3 DIFFERING ROLES OF TABLES AND GRAPHS

Tables and graphs are the two fundamental vehicles for presenting quantitative information. They have developed over time to the point that we now thoroughly understand which works best for different circumstances and why. This chapter introduces tables and graphs and gives simple guidelines for selecting which to use for your particular purpose.

Tables and graphs are the two primary means to structure and communicate quantitative information. Both have been around for quite some time and have been researched extensively to hone their use to a fine edge of effectiveness. The best practices that have emerged are easy to learn, understand, and put to use in your everyday work with numbers.

Occasionally, the best way to display quantitative information is not in the form of a table or graph. When the quantitative information you want to convey consists only of a single number or two, written language is an effective means of communication; your message can be expressed simply as a sentence or highlighted as a bullet point. If your message is that last quarter's sales totaled $1,485,393 and exceeded the forecast by 16%, then it isn't necessary to structure the message as a table, and there is certainly no need to create a graph. You can simply say something like:

Q2 sales = $1,485,393, exceeding forecast by 16%

Alternatively, it wouldn't hurt to structure this message in simple tabular form such as this:

Q2 Sales	Compared to Forecast
$1,485,393	+16%

FIGURE 3.1 This table shows sales value information, arranged in columns.

or this:

Q2 Sales	$1,485,393
Compared to Forecast	+16%

FIGURE 3.2 This table shows sales value information, arranged in rows.

If you're like a lot of folks, however, you might be tempted while structuring this information as a table to jazz it up in a way that actually distracts from your simple, clear message—perhaps something like this:

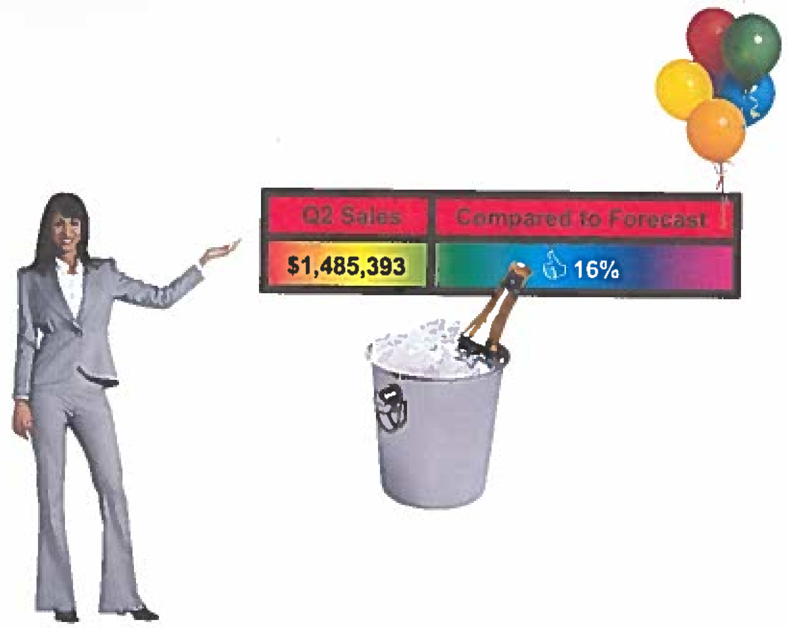


FIGURE 3.3 This table shows sales values, designed to impress, or perhaps to entertain, but not primarily to communicate.

You might even be tempted to pad the report with an inch-thick stack of pages containing the details of every sales order received during the quarter, eager to demonstrate how hard you worked to produce those two sales numbers. However, as we'll observe many times in this book, there is *eloquence in simplicity*.

Quantities and Categories

Before we launch into an individual examination of tables and graphs, let's review an important fact, common to both, that quantitative messages are made up of two types of data:

- Quantitative
- Categorical

Quantitative values measure something (number of orders, amount of profit, rating of customer satisfaction, etc.). Categorical items (i.e., members of a category) identify what the quantitative values measure. These two types of data fulfill different roles in tables and graphs. In the following simple table, which displays exempt and non-exempt employee compensation by department, all the information consists either of quantities being measured (compensation) or items belonging to categories (sales, operations, and manufacturing are items in the department category) to which the quantities relate.

Department	Exempt	Non-Exempt
Sales	950,003	1,309,846
Operations	648,763	2,039,927
Manufacturing	568,543	2,367,303
Total	$2,167,309	$5,717,076

FIGURE 3.4 This is a table of employee compensation information that you can use to practice distinguishing quantitative and categorical data.

The labels that identify the various departments in the far left column, including Total, belong to the category Department, and the labels Exempt and Non-exempt belong to a separate category that we could call Employee Type. All of the other data (i.e., all the numbers in this table) are quantitative values.

Do numbers always represent quantitative values? No. Sometimes numbers are used to label things and have no quantitative meaning. Order numbers (e.g., 1003789), numbers that identify the year (e.g., 2011), and numbers that sequence information (item number 1, item number 2, item number 3, etc.), are examples of numbers that express categorical data. One simple test to determine this distinction is to ask the question, "Would it make sense to add these numbers up, or to perform any mathematical operation on them?" For instance, would it make sense to add up order numbers? No, it wouldn't. How about numbers that rank a list of sales people as number 1, number 2, etc.? Once again, the answer is no; therefore, these numbers represent categorical, rather than quantitative, data.

Let's take a look at one more example to practice making the distinction between categorical and quantitative information. Using the graph below, test your skills by identifying which components represent categorical items and which represent quantitative values.

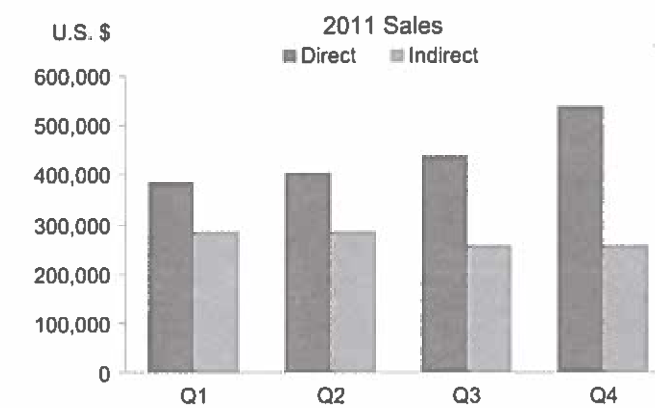


FIGURE 3.5 This graph depicts sales information for practice in distinguishing quantitative and categorical data.

Let's examine one component at a time. For each of the items below, indicate whether the information is categorical or quantitative.

1. The values of time along the bottom (Q1, Q2, etc.)
2. The dollars along the left side
3. The legend, which encodes Direct and Indirect
4. The vertical bars in the body of the graph
5. The title in the top center

Once you've identified each, take a moment to compare your answers to those on the right.

. . . .

Did you catch the dual role of the bars, that they contain both quantitative values and categorical items? With a little practice, you will be able to easily

ANSWERS

1. Categorical, labeling the quarters of the year
2. Quantitative, providing dollar values for interpreting the heights of the bars
3. Categorical, providing a distinction between direct and indirect sales
4. Both quantitative and categorical; the heights of the bars encode quantitative information about sales in dollars; the colors of the bars encode categorical data identifying which sales are direct vs. indirect
5. Categorical, identifying the year of the sales

deconstruct graphs into quantitative and categorical data. This ability will enable you to apply the differing design practices that pertain to each type of data.

Choosing the Best Medium of Communication

Choosing whether to display data in one or more tables, one or more graphs, or some combination of the two, is a fundamental challenge of data presentation. This decision should never be arbitrary. It is sad, however, that this choice is often made using the "eeney, meeney, miney, moe" method. Imagine that you're Joe, and you've just interviewed three candidates for a new position in your department. It's now time to report the results to your boss, who's responsible for making the hiring decision. During interviews with the candidates, you used your company's handy interview score sheet to evaluate each person's aptitudes on a zero to five point scale in six areas: experience, communication, friendliness, subject matter knowledge, presentation, and education. How do you display the results? Well, if you're like a lot of people who feel pressure to make an impression, you might decide to use something unusual, like one of those radar charts that are available in your spreadsheet software. As you hand your boss the following report, you hope that he's thinking: "Wow, that Joe is an exceptional employee. Perhaps he deserves a raise."

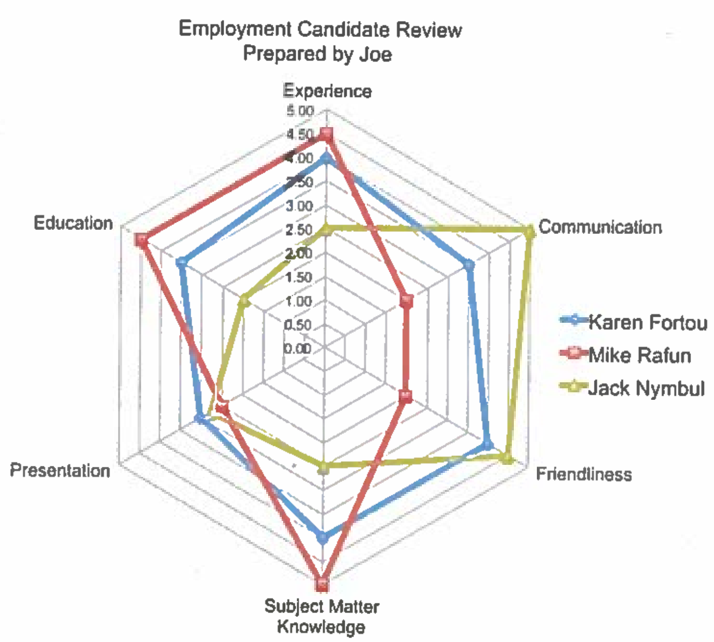


FIGURE 3.6 This radar chart presents aptitudes of job candidates in an overly complicated way.

What's sad is that the boss, upon first glance, might actually think, "That Joe certainly outdid himself," despite the fact that he hasn't a clue how to read this spider-web of a chart. He might actually blame himself for lacking the skill that's needed to read this chart, assuming he must have missed that day in math class when they covered this. Regardless of how the boss responds, Joe would have made his job easier if he'd prepared something like this instead:

Employment Candidate Review

	Candidates		
Rating Areas	Karen Fortou	Mike Rafun	Jack Nymbul
Experience	4.00	4.50	2.50
Communication	3.50	2.00	5.00
Friendliness	4.00	2.00	4.50
Subject matter knowledge	4.00	5.00	2.50
Presentation	3.00	1.50	2.75
Education	3.50	4.50	2.00
Average Rating	3.67	3.25	3.21

FIGURE 3.7 This table presents the same information as Figure 3.6 but in a way that is simple and clear.

This table presents the information in a way that is simple to understand and efficient to use. To select the appropriate medium of communication, we must understand the needs of our audience as well as the purposes for which various forms of display can be effectively used. Let's begin by considering the overall strengths and weaknesses of tables and graphs.

Tables Defined

A table is a structure for organizing and displaying information; a table exhibits the following characteristics:

- Information is arranged in columns and rows.
- Information is encoded as text (including words and numbers).

A single set of values, occupying a single column or row, is merely a list, not a table.

Although the column and row structure of tables is often visually reinforced by grid lines (i.e., horizontal and vertical lines outlining the columns and rows), it is the arrangement of the information that characterizes tables, not the presence of lines that visibly delineate the structure of the underlying grid. In fact, as we will see later in the chapter on table design, grid lines must be used with care to keep them from diminishing a table's usefulness.

Tables are not used exclusively to display quantitative information. Whenever you have more than one set of values, and a relationship exists between values in the separate sets, you may use a table to align the related values by placing them in the same row or column. For instance, tables are often used to display meeting agendas, with start times in one column, the names of the topics that will be covered in the next, and the names of the facilitators in the next, as in the following example:

Time	Topic	Facilitator
09:00 AM	Opening remarks	Scott Wiley
09:15 AM	Product demo	Sheila Prescott
10:00 AM	Discussion	Jerry Snyder
10:45 AM	Planning	Pamela Smart

FIGURE 3.8 This is an example of a table that does not contain quantitative data, in this case a meeting agenda.

Tables have been in use for almost two millennia, so they are readily understood by almost everyone who can read.

When to Use Tables

A handful of conditions should direct you to select a table, rather than a graph, as the appropriate means of display, but tables provide one primary benefit:

> Tables make it easy to look up individual values.

Tables excel as way to display simple relationships between quantitative values and the categorical items to which they're related so that these individual values can be easily located.

When deciding whether to use a table or graph to communicate your quantitative message, always ask yourself how the information will be used. Will you or others use it to look up one or more particular values? If so, it's a prime candidate for expression in a table. Or might the information be used to examine a set of quantitative values as a whole to discern patterns? If so, it's a prime candidate for expression in a graph, as we'll see soon.

Tables also make it easy to compare pairs of related values (e.g., sales in quarter 1 to sales in quarter 2). Here's a typical example:

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Monthly Average
2000	138.1	138.6	139.3	139.5	139.7	140.2	140.5	140.9	141.3	141.8	142.0	141.9	**140.3**
2001	142.6	143.1	143.6	144.0	144.2	144.4	144.4	144.8	145.1	145.7	145.8	145.8	**144.5**
2002	146.2	146.7	147.2	147.4	147.5	148.0	148.4	149.0	149.4	149.5	149.7	149.7	**148.2**
2003	150.3	150.9	151.4	151.9	152.2	152.5	152.5	152.9	153.2	153.7	153.6	153.5	**152.4**
2004	154.4	154.9	155.7	156.3	156.6	156.7	157.0	157.3	157.8	158.3	158.6	158.6	**156.9**
2005	159.1	159.6	160.0	160.2	160.1	160.3	160.5	160.8	161.2	161.6	161.5	161.3	**160.5**
2006	161.6	161.9	162.2	162.5	162.8	163.0	163.2	163.4	163.6	164.0	164.0	163.9	**163.0**
2007	164.3	164.5	165.0	166.2	166.2	166.2	166.7	167.1	167.9	168.2	168.3	168.3	**166.6**
2008	168.8	169.8	171.2	171.3	171.5	172.4	172.8	172.8	173.7	174.0	174.1	174.0	**172.2**
2009	175.1	175.8	176.2	176.9	177.7	178.0	177.5	177.5	178.3	177.7	177.4	176.7	**177.1**
2010	177.1	177.8	178.8	179.8	179.8	179.9	180.1	180.7	181.0	181.3	181.3	180.9	**179.9**

FIGURE 3.9 This is an example of a simple table that can be used to look up several years of monthly rates.

Tables work well for look-up and one-to-one comparisons, in part because their structure is so simple, and in part because the quantitative values are encoded as text, which we can understand directly, without translation. Graphs, by contrast, are visually encoded, which requires translation of the information into the numbers it represents.

The textual encoding of tables also offers a level of precision that cannot be provided by graphs. It is easy to express a number with as much specificity as you wish using text (e.g., 27.387483), but the visual encoding of individual numbers in graphs doesn't lend itself to such precision.

Another strength of tables is that they can include multiple sets of quantitative values that are expressed in different units of measure. For instance, if you need to provide sales information that includes the number of units sold, the dollar amount, and a comparison to a forecast expressed as a percentage, doing so in a single graph would be difficult, because a graph usually contains a single quantitative scale with a single unit of measure.

And a final strength of tables is their ability to combine summary and detail information in a single display. For example, a table might include the amount of revenue earned per month (detail), with a total for the year (summary).

To summarize, tables are used to display simple relationships between quantitative values and corresponding categorical items, which makes tables ideal for looking up and comparing individual values. The entire set of reasons to use a table consists of the following; if one or more of these are true, you should probably display the data in a table:

1. The display will be used to look up individual values.
2. It will be used to compare individual values but not entire series of values to one another.
3. Precise values are required.
4. The quantitative information to be communicated involves more than one unit of measure.
5. Both summary and detail values are included.

Graphs Defined

Graphs exhibit the following characteristics:

- Values are displayed within an area delineated by one or more axes.
- Values are encoded as visual objects positioned in relation to the axes.
- Axes provide scales (quantitative and categorical) that are used to label and assign values to the visual objects.

Axes delineate the space that is used to display data in a graph.

Essentially, a graph is a *visual display of quantitative information*. Whereas tables encode quantitative values as text, graphs encode quantitative values visually. Consider this simple example:

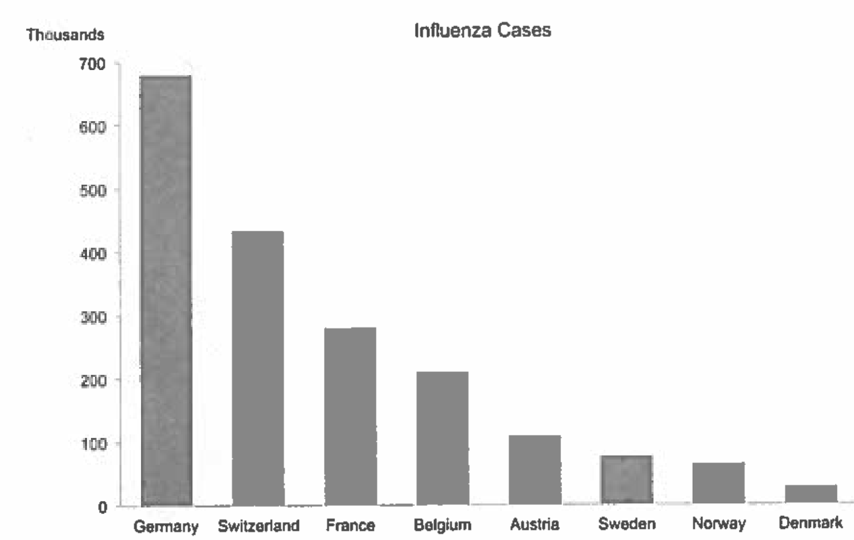


FIGURE 3.10 This is an example of a simple graph, which displays a count of influenza cases per country.

This graph has two axes: one that runs horizontally, called the *X axis*, and one that runs vertically, called the *Y axis*. In this graph, the categorical scale, which labels the countries, resides along the X axis, and the quantitative scale (i.e., counts of influenza cases) resides along the Y axis. The values themselves are encoded as rectangles, called *bars*. Bars are one of several visual objects that can be used to encode data in graphs. The number of influenza cases in each country is encoded as the height of its bar and the position of its top in relation to the scale on the Y axis. The horizontal position of each bar along the X axis is labeled to denote the specific categorical item to which the values are related (e.g., Belgium).

With a little practice, even someone who has never previously used a graph can learn to interpret the information contained in a simple one like this. Although the values of sales for each country cannot be interpreted to the exact number, this isn't the graph's purpose. Rather, the graph paints the picture that influenza has affected these countries to varying degrees, with the greatest effect in Germany and the least in Denmark, and significant differences in between. Information like this, which is intended to show patterns in data, is best presented in a graph rather than a table, as we'll see in the section *When to Use Graphs*. But first, a little history.

A Brief History of Graphs

Graphs of quantitative information have been in use for only a few hundred years, which is a relatively short time given the thousands of years that mathematics has existed. Despite how natural it may seem to see quantitative information displayed in graphs, the original notion that numbers could be displayed visually in relation to two perpendicular axes involved a leap of imagination. The launching pad for this leap had already been around for many centuries before quantitative graphs emerged. An earlier type of visual information display, also assisted by a scale of measurement along perpendicular axes, eventually suggested the possibility of graphs. Can you guess what it was? It is still in common use today for the purpose of navigation. It is a two-dimensional representation of the physical world that's used to measure distances between locations. I'm referring to a *map*. The earliest known map dates back about 4,300 years. It was drawn on a clay tablet and represented northern Mesopotamia. When a map depicts the entire world, or some large part of it, the standard set of grid lines that allow us to determine location and distance are longitudes and latitudes. These grid lines form a quantitative scale of sorts.

In the 17th century these grids were adapted for the representation of numbers alone. In his *La Géométrie* (1637), René Descartes introduced them as a means to encode numbers as coordinate positions in a two-dimensional (2-D) grid. This innovation provided the groundwork for an entire new field of mathematics that is based on graphs. To some extent even prior to Descartes, others had already experimented with graphical displays of numbers. Ron Rensink writes:

> *Although Descartes did contribute to the graphic display of quantitative data in the 17th century, other forms of quantitative graphs had already been used to represent things such as temperature and light intensity three centuries earlier. Indeed, as Manfredo Massironi discusses in his book (Massironi, M. (2002) The Psychology of Graphic Images: Seeing, Drawing, Communicating. Erlbaum, page 131), quantities such as displacement were graphed as a function of time as far back as the 11th century. But while these facts may be of interest in their own right, the more important point is that techniques in graphic representation have been developed over many centuries, and many of these techniques have been subsequently forgotten—perhaps fallen out of vogue, or never found wide use to begin with. But the reasons for their dismissal may not necessary apply in this day and age. Indeed, several techniques might lend themselves quite well to modern technology, and so might be worth resurrecting in one form or other. Books such as Massironi's are helpful in discovering such possibilities.* [1]

1. Ron Rensink (2011) "Four Futures and a History," www.Interaction-Design.org.

Despite these earlier ventures, it wasn't until the late 18th century that the use of graphs to present numbers became popular. William Playfair, a Scottish social scientist, used his imagination and design acumen to invent many of the graphing techniques that we use today. He pioneered the use of graphs to reveal the shape of quantitative information, thus providing a way to communicate quantitative relationships that numbers expressed as text could never convey. He invented the bar graph, was perhaps the first person to use a line to show how values change through time, and on a day when he was probably under the weather, invented the pie chart as well, but we'll forgive his brief lapse of judgment.

Information about the early development of the graph, including its precursor, the map, may be found in Robert E. Horn (1998) *Visual Language*. MacroVU, Inc. Robert Horn provides an informative timeline, which cites the milestones in the historical development of visual information display.

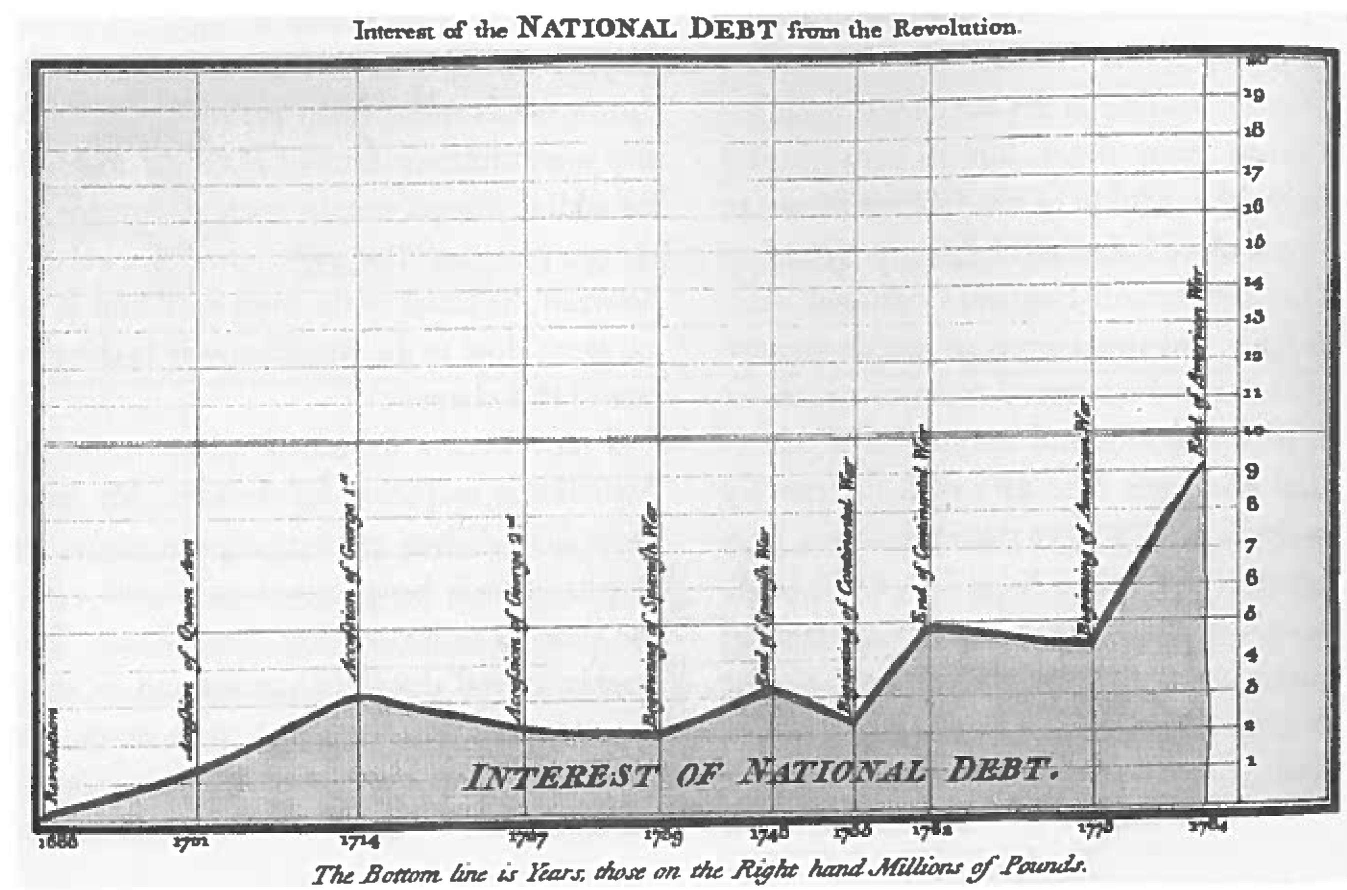


FIGURE 3.11 This graph was included in William Playfair's book *The Commercial and Political Atlas* in 1786 to make a case against England's policy of financing colonial wars through national debt.

The old saying, "A picture is worth a thousand words" applies quite literally to graphs. By presenting quantitative information in visual form, graphs efficiently communicate what might otherwise require a thousand or even a million words, and sometimes communicate what words could never convey.

From the time of Playfair until today, many innovators have added to the inventory of graph designs available for the representation, exploration, analysis, and communication of quantitative information. During the past 50 years, none has contributed more to the field as an advocate of excellence in graphic design than Edward Tufte, who in 1983 published his landmark treatise on the subject, *The Visual Display of Quantitative Information*. With the publication of additional books and articles since, Tufte continues to be respected as a major authority in this field.

The work of William S. Cleveland, especially his book *The Elements of Graphing Data*, is also an outstanding resource.[2] Cleveland's work is particularly useful to those with statistical training who are interested in sophisticated graphs, such as those used in scientific research.

2. William S. Cleveland (1994) *The Elements of Graphing Data*. Hobart Press.

When to Use Graphs

Graphs reveal more than a collection of individual values. Because of their visual nature, graphs present the overall shape of the data. Text, displayed in tables, cannot do this. The patterns revealed by graphs enable readers to detect many points of interest in a single collection of information. Take a look at the next example, and try to identify some of the features that graphs can reveal. Approach this by first determining the messages in the data, then by identifying the visual cues—the shapes—that reveal each of these messages.

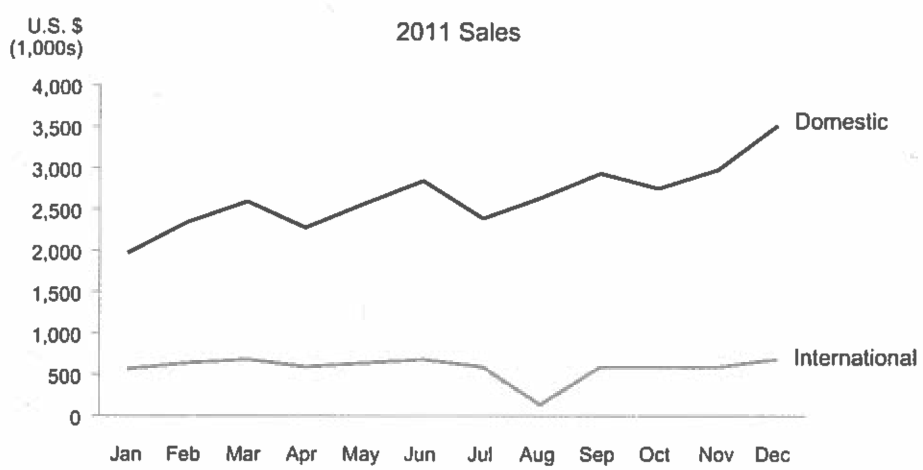


FIGURE 3.12 This fairly typical line graph is an example of the shapes and patterns in quantitative data that graphs make visible.

What insights are brought to your attention by the shape of this information? Take a moment to list them in the right margin.

· · · · · · ·

Let's walk through a few of these revelations together, beginning with domestic sales. What does the shape of the black line tell you about domestic sales during the year 2011? One message is that, during the year as a whole, domestic sales increased; these sales ended higher than they started, with a gradual increase through most of the year. One name for this type of pattern is a *trend*, which displays the overall nature of change during a particular period of time.

Was this upward trend steady? No, it exhibits a pattern that salespeople sometimes call the *hockey stick*. Sales go down in the first month of each quarter and then gradually go up to a peak in the last month of each quarter. If you examine the shape of the line from the last month of one quarter, such as March, to the last month of the next quarter, such as June, you'll recognize that these segments each look a little like a hockey stick. This pattern in sales usually occurs when salespeople are given bonuses based on reaching or exceeding a quarterly quota.

Now, if you look at sales in the first quarter of the year versus sales in the second quarter, then the third, and finally the fourth, you find that the graph makes it easy to see how these different periods compare. When information is given shape in a graph, it becomes possible to compare entire sets of data. In this case the comparison is between different quarters.

Now look for a moment at international sales. Once again you are able to easily see the trend of sales throughout the year, which in this case is relatively flat. Compared with domestic sales, international sales seem to exhibit less fluctuation through time and relatively little difference between the beginning and end of the year. Although international sales appear to be less affected by quarters and seasons, one point along the line stands out as quite different from the rest: the month of August. Sales in August took an uncharacteristic dip compared to the rest of the year. As an analyst, this abnormal sales value would make you want to dig for the cause. If you did, perhaps you would discover that most of your international customers were vacationing in August and therefore weren't around to place orders. Whatever the cause, the current point of interest to us is that graphs make exceptions to general patterns stand out clearly from the rest. This wouldn't be nearly so obvious in a table of numbers.

Finally, if you widen your perspective to all the quantitative information, you find that the graph makes it easy to see the similarities and differences between the two sets of values (domestic and international sales), both overall and at particular points in the graph. We could go on, adding more to the list of characteristics that graphs reveal, but we've hit the high points and are now ready to distill what we've detected to its essence:

> Graphs are used to display relationships among and between sets of quantitative values by giving them shape.

The visual nature of graphs endows them with their unique power to reveal patterns of various types, including changes, differences, similarities, and exceptions. Graphs can communicate quantitative relationships that are much more complex than the simple associations between individual quantitative values that tables can express.

Graphs can display large data sets in a way that can be readily perceived and understood. You could gather data regarding the relationship between employee productivity and the use of two competing software packages, involving thousands of records across several years, and, with the help of a graph, you would be able to immediately see the nature of the relationship. If you have ever tried to use a huge table of data for analysis, you would quickly fall in love with graphs like scatter plots, which can make the relationships among thousands of individual data points instantly intelligible.

Patterns in data are difficult to discern even in a small table of numbers. Despite our agreement on most matters, Tufte and I disagree slightly about this. According to Tufte:

> *Tables usually outperform graphics in reporting on small sets of 20 numbers or less. The special power of graphics comes in the display of large data sets.* [3]

3. Edward Tufte (2001) *The Visual Display of Quantitative Information*, Second Edition. Graphics Press, page 56.

Although it is true that one's chance of seeing a meaningful pattern in small table of numbers is greater than in one that is large, those patterns are much easier to see in a graph. Take a look at the following table.

Job Satisfaction By Income, Education, and Age

	College Degrees		No College Degrees	
Income	Under 50	50 & over	Under 50	50 & over
Up to $50,000	643	793	590	724
Over $50,000	735	928	863	662

FIGURE 3.13 This table displays measures of employee job satisfaction, divided into categories.

Do any unusual patterns of job satisfaction pop out? Can you see that one group of employees exhibits a different pattern of satisfaction from the others? Now take a look at the following graph.

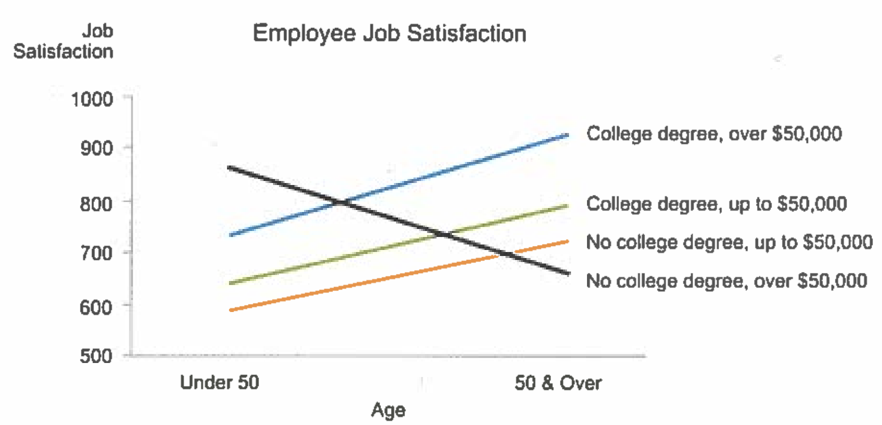


FIGURE 3.14 This graph causes the pattern represented by the black line to pop out.

