorney Last Name	String (45)	
Attorney First Name	String (45)	
Attorney MI	String (45)	
Attorney Phone	String (10)	

Party Case Attorney

Column Names	Data Types	Keys
Case Number	Longint	PK1 FK1
Party ID	Longint	PK2 FK2
Attorney ID	Longint	PK3 FK3
Defendant	Boolean	

Table load listings

Client

Current Storage	3,500
Add	1,050
Delete	0
Net Storage Change	1,050
Modify	1,000
Peak Monthly Transactions	170

Case

Current Storage	5,000
Add	1,500
Delete	1,000
Net Storage Change	500
Modify	60,000
Peak Monthly Transactions	6,125

Client Case

Current Storage	5,000
Add	1,500
Delete	1,000
Net Storage Change	500
Modify	0
Peak Monthly Transactions	1,125

Advertiser

Current Storage	35
Add	1
Delete	0
Net Storage Change	1
Modify	0
Peak Monthly Transactions	1

Ad

Current Storage	60
Add	60
Delete	60
Net Storage Change	0
Modify	0
Peak Monthly Transactions	65

Physician

Current Storage	18
Add	1
Delete	0
Net Storage Change	1
Modify	0
Peak Monthly Transactions	1

Party

Current Storage	5,000
Add	1,500
Delete	1,000
Net Storage Change	500
Modify	5,000
Peak Monthly Transactions	1,541

Attorney

Current Storage	100
Add	10
Delete	0
Net Storage Change	10
Modify	100
Peak Monthly Transactions	9

Party Case Attorney

Current Storage	5,000
Add	1,500
Delete	1,000
Net Storage Change	500
Modify	5,000
Peak Monthly Transactions	1,541

Table constraint listings:

Case

Column Names	Minimum	Maximum	Default	Choice List
Case Amount	100,000			

Search/sort listings:

Client

Search Columns	Frequency

Client

Client ID	Daily +
Client Last Name + Client First Name	Daily +
Ad Result	Monthly
Physician Referral	Weekly
Sort Columns	**Frequency**
Client ID	Daily +
Client Last Name + Client First Name	Daily +
Client Zip Code	Monthly
Advertiser Name + Ad Date	Monthly
Physician Last Name + Physician First Name	Monthly

Case

Search Columns	**Frequency**
Case Number	Daily +
Case Amount	Daily +
Sort Columns	**Frequency**
Case Number	Daily +
Case Amount	Daily +

Client Case

Search Columns	**Frequency**
Client ID	Daily +
Case Number	Daily +
Client ID + Case Number	Daily +
Client Last Name	Daily +
Client First Name	Daily +
Client Last Name + Client First Name	Daily +
Sort Columns	**Frequency**
Client ID	Daily +
Case Number	Daily +

Client Case

Client ID + Case Number	Daily +
Client Last Name + Client	Weekly
First Name	

Advertiser

Search Columns	Frequency
Advertiser ID	Daily +
Advertiser Name	Daily +
Sort Columns	**Frequency**
Advertiser ID	Daily +
Advertiser Name	Daily +

Ad

Search Columns	Frequency
Advertiser ID	Daily +
Ad Date	Daily +
Sort Columns	Frequency
Advertiser ID	Daily +
Ad Date	Daily +
Advertiser Name + Ad Date	Monthly

Physician

Search Columns	Frequency
Physician ID	Daily +
Physician Last Name	Daily +
Physician First Name	Daily +
Physician Last Name + Physician First Name	Daily +
Sort Columns	**Frequency**
Physician ID	Daily +
Physician Last Name	Daily +

Physician

Physician First Name	Daily +
Physician Last Name + Physician First Name	Daily +

Party

Search Columns	Frequency
Party ID	Daily +
Party Last Name	Daily +
Party First Name	Daily +
Party Last Name + Party First Name	Daily +
Sort Columns	**Frequency**
Party ID	Daily +
Party Last Name	Daily +
Party First Name	Daily +
Party Last Name + Party First Name	Daily +