The fact that employees with salaries over $50,000 but no college degrees experience a significant decrease in job satisfaction in their older years now jumps out. Even with only eight numbers, this graph did what the table couldn't do—it made this diverging pattern obvious. This results not only because the information is displayed graphically, but also because the graph was specifically designed to feature this particular pattern. Had I designed the graph in the following manner, that pattern would no longer be obvious.

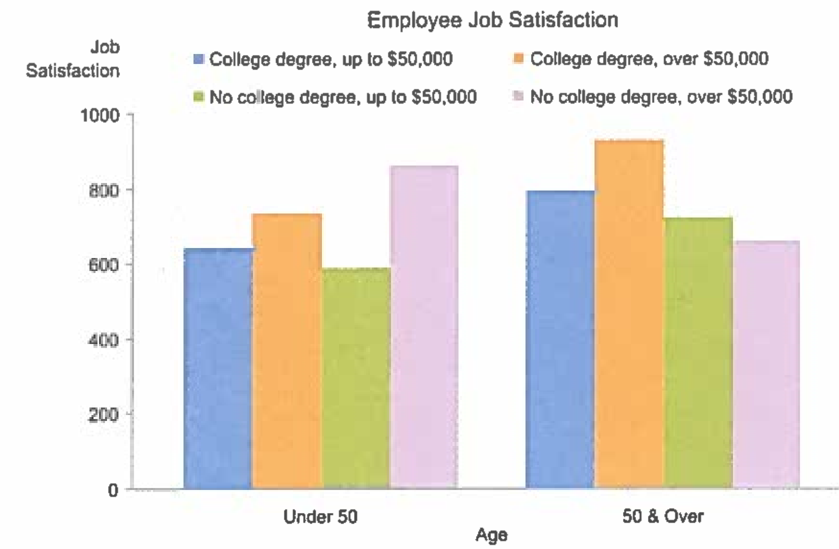


FIGURE 3.15 Unlike the graph in *Figure 3.14*, this graph does not make the pattern of decreasing job satisfaction among the one group of employees obvious.

This example is not based on real data, so if you make more than $50,000 a year but don't have a college degree and will soon turn 50, don't worry, you'll probably do just fine.

So displaying information in a graph rather than a table does not by itself make meaningful patterns visible. We must design the graph to feature evidence of the particular story that we're trying to tell. Many possible stories dwell in a set of data, even in a small one such as illustrated above. Later in this book, we'll learn to make the necessary graph design choices to tell particular stories.

Summary at a Glance

Use Tables When	Use Graphs When
• The display will be used to look up individual values. • It will be used to compare individual values. • Precise values are required. • The quantitative values include more than one unit of measure. • Both detail and summary values are included.	• The message is contained in the shape of the values (e.g., patterns, trends, and exceptions). • The display will be used to reveal relationships among whole sets of values.

4 FUNDAMENTAL VARIATIONS OF TABLES

Tables should be structured to suit the nature of the information they are meant to display. This chapter breaks tables down into their fundamental variations and provides simple rules of thumb for pairing your message with the best tabular means to communicate it.

We'll begin this chapter by identifying *what* tables can be used to display, followed by *how* they can be structured visually, and then we'll link the *what* to the *how*.

Relationships in Tables

Information that we display in tables always exhibits a specific relationship between individual values. Tables are commonly used to display one of five potential relationships, which can be divided into two major types:

- Quantitative-to-categorical relationships
  - Between one set of quantitative values and one set of categorical items
  - Between one set of quantitative values and the intersection of multiple categories
  - Between one set of quantitative values and the intersection of hierarchical categories
- Quantitative-to-quantitative relationships
  - Among one set of quantitative values associated with multiple categorical items
  - Among distinct sets of quantitative values associated with a single categorical item

This might sound like gobbledygook, but the meaning of each relationship will become clear as we proceed.

Quantitative-to-Categorical Relationships

Tables of this type are primarily used for looking up one quantitative value at a time; each value relates either to a single category or to the intersection of multiple categories.

BETWEEN ONE SET OF QUANTITATIVE VALUES AND ONE SET OF CATEGORICAL ITEMS

The simplest type of relationship displayed in tables is an association between one set of quantitative values and one set of categorical items. Typical examples include sales dollars (quantitative values) associated with geographical sales regions (categorical items), ratings of performance (quantitative values) associated with individual employees (categorical items), or expenses (quantitative values) associated with fiscal periods (categorical items). Here's an example:

Salesperson	QTD Sales
Robert Jones	13,803
Mandy Rodriguez	20,374
Terri Moore	28,520
John Donnelly	34,786
Jennifer Taylor	36,973
Total	$134,456

FIGURE 4.1 This table displays a simple relationship between quantitative values and categorical items, in this case sales in dollars per salesperson.

Tables of this type function as simple lists used for look-up. You want to know how much Mandy has sold so far this quarter? You simply find Mandy's name on the list, and then look at the sales number next to her name. Tables of this sort are a common means of breaking quantitative information down into small chunks so we can see the details behind the bigger picture.

BETWEEN ONE SET OF QUANTITATIVE VALUES AND THE INTERSECTION OF MULTIPLE CATEGORIES

One small step up the complexity scale, tables can also display quantitative values that are simultaneously associated with multiple sets of categorical items. Here's the same example as the one above, but this time a second category has been added:

Salesperson	Jan	Feb	Mar
Robert Jones	2,834	4,838	6,131
Mandy Rodriguez	5,890	6,482	8,002
Terri Moore	7,398	9,374	11,748
John Donnelly	9,375	12,387	13,024
Jennifer Taylor	10,393	12,383	14,197
Total	$35,890	$45,464	$53,102

FIGURE 4.2 This table displays a relationship between quantitative values and multiple categories, in this case between sales dollars and particular salespeople (category 1) in a particular month (category 2).

In this example, each quantitative value measures the sales for a particular salesperson in a particular month. A single quantitative value measures sales for the intersection of two categories (salesperson and month). This is still a relationship between quantitative values and categorical items, but it is slightly more complex in that it addresses the intersection of multiple categories. Because each category represents a different dimension of the information, this type of table provides a multi-dimensional view.

BETWEEN ONE SET OF QUANTITATIVE VALUES AND THE INTERSECTION OF HIERARCHICAL CATEGORIES

A variation of the relationship shown in the previous example is when multiple sets of categorical items relate to one another hierarchically. For instance, let's consider the following three categories of time: years, quarters, and months. They are related hierarchically in that years consist of quarters, which, in turn, consist of months. Another common example involves the hierarchical categories that organize and describe products. These might consist of product lines, which consist of product families, which consist of individual products. Just as in the previous type of relationship, a quantitative value measures the intersection of multiple categories. The only difference is that in this case there is a hierarchical relationship among the categories. Here's an example:

Product Line	Product Family	Product	Sales
Hardware	Printer	PPS	6,131
		PXT	8,002
		PQT	11,748
	Router	RRZ	13,024
		RTS	14,197
		RQZ	23,293
Software	Business	ACT	12,393
		SPR	9,393
		DBM	5,392
	Game	ZAP	10,363
		ZAM	15,709
		ZOW	13,881
Total			$143,526

FIGURE 4.3 This table displays a relationship between quantitative values and hierarchical categories, in this case between sales dollars and a hierarchically arranged combination of product line, product family, and product.

Quantitative-to-Quantitative Relationships

In addition to permitting us to show direct relationships between quantitative values and categorical items, tables also allow us to examine relationships among multiple quantitative values. These relationships are primarily used to compare multiple quantitative values of a single measure (e.g., expenses in U.S. dollars) associated with multiple categorical items (e.g., the months January and February), or multiple measures (e.g., expenses and revenues in U.S. dollars) for a single categorical item (e.g., the month of January).

AMONG ONE SET OF QUANTITATIVE VALUES ASSOCIATED WITH MULTIPLE CATEGORICAL ITEMS

Rather than merely looking at the sales associated with an individual salesperson, you might want to compare sales among several salespeople. In the next example, how did Mandy do compared to Terri in February?

Salesperson	Jan	Feb	Mar
Robert Jones	2,834	4,838	6,131
Mandy Rodriguez	5,890	6,482	8,002
Terri Moore	7,398	9,374	11,748
John Donnelly	9,375	12,387	13,024
Jennifer Taylor	10,393	12,383	14,197
Total	$35,890	$45,464	$53,102

FIGURE 4.4 This table examines a relationship among quantitative values associated with multiple categorical items, in this case sales by several salespeople in the months of January, February, and March.

As you can see, this table is identical in design to the table in *Figure 4.2*, but in this case the primary activity is comparison rather than look-up.

AMONG DISTINCT SETS OF QUANTITATIVE VALUES ASSOCIATED WITH A SINGLE CATEGORICAL ITEM

Tables often contain more than one set of quantitative values (i.e., distinct measures). In this case, we can examine relationships among different quantitative measures that are associated with a single categorical item. The table below extends the previous example to three distinct measures: sales, returns, and net sales:

Salesperson	Sales	Returns	Net Sales
Robert Jones	13,803	593	13,210
Mandy Rodriguez	20,374	1,203	19,171
Terri Moore	28,520	10,393	18,127
John Donnelly	34,786	483	34,303
Jennifer Taylor	36,973	0	36,973
Total	$134,456	$12,672	$121,784

FIGURE 4.5 This table examines a relationship among distinct measures associated with a single categorical item, in this case the salespeople's sales, returns, and resulting net sales.

This table makes it easy to see how each salesperson is doing by comparing three measures of performance.

Here's a summary of *what* tables can be used to display:

Primary Function	Relationship Type	Relationship
Look-up	Quantitative-to-Categorical	Between a single set of quantitative values and a single set of categorical items
		Between a single set of quantitative values and the intersection of multiple categories
		Between a single set of quantitative values and the intersection of multiple hierarchical categories
Comparison	Quantitative-to-Quantitative	Among a single set of quantitative values associated with multiple categorical items
		Among distinct sets of quantitative values associated with a single categorical item

It is important to distinguish these relationships because, as we'll see in the next section, the layout of a table is primarily determined by the relationships the table is meant to feature.

Variations in Table Design

Now let's look at *how* tables can display the types of relationships we've identified. Within the general structure of columns and rows, tables can vary somewhat in design. Structural variations can be grouped into two fundamental types:

- Unidirectional—categorical items are laid out in one direction only (i.e., either across columns or down rows)
- Bidirectional—categorical items are laid out in both directions

Unidirectional

When a table is structured unidirectionally, categorical items are arranged across the columns or down the rows but not in both directions. Unidirectional tables may have one or more sets of categorical items, but if there is more than one, the values are still only arranged across the columns or down the rows. Here's an example of a unidirectional table with categorical items (i.e., departments) arranged down the rows:

Department	Headcount	Expenses
Finance	26	202,202
Sales	93	983,393
Operations	107	933,393
Total	234	$2,118,988

FIGURE 4.6 This table is structured unidirectionally with the categorical items (departments) arranged down the rows.

Notice that Headcount and Expenses label two distinct sets of quantitative values, not values of a single category. Here's the same information, this time with the categorical items (i.e., departments) laid out across the columns:

Dept	Finance	Sales	Ops	Total
Headcount	26	93	107	234
Expenses	202,202	983,393	933,393	$2,118,988

FIGURE 4.7 This table is structured unidirectionally with the categorical items arranged across the columns.

These are simple unidirectional tables in that they only contain a single set of categorical items, but tables can also have multiple sets, as in the following example:

Dept	Expense Type	Expenses
Finance	Compensation	160,383
	Supplies	5,038
	Travel	10,385
Sales	Compensation	683,879
	Supplies	193,378
	Travel	125,705
Total		$1,178,768

FIGURE 4.8 This table is structured unidirectionally, consisting of two sets of categorical items: departments in the left column and expense types in the middle column.

Because the two sets of categorical items are arranged in only one direction, in this case down the rows, this table is still structured unidirectionally.

Bidirectional

When a table is structured bidirectionally, more than one set of categorical items is displayed, and these sets are laid out both across the columns and down the rows. This arrangement is sometimes called a *crosstab* or a *pivot table*. The quantitative values appear in the body of the table, bordered by the categorical items, which run across the top and along the left side. This type of table can be easily understood by looking at an example. Here's the same information found in the previous unidirectional table, but this time it is structured bidirectionally:

	Departments		
Expense Types	Finance	Sales	Total
Compensation	160,383	683,879	844,262
Supplies	5,038	193,378	198,416
Travel	10,385	125,705	136,090
Total	$175,806	$1,002,962	$1,178,768

FIGURE 4.9 This is an example of a bidirectionally structured table.

To locate the quantitative value associated with a particular department and a particular expense type, you look where the relevant column and relevant row intersect.

One of the advantages of bidirectional tables over unidirectional tables is that they can display the same information using less space. Here are the same examples of the previous unidirectional and bidirectional tables, but this time I've included a complete set of grid lines to make it easy to see the amount of space used by each. Here's the unidirectional version:

Dept	Expense Type	Expenses
Finance	Compensation	160,383
	Supplies	5,038
	Travel	10,385
Sales	Compensation	683,879
	Supplies	193,378
	Travel	125,705
Total		$1,178,768

FIGURE 4.10 This is an example of a unidirectionally structured table that contains two sets of categorical items: departments and expense types.

Here's the bidirectional version:

Expense Type by Dept	Finance	Sales	Total
Compensation	160,383	683,879	844,262
Supplies	5,038	193,378	198,416
Travel	10,385	125,705	136,090
Total	$175,806	$1,002,962	$1,178,768

FIGURE 4.11 This is an example of a bidirectional table that contains the same information as in *Figure 4.10* above but uses less space despite the fact that it displays additional values.

Count the cells (i.e., the individual rectangles formed by the grid lines) in each table. You'll find that the unidirectional table contains a grid of three columns by eight rows, totaling 24 cells, and the bidirectional table contains a grid of four columns by five rows, totaling 20 cells. That doesn't seem like much of a difference until you notice that the bidirectional version actually contains totals for each expense type in the right column that are not included in the unidirectional version, so not only is it smaller, it contains more information.

Table Design Solutions

As we explored the structural variations of tables, you might have noticed an affinity between the types of relationships that can be displayed in tables and the two primary ways to structure tables. This affinity indeed exists and is worth noting. Below is a table that lists the five types of relationships down the rows and the two structural variations across the columns, with blank cells intersecting these rows and columns. Take a few minutes to think about each type of relationship and fill in the blanks with either Yes or No to indicate whether the structural variation can effectively display the corresponding relationship. If the structural type will only work in certain circumstances, note that as well, and describe the circumstances. You might find it helpful to construct sample tables and arrange them in various ways to explore the possibilities.

Relationship	Unidirectional	Bidirectional
Between a single set of quantitative values and a single set of categorical items		
Between a single set of quantitative values and the intersection of multiple categories		
Between a single set of quantitative values and the intersection of multiple hierarchical categories		
Among a single set of quantitative values associated with multiple categorical items		
Among distinct sets of quantitative values associated with a single categorical item		

I'm confident that you've used your developing design skills effectively to identify solutions in the exercise above, but just so you have a nice, neat reference, I've included one in the *Summary at a Glance* that follows.

Now you have a conceptual understanding of tables that includes what they are, when to use them rather than graphs, what they're used for, how they're structured, and which type of structure works for particular quantitative relationships. Later, in Chapter 8, *Table Design*, we'll examine the specific design choices available to express quantitative messages in tables as clearly and powerfully as possible.

Summary at a Glance

Quantitative-to-Categorical Relationships

	Structural Type	
Relationship	**Unidirectional**	**Bidirectional**
Between a single set of quantitative values and a single set of categorical items	Yes	Not applicable because there is only one set of categorical items
Between a single set of quantitative values and the intersection of multiple categories	Yes. Sometimes this structure is preferable because of convention.	Yes. This structure saves space.
Between a single set of quantitative values and the intersection of multiple hierarchical categories	Yes. This structure can clearly display the hierarchical relationship by placing the separate levels of the hierarchy side by side in adjacent columns.	Yes. However, this structure does not display the hierarchy as clearly if its separate levels are split between the columns and rows.

Quantitative-to-Quantitative Relationships

	Structural Type	
Relationship	**Unidirectional**	**Bidirectional**
Among a single set of quantitative values associated with multiple categorical items	Yes	Yes. This structure works especially well because the quantitative values are arranged closely together for easy comparison.
Among distinct sets of quantitative values associated with a single categorical item	Yes	Yes. However, this structure tends to get messy as you add multiple sets of quantitative values.

5 VISUAL PERCEPTION AND GRAPHICAL COMMUNICATION

Because graphical communication is visual, it must express information in ways that human eyes can perceive and brains can understand. Our eyes and the parts of the brain that handle input from them work in particular ways. Thanks to science, how we see is now fairly well understood, from the initial information-carrying rays of light that enter our eyes to the interpretation of that information in the gray folds of the visual cortex. By understanding visual perception and its application to the graphical communication of quantitative information, you will learn what works, what doesn't, and why. This chapter brings the principles of graphical design for communication alive in ways that are practical and can be applied skillfully to real-world challenges in presenting quantitative information.

Vision, of all the senses, is our most powerful and efficient channel for receiving information from the world around us. Approximately 70% of the sense receptors in our bodies are dedicated to vision.

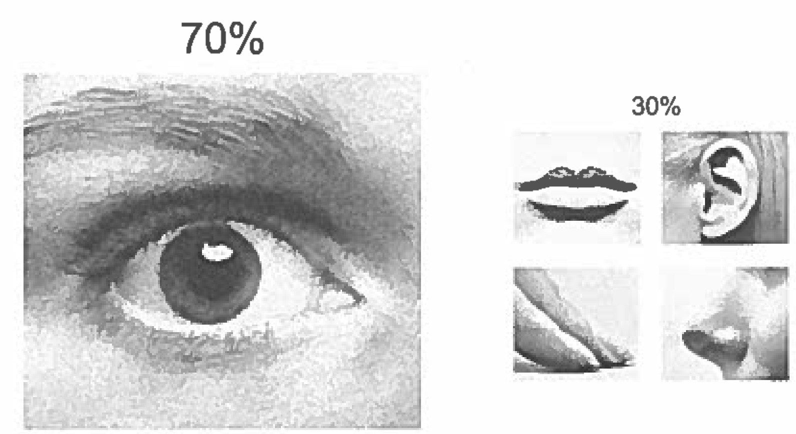


FIGURE 5.1 70% of the body's sense receptors reside in the retinas of our eyes.

There is an intimate connection among seeing, thinking, and understanding. It is no accident that the terms we most often use to describe understanding are visual in nature, such as insight, illumination, and enlightenment. "I see" is the expression we use when something begins to make sense. We call people of extraordinary wisdom seers.

Graphs, and, to a lesser extent, tables, are visual means of communication. Although tables are visual in that we receive their information through our eyes, their reliance on verbal language in the form of written text reduces the degree to which they take advantage of the power of visual perception. Nevertheless, inattention to the visual design of tables, such as improper alignment of numbers and excessive use of lines and fill colors, can greatly diminish their effectiveness. Graphs, in contrast, are primarily visual in nature. The power of graphs and the power of visual perception are intimately linked.

ICONIC MEMORY

Signals from the eyes are initially routed through the optic nerve into iconic memory (a.k.a. the *visual sensory register*) where each snapshot of input waits to be passed on to working memory. Information ordinarily remains in iconic memory for less than a second while extremely rapid processing takes place before the information is forwarded to working memory. This part of perceptual processing is automatic and unconscious. For this reason it is called *preattentive processing*, as opposed to the conscious, higher-level cognitive processing that occurs later in working memory, which is called *attentive processing*. Preattentive processing is an extremely fast process of recognition and nothing more. Attentive processing, on the other hand, is a sequential process that takes more time and can result in learning, understanding, and remembering. Preattentive visual processing detects several attributes, such as color and the location of objects in 2-D space. Because preattentive processing is tuned to these attributes, they jump out at us and are therefore extremely powerful aspects of visual perception. If you want something to stand out as important in a table or graph, you should encode it using a preattentive attribute that contrasts with the surrounding information, such as red text in the midst of black text. If you want a particular set of objects to be seen as a group, you can do this by assigning them the same preattentive attribute.

Preattentive attributes play an important role in visual design. They can be used to distinctly group and highlight objects. We'll examine them in detail later in this chapter with special attention to how we can use them to design tables and graphs that communicate effectively.

WORKING MEMORY

As visual information is moved from iconic memory into working memory, what our brains deem useful is combined into meaningful visual *chunks*. These chunks of visual information are used by the conscious, attentive process of perception that occurs in working memory. Two fundamental characteristics of working memory are:

- It is temporary.
- It has limited storage capacity.

Information remains in working memory from only a few seconds to as long as a few hours if it is periodically rehearsed. Without rehearsal, it soon vanishes. With the right kind of rehearsal, it is stored in long-term memory where it remains for later use.

Only three or four chunks of information can be stored in working memory at any one time. For something new to be brought into working memory, something that is already there must either be moved into long-term memory or forgotten. Similar to RAM in a computer, working memory in the brain stores information temporarily for high-speed processing. As this processing occurs, new sensations or memories are being moved into working memory while others are either moved into long-term memory or forgotten.

Colin Ware points out, in *Information Visualization: Perception for Design*, that our brains appear to have more than one type of working memory; each kind specializes in a different type of information processing. For instance, research has demonstrated that there are separate areas for visual and verbal information and that these areas don't compete with each other for resources.

An important fact to keep in mind about working memory is that readers of tables and graphs can only hold a few chunks of information in their heads at any one time. For instance, if you design a graph that includes a legend with a different color or symbol shape for 10 different sets of data, your readers will be forced to constantly refer back to the legend to remind themselves which is which because working memory is limited to three or four concurrent chunks of information. Chunks of information can vary in size. By designing a visual display of information to form larger, coherent patterns that combine multiple data values into chunks, you can make it easier for your readers to hold more information in working memory. This is one of the reasons that graphs are capable of communicating a great deal of information that can be perceived all at once while tables are limited to use for looking things up. We can't take a bunch of numbers from a table and chunk them together meaningfully for storage in working memory; we can, however, discern in a graph the image of a single, meaningful pattern that consists of thousands of values.

LONG-TERM MEMORY

When we decide to store information for later use, either consciously or unconsciously, we rehearse that chunk of information to move it from working to long-term memory. How we store that information involves an intricate neural network of links and cross-references (i.e., associations), like indexes in a computer that help us to find information and retrieve it from a hard disk into working memory when we need it. One piece of information can have many associations.

Long-term memory is vitally important to visual perception because it holds our ability to recognize images and detect meaningful patterns, but we don't have to understand very much about long-term memory to become better designers of tables and graphs. Mostly, we need to know how to use preattentive visual attributes to grab and direct our readers' attention and how to work within the limits of working memory.

Evolution of Visual Perception

Like all other products of evolution, visual perception developed as an aid to survival. Because of its evolutionary roots, visual perception is fundamentally oriented toward action, always looking for what we can do with the things we see. As designers of tables and graphs, we should understand how to use attributes of visual perception to encode information in ways that others can easily, accurately, and efficiently decode.

Attributes of Preattentive Processing

Preattentive processing occurs below the level of consciousness at an extremely high speed and is tuned to detect a specific set of visual attributes. Attentive processing is conscious, sequential, and much slower. The difference between preattentive processing and attentive processing is easy to demonstrate. Take a look at the four rows of numbers below and determine, as quickly as you can, how many times the number 5 appears in the list:

987349790275647902894728624092406037070570279072
803208029007302501270237008374082078720272007083
247802602703793775709707377970667462097094702780
927979709723097230979592750927279798734972608027

FIGURE 5.7 This example demonstrates the slow speed at which we perceive information using a serial process, one number at a time.

How many? The answer is six. Even if you got the right answer (many don't when I do this exercise in class), it took you several seconds to perform this task because it involved attentive processing. The list of numbers did not include any preattentive attributes that could be used to distinguish the fives from the other numbers, so you were forced to perform a sequential search looking for the specific shape of the number five. Now do it again, this time using the list below:

98734979027**5**647902894728624092406037070**5**70279072
803208029007302**5**01270237008374082078720272007083
24780260270379377**5**709707377970667462097094702780
927979709723097230979**5**927**5**0927279798734972608027

FIGURE 5.8 This example demonstrates the fast speed with which we process visual stimuli that exhibit preattentive attributes.

This time it was easy because the fives were distinguished through the preattentive attribute of color intensity. Because only the fives are black, and all the other numbers are light gray, the black fives stand out in contrast to the rest. This example shows the power of preattentive attributes used knowledgeably for visual communication.

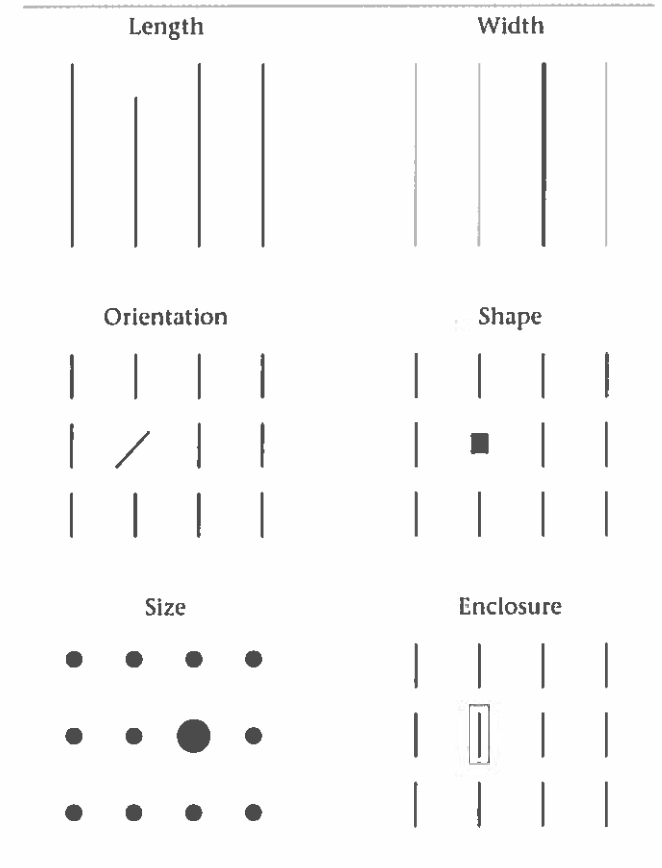
Colin Ware has organized preattentive attributes into four categories: form, color, spatial position, and motion. I've reduced his list of attributes somewhat and removed the category of motion entirely, to focus on attributes that we find most relevant to static tables and graphs:

Colin Ware (2004) *Information Visualization: Perception for Design*, Second Edition. Morgan Kaufmann Publishers, pages 151 and 152

Category	Attribute
Form	Length Width Orientation Shape Size Enclosure
Color	Hue Intensity
Spatial position	2-D position

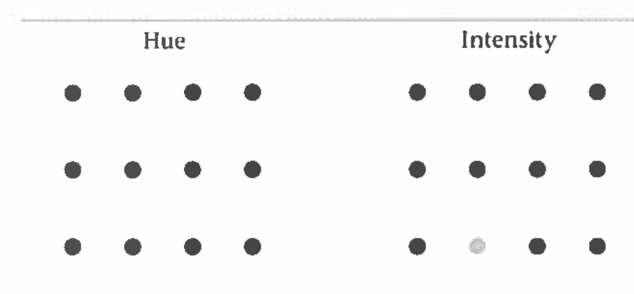
In each illustration of a preattentive attribute on the following page, only one object stands out as different from the rest, based on a variation of the attribute.

Attributes of Form



For our purposes, length is distance along the dominant dimension of an object. For example, the lines in the illustration above primarily vary in the vertical dimension only. Think in terms of bars in a bar graph, which encode quantitative values as length along a single dimension—either vertically or horizontally, but not both. Whenever we use variation in length to encode values in graphs, the objects, such as bars, will share a common baseline, which makes it extremely easy to compare their lengths. By width, we're referring to variation along the secondary dimension of an object. Once again, think of bars that vary in one dimension, such as vertical length, to encode values, but also vary in their less dominant dimension, width, to encode a second set of values.

Attributes of Color



Hue is a precise term for what we normally think of as color (red, green, blue, pink, etc.). Color is made up of three separate attributes; hue is one. *Intensity* applies to both of the other two attributes of color: *saturation* and *lightness*. In the previous illustration only intensity varies in that one object is lighter than the others.

The primary system that is used to describe color is known as the *HSL* (hue, saturation, and lightness) system. This system describes hue numerically in degrees from 0 to 360 along the circumference of a circle, illustrated by the following color wheel:

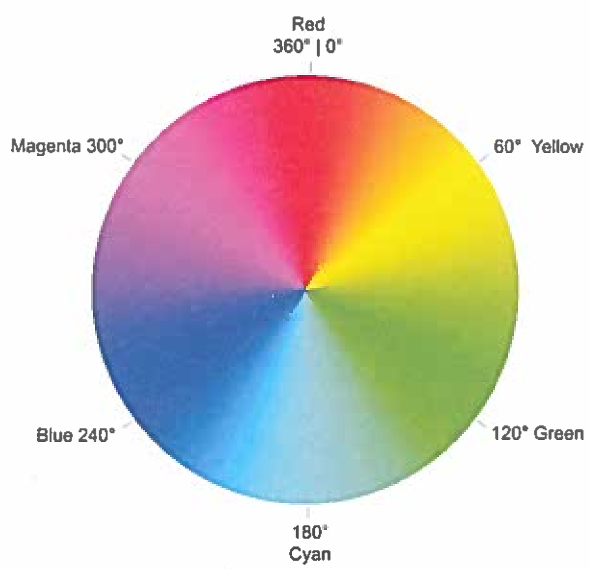


FIGURE 5.9 This is a color wheel, which represents hue in a circular manner.

Numbering starts at the top with red at 0° and continues around the wheel until it reaches the point where it started with red again, which is also assigned the value of 360°. If you could walk around this color wheel clockwise taking 60° steps, starting at red (0°), with each succeeding step you would be positioned at the following hues: yellow (60°), green (120°), cyan (180°), blue (240°), magenta (300°), then back to red again (360°).

Saturation measures the degree to which a particular hue fully exhibits its essence. In the example below, red ranges from completely pale on the left, lacking the essence of red entirely, to fully red on the right, exhibiting its full essence. Saturation is expressed as a percentage, starting with 0% on the left, which represents no saturation, to 100% on the right, which represents full saturation.

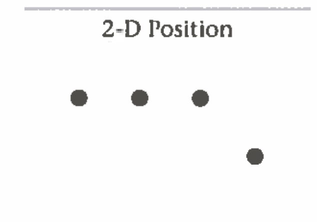
FIGURE 5.10 This is an illustration of the full range of saturation for the hue red, with 0% saturation on the left and 100% saturation on the right.

Lightness (also known as brightness) measures the degree to which a color appears dark or bright. In the next example, red ranges from fully dark (black) on the left to bright red on the right. Lightness is also expressed as a percentage, with 0% representing fully dark and 100% representing fully light.

FIGURE 5.11 This is an illustration of the full range of lightness for the hue red, with 0% lightness (dark) on the left and 100% lightness (bright) on the right.

Any color can be described numerically based on these three measures: hue (0 – 360°), saturation (0 – 100%) and lightness (0 – 100%).

Attributes of Spatial Position



Our perception of space is primarily two dimensional. We perceive differences in vertical position (up and down) and in horizontal position (left and right) clearly and accurately. We also perceive a third dimension, depth, but not nearly as well.

3-D position is also a preattentive attribute, but it cannot be applied effectively to graphs on a flat surface (e.g., a page or computer screen), which relies on illusory cues of light and shadow, occlusion, and size to simulate depth. Even if 3-D position could be used effectively on a flat surface, it is not an effective attribute to use in table and graph design because our perception of depth is weak compared to our perception of height and width.

Applying Visual Attributes to Design

Preattentive attributes can be used to make particular aspects of what we see stand out from the rest. Understanding these attributes enables us to design tables and graphs that visually emphasize the most important information they contain, keeping the other visual elements from competing for attention with key information.

Uses for Encoding Quantitative Values

Some attributes of preattentive processing can be expressed as values along a continuum. For instance, the preattentive attribute of length can be expressed as a line of any length that the eye can see, not just simply as short and long. We perceive quantitative meanings in the variations of some visual attributes but not in others. Using the attribute of length once again as an example, we naturally perceive long lines as greater than short lines. In this sense, we perceive the differing values of length quantitatively. But what about an attribute like hue? Which represents the greater value: blue, green, red, yellow, brown, or purple? Although it is true that each of these hues can be measured by instruments to determine its wavelength, and the number assigned to one hue would be greater or less than the number assigned to another, we don't think in these terms when we perceive hue. We perceive different hues only as categorically different, not quantitatively different; one hue is not more or less than another, they're just different. In contrast, we perceive color intensity quantitatively, from low to high.

Whether we perceive visual attributes as quantitative or categorical is significant. How we perceive these attributes tells us which ones we can use to encode quantitative values in graphs and which can only be used to encode categorical differences. The following list indicates which preattentive attributes are perceived quantitatively:

Type	Attribute	Quantitatively Perceived?
Form	Length	Yes
	Width	Yes, but limited
	Orientation	No
	Size	Yes, but limited
	Shape	No
	Enclosure	No
Color	Hue	No
	Intensity	Yes, but limited
Position	2-D position	Yes

Although one might argue that we can also perceive orientation quantitatively, there is no natural association of greater or lesser value with this characteristic (e.g., which is greater, a vertical or a horizontal line?).

All of these preattentive attributes can be used to encode categorical differences, including those that we perceive quantitatively. The most effective of these is 2-D position. For instance, the 2-D position of data points in a graph can simultaneously represent quantitative values based on the position of the data point relative to the Y axis and categorical differences based on their position along the X axis, as in the following example:

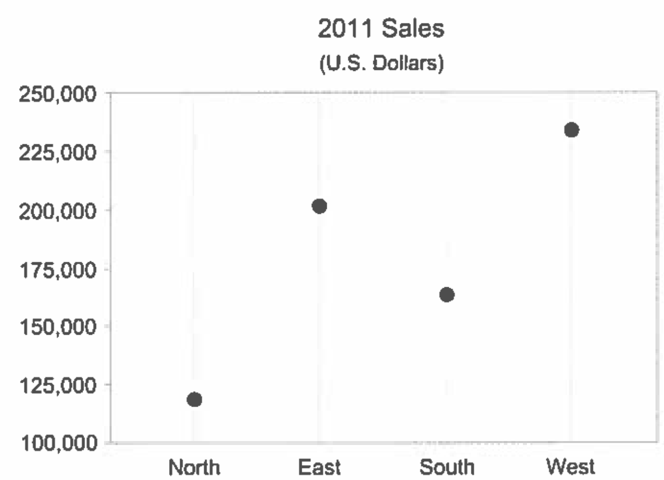


FIGURE 5.12 This graph uses the 2-D position of the data points to encode quantitative values along the Y axis and categorical items along the X axis.

Whenever you can use either length or 2-D position to encode quantitative values in graphs, you should do so rather than using other attributes that can be perceived quantitatively only to a limited degree. Even though we can tell that one value is greater than another when we use width, size, or color intensity, these attributes do not indicate precisely how much a value differs. This is true of width and size because both rely on our ability to assign values to the 2-D areas of objects, such as the slices of a pie chart or the width of a line. Although we can do a fairly good job of discerning that one object has a larger area than another, it is difficult to perceive by how much or to assign a value to the area. Take a look at the two circles on the following page. I've assigned a value to the one on the left, and it is up to you to assign a value to the one on the right.

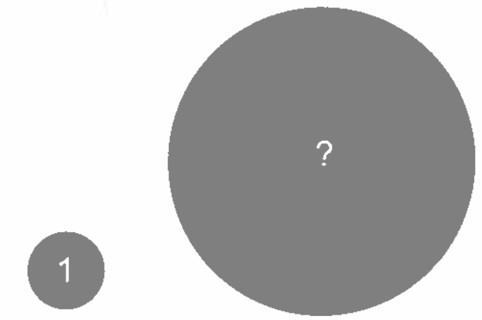


FIGURE 5.13 This figure illustrates the difficulty of perceiving differences in the 2-D areas of objects.

How much bigger is the large circle than the small circle? Given the fact that the size of the small circle equals a value of 1, what is the size of the large circle?

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The answer is 16. If you got the answer right, either you got lucky or you have rare perceptual talent. When I ask this question in a class of 70 students, answers typically range from 5 to 50.

Color intensity presents a similar problem. For instance, we can use color intensity along a gray scale ranging from white as the minimum value to black as the maximum. As long as there is enough difference in the color intensity of two objects, we can tell that one is darker than the other, but it is hard to assign a value to that difference. For this reason, it is best to avoid color intensity as a means of encoding quantitative value if the attributes of length or 2-D position are available to use instead.

Perceptual Effects of Context

One fact that may surprise you about our perception of visual attributes such as color or size is that our visual senses are not designed to perceive absolute values but rather differences in values. Your sense of the brightness of a candle will differ depending on the context, i.e., in relation to the other light in your range of vision. If you light a candle when surrounded by bright sunshine, the candle won't seem very bright. If you light the same candle while standing in a pitch-black cellar, the candle will seem extremely bright in contrast to the darkness. That's because our visual receptors measure differences rather than absolute values. Look at the four squares contained in the large rectangle below:

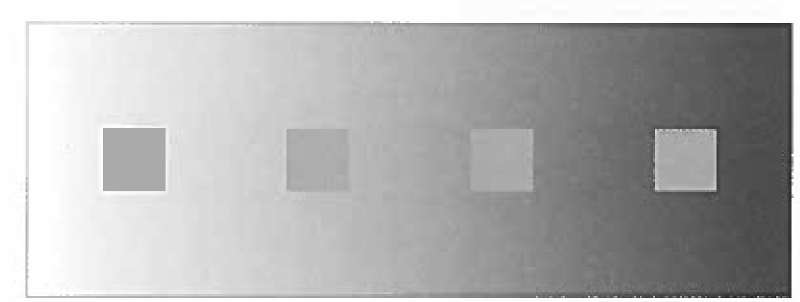

FIGURE 5.14 This illustration demonstrates the effect of context on the perception of color intensity.

How much darker is the square on the left than the square on the right?

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The truth is, there is no difference at all in the actual values of the four squares when measured by an instrument. All four are 50% gray, precisely in the middle between pure white and pure black. They appear different to us in this illustration, however, because our perception of them is influenced by the differences in the color intensity that surrounds them.

One practical application of the lesson that we learn from *Figure 5.14* is that we shouldn't use a gradient of fill color in the background of a graph. Doing so would cause objects (e.g., bars) on the left to look different from objects on the right even if they're exactly the same.

Every attribute of visual perception is influenced by context. In the following figure, the upper horizontal line looks longer than the lower, but they are exactly the same. The different shapes at the ends of the two horizontal lines affect our perception of their lengths

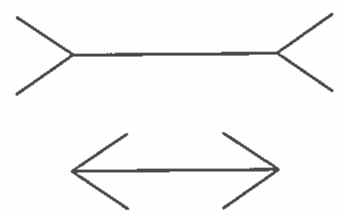

FIGURE 5.15 This figure demonstrates the effect of context on the perception of length.

Optical illusions such as these clearly demonstrate the effect of context on visual perception. Even when we know we are looking at an optical illusion, misperception persists, because visual perception measures differences in the attributes of what we see, not absolute values. It's up to us to use this knowledge when designing tables and graphs to prevent context from causing a misperception of the message we're trying to communicate.

Some combinations of an object's visual attributes and its context can work well to highlight the object, but some can render it imperceptible. For instance, black text on a white background is easy to read. Other combinations are also acceptable, such as white text on a black background, and, to a lesser degree, red or dark blue text on a white background. In contrast, some combinations simply don't work, such as yellow on a white background or blue on a black background.

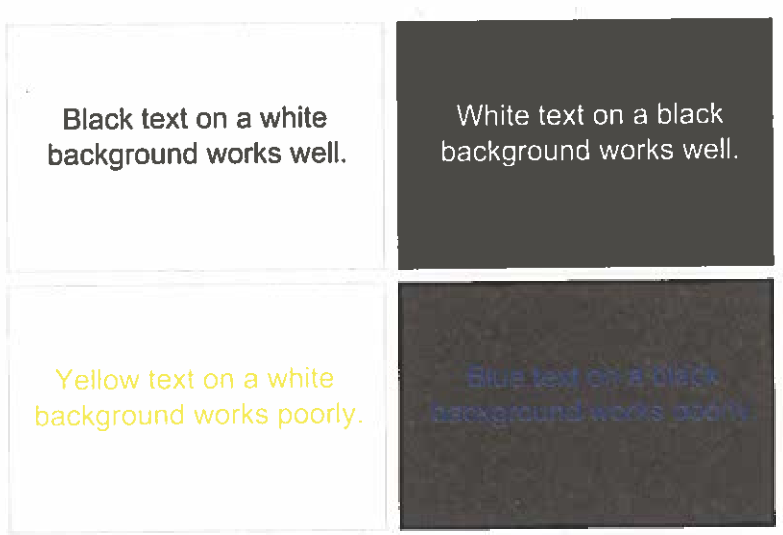

FIGURE 5.16 Some contrasting hues work well for clear perception, and some don't. You must look closely to see that there is any text at all in the lower right rectangle because blue does not stand out distinctly against a black background.

We could examine many more examples, both good and bad, but it's not necessary to memorize the combinations that do and don't work. As you can see

from these examples, it's fairly easy to tell the difference when you take the time to look. Pay attention and use your own sense of visual perception to select combinations that are effective for clear and efficient communication and avoid those that aren't.

Limits to Distinct Perceptions

There is a limit to the number of expressions of a single attribute that can be clearly distinguished in a graph. For instance, if you create a line graph displaying departmental expenses across time, with a separate line of a distinct hue to represent each department in your company, readers of the graph will only be able to easily distinguish a limited number of hues. This is true for each visual attribute that can be used to encode categorical items.

Our ability to distinguish visual attributes diminishes as the number of alternatives increases. According to Ware:

> *Pre-attentive symbols become less distinct as the variety of distracters increases. It is easy to spot a single hawk in a sky full of pigeons, but if the sky contains a greater variety of birds, the hawk will be more difficult to see. A number of studies have shown that the immediacy of any pre-attentive cue declines as the variety of alternative patterns increases, even if all the distracting patterns are individually distinct from the target.*[3]

According to research, when reading graphs, we can distinguish preattentively between no more than about eight different hues, about four different orientations, and about four different sizes. All the other visual attributes of preattentive perception should be limited to a few values as well.[4] When we introduce a greater number of alternatives, people can no longer distinguish them preattentively and must therefore switch to slower attentive processing.

You might think that it would be worthwhile to use a larger number of distinct values even though this would force your readers make use of slower, attentive processing to interpret your graph. Unfortunately, if you do this, your readers will run up against the limits of working memory, which allows them to remember no more than four distinct values at a time.

Another limitation to keep in mind is that preattentive processing usually cannot handle more than one visual attribute of an object at a time. Let me illustrate. In the figure below, only the attribute of color intensity is used to distinguish between three values, represented with black, dark gray, and light gray:

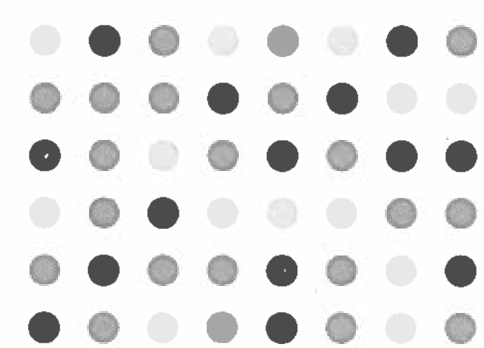

FIGURE 5.17 This figure illustrates the use of distinct values of a single visual attribute, in this case color intensity, to encode objects as different from one another.

3. Colin Ware (2004) *Information Visualization: Perception for Design*, Second Edition. Morgan Kaufmann Publishers, page 152.

4. Ibid. page 182

It is not difficult to pick out the black circles as distinct from those that are dark gray or light gray, the dark gray circles as distinct from those that are black or light gray, and so on. Let's complicate it now by introducing a second preattentive attribute. By using two shapes (circles and squares), along with the three color intensities (black, dark gray, and light gray), we double the number of distinct values, but we do so at a cost. Take a look.

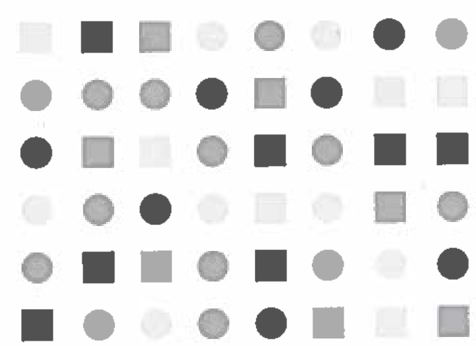

FIGURE 5.18 This figure illustrates the problem that results from encoding distinct values using more than one visual attribute, in this case color intensity and shape.

It's still fairly easy to focus on just the squares, or just the circles, or just the black objects, or just the dark gray objects, or just the light gray objects, but try to pick out the dark gray squares or the light gray circles. The process of simultaneously focusing on multiple visual attributes (e.g., shape and color intensity) requires slower, attentive processing. You can imagine how much more complicated it would get if we threw in a few more shapes or added the third attribute of size.

A related consideration is that when you select the expressions of a single attribute that you will use in a graph (e.g., multiple hues to distinguish categorical items), you must make sure that they are far enough apart from each other along the continuum of potential expressions to stand out clearly as distinct. Although I can choose up to four different shades of gray, shades that are too close to one another won't work. Here are two sets of four distinct values, encoded as different shades of gray. The four shades on the left were carefully chosen from the full range of potential values so they could easily be distinguished from one another, but those on the right were not.

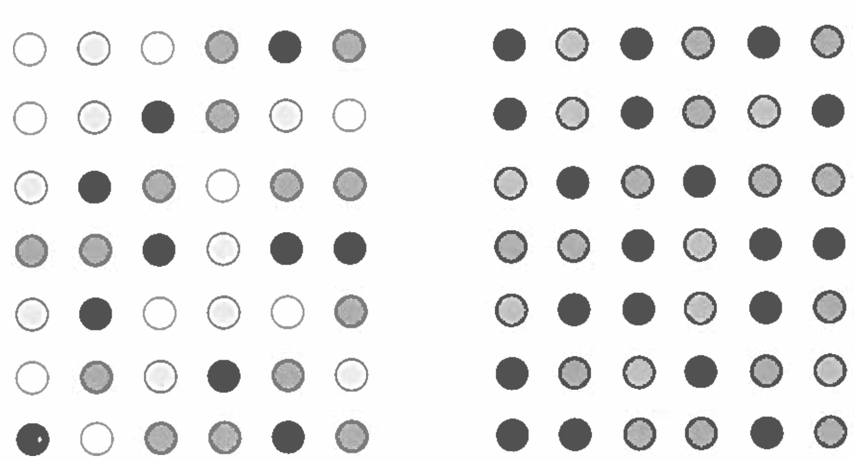

FIGURE 5.19 This figure illustrates the importance of selecting values of a visual attribute that can be easily distinguished. The four shades of gray encoded in the circles on the left are distinct, but the four on the right are not.

With a little effort, you can develop once and for all a set of distinct values for each of the visual attributes, and you can use this set over and over, rather than repeatedly going through the process of determining the distinctions that work.

Here's a list of nine hues that are easy to recognize and distinct enough to work well together:

1. Gray
2. Blue
3. Orange
4. Green
5. Pink
6. Brown
7. Purple
8. Yellow
9. Red

An excellent source of color combinations that work well together for data presentation can be found on the website www.ColorBrewer.org.

Each of these hues meets the requirement of distinctness, but the context of their use should sometimes lead you to select some and reject others. A good example, especially if you communicate with an international audience, involves cultural context. Particular hues carry meanings that vary significantly among cultures. In most western cultures, we think of red as signifying danger, warning, heat, and so on, but in China, red represents good fortune. The key is to be in touch with your audience and take the time to consider any possible associations with particular hues that might influence their interpretation of your message.

Various colors also affect us in different ways on a fundamental psycho-physical level. Some colors are strong and exciting, grabbing our attention, and others are more neutral and soothing, fading more into the background of our attention. Edward Tufte suggests that colors found predominantly in nature, especially those that are not overly vibrant (e.g., medium shades of gray, green, blue, and brown), are soothing and easy on our eyes.[5] Such colors are particularly useful in tables and graphs for anything that you don't want to stand out above the other content. On the other hand, fully saturated, bright versions of just about any hue will demand attention. These should only be used when you want to highlight particular information. Notice the difference between the medium shades on the left and the brighter shades on the right:

5. Edward R. Tufte (1990) *Envisioning Information*. Graphics Press, page 90.

FIGURE 5.20 This figure shows soft, soothing hues on the left, and bright, attention-getting hues on the right.

Another consideration when selecting a palette of colors is that our ability to distinguish colors decreases along with the sizes of objects. For this reason, small objects such as data points in graphs should be darker than large, visually weighty objects such as bars. In the two graphs below, the same colors are used in both. The colors of the bars in the upper graph are quite distinct, but they are somewhat difficult to distinguish in the lower graph because the points are small.

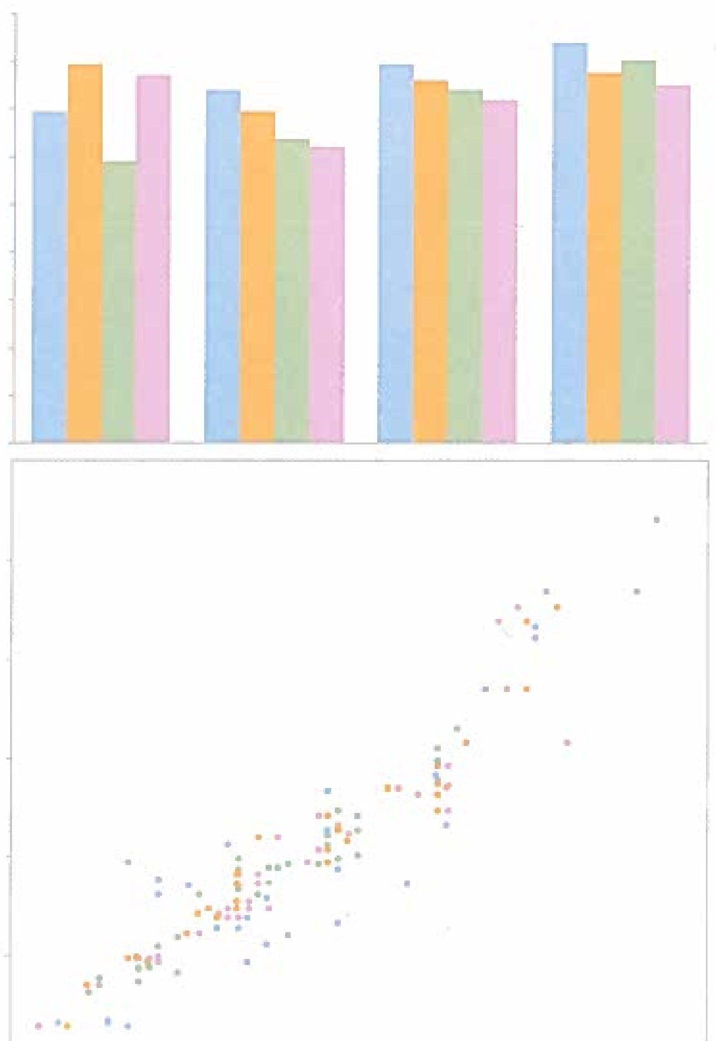

FIGURE 5.21 The same colors that allow us to easily distinguish bars are much harder to distinguish when used for small objects such as data points.

When selecting your palettes of colors for encoding categorical distinctions in graphs, it works best to maintain three versions: one with relatively light, yet distinct colors for large objects such as bars, one with darker versions of the same colors for small objects such as lines, and one with bright versions of the same colors for objects that must stand out above the rest. Here's an example of three versions of the nine distinct hues that were listed previously, two versions for ordinary use and one for highlighting:

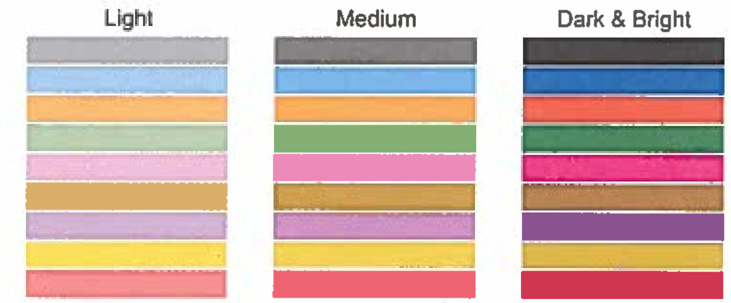

FIGURE 5.22 These sample colors could be used for the three color palettes that you should maintain for displaying data. The RGB values of each are provided in Appendix I – *Useful Color Palettes*.

Another consideration when using hues to encode data is that about 10% of males and 1% of females suffer from colorblindness, unable to distinguish certain colors because of a lack of cones (color receptors) in the eye that detect a certain range of hue. Most people who are colorblind lack the cones that enable them to distinguish between red and green so that, to these viewers, both colors appear brown. When your audience is likely to include people who are colorblind, it is best to use only red or green, but not both, unless you are careful to vary their intensities sufficiently so that they appear different from one another.

Limits to the Use of Contrast

Visual perception evolved in a way that makes us particularly aware of differences, i.e., features that stand out in contrast to the rest. When we look at something, our eyes are not only drawn to differences, but our brains insist on making some sense of those differences. If you create a table of information and all the text is black except for one column that is red, readers will assume that the difference is significant and that the red text is especially important. It is up to us to only include visual differences that are meaningful.

Contrast is most effective when only one thing is different in a context of other things that are the same. As the number of differences increases, the degree to which those differences stand out decreases. In the graph below, the attributes were controlled so that the bar representing "Contributions from People like You" would clearly stand out from the rest because of a single difference: its color.

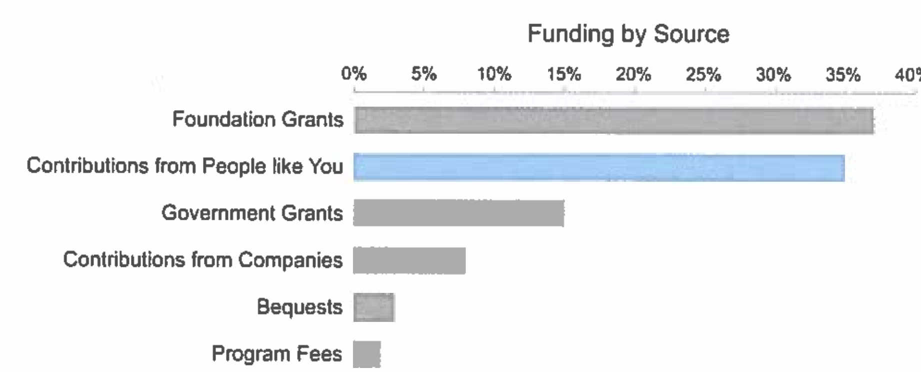

FIGURE 5.23 This graph uses contrast effectively to highlight the most important information.

If you try to emphasize so many things that emphasis becomes the rule rather than the exception, your message will become buried in visual clutter. When everyone in the room shouts, no one can be heard.

FILL PATTERN

Fill patterns are only used to encode categorical items when the quantitative values are encoded as bars or boxes. The 2-D portion of either can be filled with differing patterns to distinguish categorical items, such as Direct and Indirect sales in the following example.

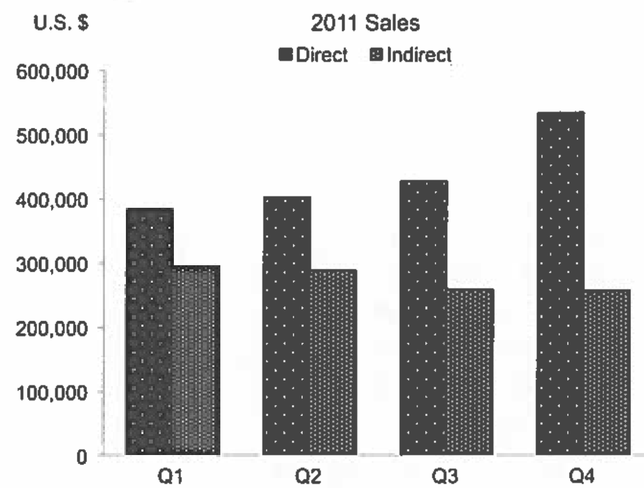

FIGURE 6.20 This graph uses fill patterns, in this case different arrangements of dots, to encode the categorical items of direct and indirect sales.

Only use fill patterns as a last resort. Not only are they harder for our eyes to distinguish than colors, they can also play real havoc with our vision, causing a dizzying effect called *moiré vibration*. This effect is especially strong if the patterns consist of vivid lines running in various directions, as in the next example:

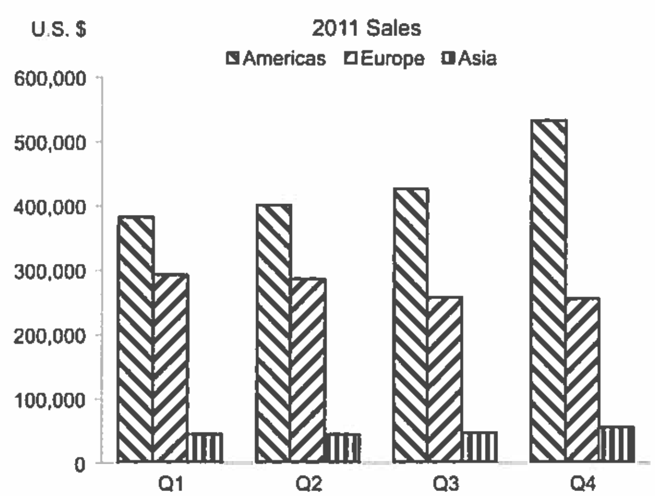

FIGURE 6.21 This graph uses fill patterns that are hard on the eyes and therefore difficult to read.

Try looking at this graph for awhile and you may actually feel ill because of the appearance of vibration created by the lines, so it isn't hard to understand why fill patterns should be avoided whenever possible. If you must use them, do so with great care, muting the patterns and selecting ones that can be displayed together with minimal visual vibration. The primary reason that you may sometimes need to use fill patterns is when you must print your graph on paper or photocopy it for distribution, and color printing is not an option. In such

cases, if you only need a few categorical distinctions, distinct shades of gray (e.g., black, dark gray, medium gray, and light gray), which are variations in color intensity, usually work better than fill patterns.

LINE STYLE

Varying line styles can be used to encode categorical items when the quantitative values are encoded as lines. Lines may be solid, dashed, dotted, and so on. Here's an example:

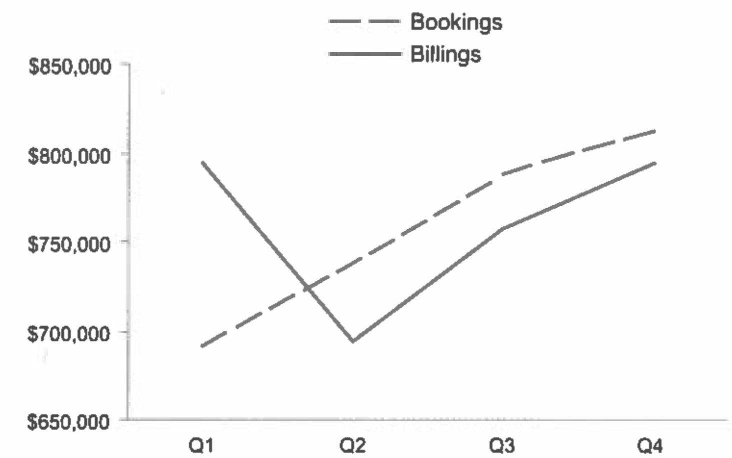

FIGURE 6.22 This graph uses line style, in this case a solid and a dashed line, to encode the categorical items of bookings and billings.

Line styles don't work as well as colors because lines are usually used to represent the pattern in an entire series of values, so breaks in the lines undermine our perception of the continuous series of values as a whole. Consequently, like fill patterns, line styles are best reserved for occasions when color printing is not an option. Differing the color intensity or thickness of lines usually works better.

Relationships in Graphs

Graphs display relationships in quantitative information by giving shape to those relationships. Graphs vary primarily in terms of the types of relationships they are used to communicate, so it is useful to understand the specific types of relationships that graphs can display. With this knowledge, you will be able to quickly match the quantitative message you wish to communicate to the structural design that can do the job most effectively.

Essentially, there are eight types of relationships that we typically use graphs to display:

- Time series
- Ranking
- Part-to-whole
- Deviation
- Distribution
- Correlation
- Geospatial
- Nominal comparison

The categorization of graphs into five of these relationship types was proposed by Gene Zelazny (2001) *Say It with Charts*, Fourth Edition. McGraw-Hill. His taxonomy includes the following: 1) component comparison (i.e., part-to-whole), 2) item comparison (i.e., ranking), 3) time-series comparison, 4) frequency distribution comparison, and 5) correlation comparison. I've expanded this list to include nominal comparison, deviation, and geospatial relationships.

Time Series

A time-series relationship is nothing more than a series of quantitative values that feature how something changed with time, such as by year, quarter, month, week, day, hour, minute, or even second. This relationship deserves to be treated separately because of the unique characteristics of time when displayed graphically. Graphs are a powerful way to view patterns and trends in values over time, which is why they are commonly used to display time series. A typical example is the closing price of a stock on each day of the last three months.

To determine whether your quantitative message involves a time series, first state the message in writing, and then look to see whether you used any of the following words:

- Change
- Rise
- Increase
- Fluctuate
- Grow
- Decline
- Decrease
- Trend

These words, with the exception of "trend," were suggested by Gene Zelazny (2001) *Say It with Charts*, Fourth Edition, McGraw-Hill. The subsequent lists of words that accompany each relationship type below were derived primarily from the same source.

If you did, then your message likely involves a time series.

Ranking

A graph displays a ranking relationships when it displays how a set of quantitative values relate to each other sequentially, sorted by size from lowest to highest or vice versa. A typical example is a ranking of donors based on the amounts of their donations.

Words and phrases that suggest a ranking relationship include:

- Larger than
- Smaller than
- Equal to
- Greater than
- Less than

Part-to-Whole

A graph displays a part-to-whole relationship when it features how individual values that make up the whole of something (e.g., total sales) compare to one another and how each compares to the whole. The individual values (the parts) compare to the whole as ratios, which may be expressed either as percentages that sum to 100% or as rates that sum to 1. A typical example is the percentage of sales attributed to various sales regions, which together add up to total sales.

Words and phrases that suggest a part-to-whole relationship include:

- Rate or rate of total
- Percent or percentage of total
- Share
- Accounts for X percent

If your message uses one of these expressions, you are likely presenting a part-to-whole relationship.

Deviation

A graph displays a deviation relationship when it features how one or more sets of quantitative values differ from a reference set of values. The graph does this by directly expressing the differences between the two sets of values. Common examples include the following:

- The degree to which actual worker productivity differs from target productivity
- The degree to which donations over time differ from donations at some specific time in the past
- The degree to which headcount in each month varied from headcount in the previous month
- The degree to which sales of various products differ from sales of a particular product

Deviations are usually expressed using one of the following units of measure:

- Positive or negative amounts relative to the reference values
- Positive or negative rates or percentages relative to the reference values (i.e., where the reference values always equal 0 or 0%, and all other values are expressed as plus or minus rates or percentages)
- Rates or percentages relative to the reference values (i.e., where the reference values always equals either a rate of 1 or 100%, and all other values are expressed as relative rates or percentages)

Words and phrases that express deviation relationships include:

- Plus or minus
- Variance
- Difference
- Relative to

Distribution

A graph displays a distribution relationship when it features how quantitative values are distributed across an entire range, from the lowest to the highest. When a graph displays the distribution of a single set of values, the relationship is called a *frequency distribution*, for it shows the number of times something occurs (i.e., its frequency) within consecutive intervals over the entire quantitative range. Graphs of this type visually display the same type of information that is communicated by the range and standard deviation measures of variation. For instance, you may want to display the number of employees whose salaries fit into each interval along a series of salary ranges from lowest to highest. It wouldn't make sense to count the number of employees for every distinct salary amount because there are far too many. Rather, you would break the entire range of salaries into smaller ranges (a.k.a. intervals), such as "less than $15,000," "greater than or equal to $15,000 and less than $30,000," "greater than or equal to $30,000 and less than $45,000," etc., and then count the number of employees that fit into each.

Words that suggest a distribution relationship include:

- Frequency
- Distribution
- Range
- Concentration
- Normal curve, normal distribution, or bell curve

Correlation

A graph displays a correlation when it is designed to show whether two paired sets of quantitative values vary in relation to each other, and, if so, in which direction (positive or negative) and to what degree (high or low). These graphs display the same type of information that is expressed by a linear correlation coefficient. A typical example is a correlation of marketing expenditures and subsequent sales. The existence of a correlation may indicate that one thing causes the other (i.e., a causal relationship), but not necessarily. Two variables can also be correlated because they are both caused to behave as they do by one or more external factors.

Words that indicate a correlation include:

- Increases with
- Decreases with
- Changes with
- Varies with
- Caused by
- Affected by
- Follows

Geospatial

In a display that features where quantitative values are located, the relationship is primarily spatial. Most spatial relationships feature the geographical location of values by displaying them on a map. A typical example is a map that displays how many cases of a particular disease occurred in each country throughout the world. Spatial relationships are not limited to geography, however. For example, someone who manages environmental conditions (e.g., air temperature) throughout a large, multi-story building, might want a graphical display that positions values on a floor plan of the building. Because nongeographic spatial displays of quantitative data are rare, however, we'll focus only on geospatial displays.