Attorney

Search Columns	Frequency
Attorney ID	Daily +
Attorney Last Name	Daily +
Attorney First Name	Daily +
Attorney Last Name + Attorney First Name	Daily +
Sort Columns	Frequency
Attorney ID	Daily +
Attorney Last Name	Daily +
Attorney First Name	Daily +
Attorney Last Name + Attorney First Name	Daily +

Party Case Attorney

Search Columns	Frequency
Party ID	Daily +
Party Last Name	Daily +

Party Case Attorney

Party First Name	Daily +
Party Last Name + Party First Name	Daily +
Case ID	Daily +
Attorney ID	Daily +
Attorney Last Name	Daily +
Attorney First Name	Daily +
Attorney Last Name + Attorney First Name	Daily +
Sort Columns	**Frequency**
Party ID	Daily +
Party Last Name	Daily +
Party First Name	Daily +
Party Last Name + Party First Name	Daily +
Case ID	Daily +
Attorney ID	Daily +
Attorney Last Name	Daily +
Attorney First Name	Daily +
Attorney Last Name + Attorney First Name	Daily +
Security listings:	

Client

Access	Group
Read	All
Add	Snr Partner
Modify	All
Delete	Snr Partner

Case

Access	Group
Read	All
Add	All

Case

Modify	All
Delete	Snr Partner

Client Case

Access	Group
Read	All
Add	All
Modify	All
Delete	Snr Partner

Advertiser

Access	Group
Read	All
Add	Snr Partner
Modify	Snr Partner
Delete	Snr Partner

Ads

Access	Group
Read	All
Add	All
Modify	Snr Partner
Delete	Snr Partner

Physicians

Access	Group
Read	All
Add	Snr Partner
Modify	Snr Partner
Delete	Snr Partner

Party

Access	Group
Read	All
Add	All
Modify	All
Delete	Snr Partner

Party Case Attorney

Access	Group
Read	All
Add	All
Modify	Snr Partner
Delete	Snr Partner

Chapter 10 exercises

Exercise 10.1

Products

Column Names	Data Types	Keys
Part Number	String (10)	PK
Title	String (30)	
Price	Real	
Year	Integer	
Category	String (15)	

Customers

Column Names	Data Types	Keys
Company Name	String (25)	PK
Contact First Name	String (10)	
Contact Last Name	String (20)	
Address	String (25)	
City	String (20)	
State	String (2)	
Zip	String (10)	
Phone	String (10)	
Preferred	Boolean	

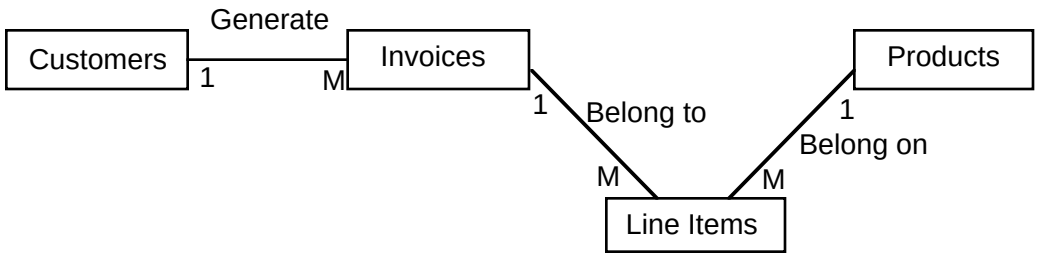
Invoices

Column Names	Data Types	Keys
Invoice Number	Longint	PK
Invoice Company Name	String (25)	FK1
Invoice Date	Date	
Invoice Total	Real	
Paid	Boolean	
Payment Method	String (15)	

Line Items

Column Names	Data Types	Keys
LI Invoice Number	Longint	PK1 FK1
LI Part Number	String (10)	PK2 FK2
Quantity Ordered	Integer	
Line Items Price	Real	
Extended Price	Real	

Here is the ERD:



Exercise 10.2

Products

Column Names	Data Types	Keys
Part Number	String (10)	PK
Title	String (30)	
Selling Price	Real	
Year	Integer	
Quantity	Longint	