Words that indicate a geospatial relationship:

- Geography
- Location
- Where
- Region
- Territory
- Country
- State
- City

Nominal Comparison

A nominal comparison relationship is the simplest of all, and also the least interesting, which is why I saved it for last. In this relationship, items along the categorical scale have no particular order because they represent a nominal scale. The goal is merely to display a set of discrete quantitative values so they can be easily read and compared. "This is bigger than that," "this is the biggest of all," "this is almost twice as big as that," and "these two are far bigger than all the others" are some of the messages that stand out in nominal comparison relationships. An example could be the relative amounts of employee turnover for a group of departments in a single month, quarter, or year. You might wonder why we wouldn't sort the values from largest to smallest or vice versa to display a more interesting ranking relationship. That might be useful, but people sometimes become accustomed to seeing a set of categorical items arranged in a particular order even though that order is arbitrary, such as geographical regions always arranged as north, east, south, and west. It might be confusing for your audience to see those regions in any other order, in which case you might stick with a nominal comparison relationship.

Graph Design Solutions

You now know the types of relationships that graphs can be used to display as well as the visual objects and attributes that are available for encoding data in graphs and some of the strengths and weaknesses of each. The next step is to learn the best structural solution for displaying each type of relationship. Let's examine the relationship types and think through the design solutions for each. Approaching the solutions in this manner will give you the required design tools in a way that deepens your understanding of them, enabling you to call them quickly to mind whenever needed.

Before we tackle the first type of graphical relationship, here's a reminder of the different objects that can be used to encode quantitative values:

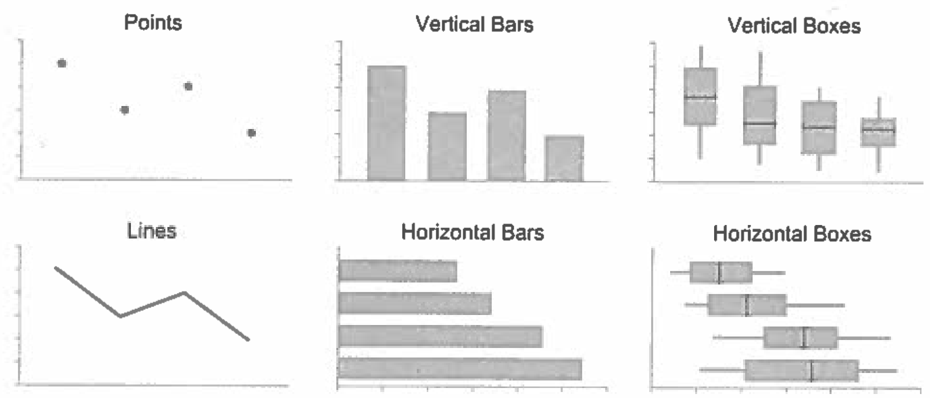

FIGURE 6.23 These objects are commonly used to encode quantitative values in graphs.

Review each for a moment to remind yourself of their individual strengths for displaying quantitative messages.

Nominal Comparison Designs

We'll begin with the simplest quantitative relationship. A nominal comparison graph displays a series of discrete quantitative values to highlight their relative sizes. Because the values are discrete, each relating to a separate categorical subdivision with no connection between them, you want to encode the quantitative values in a way that emphasizes their distinctness. Which visual encoding object emphasizes the distinctness of each value best? Bars do because they are quite distinct from one another, each carrying a great deal of visual weight. Graphs like the following example are quite common:

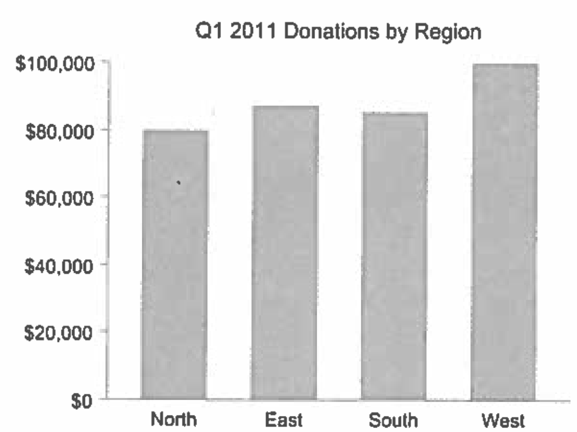

FIGURE 6.24 This is a nominal comparison relationship graph that displays donations by region.

Even though the bars in this example are vertical, horizontal bars would work just as well.

When bar graphs consist entirely of fairly long bars that are similar in length, it can be difficult to discern the subtle quantitative differences between them. Narrowing the quantitative scale so that it begins just below the lowest value and ends just over the highest value could help to make these subtle differences easier to see, but bars require a zero-based scale. So when there are subtle quantitative differences to display, you can usually replace the bars with points

(e.g., dots), which can display the values distinctly but don't require a zero-based scale as bars do. Graphs of this type usually go by the name dot plots. The following example is a dot plot of the same data that as shown in Figure 6.24:

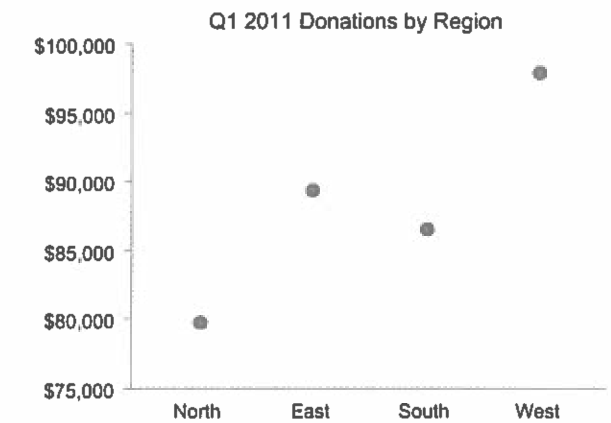

FIGURE 6.25 Dot plots are an effective alternative to bar graphs when you want to narrow the quantitative scale such that it no longer begins at zero.

Nominal comparison relationships can be effectively encoded using any of the following objects:

- Vertical bars
- Horizontal bars
- Points

Time-Series Designs

A time-series graph displays quantitative values along multiple, sequential points in time. Consequently, one axis of the graph provides the time scale, with labels for each interval of time (years, quarters, etc.). Intervals of time have a natural order. You would almost never display time other than chronologically.

When you imagine a visual representation of time, how do you see it arranged on the page? Because of an old convention in most cultures, there is only one way to lay out time on a page that wouldn't seem strange or confusing: horizontally, from left to right along the X axis. Given this fact, for time-series graphs we can eliminate two of the encoding methods shown in *Figure 6.23*. Take a look and determine which they are.

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Vertical bars and vertical boxes can both be used to display time-series values, but horizontal bars and horizontal boxes should not be used. That's because horizontal bars and horizontal boxes would use the X axis to label the quantitative scale and the Y axis to label intervals of time (e.g., months). Time-series graphs should always use the horizontal axis for the time scale and the vertical axis for the quantitative scale.

We've eliminated two graphical encoding methods, which leaves us with four more from which to choose. Keep in mind as we continue that there may be more than one encoding method that works.

Vertical bars work in time-series graphs but should only be used when you wish to emphasize and compare the values associated with individual points in time rather than the overall pattern of values as they change through time. This is because the height and visual weight of the individual bars distract from the overall shape of the data. To trace the shape of change through time along a series of bars requires that we focus exclusively on the ends of the bars, which is difficult to do.

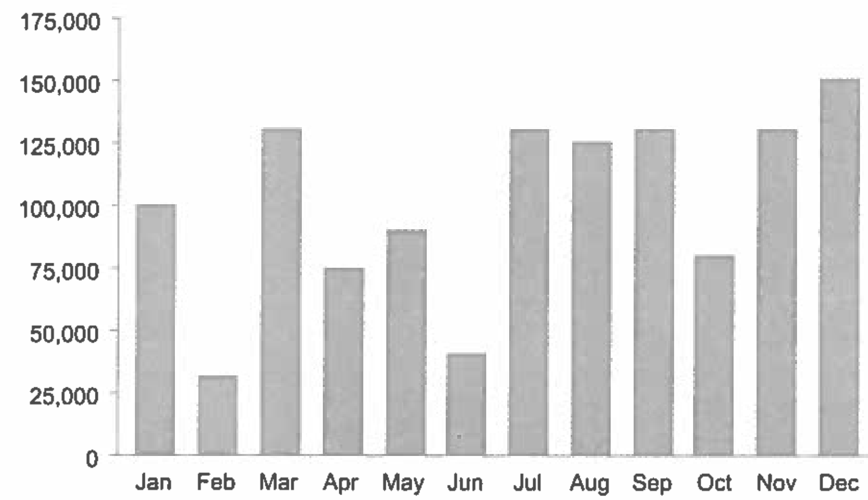

FIGURE 6.26 This graph uses bars to encode time-series values, which is not effective if you wish to clearly show the pattern of change through time.

There is another method that we can eliminate that doesn't lend itself well to a time-series display. Looking at the available objects for encoding data once again, which do you think would not be an efficient means of displaying left-to-right quantitative values related to time?

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If you imagine a graph that uses points alone to encode quantitative values across time, you will see that points, floating in space, don't help us visualize the sequential nature of time. Here's an example:

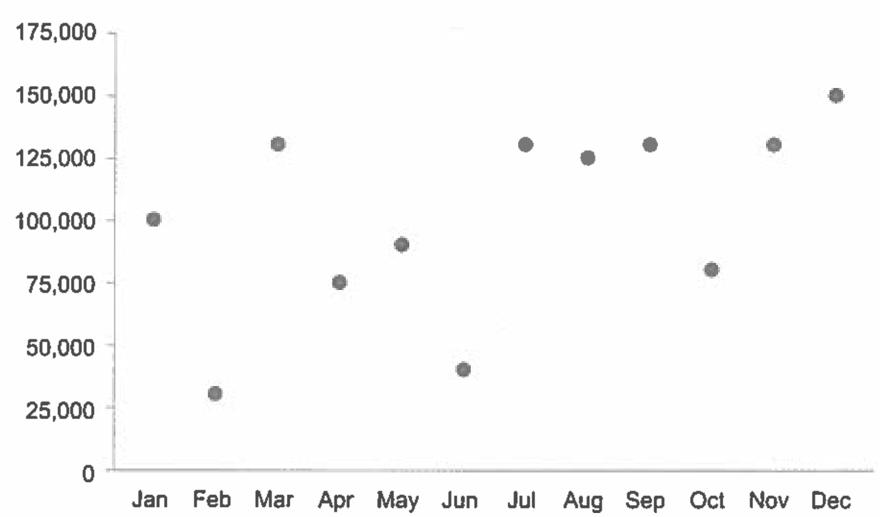

FIGURE 6.27 This graph uses points alone to encode quantitative values, which is not very effective for a time-series graph.

This graph does not give the sense of continuity that is required for displays of time, but adding a line to connect the points corrects this problem.

FIGURE 6.28 This time-series graph uses a combination of points and lines to effectively encode quantitative information.

With this simple change we have made the flow of time visible. Would we still have an effective display of time if we removed the points and used only the line? Absolutely. The points are only useful when it's necessary to show the exact position of values along the line, which is not usually the case. In Chapter 10, *Component-Level Graph Design*, we'll consider occasions when using points or other means to precisely mark the location of values along lines is useful.

There is one occasion when it actually makes sense to display time-series values as points without connecting them with a line. That is when the values in the series do not represent consistent intervals along time. The following graph displays toxin levels that were measured in a particular stream on a few days over a two-month period. By using a line to connect values that were collected at irregular intervals of time, a pattern of change is implied that might be quite different from the pattern that would appear had the values been collected at regular intervals, such as daily.

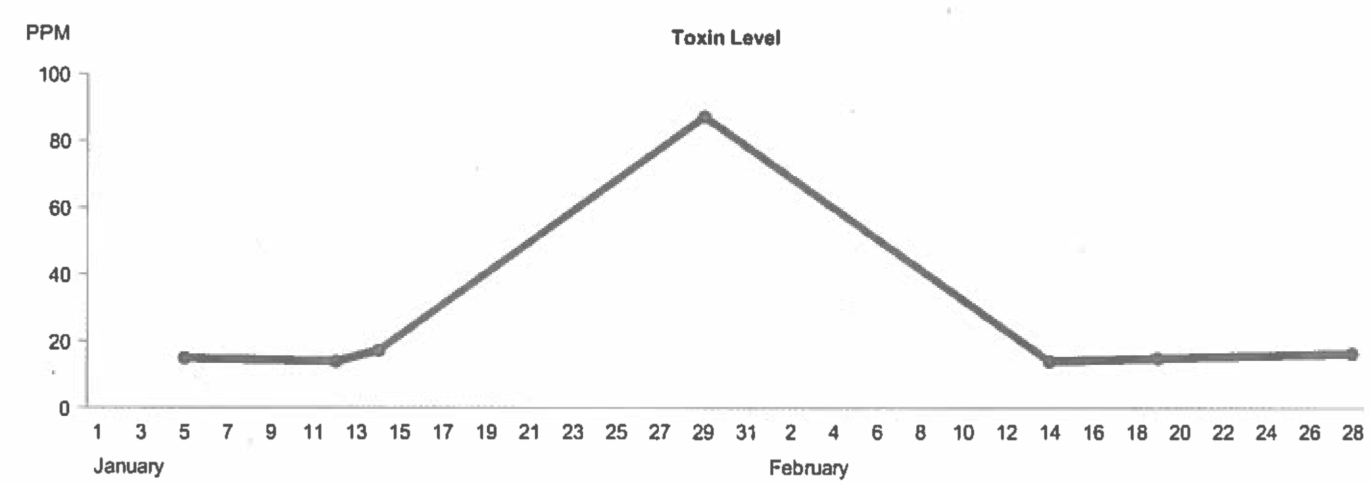

FIGURE 6.29 This line graph displays values that were not collected at consistent intervals of time.

Imagine that toxins were measured each day during this period and the actual pattern of change looks like the following.

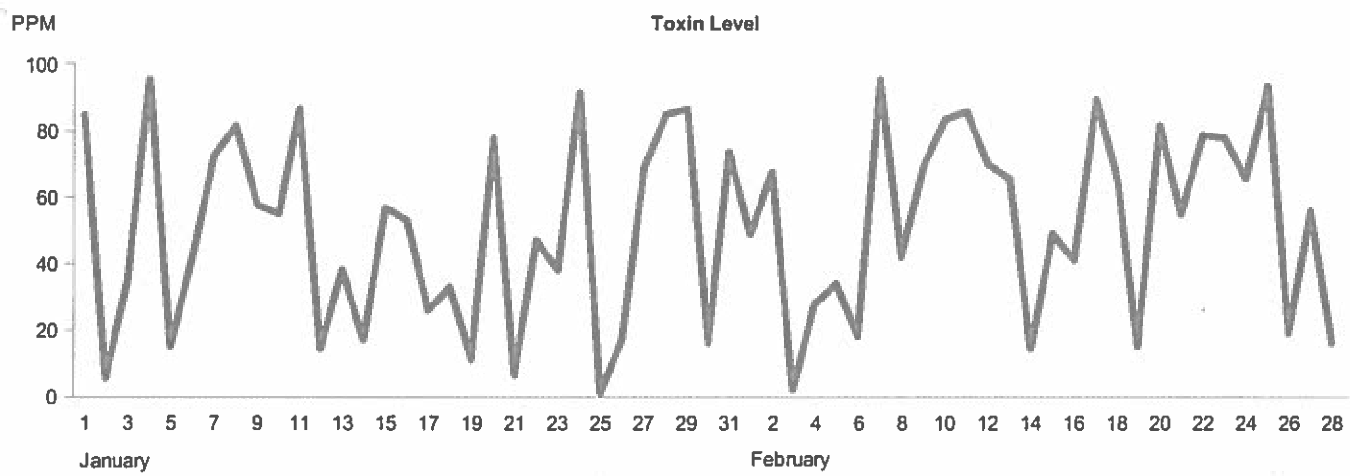

FIGURE 6.30 This line graph displays values that were collected daily during the same period of time that appears in *Figure 6.29*.

Every point in *Figure 6.29* has a corresponding value in *Figure 6.30*, but the pattern that appears in the first graph based on values that were collected at irregular intervals looks quite different from the pattern based on daily values, which does a much better job of representing what actually happened. When values were collected at irregular intervals of time, it usually works better to omit the line and display only the points in the form of a dot plot, illustrated below.

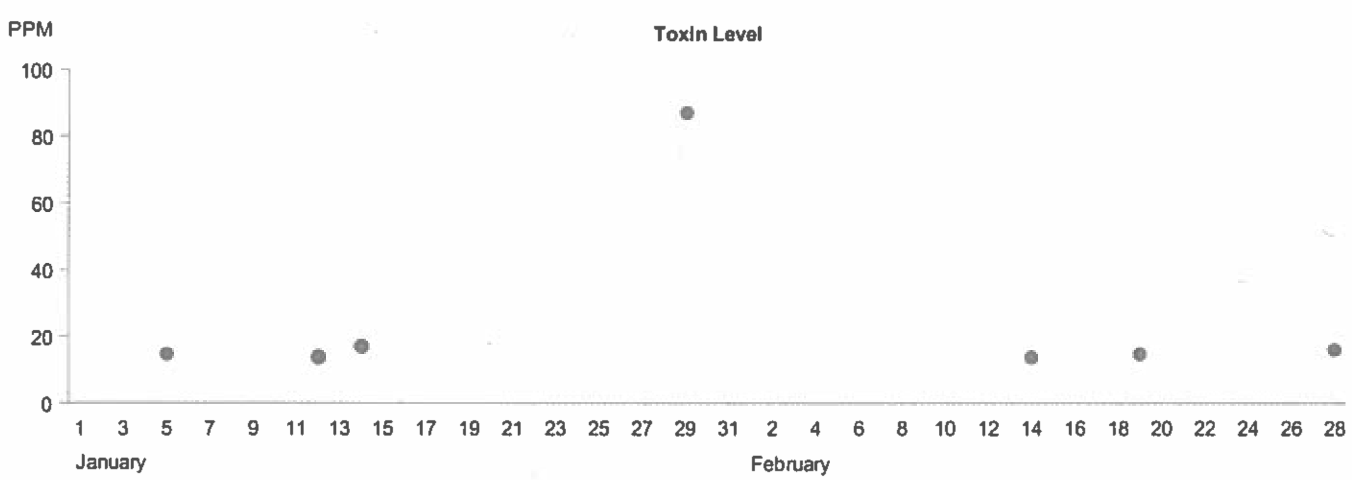

FIGURE 6.31 Because the values in this time series were not collected at regular intervals of time, it works better to show the individual values as points only, without connecting them with a line.

In addition to the line graphs, vertical bar graphs, and dot plots, when a graph shows how the distribution of a set of values changes through time, box plots or individual data points in the form of *strip plots* may also be used. We'll look at box plots and strip plots soon in the *Distribution Designs* section.

Any of the following can be used to encode quantitative values in time-series displays:

- Vertical bars (when you want to emphasize individual values, rather than the pattern of an entire series)
- Lines (with or without points when you want to show the pattern of change through time)

- Points only (when displaying values that were collected at irregular intervals of time)
- Vertical box plots (when displaying how distributions changes through time)

Ranking Designs

A ranking graph displays how discrete quantitative values relate to one another sequentially by magnitude, from low to high or high to low. One axis of the graph must label the categorical items and the other must provide a quantitative scale. Because we want to emphasize each individual value and allow the reader to easily see its rank compared to that of any other value, we should encode the values using a graphical object that visually reinforces the individuality of the values and their relative sizes. Which of the available graphical objects do this best? Bars do.

Here's a graph that uses bars, but so far it is only designed to display a nominal comparison relationship, with the categorical items sorted alphabetically:

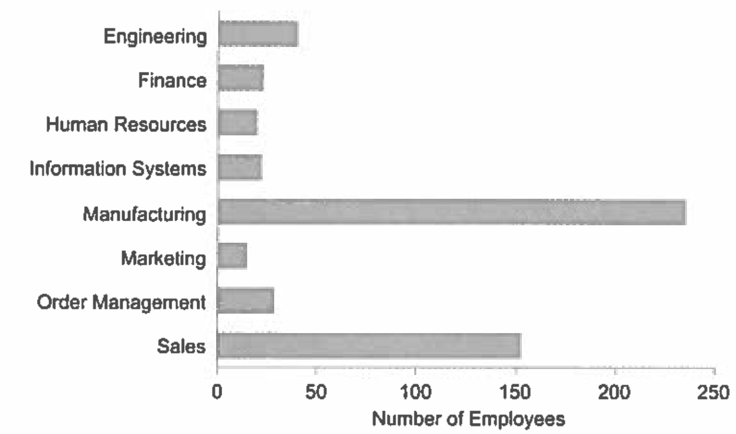

FIGURE 6.32 This graph uses bars to encode the values, which are the appropriate choice for a ranking display, but the bars are not arranged in a manner that highlights the ranking relationship.

Given the usefulness of seeing a ranking relationship based on the number of employees associated with each department, this graph works much better if we arrange the departments as follows.

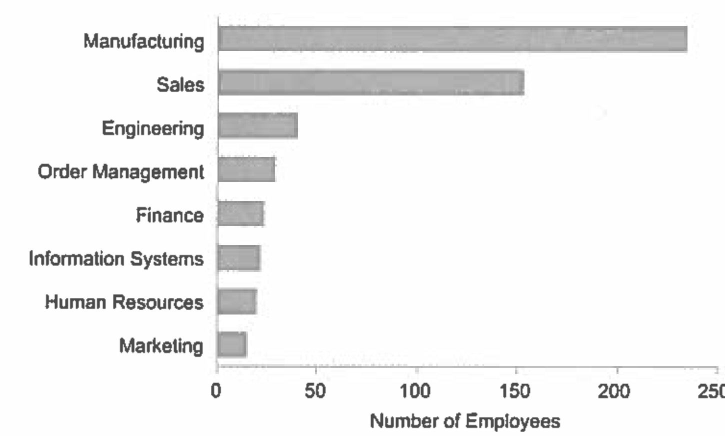

FIGURE 6.33 This ranking relationship is designed very effectively as a bar graph with the bars sorted by size.

Now the ranking message is crystal clear.

Can you think of any reason why vertical bars, as opposed to the horizontal bars, would not work as well? Both types of bars work, but there are times when horizontal bars may be preferable to vertical bars, and vice versa. We'll take a look at this later in Chapter 10, *Component-Level Graph Design*. For now, though, the following rules of thumb will come in handy:

Purpose	Sort Order	Bar Position
Highlight the highest values	Descending	Vertical bars: highest bar on left Horizontal bars: highest value on top
Highlight the lowest values	Ascending	Vertical bars: lowest bar on left Horizontal bars: lowest bar on top

In most cultures, we tend to think of the top, as opposed to the bottom, and the left, as opposed to the right, as the beginning. This convention might be rooted in written languages that are read across the page from left to right and top to bottom, or might actually be wired fundamentally into visual perception, as has been suggested by some recent research. Until further research is done, the jury is still out on this matter.

Just as in graphs showing nominal comparison relationships, in a ranking relationship graph, bars can be replaced with points when it is useful to narrow the quantitative scale and in so doing to remove zero from the graph's base. The following graphical objects can therefore be used to encode quantitative values in ranking graphs:

- Bars (vertical or horizontal, except when the quantitative scale does not begin at zero)
- Points (especially when the quantitative scale does not begin at zero)

Part-to-Whole Designs

As the name suggests, part-to-whole graphs relate parts of something to the whole. They display the proportion of the whole that each part contributes. The best unit of measure for expressing proportions is usually percentage, with the whole equaling 100% and each part equaling a lesser percentage corresponding to its value relative to the whole. In common practice, pie charts are usually used to display part-to-whole relationships, but I've already explained my objections to the use of pie charts and other area graphs in the earlier section *Shapes with 2-D Areas*. People also often use *stacked bar graphs* to display part-to-whole relationships, but a single stacked bar does the job only slightly better than a pie chart. Here are two examples of a stacked bar graph, one vertical and one horizontal:

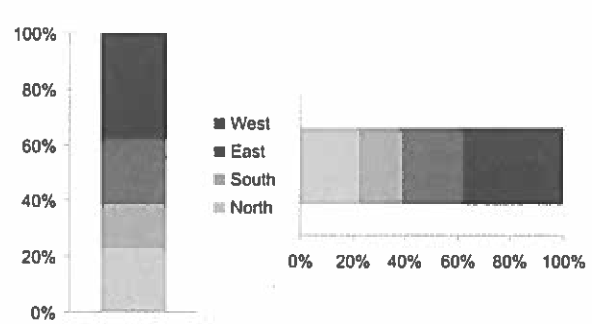

FIGURE 6.34 These examples show the same part-to-whole relationships expressed using two versions of a stacked bar graph.

Rather than comparing these two graphs to determine which works best, take a moment to look for characteristics that hinder their effectiveness.

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Did you notice that it is easy to determine the percentage value associated with the north region but not as easy to determine the value of any other region? The value of the north region is easy because all you need to do is look at the percentage scale on the axis and the value is right there. However, for the east region you must look at the values associated with the beginning and end of its portion of the bar (approximately 40% and 62%), then subtract the smaller from the larger value to get its percentage (approximately 22%). In other words, you have to do some math to determine the value. Now see whether you can tell which has the larger percentage, the north or the east region. It's difficult to tell, because they appear to be about the same size. In fact, the east region is a little larger. It's hard to see this because of the way the north and east regions are stacked in the bar.

These problems can be solved by unstacking the bars. Look at these new graphs of exactly the same information, this time displayed using individual bars:

FIGURE 6.35 These examples show the same part-to-whole relationship expressed using individual bars to clearly display the contribution of each part to the whole.

This is better, isn't it? It is easy to interpret the percentage value of each region, and it is easier to tell that the east region has a slightly larger value than the north. It would be nice, however, if we could make it even easier to compare values that are close in size. What could we change about these graphs to accomplish this? We could sort the regions in order of size, thereby placing those of similar size next to each other, which should make the differences easier for the eye to detect. Let's try it:

FIGURE 6.36 These two examples display the same part-to-whole information that was displayed in *Figure 6.35*. This time the bars, each representing a different sales region, are sorted by value to make it easier to detect their relative sizes.

Now it's easy to compare the regions to one another. By sorting the regions by size, we've combined a display of ranking and part-to-whole relationships into a single graph.

The one thing that a pie chart has going for it that a bar graph lacks when used for a proportional relationship is the fact that people immediately recognize a pie chart as a part-to-whole display. Unlike a pie chart, which is used exclusively for displaying parts of a whole, bar graphs are used for several purposes. For this reason, when you use a bar graph to display parts of a whole, it is helpful to do a little extra to make this obvious. At a minimum, we should always give the graph a title that states that the bars represent parts of some whole. In the examples above, the title clearly states that the values add up to total sales (i.e., the whole of sales). Something else that I've found helpful is to cause the bars to touch. Because bars usually have spaces between them, people notice when they don't. This clues people into the fact that there's something different about the graph. The fact that the bars touch visually indicates that they are connected to one another, which is indeed the case because they are parts of the same whole. I also often include the precise value of each bar as text, below the labels in vertical bar graphs and to the right of the labels in horizontal bar graphs, not because precise values are needed to read the graph, but because I want to include "100%" as the total, which makes the part-to-whole nature of the graph crystal clear.

Despite the disadvantages associated with stacked bars, one type of quantitative message justifies their use: when you wish to display the whole using a unit of measure other than percentage (e.g., U.S. dollars) but also wish to provide an approximate sense of the relative proportions of the parts. In the next example, the primary message is total sales per channel in U.S. dollars, but the use of stacked bars conveys the secondary message of relative regional sales as well.

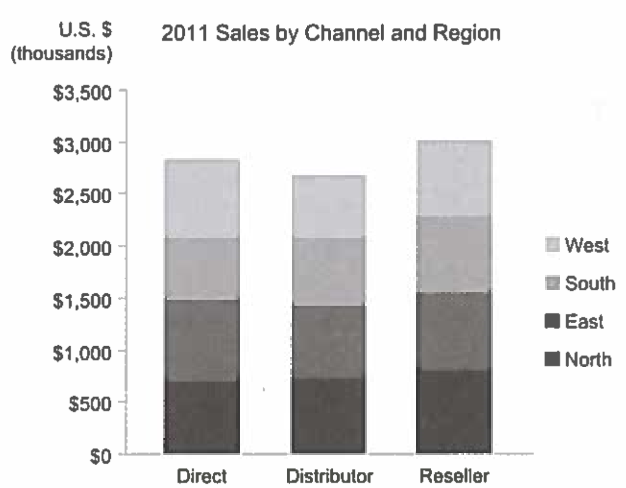


FIGURE 6.37 This is an example of a circumstance when stacked bars are useful.

Even though the stacked bars can't present the parts ideally, they work well enough here to provide additional useful information.

Our investigation leaves us with two variations of a single graphical object for encoding quantitative values in part-to-whole graphs:

- Bars (vertical or horizontal)
- Stacked bars (vertical or horizontal, when you want to feature totals and provide an approximate sense of their parts)

Deviation Designs

A deviation graph displays the degree to which one or more sets of quantitative values differ in relation to a primary set of values. Imagine that you want to provide a way for the Director of Human Resources to see how the number of employees in each department (headcount) differs from the plan. You could display this information in the following way:

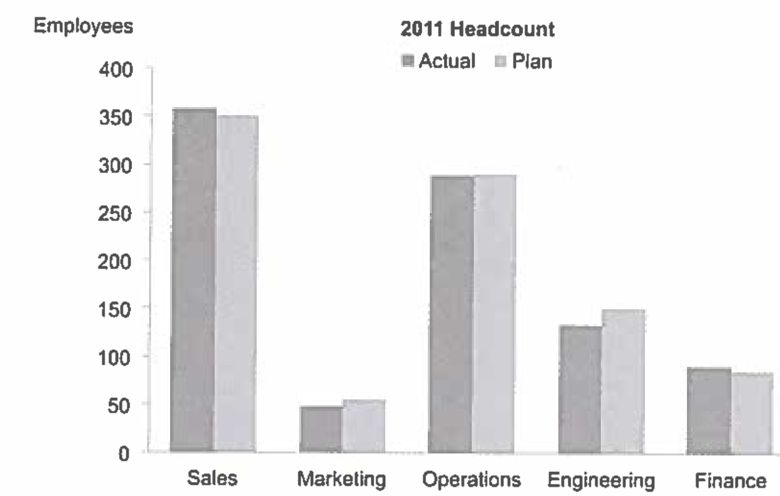


FIGURE 6.38 This graph compares actual headcount to the plan for each department.

However, if the director is only interested in how much actual headcount varies from the plan, this graph forces her to work harder than necessary, doing calculations in her head, to discern the differences. Why not display the differences directly? The next graph does just that.

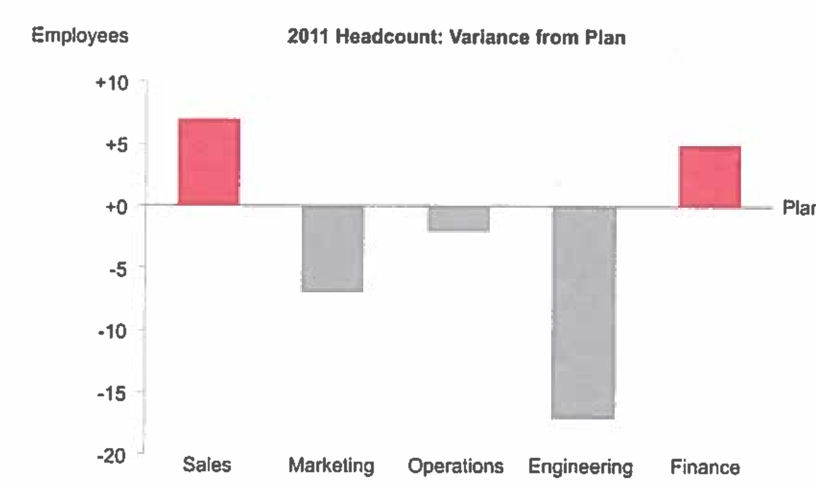


FIGURE 6.39 This graph directly displays the variance of actual headcount from the plan.

A graph should always display as directly as possible the information that people need. In the preceding example, positive headcount variances, which are usually what organizations try to avoid most, are highlighted in red to draw attention to them as unfavorable. Sometimes people want to see deviations expressed in raw numbers, such as the actual number of employees shown in the previous graph, and sometimes they want to see them as percentages, as in the example below.

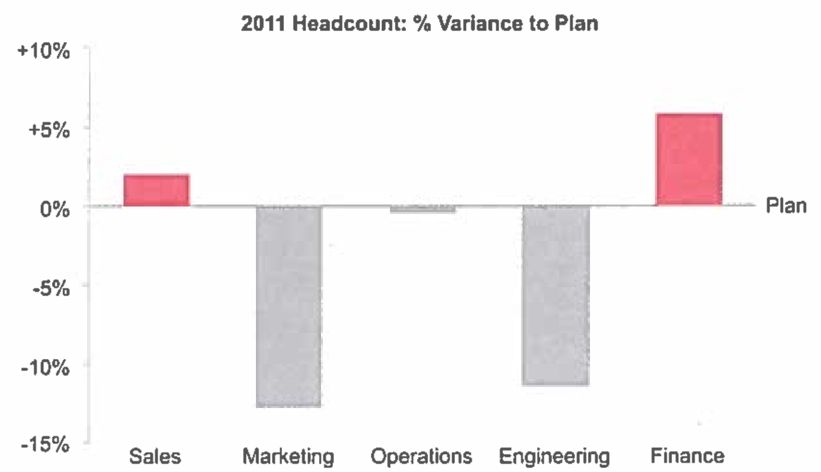


FIGURE 6.40 This graph directly displays the variance of actual headcount from the plan as a percentage.

Both graphs above are valid, but they tell different stories. In the case of *Figure 6.39*, viewing the actual number of employees above and below the headcount plan would help the director understand the overall impact of the variance on the organization while the percentage variance would help her compare how well each of the departments is performing in relation to the plan.

Deviation relationships are often teamed with other relationships, especially time series. Displaying the difference between various measures and a reference measure over time is common practice in the workplace. When combined with a time-series relationship, deviations are often encoded as lines to represent the continuous, flowing nature of time. When combined with other types of relationships (e.g., ranking and part-to-whole), or when functioning on their own, deviation relationships usually use bars. The following example combines a deviation and a time-series relationship. In this case, a line is used to show how the variance changes through time.

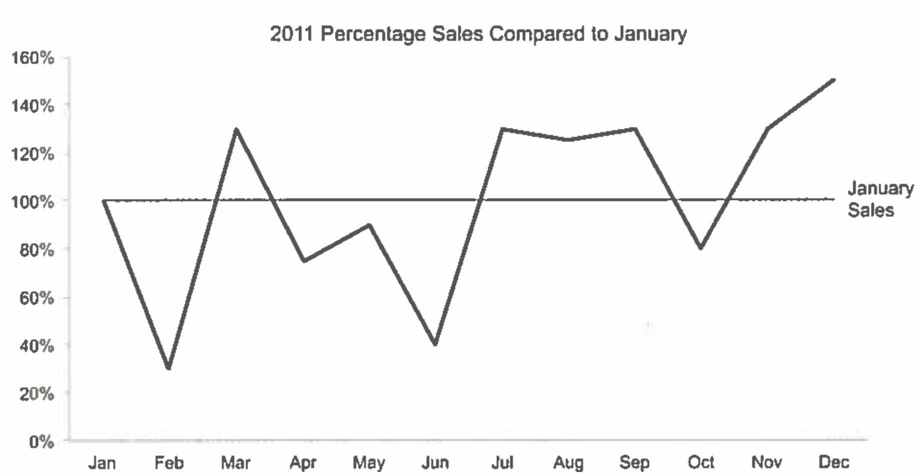


FIGURE 6.41 This combination of a deviation and a time-series relationship displays the variance of monthly sales from January sales, expressed as percentages.

If you wanted to display the relationship of each month's sales to those of the prior month, the graph would look something like this:

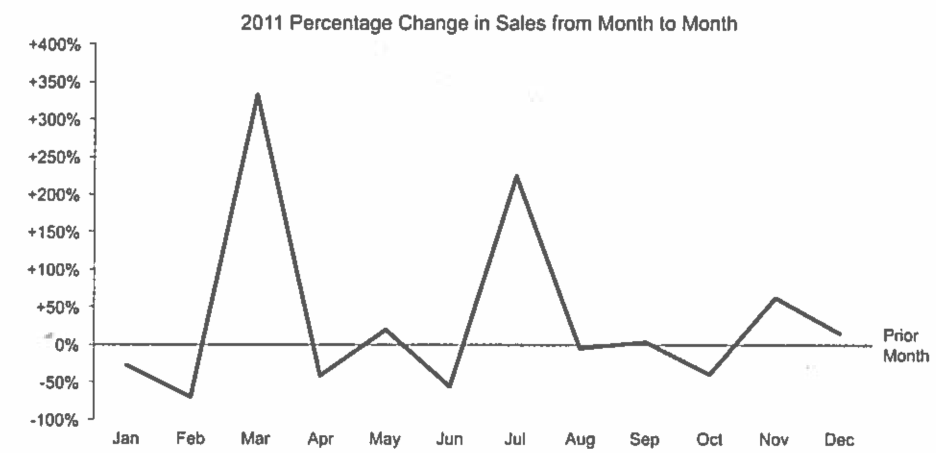


FIGURE 6.42 This combination of a deviation and a time-series relationship displays the variance between sales in a given month and those of the previous month, expressed as positive and negative percentages.

Our investigation has shown that deviation relationships can be effectively displayed using the following objects:

- Bars (vertical or horizontal)
- Lines (when displaying deviation through time)

Distribution Designs

A distribution graph displays the way in which one or more sets of quantitative values are distributed across their full quantitative range from the lowest to the highest and everything in between. The best type of graph to use depends in part on whether we need to display the distribution of a single set of values or distributions of multiple sets so that they can be compared.

SINGLE DISTRIBUTION

A graph of a single distribution shows how often something occurs, expressed either as a count or percentage, distributed across a series of consecutive, quantitative ranges (a.k.a. intervals). The type of graph that works best for displaying a single distribution varies somewhat, depending on whether you want to emphasize the number of occurrences in each interval of the thing being measured or the overall shape of the distribution across the entire range. Given what you know about the unique strengths and weaknesses of each available object for encoding quantitative values, take a moment to determine which would work best for each of the following quantitative messages:

1. The number of orders that fall into each of the following dollar ranges:
   - Less than $5,000
   - Greater than or equal to $5,000 and less than $10,000
   - Greater than or equal to $10,000 and less than $15,000
   - Greater than or equal to $15,000 and less than $20,000
   - Greater than or equal to $20,000 and less than $25,000

2. The time it is taking overall to ship orders from the warehouse once they've been received, based on the following intervals:
   - 1 day
   - 2 days
   - 3 days
   - 4 days
   - 5 days
   - 6 days
   - 7 days
   - 8 days

. . . .

Given the emphasis in the first message on the frequency of occurrences in each of the dollar categories, which graphical object would work best to highlight these individual measures? Both bars and points highlight individual values, but bars, because of their greater visual weight, do a better job of making individual values stand out. A graph that uses bars to display a distribution is called a *histogram*. Here's an example of the first scenario above displayed as a histogram:

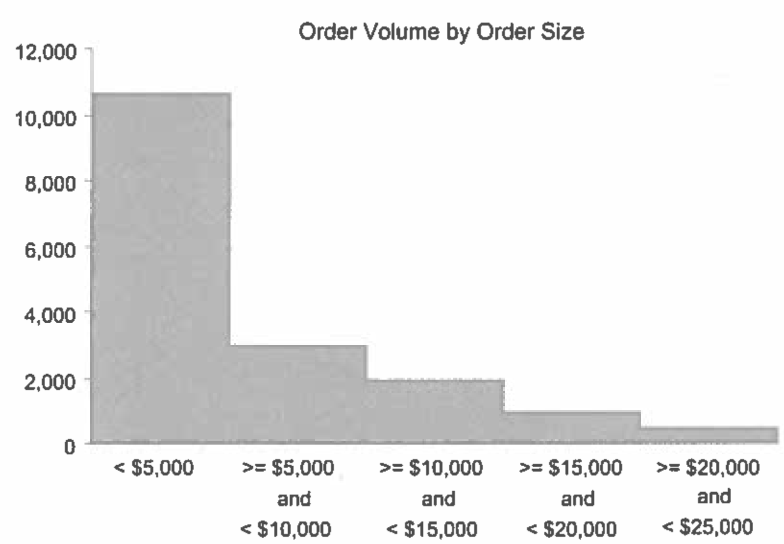


FIGURE 6.43 This histogram displays a single distribution. The bars in a histogram do not conventionally have spaces between them, which visually suggests the continuous rather than discrete nature of the scale.

Histograms are by far the most common way to display distributions. Although horizontal bars work just as effectively, vertical bars are used more often and are therefore more familiar.

Given the emphasis in the second scenario above on the shape of the distribution rather than on values of particular intervals, which graphical object would most effectively display this information? Lines draw the shape in simple visual terms. The name for a graph that uses a line to encode the shape of a frequency distribution is a *frequency polygon*. Here's an illustration of the second scenario, displayed as a frequency polygon:

FIGURE 6.44 This graph, known as a frequency polygon, uses a line to emphasize the shape of a distribution.

Even though the shape of the distribution can be seen in a histogram as well, a frequency polygon focuses the viewer's attention exclusively on the shape by eliminating any visual component that would draw the eye to the values of the individual intervals. The slight disadvantage of frequency polygons is the fact that they cannot be used as easily as histograms to compare the number or percentage of values in one interval to another. Because histograms do an adequate job of showing the shape of a distribution and excel for comparing the number or percentage of values in one interval to another, they are preferred for general use.

In Chapter 2, *Simple Statistics to Get You Started*, I mentioned a name for a distribution that has a shape similar to the one formed by the line in this graph; it is called a bell-shaped or normal curve.

A frequency polygon works superbly for cumulative distributions. It's sometimes useful to show cumulative occurrences from interval to interval along the entire distribution starting from one end and continuing through the other. For example, in addition to seeing shipping performance in *Figure 6.44*, it might be useful to see the total percentage of orders that shipped in one day, two days, three days, and so on up to eight days when all order have shipped, which would look like this:

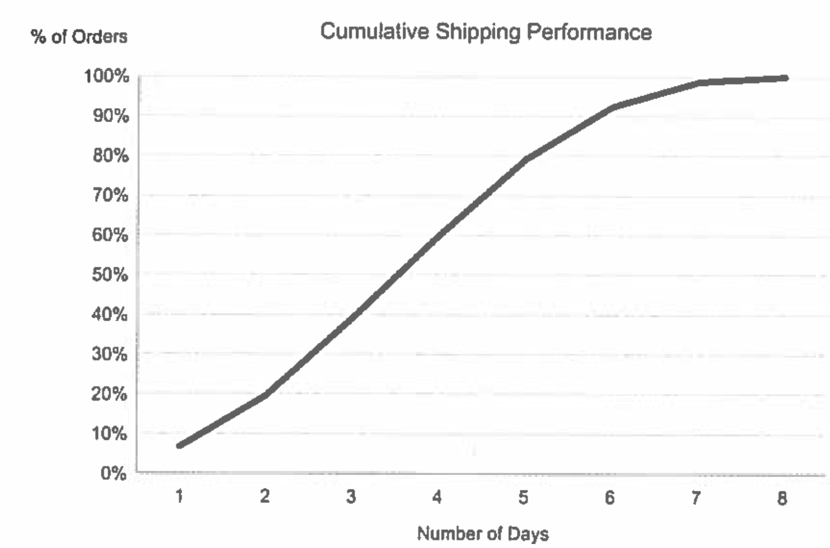


FIGURE 6.45 This frequency polygon is based on the same data as *Figure 6.44* but displays cumulative percentages for shipping periods from one through eight days.

A cumulative distribution sometimes tells the story in a way that directly addresses your audience's interests.

Another type of graph, which uses points to display a single distribution, is called a *strip plot*. Unlike histograms and frequency polygons, strip plots display each value in the data set rather than aggregating the number or percentage of values into intervals. The following example displays 25 people in an office by age:

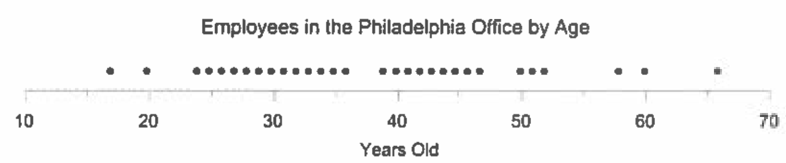


FIGURE 6.46 This graph, called a strip plot, uses individual points for each value in a data set.

Strip plots don't show the shape of a distribution very well, but they're especially useful when you have a small set of values and you want show precisely where each value falls along the quantitative scale. Looking at the example above, you might notice that if 10 employees were 30 years old, you would only see a single point, because all 10 would be located in the same exact space. The best way to solve this problem when you have relatively few values is to *jitter* them. Jittering is the act of repositioning points that are on top of one another either horizontally or vertically so that they're no longer on top of one another. For example, points could be jittered vertically to display a larger set of employees by age as follows:

In Excel, a scatter plot can be used to create a strip plot like the one in *Figure 6.46*. To create a strip plot this way, you must associate the quantitative values in the data set with the X axis and a single value such as 1 with the Y axis, which will line the values up in a single horizontal row. The graph can then be cleaned up by removing the Y axis.

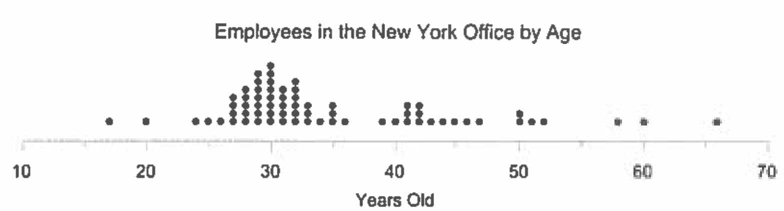


FIGURE 6.47 Points that represent the same ages have been jittered vertically in this strip plot so that each value can be seen.

For large data sets, another way to solve the problem of multiple points in the same location is to make the points transparent. The result is that areas where more values appear in the same location are denser in color than elsewhere, which allows variation in the number of values to be seen. The following example contains profits and losses associated with more than 8,000 orders ranging roughly from a loss of $16,000 to a profit of $27,000.

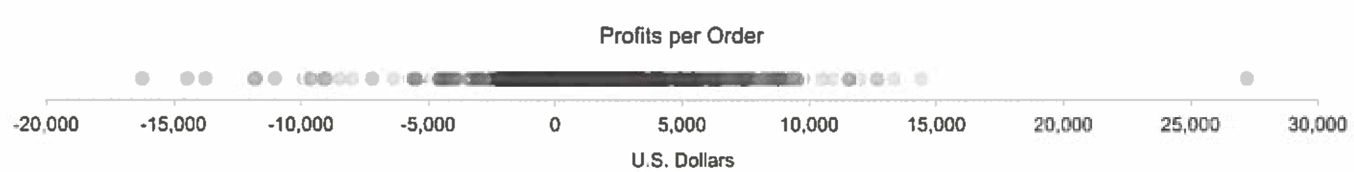


FIGURE 6.48 In this strip plot, transparency has been used so that color intensity reveals variation in the number of points along the scale.

We can see that most of the values fall roughly within the range of -$2,500 to +$6,000, with a lesser but still large number of values in the range from +$6,000 to nearly +$10,000. Although this strip plot doesn't display differences in the number of values along the scale as precisely as a histogram or frequency polygon would, it shows us a number of abnormally low and abnormally high values as individual points extending below and above the range where most of the values fall. In a simple strip plot such as this, you can provide more information by adding marks to show the location of the distribution's center (usually the median) as well as other points of interest, such as the 25th and 75th percentiles to show the range in which the middle half of the values fall. A histogram and a strip plot of this distribution could both be shown to provide a richer picture than either alone could display.

We've learned that the following graphical objects can be used to display a single distribution:

- Bars (vertical or horizontal, in the form of a histogram)
- Lines (especially when you want to feature the shape of the distribution, in the form of a frequency polygon)
- Points (especially for small data sets when you want to show each value, in the form of a strip plot)

MULTIPLE DISTRIBUTIONS

It is often useful to display the distributions of multiple data sets in a single graph so that they can be compared. One simple way to do this, which extends a graph that we've already examined, the frequency polygon, is to combine multiple lines into a single graph, with one line for each data set. Here's an example:

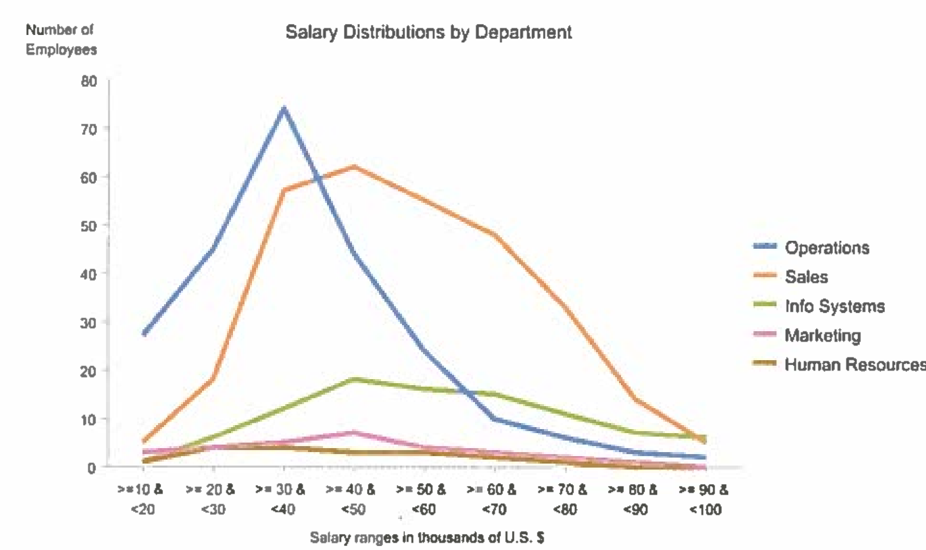


FIGURE 6.49 Lines can sometimes be used to display the distributions of multiple data sets in a single graph.

Rather than counting the number of employees whose salaries fall into each interval along the range, these distributions could also be expressed as the percentage of employees that fall into each. Because the number of employees in each department varies so dramatically, some of the lines in the graph above are relatively flat near the bottom of the scale, which makes it more difficult to see their shapes. If we express the percentage of employees that fall into each interval with the values along each line summing to 100%, the shapes of all distributions are easier to see and compare, as in the example on the next page.

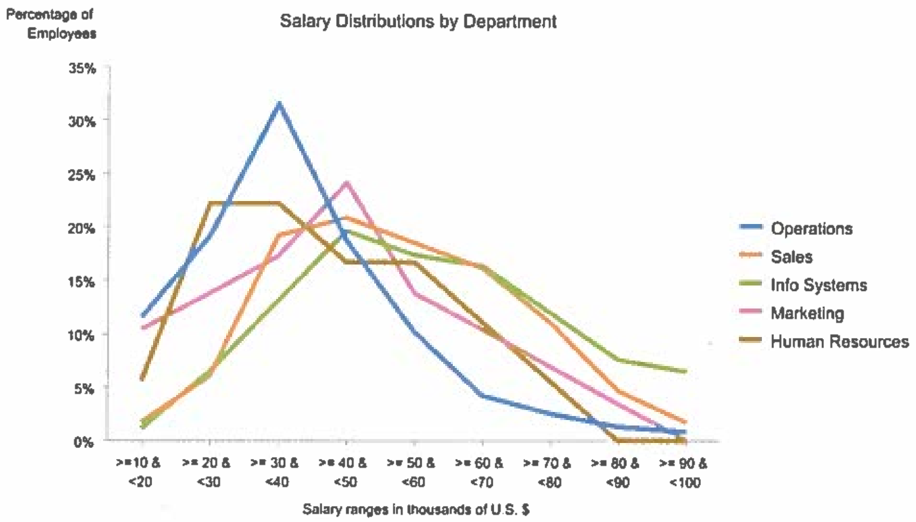


FIGURE 6.50 When the number of values in different distributions varies significantly, it can be useful to use percentages rather than a count of values as the quantitative scale.

Frequency polygons work well for comparing distributions—especially their shapes—as long as there are relatively few lines. Too many lines would look cluttered and would be difficult to read.

When you need to display more than a few distributions or to display how a distribution changes over time, frequency polygons are rarely a good solution. An alternative that works elegantly was invented by John Tukey, a Princeton University statistician who contributed a great deal to the visual presentation of quantitative data, especially to support the exploration and analysis of data. Tukey's solution is called the box plot or *box-and-whisker plot*. What he calls a box is really just a bar—actually a range bar that encodes a range (or distribution) of values from one end of the bar to the other. To this he added a point in the middle (in this case, a horizontal line that divides the box in two) to mark the center of the distribution (usually the median) and two lines, called whiskers: one extending upwards from the top of the box and one extending downwards from the bottom to encode additional information about the distribution's shape. Here's an example of a box and whisker display, with its components labeled:

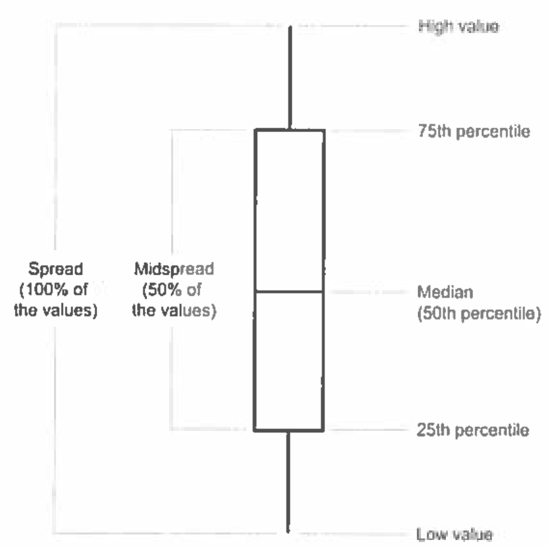


FIGURE 6.51 This is a typical box-and-whisker representation of a single distribution.

As you can see, this simple combination of geometrical shapes communicates quite a lot about a distribution. Here's a list of the full set of facts that it presents:

- The highest value
- The lowest value
- The range of the values from the highest to the lowest (the spread)
- The median of the distribution
- The range of the middle 50% of the values (the midspread)
- The value at or above which the highest 25% of the values reside (the 75th percentile)
- The value at or below which the lowest 25% of the values reside (the 25th percentile)

Now let's look at the sample distribution displayed as a box plot below, to see what we can learn from it.

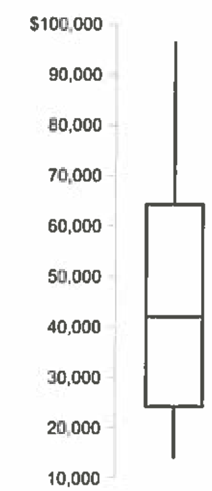


FIGURE 6.52 This example of a salary distribution gives us a chance to practice making sense of box plots.

Assuming that *Figure 6.52* represents a distribution of salaries, the first thing it tells us is that the full range of salaries is quite large, extending from around $14,000 on the low end to around $97,000 on the high end. We can also see that more people earn salaries toward the lower rather than the higher end of the range. This is revealed by the fact that the median, encoded as the short horizontal line in the middle of the box at approximately $42,000, is closer to the bottom of the range than the top. Half of the employees earn between $25,000 and $65,000, which definitely indicates that this distribution is skewed toward the top end of the range. The 25% of employees who earn the lowest salaries are grouped closely together across a relatively small $10,000 range of salaries. Notice the large spread represented by the top 25% of the salaries. This tells us that as we proceed up the salary scale there appear to be fewer and fewer people within each interval along the scale, such as from over $60,000 to $70,000, from over $70,000 to $80,000, and from over $90,000 to $100,000. In other words, salaries are not evenly spread across the entire range; they are tightly grouped near the lower end and spread more sparsely toward the upper end where the salaries are more extreme compared to the norm.

When you need to display multiple distributions for comparison, box plots are hard to beat. Take a minute to study the example below, and see what you can learn about how male and female salaries compare.

FIGURE 6.53 This box plot separately displays male and female salaries in five different pay grades.

Here are a few of the insights that are revealed in this display:

- On average, women are paid less than men in all salary grades.
- The disparity in salaries between men and women becomes increasingly greater as one's salary increases.
- Salaries vary the most for women in the higher salary grades.

These insights were submitted by Christopher Hanes in response to a data visualization competition that I judged for *DM Review* magazine, which used this graph.

In a new version of the same box plot below, I've made a slight change. Do you see what's different?

FIGURE 6.54 This box plot is slightly different from the one in *Figure 6.53*, and the difference influences what's emphasized in its story.

All that's different is the order of the male and female boxes. Notice how this simple change alters your perception of the same data. To your eyes, which version of the box plot makes the discrepancy between male and female salaries more apparent? To most people's eyes, the second version highlights the discrepancy more clearly. Why? If you imagine a line being drawn through the medians of all the boxes from left to right using the first version, the line forms a smooth curve. If you do the same with the second version, however, the line is jagged, and that jaggedness is jarring, which increases the salience of the discrepancy. Both of these box plots tell the truth, but one brings this particular aspect of the truth to our attention more.

Before moving on, it's worthwhile to mention that box plots must be used with care for presenting information to others because most people in the world have never learned how to read them. Even if you had never used them before now, you can see that they are easy to understand after a brief introduction, but you won't always have an opportunity to take people through an introduction like the one that I've provided here. For this reason, it is often useful to make box plots as simple as possible. While a five-value box plot (low, 25th percentile, median, 75th percentile, high) might require five minutes of instruction to understand, a simpler three-value box plot requires a few words only. Here's an example of the same salary distribution information as before, this time displayed as simpler three-value boxes:

FIGURE 6.55 This is a simple three-value box plot.

With the simpler version of the graph, the legend on the right might be all that's needed to clarify its use even for people who are not already familiar with box plots. For some, the term "median" might not be clear, so a bit more explanation might be needed, but not much. Obviously, some of the information is lost in reducing the graph from a five-value to a three-value representation of distribution, but for many purposes, the simpler version would suffice.

Box plots are not a standard chart type in Excel, but simple versions can be created by using features that reside in Excel for other purposes. For instructions on creating box plots in Excel, see Appendix E, *Constructing Box Plots in Excel*.

Although boxes are more often oriented vertically, there is no reason why they cannot be arranged horizontally, as illustrated below. If for any reason a horizontal arrangement offers advantages, don't hesitate to use it.

FIGURE 6.56 Boxes may be arranged horizontally or vertically.

Strip plots can also be used to display and compare multiple distributions. In strip plots, multiple distributions are displayed as several rows or columns rather than as a single row or column of points. Strip plots are especially useful when there are relatively few values in the data sets and you have a reason for displaying each value individually. Here's an example, which displays the distribution of student grade point averages (GPAs) for eight schools, one distribution per year for four years.

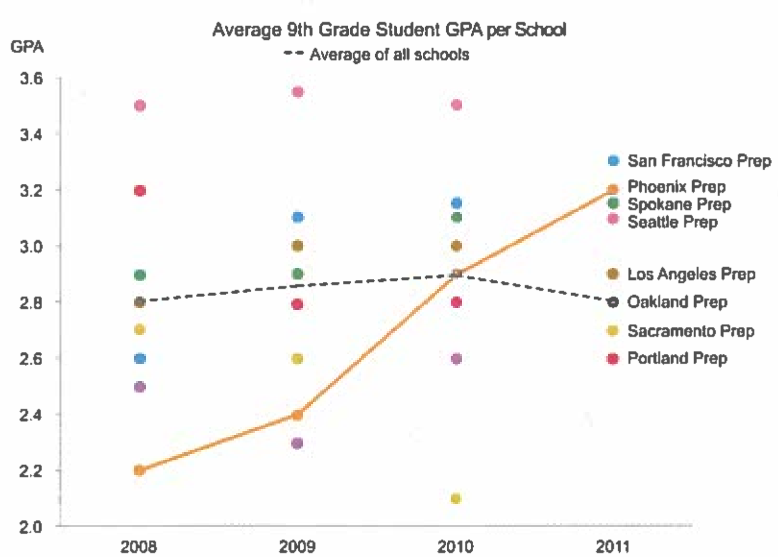


FIGURE 6.57 This strip plot displays the distribution of average GPAs for eight schools by year.

The strip plot displays each school as a separate dot, which makes it possible not only to see the full spread of values in each year from low to high along with a measure of average (the dashed line), but also to see how individual schools performed relative to the others and how the performance of each changed from year to year. In this example, by connecting the four dots that represent Phoenix

Prep's scores with a line, the graph features this school's performance. This view of the data has been customized for administrators at Phoenix Prep, to highlight what's of interest to them. Because this example includes time-series data, it was important to arrange the dots for each distribution vertically so that time could be on the X axis. When time isn't involved, the dots may be arranged either vertically or horizontally.

To summarize, we've learned that multiple distributions can be displayed using any of the following objects:

- Lines (in the form of frequency polygons)
- Boxes (vertical or horizontal)
- Points (arranged vertically or horizontally, in the form of strip plots)

Correlation Designs

Correlation graphs display the relationship between two paired sets of quantitative values to demonstrate whether or not they are related, and, if so, the direction of the relationship (positive or negative) and the strength of the relationship (strong or weak). Because the relationship is between two sets of quantitative values rather than between categorical items and quantitative values, both the X and Y axes of the graph provide quantitative scales. The graph that was created specifically for this purpose is a scatter plot. It is a lot like a strip plot, except that each point is positioned in relation to two quantitative scales—one horizontal along the X axis and one vertical along the Y axis—rather than a single scale. In a sense, just as a strip plot displays a single frequency distribution with one point per value, a scatter plot displays two frequency distributions: one based on the horizontal positions of the points and the other based on the vertical positions.

Let's say that you need to display the potential correlation between the heights of male employees and their salaries. To encode the values for an employee who is 70 inches tall and earns a salary of $60,000, you would find 70 on the X axis, and then move up until you are in line with $60,000 on the Y axis, and then mark that spot on the graph with a point, as illustrated below:

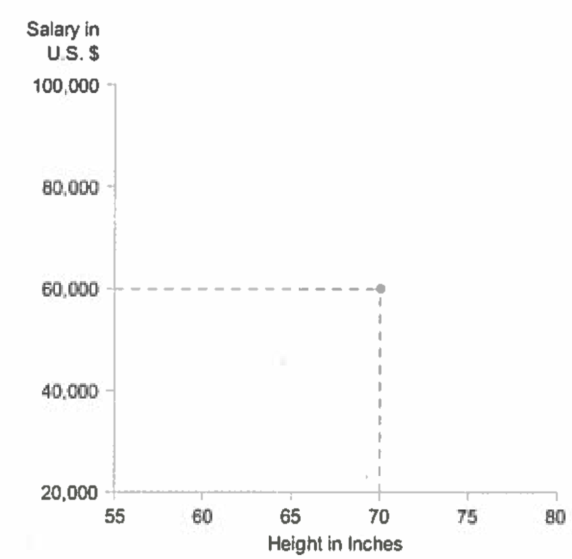


FIGURE 6.58 This illustrates the method used to position correlated values on a graph with X and Y axes.

Based on this illustration, it doesn't take much imagination to recognize that points work perfectly for encoding correlation values. Here's a graph that displays an entire series of paired employee heights and salaries:

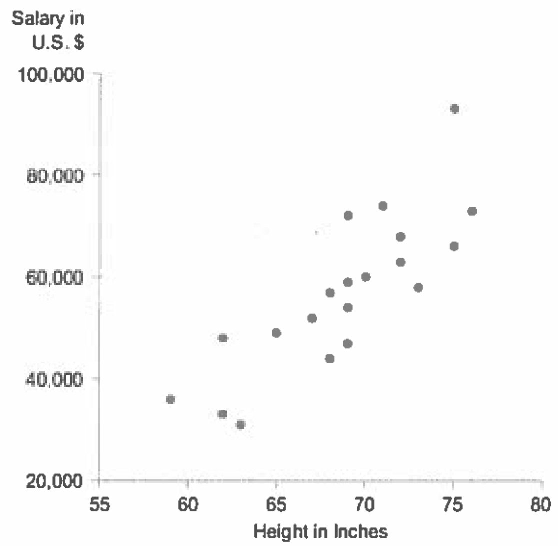


FIGURE 6.59 This graph displays the correlation between employees' heights and their salaries using points to represent the correlated values.

Does the scatter plot above seem to indicate that there is a correlation between these employees' heights and salaries? What could we do to make the potential correlation more visible? We could add a trend line.

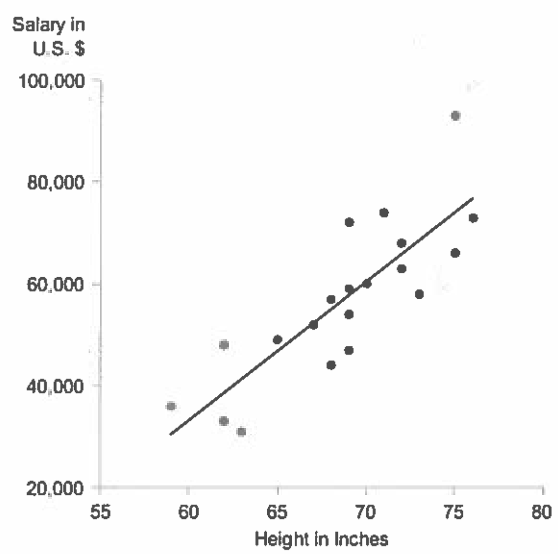


FIGURE 6.60 This scatter plot includes a trend line to highlight the overall pattern of correlation.

It is now easier to see by the upward direction of the trend line from left to right that there is a positive correlation between employee height and salary, but it is not strong; the points are loosely grouped around the line.

Scatter plots are very effective for displaying correlations, with points to mark the values and lines to highlight the pattern. We could end our examination of structural solutions to the display of correlations right here, but a fundamental problem crops up occasionally that motivates us to consider additional solutions.

Think about the audience for the graphs that you prepare. Do they all know how to interpret scatter plots, and, if not, are there those who are not willing to learn? Because it might not be possible to rely on scatter plots in all circumstances, let's look at additional solutions.

Can you come up with a different way to display correlations? Use the example that we've already been working with, the correlation of employee heights and salaries. Can you somehow combine the components available for use in graphs to display the correlation in a way that can be understood more intuitively than a scatter plot?

. . . .