Customers

Column Names	Data Types	Keys
First Name	String (25)	PK
Last Name	String (10)	
Company Name	String (20)	
Address	Text	
City	String (20)	
State	String (2)	
Zip	String (10)	
Phone	String (10)	
Preferred	Boolean	
Taxable	Boolean	
Tax ID Number	String (20)	

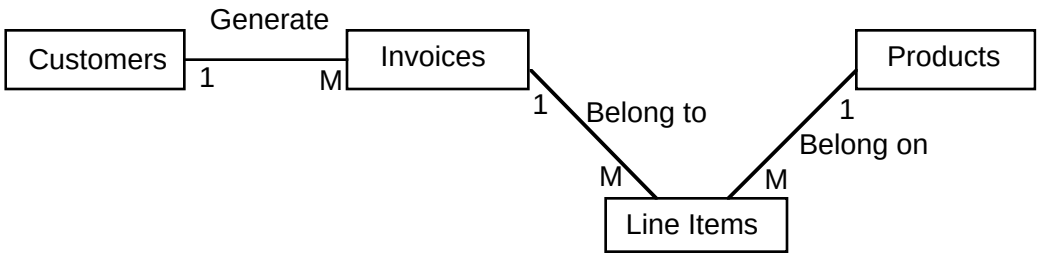
Invoices

Column Names	Data Types	Keys
Invoice Number	Longint	PK
Invoice Company Name	String (25)	FK1
Invoice Date	Date	
Subtotal	Real	
Sales Tax	Real	
Grand Total	Real	

Invoices

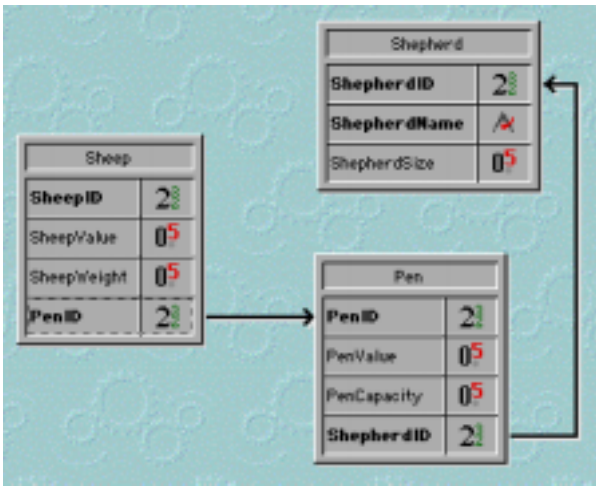
Payment Due Date	Date	
Paid	Boolean	
Payment Method	String (15)	
Comment	Text	

Here is the ERD:

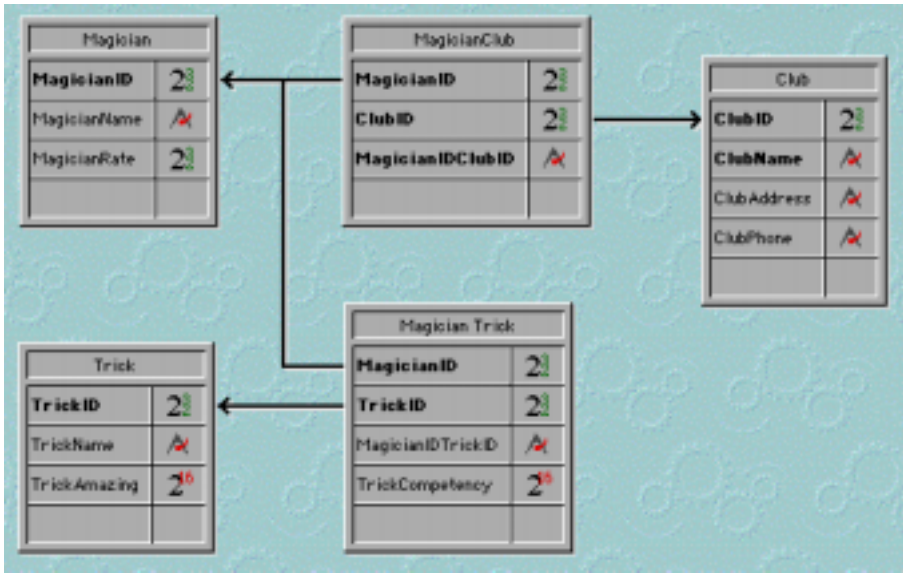


Chapter 11 exercises

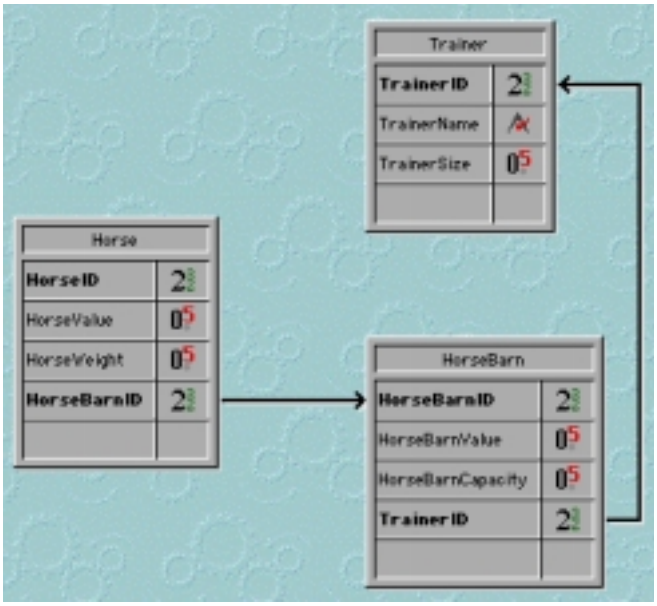
Exercise 11.1



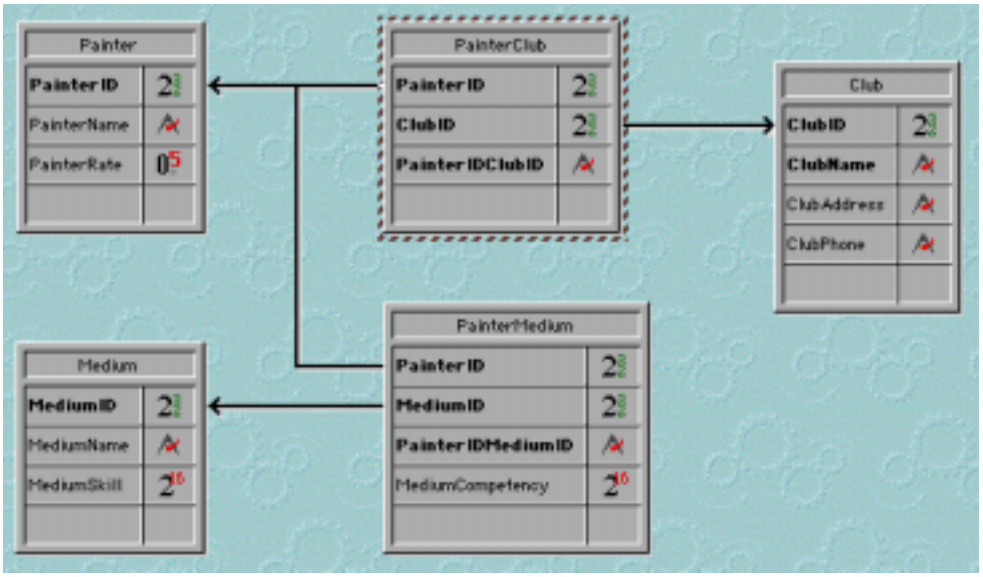
Exercise 11.2



Exercise 11.3



Exercise 11.4



Chapter 12 exercises

Exercise 12.1

A solution to this exercise is included in 4D format on your handout disk. There are

many correct solutions to this problem based upon answers given during the client interview process or class discussion. Therefore, no one solution is presented here.