Were you able to come up with a viable solution? Even if you couldn't, I'm sure the attempt was well worth the effort as a means to reinforce what you've learned about graphs. I'm going to offer a solution that uses two sets of bars to encode the two sets of paired quantitative values. Because we have two quantitative scales, inches for height and U.S. dollars for salary, we need two axes to display them, but we can't use our normal arrangement of an X and Y axis because it wouldn't work to display one set of bars going horizontally and one going vertically. I want to position the bar that represents a particular employee's height and the bar that represents that same employee's salary in a way that clearly associates them with one another. This can be done in more than one way, but the solution that usually works best looks like this:

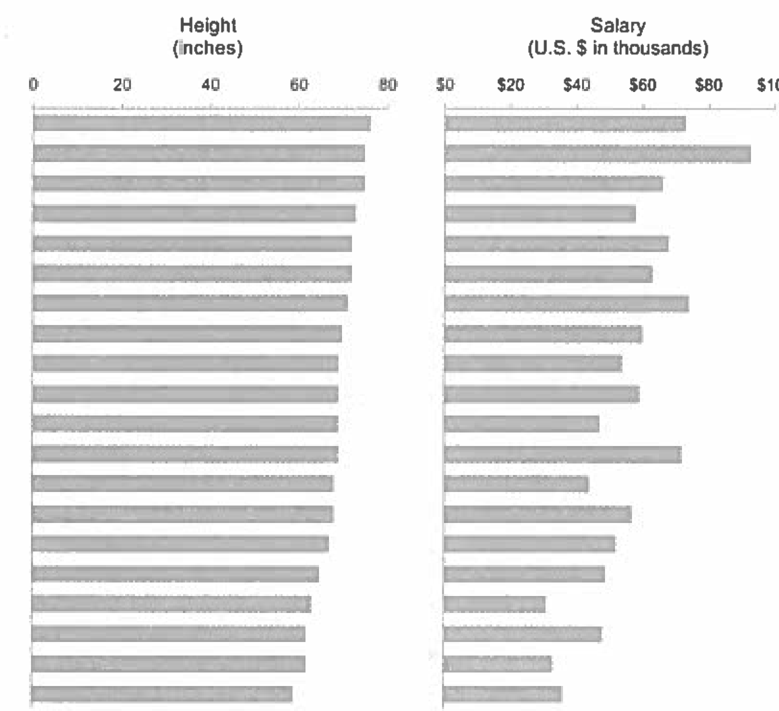


FIGURE 6.61 Two sets of bars, one for each variable, arranged in this manner make it possible to see correlations.

For instructions in how to create a display such as this in Excel, see Appendix D, *Constructing Table Lens Displays in Excel*.

The table lens was first invented by Ramana Rao and Stuart Card. It was designed to do a lot more than the simple examples that I've shown.

Separate sets of bars arranged in this manner for the purpose of revealing correlations are called a *table lens*. In essence, two bar graphs are placed side by side: one displays employees' heights from tallest to shortest and the other displays employees' salaries in the same order. A single row of bars from left to right contains a single employee's height and salary. To look for a potential correlation, you should simply see whether there is a tendency for the salary bars to either decrease or increase fairly consistently as the heights decrease. If the two sets of bars tend to increase together, there is a positive correlation; if salaries tend to increase as heights decrease, there is a negative correlation. Does a correlation appear to exist? Although it isn't perfect, there definitely appears to be a correlation: as height decreases, salary tends to decrease in a corresponding manner. In a table lens, it isn't necessary to use sets of horizontal bars arranged side by side. Sets of vertical bars work as well when you stack them one above the other.

We were able to reveal the same basic information about the correlation between employee heights and salaries in the above graph using horizontal bars as we did in the earlier scatter plot. Scatter plots are superior overall, but if you suspect that your readers will struggle trying to understand a scatter plot, a table lens may produce better results. In addition to being easy to understand, a table lens has another advantage: you can look for correlations among more than two quantitative variables at a time. For example, imagine five sets of bars, one for each variable, rather than two. If your data sets are huge, however, you may be forced to use a scatter plot because you can get only so many bars in a limited amount of space, but thousands of points can fit into a scatter plot.

To summarize, we've learned that correlations can be displayed using the following objects:

- Points (in the form of a scatter plot)
- Bars (in the form of a table lens)

Geospatial Designs

Geospatial displays feature the geographical location of values, positioning values on a map. On geospatial displays, the two best means of encoding quantitative values in graphs—2-D position and the length of objects that share a common baseline—are not available. Because 2-D position is used on a map to represent geographical location, we can't use it to represent a value as we do in scatter plots, dot plots, and line graphs. Because values must be positioned on a map to mark their geographical location, the length of objects such as bars cannot be aligned to share a common baseline. For this reason, we must rely on size, color intensity, and width to encode quantitative values even though these attributes cannot be perceived as precisely as others. Specifically, we'll use the following to encode quantitative values in geospatial displays:

- Points of varying size
- Points or areas of varying color intensity
- Color intensities applied directly to geographical regions
- Lines of varying thicknesses or color intensity

Points can be used to place values in precise locations on a map. The point shape that is typically used on maps is a circle. The quantitative values of points can be encoded by size, color intensity, or both. When you want to encode a single quantitative variable with points on a map, and both size and color intensity are available, size is usually the better choice. It is slightly easier to perceive differences in the sizes of points than differences in color intensities, in part because our ability to perceive color differences decreases with the size of objects, and points are usually fairly small. The number of 911 emergency calls in a particular section of Seattle, Washington have been encoded on the following map by the size of each circle:

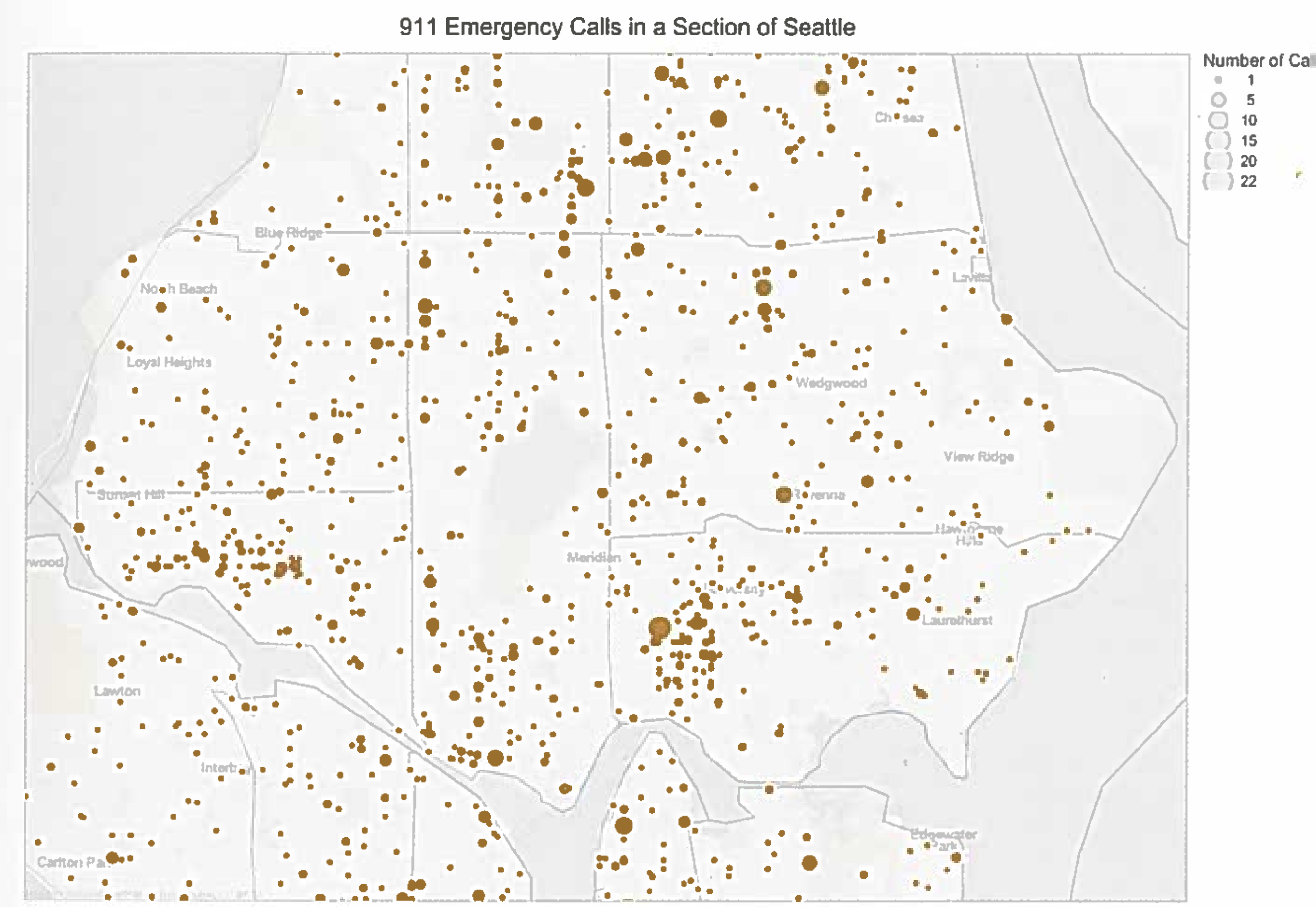


FIGURE 6.62 Points that vary in size work well for displaying values at specific locations on a map. This geospatial visualization and those that follow were all created using Tableau.

In a case such as this, when the precise location of values must be pinpointed on the map, points are the only means of encoding the values. Because the circles must be relatively small, varying their sizes rather than varying the color intensity of consistently sized circles is the best solution.

Points can be used not only to encode values at specific locations but also to encode aggregated values for entire regions. In the example on the following page, sales revenues are shown at the state level.

FIGURE 6.63 Points that vary in size can be used to display values for entire regions, such as states.

Because the circles can vary by size and color intensity at the same time, each attribute can be used to encode a separate set of values. In the example below, profit, encoded by color intensity, has been added to the map.

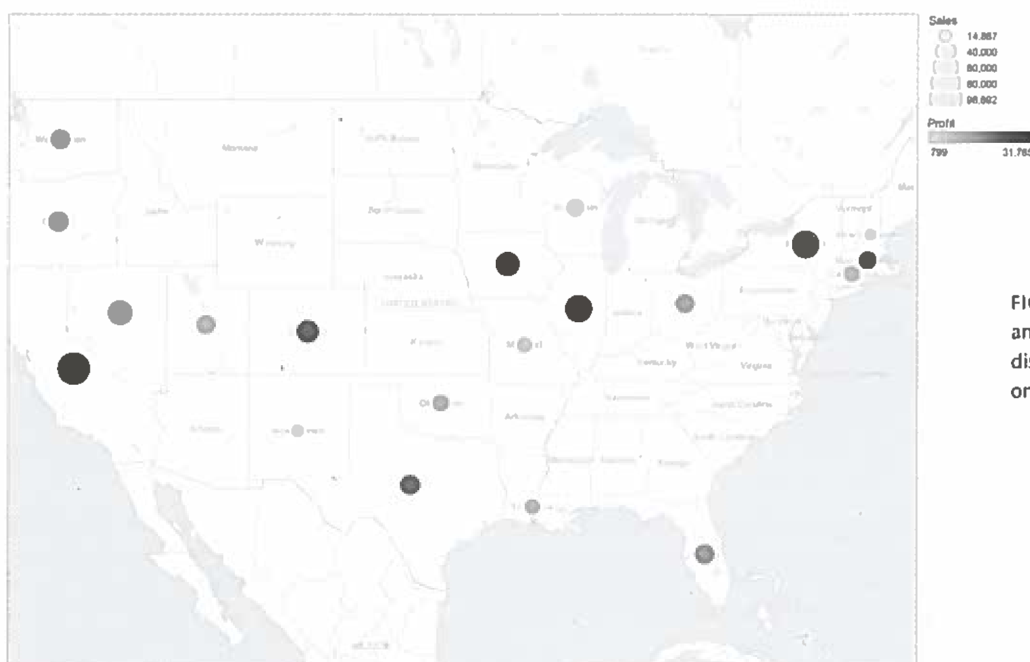


FIGURE 6.64 Points that vary in size and color intensity can be used to display two quantitative variables at once.

In addition to using points that vary by size and color intensity, we can assign color intensities to the geographical regions themselves to encode aggregate values associated with those regions. Geographical displays that encode values in this way are called *choropleth maps*. In the following example, color intensities encode the populations of states.

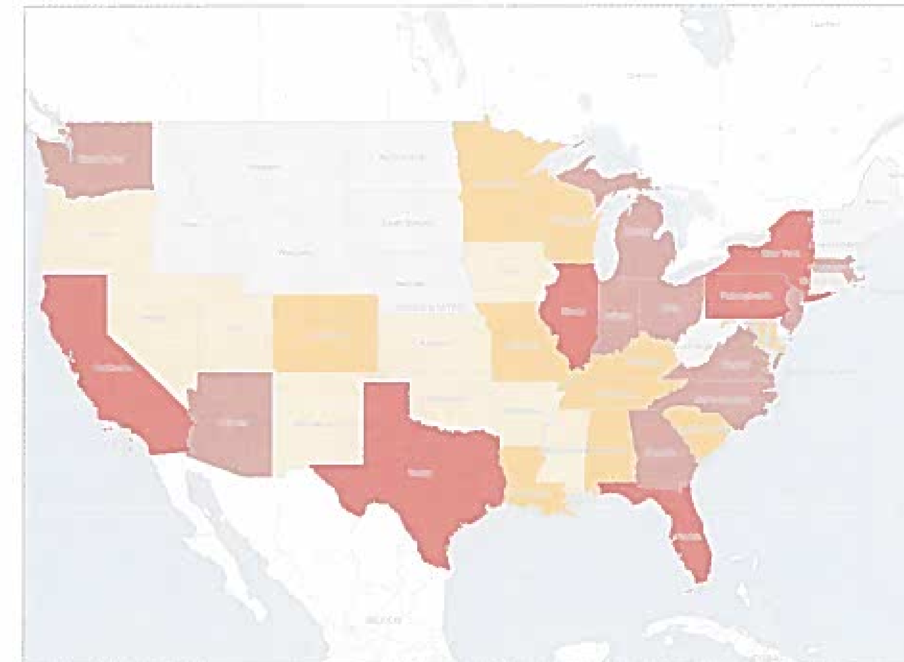


FIGURE 6.65 Variations in color intensity can be used to assign values to geographical regions.

By combining all three means of encoding values on a map, we can display three quantitative variables simultaneously, as in the following example where the circle sizes represent sales revenues, the circle color intensities represent profit, and the state colors represent population.

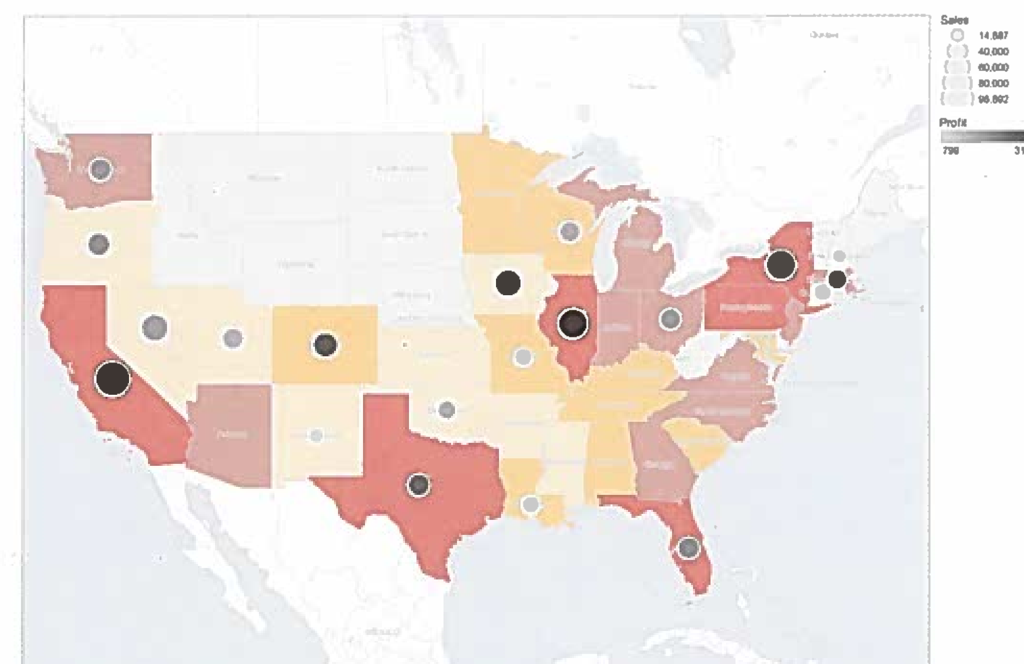


FIGURE 6.66 Three quantitative variables can be associated with geographical regions at once.

In addition to associating quantitative values with specific locations or regions, it's sometimes useful to associate them with routes from place to place. For example, if you wanted to display varying amounts of traffic along specific roads, you might vary the thickness or the color intensity of the lines that represent those roads on the map. In the following example, the route and strength of each large storm in the Atlantic Ocean during the 2005 hurricane season is recorded using lines that vary in thickness.

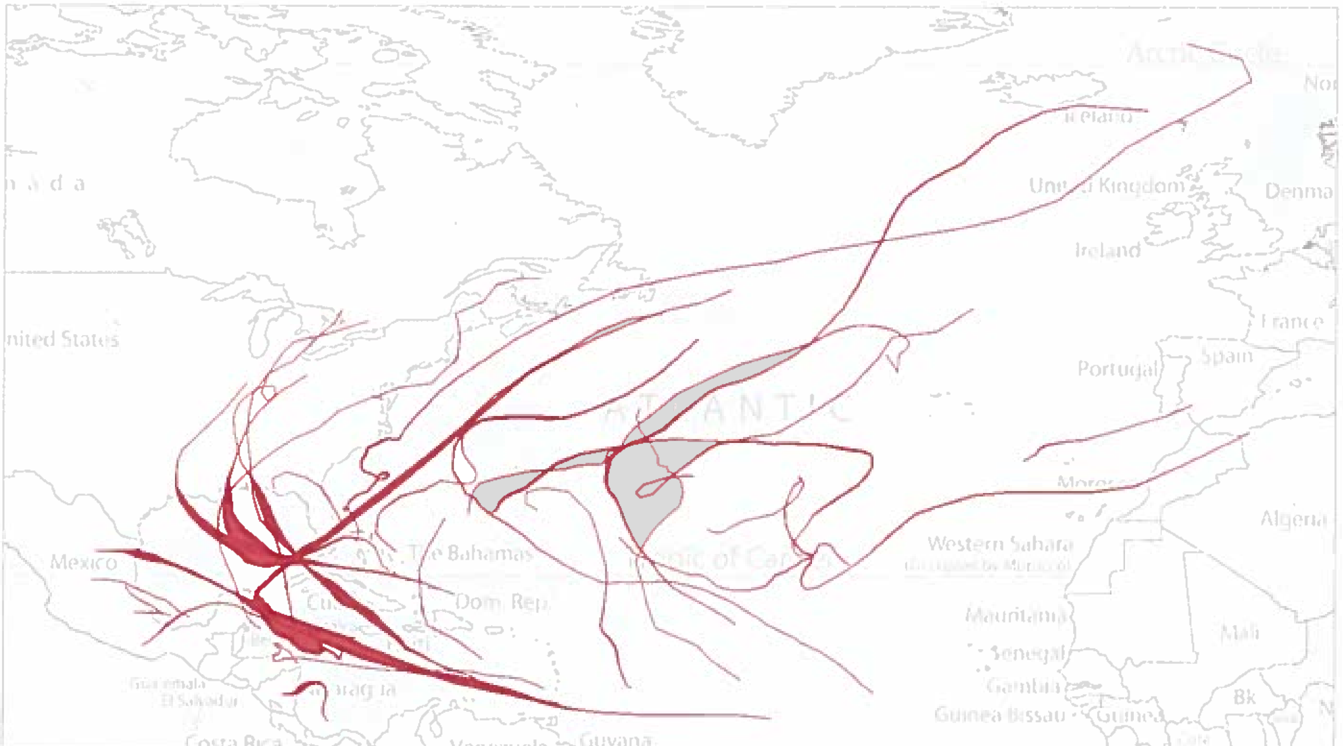


FIGURE 6.67 Varying line widths can associate values with geographical routes. This example was created by Richard Wesley and Chris Stolte of Tableau Software.

To summarize, we've learned that values can be displayed geospatially using the following means:

- Points of varying size (to pinpoint specific locations or for entire regions)
- Points or areas of varying color intensity (to pinpoint specific locations or for entire regions)
- Lines of varying thickness or color intensity (to display values associated with routes)

Summary at a Glance

	Value-Encoding Objects			
Relationship	**Points**	**Lines**	**Bars**	**Boxes**
Nominal Comparison	In the form of a dot plot when you can't use bars because the quantitative scale does not begin at zero	Avoid	Horizontal or vertical	Avoid
Time Series	In the form of a dot plot, but only when values were not collected at consistent intervals of time	Emphasis on overall pattern; categorical items on X axis, quantitative values on Y axis	Emphasis on individual values; categorical items on X axis, quantitative values on Y axis	Only when showing distributions as they change through time; categorical items on X axis, quantitative values on Y axis
Ranking	In the form of a dot plot, especially when you can't use bars because the quantitative scale does not begin at zero	Avoid	Horizontal or vertical	Only when ranking multiple distributions; horizontal or vertical
Part-to-Whole	Avoid	To display how parts of a whole have changed through time	Horizontal or vertical	Avoid
Deviation	As a dot plot when the quantitative scale does not begin at zero	Useful when combined with a time series	Horizontal or vertical, but always vertical when combined with time series	Avoid
Distribution				
Single	Known as a strip plot; emphasis on individual values	Known as a frequency polygon; emphasis on overall pattern	Known as a histogram; emphasis on individual intervals	Avoid
Multiple	Known as a strip plot; emphasis on individual values	Known as a frequency polygon; limit to a few lines	Avoid	Known as a box plot
Correlation	Known as a scatter plot	Avoid	Horizontal or vertical, in the form of a table lens	Avoid
Geospatial	Vary point sizes to encode values	To mark routes	Avoid	Avoid

11 DISPLAYING MANY VARIABLES AT ONCE

Graphs can be used to tell complex stories. When designed well, graphs can combine a host of data spread across multiple variables to make a complex message accessible. When designed poorly, graphs can bury even a simple message in a cloud of visual confusion. Excellent graph design is much like excellent cooking. With a clear vision of the end result and an intimate knowledge of the ingredients, you can create something that nourishes and inspires.

We often need to tell stories that involve more than we can clearly express in a single graph. To communicate effectively, we sometimes need to help our readers see the information from more than one perspective. A single graph can sometimes be used to tell a complex story elegantly, but frequently a single graph won't do. This chapter focuses on design strategies that address the presentation of many variables in two useful ways: combining multiple units of measure in a single graph and combining multiple graphs in a series.

Combining Multiple Units of Measure

It is often easy to combine multiple quantitative variables in a single graph when they all use the same unit of measure. For instance, in a single time-series graph as shown below, you could easily display revenues, expenses, and profits because they are all expressed in U.S. dollars.

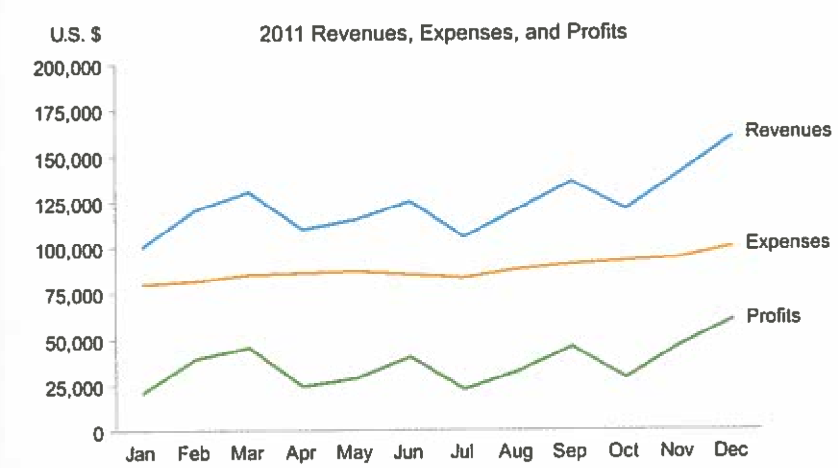


FIGURE 11.1 This graph displays multiple sets of quantitative data, all sharing the same unit of measure.

This does the job unless the values of different variables differ by a large amount, which might cause lines with low values to look relatively flat, thus making it difficult to discern their patterns. But what do you do to combine related sets of quantitative data so they can be compared when they're expressed as different units of measure? A typical example involves time-series sales information consisting of revenue in dollars and order volume as a count. One solution is to create two graphs and place them close to one another in a manner that makes comparisons easy, as illustrated below:

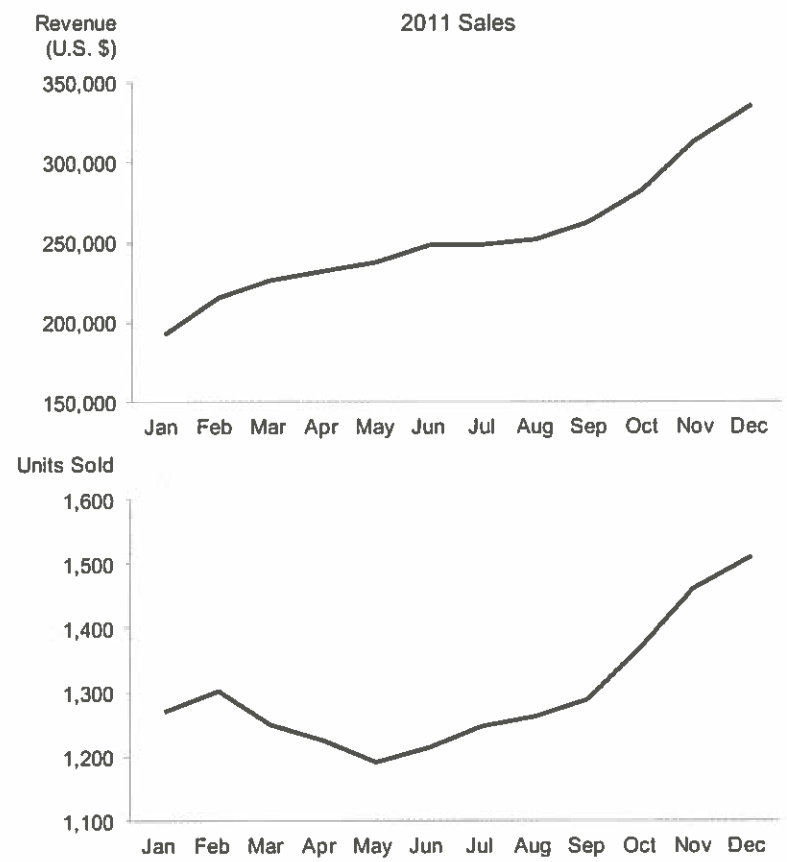


FIGURE 11.2 Arranging these two graphs in this manner allows easy comparison of patterns of change through time.

This is usually the best solution. You can, however, combine two units of measure in a single graph by using two quantitative scales as shown below:

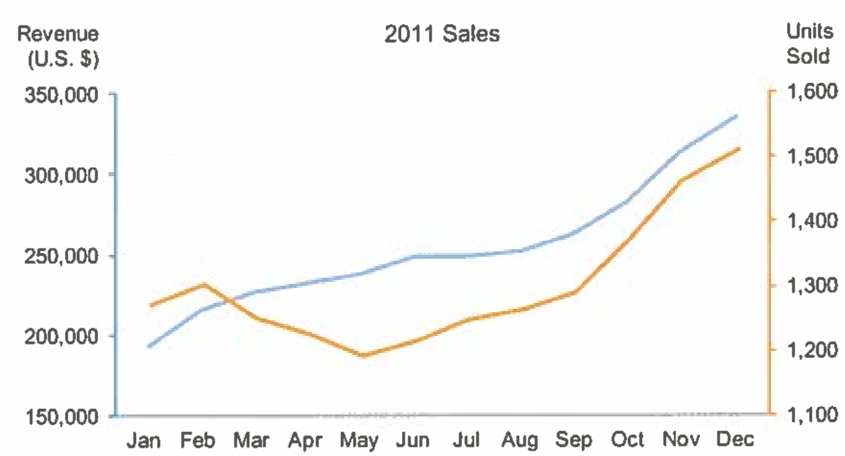


FIGURE 11.3 This single graph displays two quantitative scales on the Y axis: one on the left and one on the right.

In this configuration, even though they use different units of measure, the two related measures can be compared quite easily—perhaps too easily. Although each line is associated with a different scale, we are, by displaying them in a single graph, tempting people to do something they shouldn't: to compare the

magnitudes of values on one line to those on the other. Because the scales of the two lines are different, this comparison is meaningless.

Looking again at the previous graph, do you find that your eyes are drawn to a particular spot? If you're like most people, the place where the two lines intersect catches your attention. In a normal line graph with a single quantitative scale, points of intersection actually mean something: that one set of values exceeded the other during that period of time. However, in a graph with two quantitative scales such as the one above, points of intersection are meaningless but the configuration of the graph features the intersection. This is a problem. Graphs with two quantitative scales can easily confuse and even mislead your readers. For this reason, unless you are certain that your readers are comfortable with dual-scaled graphs, it is best to avoid them.

Combining Graphs in a Series of Small Multiples

You can only squeeze so many sets of data into a single graph. It is this limitation of 2-D graphs that often tempts people to use 3-D graphs, with disappointing results. However, there is a solution that extends the number of data sets that can be displayed: multiple graphs arranged together as a series. Edward Tufte refers to the arrangement of related graphs that we'll examine in this section as *small multiples* and others call it a *trellis chart*. Tufte explains that "Small multiples resemble the frames of a movie: a series of graphics, showing the same combination of variables, indexed by changes in another variable."[1]

1. Edward R. Tufte (2001) *The Visual Display of Quantitative Information*, Second Edition. Graphics Press, page 170.

Let's walk through a typical scenario. Imagine that you need to display sales—both bookings and billings separately—by sales region for last month. Here's what you have so far:

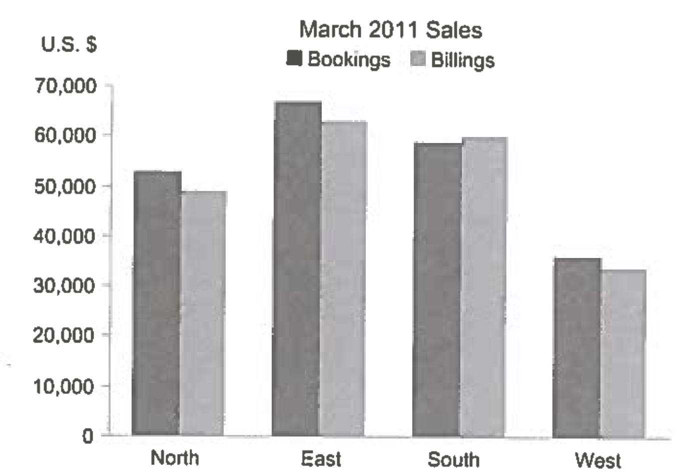


FIGURE 11.4 This graph displays two sets of quantitative values (bookings and billings) and one set of categorical items (sales regions).

Simple, so far. Now, if you need to show another set of related quantitative values (e.g., profits), you could do so easily by adding another set of bars. But what if you need to show sales not only by sales regions but also by sales channels (e.g., direct, distributor, and reseller sales)? This requires the addition of another set of categorical items. Adding a third axis would result in utter visual confusion, so this option is out. What can you do?

The answer involves multiple graphs arranged closely together so they can be easily compared. Here's a simple example that solves our problem:

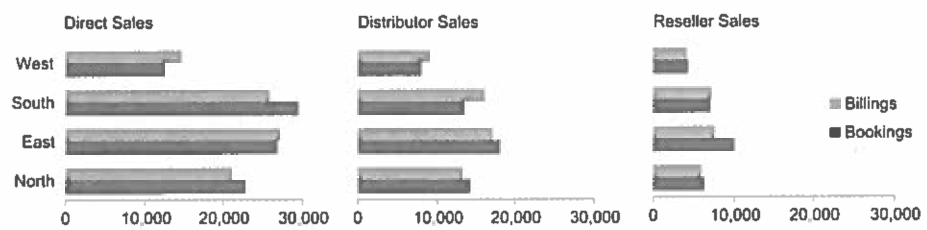


FIGURE 11.5 This is a series of related graphs that displays two sets of quantitative values (bookings and billings) by two sets of categorical items (sales regions and channels).

Even though this involves three separate graphs, the nature of the arrangement allows them to be examined as one composite graph with three sets of axes. This particular series happens to consist of three graphs because there are three sales channels, but it could consist of as many graphs as you could fit together on a page or screen. As the number of graphs grows, the trick is to reduce their individual size enough to allow them to be seen together. You can arrange the graphs horizontally (side by side), vertically (one above the next), or in both directions to produce a matrix of graphs arranged in multiple columns and rows.

Graphs in a series like this should be consistent in design, varying in that each contains a different subset of data. In the example above, the graphs vary by sales channel. Because all of the graphs share a common quantitative scale, they are easy to compare.

When graphs are displayed as a series, redundant labels can often be eliminated. Notice that labels for the four regions only appear in the left-most graph and that the legend that labels billings and bookings only appears on the right. Because the graphs are close to one another, these labels don't need to be repeated in each graph. Repeating them would result in redundant and therefore unnecessary data ink.

To learn how to effectively design related graphs in a series, we'll examine the following topics:

- Consistency
- Arrangement
- Sequence
- Grid lines

Consistency

It is important when designing a series of small multiples to maintain consistency among them. Consistency is required for comparison. Consistency also contributes a great deal to efficient interpretation. Your readers only need to learn how the first graph works and can then quickly apply that knowledge to each graph in the entire series because all of the graphs work in precisely the same way.

When you design a series of small multiples, make sure that every visual characteristic of each graph within the series is the same. This includes the aspect ratio of the axes, the colors used to encode the data, the font used for text, and so on. Any difference will slow your readers down and induce them to search for meaning in that difference.

Pay particular attention to the scales along both axes. Many software products that generate graphs automatically adjust quantitative scales to fit the range of values. When graphs are combined in series of small multiples, this is a significant problem, because the graphs can only be compared accurately if their scales are the same. Look at what happens to our previous example when we allow the software to adjust the quantitative scale:

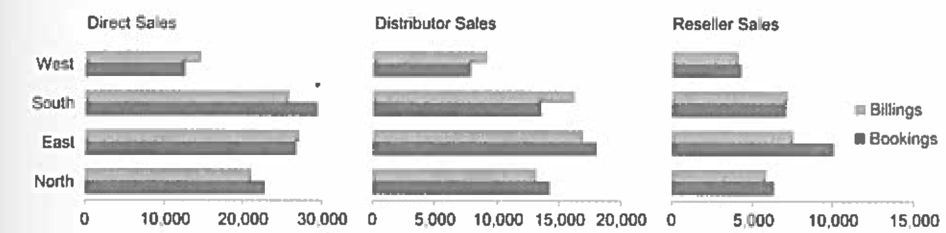


FIGURE 11.6 This example demonstrates the problem that results when quantitative scales vary in a series of related graphs.

As you can see, the differences in sales between the three sales channels appear smaller because of the variations in scale.

Make sure that the categorical scale also remains consistent with the same items in the same order (e.g., always West, South, East, and North) and the same full set of items in each graph even when a value is zero or null. Here's the same series again, but this time there are no distributor sales in the south. Rather than displaying a value of zero, the south region was excluded from the graph entirely, resulting in a confusing inconsistency:

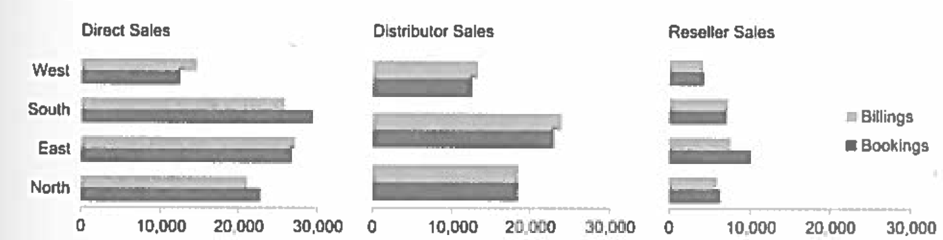


FIGURE 11.7 This series of related graphs exhibits an inconsistency in the sets of sales regions: the south region is missing in the middle graph of distributor sales.

Arrangement

The best arrangement for a series of small multiples, whether horizontally side by side, vertically one on top of the other, or both in the form of a matrix, depends primarily on your answer to the question "Which items do you want to make easiest for your readers to compare?" Take a look at the next example to see which values are easy to compare and which are harder.

FIGURE 11.8 This arrangement of small multiples works best for comparing regions within a given sales channel and also works well for comparing values across sales channels.

This arrangement makes it easiest to compare the magnitudes of regional values within each sales channel because they are in the same graph, slightly less easy to compare values for all regions and sales channels because they are spread among three separate graphs, and least easy to compare values for a specific region in all sales channels because they are spread among three separate graphs and you must focus on one region while trying to ignore the other three.

If you wanted to make it easier to isolate particular regions for comparison across all sales channels merely by scanning across a given row, the following arrangement would support that well, but it would be harder to compare these values precisely because their quantitative scales are not aligned but are side by side.

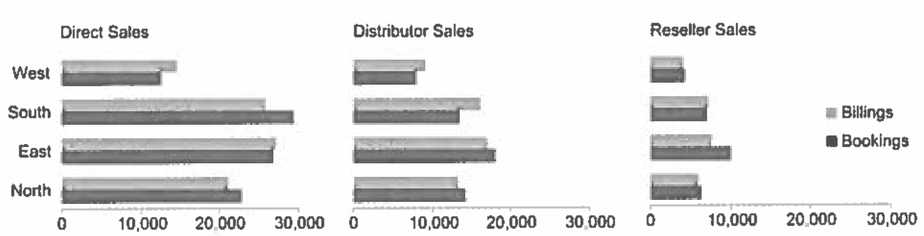


FIGURE 11.9 This arrangement of small multiples makes it easier to focus on a particular region across all sales channels.

If you wanted to make it as easy as possible to compare sales performance for a given region across all three sales channels, then it would make sense to place the sales channels along the Y axis and create four graphs, one for each region, as follows:

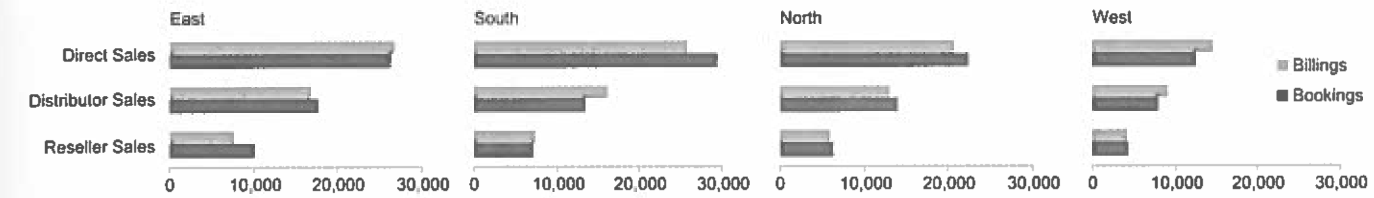


FIGURE 11.10 This arrangement of small multiples makes it easiest to compare sales channels in a specific region.

Every arrangement has its strengths and weaknesses. The best arrangement depends entirely on which comparisons your readers will most need to make. If a single arrangement won't support most of what they need to do, then multiple arrangements would be useful. Just as one graph won't always give readers everything they need, one arrangement of small multiples won't always suffice.

When a single column or row can't display all the small multiples in a series, you can arrange them as a matrix. A matrix of small multiples allows you to squeeze many onto a single page or screen. Here's an example with six scatter plots.

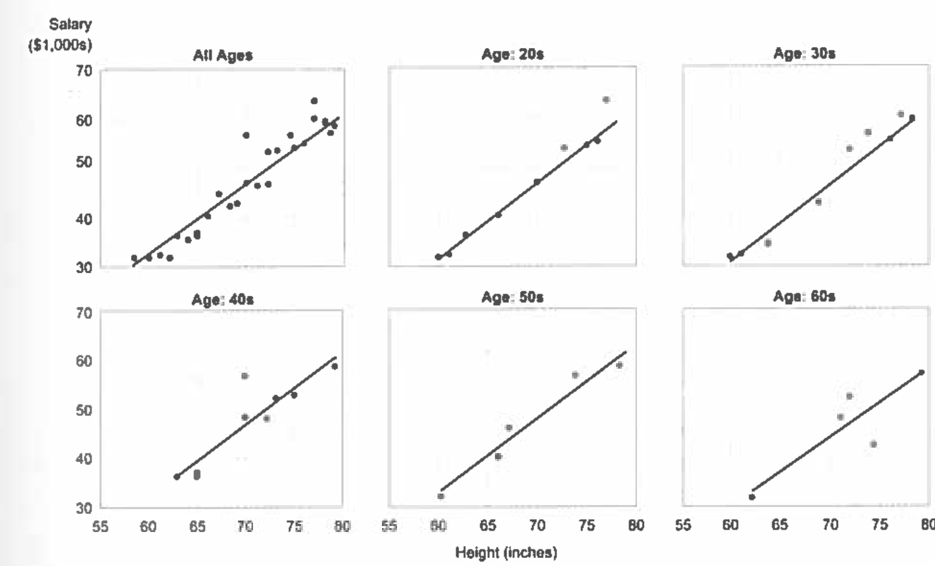


FIGURE 11.11 This series of scatter plots is arranged as a matrix. Employees' heights and salaries are correlated along the X and Y axes, and their ages are grouped into separate graphs.

As you can see, many more than six graphs could have been squeezed onto a single page or screen.

Any type of graph can be arranged in a matrix of small multiples, but this arrangement excels for the display of scatter plots, which can incorporate an extremely large amount of information for simultaneous viewing and comparative pattern detection. This allows you to display correlations among three sets of variables: two associated with the X and Y axes and a third per graph. Even when you're not using scatter plots, if you can't fit the entire series across or down a single page or screen, a matrix arrangement is a good alternative. For instance, having to scan one graph at a time across five rows of bar graphs on a single page or screen is a negligible disadvantage compared to our inability to remember them if they were spread across multiple pages or screens. Notice how nicely this works:

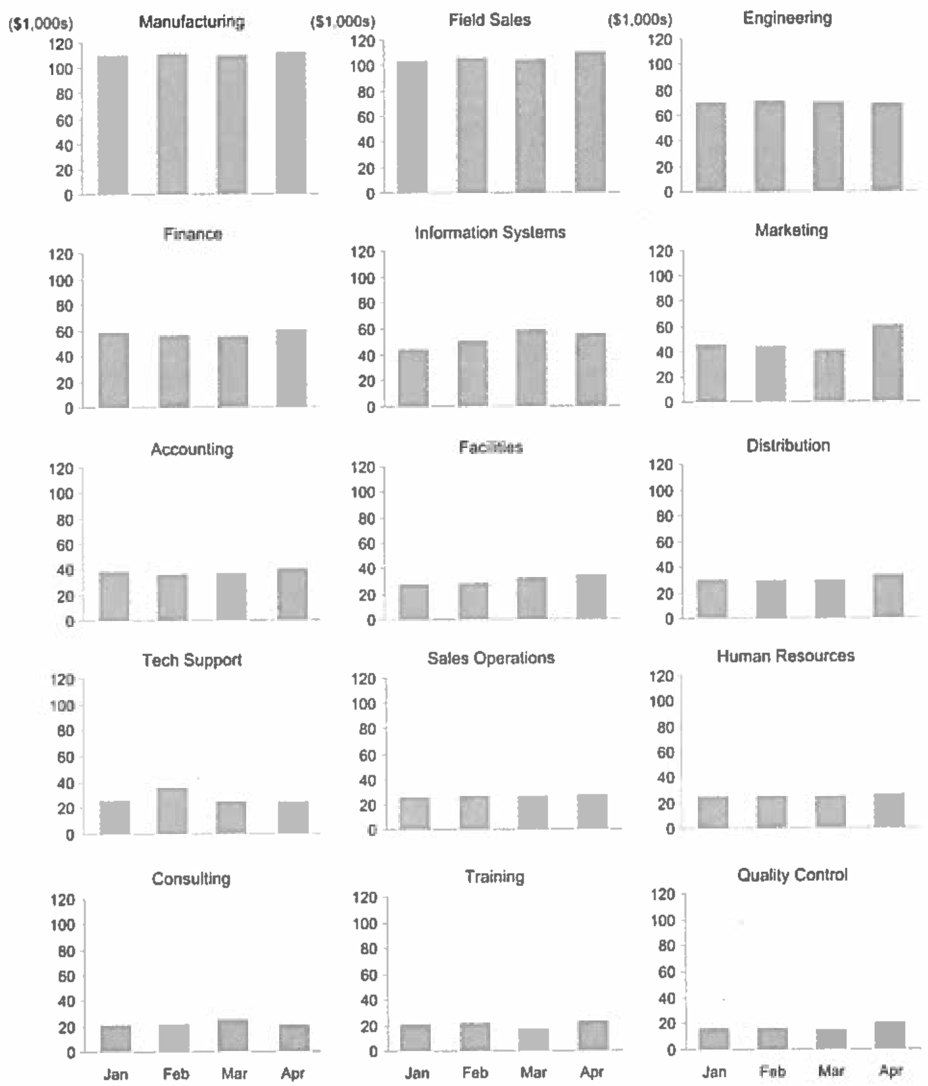


FIGURE 11.12 This series of small multiples has been arranged in a matrix even though it includes a categorical scale on one of the axes.

Sequence

Just like the sequencing of categorical items in a single graph, the sequencing of small multiples can contribute a great deal to their effectiveness, especially to your readers' ability to see meaningful patterns and to compare values that appear in different graphs. Take a look at the same series of small multiples that appears in *Figure 11.12* arranged alphabetically rather than from the department with the highest expenses to the one with the lowest.

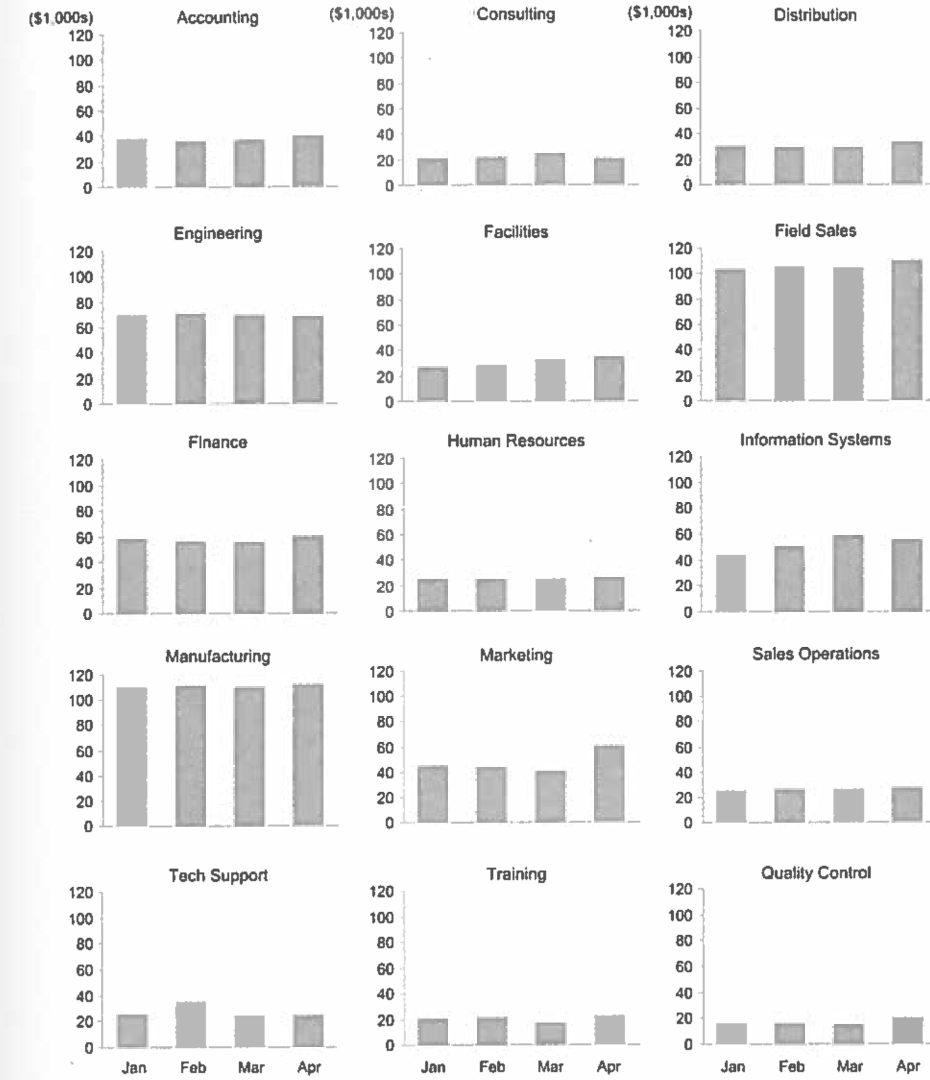


FIGURE 11.13 This series of small multiples is sequenced alphabetically by department name.

It is now more difficult to compare values among the various graphs because sets of values that are close in size are no longer near one another.

The category that varies from graph to graph in a series of small multiples is called the *index variable*. Items in the index variable sometimes have a proper order. This order can help us determine how to sequence the graphs. For instance, if each of the graphs represents a different year, then you will usually want to sequence the graphs chronologically. When a meaningful order is built into the index variable and there is no overriding reason to sequence the graphs in a different order, you should sequence them accordingly. When there is no intrinsic order built into the index variable, you should sequence the graphs according to their quantitative values from low to high or high to low. Imagine that you have a series of graphs displaying sales data, and the index variable is product. Two ways of sequencing the graphs appear on the following page:

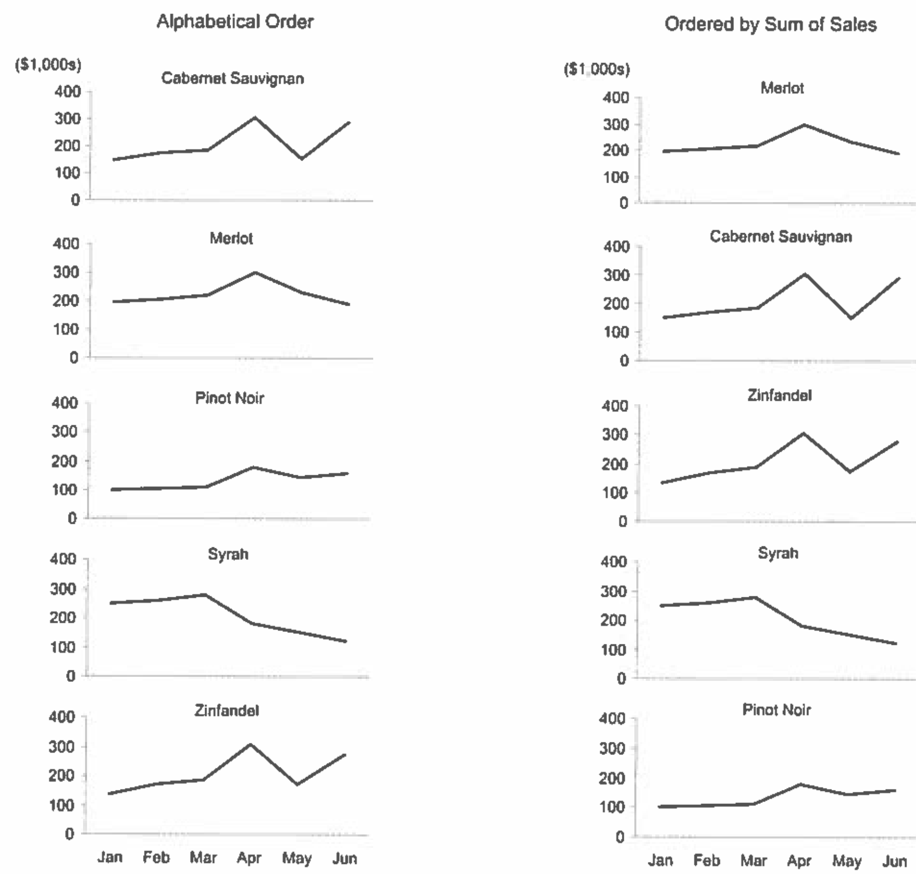


FIGURE 11.14 Two ways of sequencing a series of small multiples.

The series on the left is sequenced alphabetically by product name, but this arrangement isn't helpful, is it? The only purpose of alphabetical order is to make it easy to find individual items in a long list. With a small collection of graphs such as this, no one would need an alphabetical arrangement to find a particular product. It is much more useful to sequence these graphs by sales amounts as on the right, which makes their relative performance clear. When sequencing graphs in rank order by value, you must decide whether to base the sequence on an aggregation of all values in each graph (usually the sum or mean) or on a particular value (e.g., the final month of June). Choose the one that is most relevant to your message. If each graph includes more than one set of values, such as bookings and billings, base the sequence on the set of values that is most significant to your message.

Sums and means aren't always the appropriate values on which to base your sequence. The best choice depends on the relationship you're displaying, the values you're using to display that relationship, and the essential point you're trying to make. If you were displaying correlations using a matrix of scatter plots, it might be appropriate to rank the graphs based on the linear correlation coefficient. If you were displaying frequency distributions, the spread or median might be the best value to use for sequencing the graphs. No matter what value you use, the objective is to sequence the graphs to reveal most clearly the relationships that are central to your message.

Unless the order in which you've sequenced the graphs in a series of small multiples is obvious, it's helpful to add a note to make clear what the order is.

Rules and Grid Lines

Rules or grid lines can be used to delineate graphs in a series of small multiples but are rarely needed. They are only useful when one of the following circumstances exists:

- White space alone is not sufficient to delineate the graphs because of space constraints.
- The graphs are arranged in a matrix, and white space alone cannot be used to direct your readers to scan the graphs in a particular sequence, either across the rows or down the columns.

The following examples illustrate how rules can be used to direct readers to scan primarily in a horizontal direction.

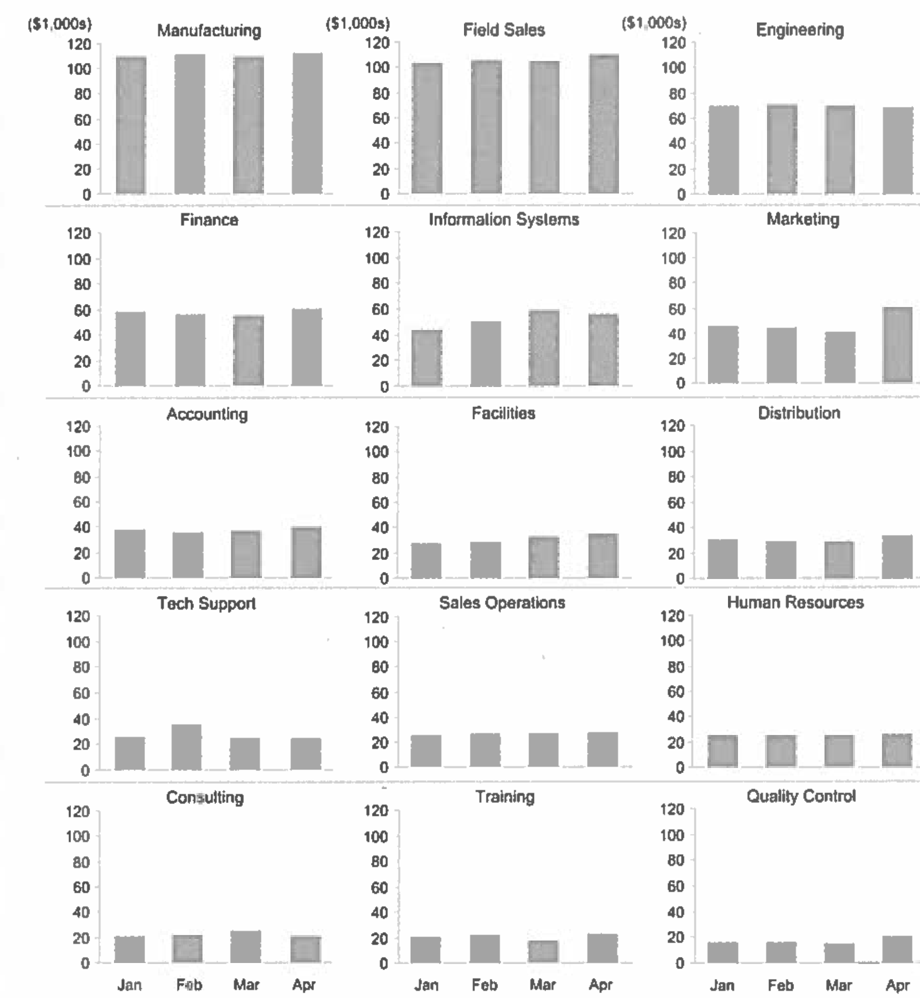


FIGURE 11.15 This matrix of graphs uses rules to direct readers to scan the graphs sequentially by row.

Keep in mind that rules and grid lines should always be rendered subtly, never prominently in the form of thick, dark, or bright lines.

Other Arrangements of Multi-Graph Series

Graphs in a series of small multiples like those that we've already examined all share the same categorical and quantitative scales. The same unit of measure is used in each graph, such as sales in dollars, order count, expenses in dollars, or headcount. Two variations on the small multiples theme are also useful. When you have a matrix of graphs (rather than a single series of small multiples that vary along one variable only, such as department in *Figure 11.15*), the graphs can vary along two variables simultaneously if you assign one variable to the columns and the other to the rows. This arrangement can be thought of as a *visual crosstab* or *visual pivot table*. This is easier to explain by showing. Here's a simple example:

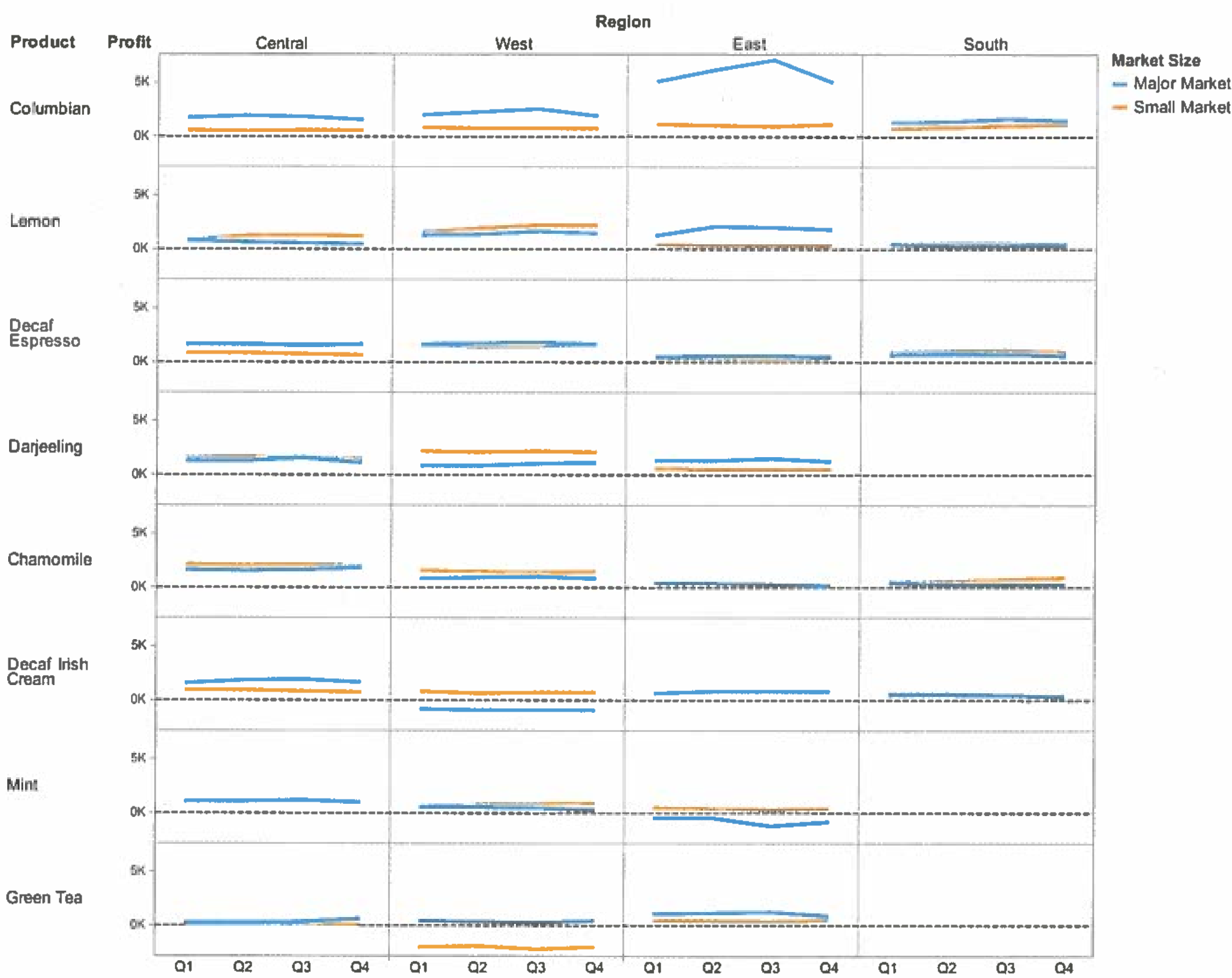


FIGURE 11.16 This matrix of graphs, created using Tableau, displays products by row and regions by column.

A normal series of small multiples introduces one additional categorical variable to the display; multiples arranged in a visual crosstab introduce two variables.

It is also useful at times to compare multiple units of measure. Imagine that you want to display forecast versus actual revenue, order count, and average order size across four quarters of a year for five separate products. You want to arrange these separate measures of sales in a way that enables easy comparisons. A matrix is an ideal solution. Take a look:

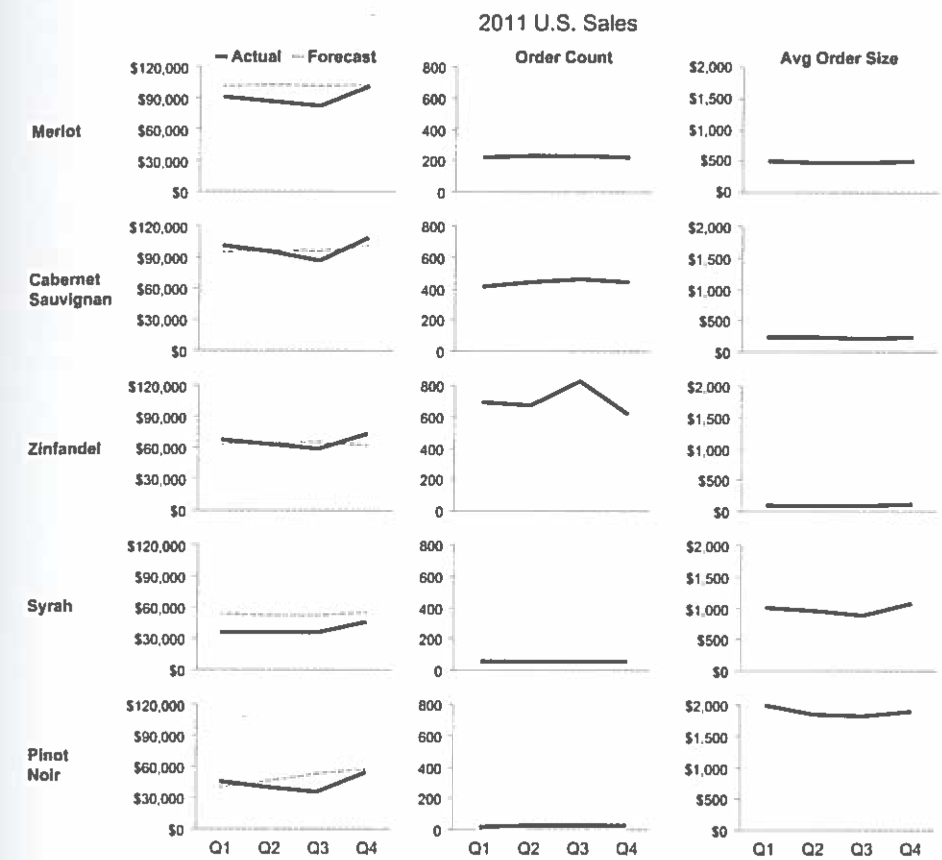


FIGURE 11.17 This matrix of graphs includes three separate but related series: forecast versus actual, order count, and average order size.

Note that a matrix of graphs consisting of multiple but related series must share a categorical variable, which in this case is product. Otherwise, the series of graphs wouldn't be related. This type of design allows readers to examine each series of sales measures independently (down a single column), examine all sales measures for a single product (across a single row), or view both at the same time looking for overall patterns. This is a powerful method for quantitative communication.

Summary at a Glance

Combining Multiple Units of Measure

When you wish to display two units of measure for purposes of comparison, the best way to avoid confusion is usually to use separate graphs rather than a single graph with two quantitative scales.

Combining Multiple Graphs in a Series

When you need to add one more variable (i.e., another set of categorical subdivisions) to a graph, but you've already used all the practical means to visually encode values in it, you can do so by constructing a series of related graphs, in which each graph in the series displays a different instance of the added variable.

Topic	Practices
Consistency	• Graphs in a series of small multiples should be consistently designed with only one exception: text used for labels, titles, or legends does not need to appear redundantly in each graph.
Arrangement	• Arrange the graphs in a series of small multiples in the way that makes it as easy as possible to focus on and compare the values that are most relevant to your readers' interests.
Sequence	• If the index variable has an intrinsic order, you should sequence the graphs in this order unless you wish to display a ranking relationship. • Otherwise, rank the graphs in order based on a quantitative measure associated with the index variable.
Rules and grid lines	• Only use rules or grid lines between graphs in a series when either of these two conditions exists: ◦ The graphs must be positioned so closely together that white space alone cannot adequately delineate them. ◦ The graphs are arranged in a matrix and are positioned so closely together that white space alone cannot adequately direct your readers to scan either across or down in the manner you intend.

12 SILLY GRAPHS THAT ARE BEST FORSAKEN

Several graphs that are readily available in software fail miserably at data presentation even though their popularity is growing. The stories that people attempt to tell with these graphs can be told simply and clearly using alternatives that are described in this chapter.

In this chapter we'll take a look at several graphs that are almost never useful. The reason is straightforward: they don't communicate data effectively. In every case the stories that these graphs attempt to tell can be told quite well using other graphs. We'll examine the following seven graphs—why they don't work and how their stories can be better told:

- Donut charts
- Radar charts
- Area charts for combining part-to-whole and time-series relationships
- Circle charts
- Unit charts
- Funnel charts
- Waterfall charts for simple part-to-whole relationships

These graphs are sometimes used because they're cute, sometimes because they're based on a meaningful metaphor (e.g., funnel charts), and often for the simple reason that they are readily available in software. No matter how convenient these graphs are or how impressive they seem—they might even be beautiful—they fail if they don't present information clearly, accurately, efficiently, and accessibly. They all fail for reasons, mostly perceptual, that we've considered in earlier chapters.

Donut Charts

A *donut chart* is a pie chart with a hole in the middle. Both pie and donut charts attempt to display parts of a whole. If pie charts are graphical pastries filled with empty calories, donut charts are the same and more. Here's a typical example:

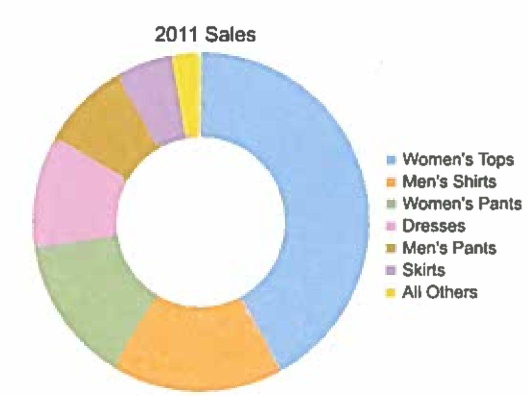


FIGURE 12.1 This is a typical donut chart.

Exercise #8

For this last exercise, you are a Sales Analyst. Based on analysis of sales revenues for the past four years, you've noticed that there is a clear cyclical trend. The highest revenues are always generated during the last month of each quarter and the last quarter of each year, without exception. You want to use this information to point out the need for distributing sales activity more evenly across the year so that sales operations are not hit with such spikes in activity at quarter ends, especially at year ends. The following table contains the data, in U.S. dollars:

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008	50,000	52,000	55,000	51,000	52,000	55,000	48,000	49,000	50,000	53,000	56,000	62,000
2009	54,000	56,000	57,000	53,000	53,000	57,000	53,000	55,000	59,000	60,000	65,000	71,000
2010	61,000	60,000	65,000	62,000	64,000	68,000	59,000	60,000	65,000	67,000	70,000	75,000
2011	60,000	61,000	68,000	63,000	63,000	67,000	60,000	61,000	67,000	66,000	68,000	74,000

Create one or more graphs to display this information. Once you've completed your graph, take a few minutes to describe its design, including your rationale for each design feature.

You can find answers to these exercises in Appendix H, *Answers to Practice in Graph Design*.

13 TELLING COMPELLING STORIES WITH NUMBERS

Important stories live in the numbers that measure what's going on in the world. Before we can present quantitative information, we must first uncover and understand its stories. Once we know the stories, we can tell them in ways that help others to understand them as well.

We are natural-born storytellers. Humans have been creating and preserving culture through stories since we learned to speak. The numbers that are stored in our databases and spreadsheets have important stories to tell, and only we can give them a voice. However, before stories can be told, they must be discovered and understood. Data sensemaking precedes data presentation. Before you present data to others, you should always ask: "What's the story?" The nature of the story and the nature of the audience will determine the best way to tell it. Once you know the story, presenting it is much like storytelling of all types; it boils down to clear communication. Telling stories with numbers—statistical narrative—involves a few specialized skills, but they're not complicated. In this chapter, we'll examine a few of the principles and practices that will help to bring quantitative stories to life.

For instruction in the use of graphs for data exploration and sensemaking, see my book *Now You See It: Simple Visualization Techniques for Data Analysis* (2009).

In 2006, when Hans Rosling of www.GapMinder.org spoke at the TED Conference, it was probably the first time in history that an audience arose to its feet in applause after viewing a bubble plot.

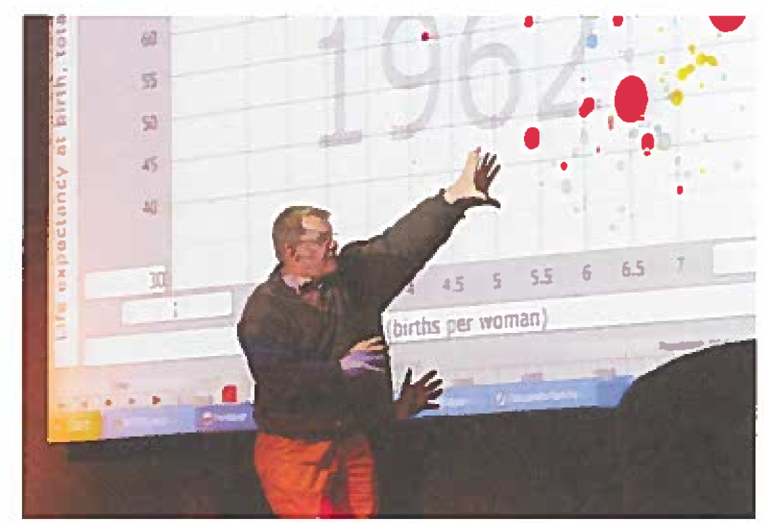


FIGURE 13.1 Hans Rosling of www.GapMinder.org, presenting for the first time at the TED Conference in 2006.

Rosling's bubble plot went further than most by displaying a fourth variable in a way that was novel: through animation. Bubbles moved around in the plot area to show how values changed through time. In this particular presentation, the bubble plot displayed a bubble for each country in the world, sized according to population and colored to group countries by region. Horizontal position along the X axis represented the average number of births per woman of childbearing age, and vertical position along the Y axis represented average life expectancy at birth in years. Beginning with United Nations data from 1962, the graph shows that countries at that time were roughly divided into two groups: developed countries in the upper left section of the graph, with few children per woman and long lives, versus developing countries in the lower right, with many children per woman and short lives. When the bubbles began to move around to show how these values changed from 1962 through 2003, Rosling drew the audience's attention to particular bubbles that exhibited interesting behavior, such as Bangladesh, which began a rapid decrease in the number of children per woman and increase in longevity when the imams in that country began to promote family planning. By the time the bubbles ceased their movement in the year 2003, the graph displayed a completely different world—one in which most countries had small families and long lives, with exceptions almost entirely among African countries where the HIV epidemic kept average lifespans short.

Why did people find Rosling's graph more engaging than most? I suspect for three reasons:

1. The story that he told was important; it revealed facts about life expectancy and family size that the audience could easily care about.
2. The story was told in a way that the audience could understand.
3. Rosling is a skilled storyteller.

Just as Rosling brings important quantitative stories to life in ways that enlighten and move his audience, you can find compelling ways to tell your own stories. If a story is worth telling, it's worth telling it well. To do so, you need a few skills that apply to communication in general, and a few that are specific to stories contained in numbers.

Learning these skills has, in recent years, become the interest of diverse groups that work with data, especially journalists. Journalistic infographics have attracted a great deal of attention recently, at times with breathtakingly informative visualizations but more often with silly eye-catching displays that dazzle while saying little and saying it poorly. Even Rosling was lured into this trap when he allowed the video crew of BBC4 to add video effects to one of his presentations that made it almost impossible to see and follow the data. The presentation was flashy, but the story got lost behind the glaring lights and visual effects.

FIGURE 13.2 Hans Rosling presenting information while standing behind a virtual graph placed on the screen by means of a video effects in a BBC4 documentary entitled "The Joy of Stats."

Had the video effects been eliminated, Rosling's presentation would have engaged viewers in the data, drawing them into the story, rather than distracting them with the special effects. Stories can be told in ways that thrill and move an audience without using silly tricks that obscure the information.

Characteristics of Well-Told Statistical Stories

Stories can be told in various ways involving multiple media. Words can be complemented by pictures and diagrams. You can rarely tell quantitative stories by expressing numbers as text alone; you must use pictures as well. Whether expressed as text or graphically, numbers are numbers, but text and graphics each possess different strengths. Visual representations of numbers feature patterns, trends, and exceptions and make it possible for people to compare whole series of values to one another, such as domestic versus international sales throughout the year. You must learn when words work best and when graphs and other forms of visual display are needed, and then interweave them in powerful, engaging, and informative ways.

Let's examine several of the principles and practices that are required to tell stories with numbers in ways that inform and matter. Statistical narrative usually works best when it exhibits the following characteristics:

- Simple
- Seamless
- Informative
- True
- Contextual
- Familiar
- Concrete
- Personal
- Emotional
- Actionable
- Sequential

Simple

A story is more likely to take hold in the minds of your audience if you tell it simply. You must identify the essential message and then present it as simply as possible without distraction. Simplicity isn't always easy. In fact, it is often quite difficult to achieve. You must carefully discern the vital beating heart of your message—its essence—before constructing your story and crafting its presentation. Once your vision is clear, you must then find the clearest possible way to present it, both in content and means of expression.

Paul Grice, a philosopher of language, developed a series of "conversational maxims"—rules for communicating to one another courteously and effectively. Among his guidelines are these two:

- Make your contribution as informative as is required for the current purposes of the exchange.
- Do not make your contribution more informative than is required.

When telling a story, you should present all that must be known to get the message across, but no more. The effectiveness of the story relies on a fine balance between too little and too much. Comic book artist Scott McCloud explains how he crafts his stories to achieve "amplification through simplification"—amplification of meaning and understanding by simplifying the means of expression. He illustrates the concept in the following panel:

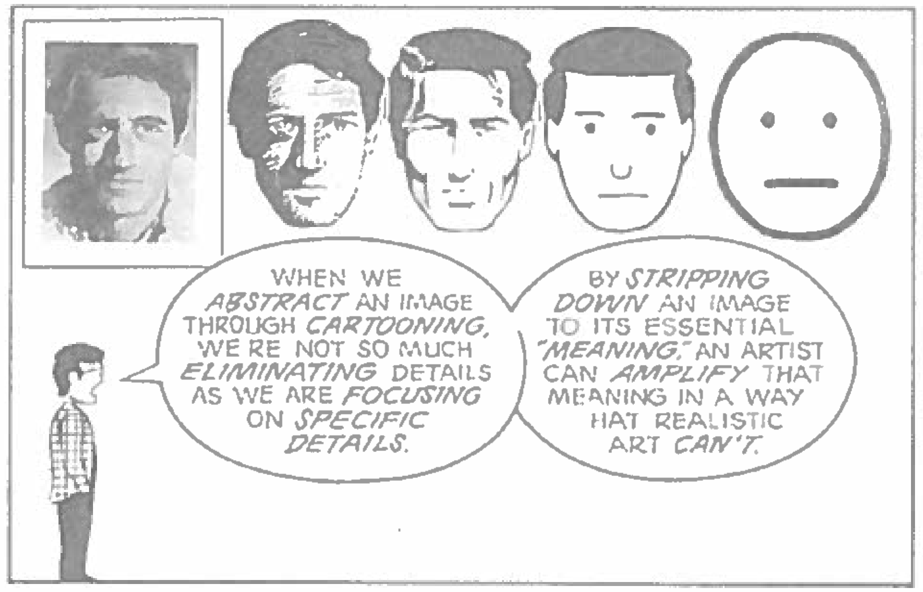


FIGURE 13.3 An excerpt from Scott McCloud (1994) *Understanding Comics: The Invisible Art*. HarperCollins, page 30.

Simplification involves a stripping away of all that's non-essential, which allows your audience to easily focus without distraction on what's most important. As Leonardo da Vinci wisely recognized, "Simplicity is the ultimate sophistication."

Seamless

Unlike some stories, statistical narrative almost always involves integrating words and images. The patterns, trends, and exceptions that constitute the meanings in data must be given visual form, for they are difficult—sometimes impossible—to weave together in our heads from words and tables of numbers. Verbal and visual forms of expression are both languages of sorts. Just as letters combine to form words, and words combine to form sentences, graphical marks combine to form visual objects, and those objects combine to form more complex objects such as graphs, which we can use to tell quantitative stories. As Jacques Bertin taught in his groundbreaking book *Semiologie graphique* (*Semiology of Graphics*) and Robert Horn extended in *Visual Language: Global Communication for the 21st Century*, graphics are a specialized language that can communicate quite effectively if we learn its rules of syntax and semantics.

Edward Tufte has long taught the power of seamlessly integrating words and pictures to tell stories. He and I both labor hard to interweave graphs and other images with the text that describes them, rather than the easier (and cheaper) method of referencing figures by number and placing them wherever they most conveniently fit. Verbal language expresses some information best, but other

information is better communicated visually. Words and images collaborate elegantly when we resist arbitrarily separating them. Tufte says:

> *Data graphics are paragraphs about data and should be treated as such.*
>
> *Words, graphics, and tables are different mechanisms with but a single purpose—the presentation of information. Why should the flow of information be broken up into different places on the page because the information is packaged one way or another?*[1]

1. Edward Tufte (2001) *The Visual Display of Quantitative Information*, Second Edition. Graphics Press, page 181.

One of the finest early examples of this seamless tapestry of words and pictures comes from the writings of Leonardo da Vinci:

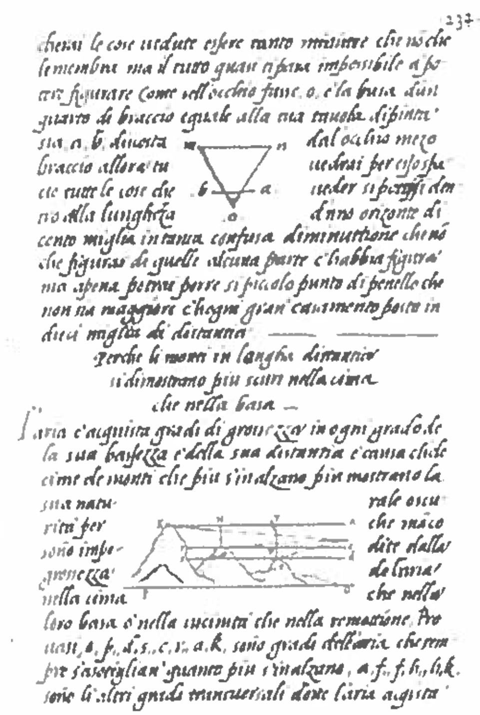


FIGURE 13.4 A seamless integration of words and pictures from Leonardo da Vinci's notebooks, later published under the title *A Treatise on Painting*.

As you can see, da Vinci saw no reason to arbitrarily separate words and pictures that are meant to work together.

When you combine words and pictures to tell a story to a live audience or by means of an audio-video recording, you can speak the words and show the pictures simultaneously. If the images are projected on a screen, you can gesture to those parts that you want your audience to focus on in any given moment. If you speak the words, there is no reason to display them as text on the screen as well. In fact, doing so interrupts the flow of communication. When your audience attempts to both read words on the screen and listen to the words coming from your mouth, the information gets into their brains less effectively than words coming through one channel only. Don't force your audience to read when they could be using their eyes to contemplate an image that complements your words. Visual and verbal content are processed by different parts of the brain and can be perceived and processed together with ease, resulting in richer understanding.

Informative

Stories should inform, revealing facts or interpretations of facts that your audience doesn't already know. Few experiences are more sleep-inducing than sitting through a presentation that repeats what you already know. If you want to arouse your audience's curiosity and interest, give their brains something new to chew on.

In their marvelous book *Made to Stick*,[2] the brothers Chip and Dan Heath describe what's needed to get a message to stick: to communicate it in a way that is understood, remembered, and has a chance to produce the hoped-for response. Several of the points that I'm making in this chapter are eloquently described in *Made to Stick*. One way to make a message stick is to elicit surprise by revealing something unexpected. This can often be done with images that force people to look at something from a new perspective. Hans Rosling's 2006 presentation at the TED Conference stuck, in part because he revealed a relationship between fertility (measured as the average number of children per woman of child bearing age) and life expectancy at birth (measured as the average number of years a child will live) that surprised many in the audience. Afterwards, they left the auditorium informed and thoughtful.

2. Chip Heath and Dan Heath (2007) *Made to Stick: Why Some Ideas Survive and Others Die*. Random House.

True

Let's go no further without acknowledging the importance of truth. Stories need not be true to stick—history is strewn with the destructive fallout of lies—but they should be true if you hope to make the world a better place. If your audience perceives the story as true, they will care about it more and are more likely to respond. This means that the story should not only be true, but should also be perceived as true. You should validate the story with relevant evidence. You should name your sources to lend credibility both through transparency and by virtue of the source's perceived credibility. If you yourself believe the story to be true, convinced through solid evidence, your conviction will be noticed. If you have integrity and consistently exhibit it through your actions, the trust that you earn will extend to your stories as well.

Contextual

Quantitative stories cannot be told effectively merely by presenting numbers. Numbers alone—even those that measure something worthwhile—are meaningless unless you present them in context. In part, this means that you should reveal the pedigree of the numbers (that is, where they came from and how you might have adjusted them). Even more importantly, however, this means that you must provide additional information to which the numbers can be compared. People discover meanings in numbers primarily by comparing them to other numbers, and by comparing the patterns, trends, and exceptions that live within them to those that dwell in others. Relevant comparisons make numbers meaningful in a way that can be used to form judgments, make decisions, and take action.

Appropriate comparisons span a long list of possibilities. One of the most meaningful and informative involves comparing what's going on today to what happened in the past. History provides context that we dare not ignore, lest we relive its dark moments. Other examples of useful objects of comparison include:

- Targets (e.g., budgets and plans)
- Forecasts (i.e., what you predict will happen)
- Other things in the same category (e.g., comparing a product to other products, or comparing your company to competitors)
- Norms (e.g., comparing the performance of one hospital to the average performance of all hospitals in the cohort group)

Is it enough to tell the Vice President of Sales that $8,302,563.38 in revenue has come in so far this year? What does that mean? Let's add some context:

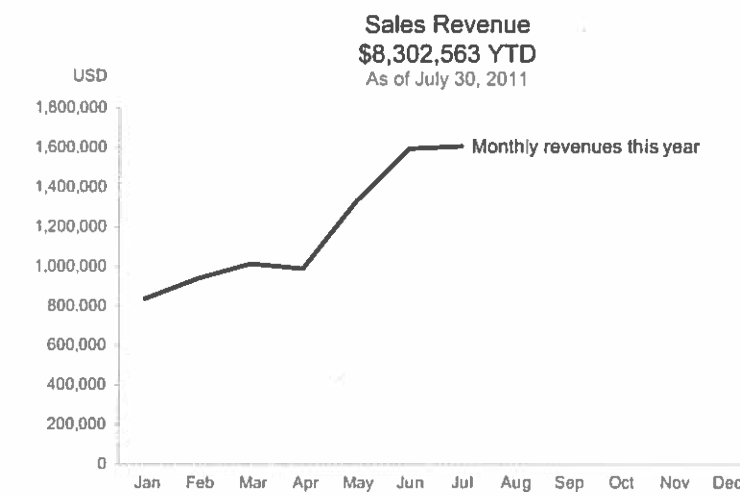


FIGURE 13.5 Several months of history has been added to provide context for current revenues.

Now, with monthly revenue values so far this year and only one more day left in July, it is easy to see that revenues have leveled off in this month after two months of significant increase. Let's add some more context:

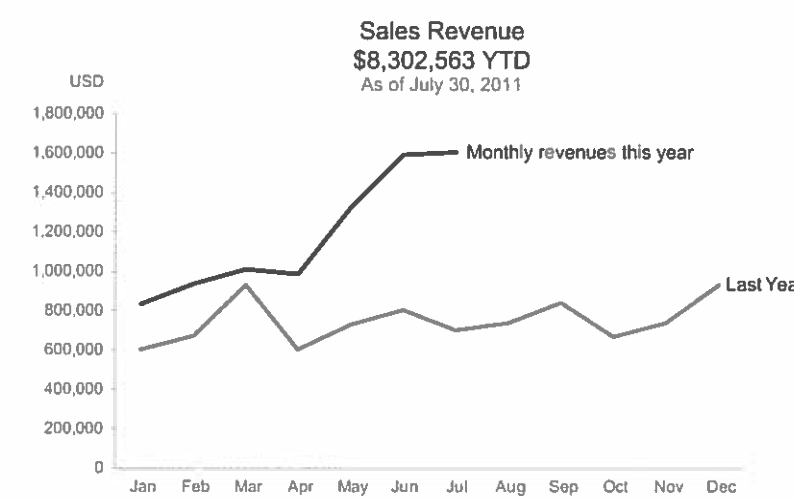


FIGURE 13.6 Last year's revenues have now been added to provide even more historical context.

With the addition of last year's revenues, it is now easy to see that the pattern of sales this year is quite different from the pattern last year. The fact that revenues leveled off this year in July doesn't look so bad in light of the fact that they decreased in July last year. Let's add one final bit of context:

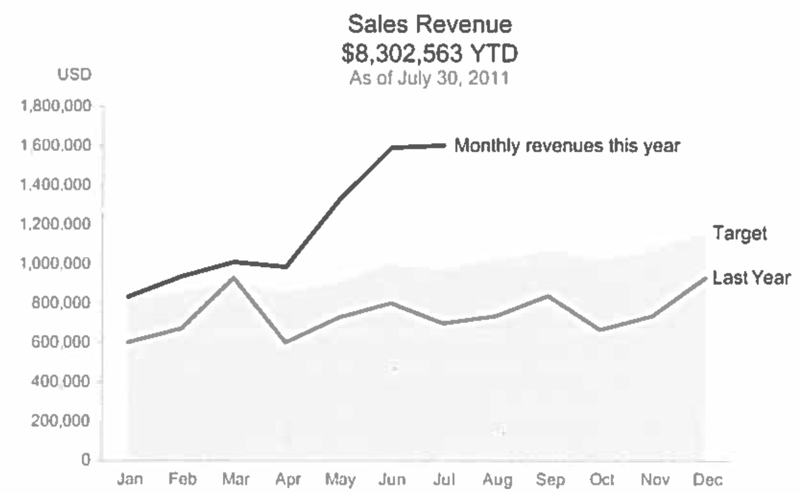


FIGURE 13.7 Target revenues have now been added to provide richer context for understanding revenue performance.

For quantitative information, meaning only becomes visible against the backdrop of comparisons.

Familiar

Know your audience. It's no secret that you must have a sense of the people you're addressing and customize the presentation to reach them. I don't speak to trained statisticians in exactly the same way that I speak to non-statisticians. I don't speak to doctors and nurses the same as I speak to people who work in a marketing department. I might be telling the same essential story to both groups, but I'll choose some of my words and images differently. Why? I want to express the story in familiar and relevant terms so that my audience will understand and care about it.

If you spend your life in a cloister without interaction with those outside the walls, you'll struggle to talk to those who live in the nearby village. If you're an expert data analyst, you probably speak and think in ways that aren't familiar to others in your organization who lack your training. If you can tell your story using simple words and images that are familiar to everyone, why would you use cryptic terms and complicated graphs, unless you're trying to impress them with your superior knowledge? If people care about the story, they will be much more impressed if you tell it in a way that they understand. Although Hans Rosling is a university professor who could confound most of us with the specialized knowledge of his field, we respect his work because he cares enough to boil his stories down (without watering them down) to simple terms. People who can't tell their stories in understandable ways are either naive (unaware of the world outside of their own small spheres), lazy (unwilling to craft the story in familiar terms), full of themselves (more interested in impressing than communicating), unskilled in the use of everyday language, or just don't understand their stories well enough to tell them clearly.

Concrete

Even though humans have evolved the extraordinary ability to think abstractly, we don't dwell entirely in the abstract. When our stories involve abstract concepts, which they often do, we can help people make sense of those abstractions by using concrete examples and metaphors. Chip and Dan Heath say it well:

> *Concrete language helps people, especially novices, understand new concepts. Abstraction is the luxury of the expert. If you've got to teach an idea to a room full of people, and you aren't certain what they know, concreteness is the only safe language.*[3]

Many organizations express their mission statements in shallow, ethereal, and uninspiring abstractions. Smart organizations express them in concrete terms that people can embrace with their heads and hearts. Some people intentionally use abstractions to hide the truth. Read the following excerpt from Enron's annual report for the year 2000:

> *Enron's performance in 2000 was a success by any measure, as we continued to outdistance the competition and solidify our leadership in each of our major businesses. We have robust networks of strategic assets that we own or have contractual access to, which give us greater flexibility and speed to reliably deliver widespread logistical solutions...We have metamorphosed from an asset-based pipeline and power generating company to a marketing and logistics company whose biggest assets are its well-established business approach and its innovative people.*[4]

We now know that, had the story been told in concrete ways in that annual report, employees could have willingly left in disgust before the company's implosion. The leaders of Enron intentionally kept the story abstract. They weren't trying to communicate; they were trying to obfuscate.

Some numbers are difficult to understand. This is especially true of extremely large and extremely small numbers. You can make it possible for people to wrap their heads around such numbers by expressing them in concrete terms, usually by comparing them to other numbers that are familiar and easy to understand. In the year 2010, the richest person in the world was Carlos Slim Helu, a Mexican Telecommunications mogul, whose net worth came to a total of $53.5 billion (USD). Most of us can't think in terms of this much money. Expressed in this way, the number is almost meaningless. One way to express the amount more concretely is to compare it to numbers that are more comprehensible, such as:

> Carlos Slim Helu's net worth of $53.5 billion (USD) is equal to the annual income of 1.7 million workers in the U.S. or 9.2 million workers in Mexico.

Even though we're still using numbers in the millions, they're within reach and concrete.

3. Chip Heath and Dan Heath (2007) *Made to Stick*. Random House, page 104.

4. Brian Fugere, Chelsea Hardaway & Jon Warshawsky (2005) *Why Business People Speak Like Idiots*. Free Press, page 11.

Personal

Stories have a greater effect when people connect with them in personal ways. Sometimes it's easy to make stories personal because they relate to your audience directly. In such cases, you can point out in concrete ways how the story addresses their interests. Even when the story is about people and things taking place in some remote part of the planet, there is usually a way to help people connect in some personal way if the story's important. The fact that global warming will literally bury beneath the sea islands where people now live might not affect us directly, but if you show where those islands are on a map along with pictures of those people, your audience might begin to care about those strangers and imagine facing their plight.

Emotional

The emotional element of an effective story is intimately related to the personal characteristic we just discussed. When things are personal, they stir up emotions in us; when our emotions are stirred, we tend to experience things personally. As much as we'd like to believe that we're rational creatures, research has shown that most decisions are based on emotion. Our brains are wired to fire up and take action when our emotions are aroused. People will only respond to a story if they care about the message. They must feel something. Knowledge of this fact can be used for good or ill, however. If you rile emotions to promote decisions that hurt people, you manipulate emotions for your benefit, not theirs. Out of shameful self-interest, many individuals and organizations promote outright lies to incite emotions in the service of their own agendas.

The best way to get people to care is to connect the story to something they already care about. When I read *Made to Stick*, I learned about a hospital that wanted to improve its workflow. Its administrators hired the design firm IDEO to help them convince the hospital staff that improvement was necessary. To do this, IDEO made a video that was shot from the perspective of a patient who enters the emergency room with a fractured leg. When hospital workers watched this video, they experienced what it was like to be a patient helplessly caught in a dysfunctional workflow, moved from place to place, waiting for long periods, all the while in pain. For the first time they saw hospital workflow from a different perspective, through the eyes of their patients, and they were suddenly able to care.

Videos are not always needed to help people connect with stories emotionally. Sometimes emotional connection can be accomplished by doing nothing more than showing the photograph of a real person who's involved in the story, which puts a face on an otherwise abstract problem. Sometimes it can be done by showing a graph that reveals the extent of the problem in simple and straight-forward terms. Bill Gates, the founder of Microsoft, first decided to focus many of the Bill and Melinda Gates Foundation's philanthropic efforts on solving world health problems when he saw a graph on the topic in the *New York Times* that caught his eye and touched his heart. More than anything else, however, we can help others care about our stories if we care about them ourselves. Nothing is more powerful than genuine passion.

Actionable

Despite my reservations about the term "actionable" because of the marketing hype surrounding it, I can't come up with another single word that says what I want to say better here. Effective stories make it easy for people to respond—to take action. Stories do this by suggesting, either directly or subtly, one or more ways to respond. If you want your stories to have an effect, you must suggest practical ways to build a bridge between the world that is and the world you desire.

Sequential

Narrative unfolds in a serial fashion, with a beginning, a middle, and an end. Stories are usually told sequentially by revealing facts at the proper moment. You might hint at things to come to build anticipation, but you should reveal a story's parts in a way that matches the chronology of events; builds concepts from simple ideas to more complex wholes; or states a thesis, validates it with evidence, and connects it to the audience's values, one point at a time in logical order.

When you tell a story verbally with the assistance of visuals, those visuals should not be revealed until the moment when they're relevant. As you refer to parts of a visual image, do something to highlight that part, such as pointing to it or visibly emphasizing it on the screen. Your audience should never struggle to locate what you're talking about. Whether you deliver the narrative verbally or in writing, if you are presenting complex concepts, build them piece by piece, adding complexity in stages as each previous stage is absorbed by the audience.

Despite their many problems, slideware products like PowerPoint and Keynote can be used quite effectively for statistical narrative. Slides are appropriate when verbal presentations can be enhanced through visual images. The sequential nature of slides, transitions, and the sudden appearance of words and images often pairs nicely with storytelling. Although I share Edward Tufte's opinion that PowerPoint encourages horrible presentations, I believe that its limitations and counterproductive recommendations can be bypassed to produce compelling stories. Tufte argues:

> *With information quickly appearing and disappearing, the slide transition is an event that attracts attention to the presentation's compositional methods. Slides serve up small chunks of promptly vanishing information in a restless one-way sequence. It is not a contemplative analytical method; it is like television, or a movie with over-frequent random jump-cuts.*[5]

In fact, slideware in no way forces us to show only tiny fragments of information at a time or to venture forward and never backward. Tufte further asserts: "The rigid slide-by-slide hierarchies, indifferent to content, slice and dice the evidence into arbitrary compartments, producing an anti-narrative with choppy continuity."[6] But slides are no more prisoners of a hierarchy than pages of a book. Used properly, slides can complement the words of a gifted speaker with images that bring the story to life and express it clearly.

Slideware certainly isn't the only way to tell a quantitative story sequentially.

5. Edward Tufte (2006) *Beautiful Evidence*. Graphics Press, page 160.

6. *ibid.* page 166

When using a medium that doesn't enforce a sequence by dividing content into slides, pages, or chapters, you must find another way to make the sequence obvious. For instance, you could tell a quantitative story on a single large screen or sheet of poster-sized paper. In such a case, you could choose from several methods to guide the reader through the information in the proper order. Comic books and graphic novels sequence narrative into panels arranged from left to right, top to bottom. A poster can number sections of the display or use arrows to reveal the suggested path.

Stories in the Wings

Hiding in the wings are more quantitative stories than we will ever know, waiting for their moments of truth. We must try to find them, coax them from the shadows, lead them to the stage, and give them a voice. You can apply these storytelling skills to make your own part of the world a better place.

14 THE INTERPLAY OF STANDARDS AND INNOVATION

When you design tables and graphs, you face many choices. Of the available alternatives, some are bad, some are good, some are best, and others are simply a matter of preference among equally good choices. By developing and following standards for the visual display of quantitative information, you can eliminate all but good choices once and for all. This dramatically reduces the time it takes to produce tables and graphs as well as the time required by your readers to make good use of them. Doing this will free up time to put your creativity to use where it's most needed.

Ask any of my friends, and they will tell you, without hesitation, that I have little respect for authority. Please don't misunderstand. I'm not living under an assumed name or hiding from the law. I simply don't like being told what to do. I prefer to examine things myself, get to know them, and then make my own informed decisions. Consequently, I'm not one who advocates rules for rules' sake. The term "standards" often leaves a bitter taste in my mouth. I don't like anything that gets in the way of doing good work and doing it efficiently. Nevertheless, through the course of my professional life, I've come to appreciate standards when they grow out of genuine need for direction, address only what must be addressed, and save me time. Standards that reside in huge tomes generally remain on the shelf gathering dust. Standards that actually get used are concise, easy to learn, easy to follow, and undeniably beneficial.

Ralph Waldo Emerson, one of the great practical philosophers of all time, wrote in his essay on self-reliance: "A foolish consistency is the hobgoblin of little minds."[1] This is often misquoted by omitting the word "foolish." Not all consistent practices are foolish. There are wise consistencies as well. These are standards that we follow because they produce the best result. These are practices that free us from redundant choices, conserving our energy and intelligence for the most deserving tasks. A good set of standards for the design of tables and graphs provides a framework for innovation in the face of important communication challenges. Standards and innovation are partners in the pursuit of excellence.

1. Ralph Waldo Emerson (1841) *Essays: First Series, "Self-Reliance."*

I'm amazed at how much time we waste making the same decisions over and over again simply because we've never taken the time to determine what works best for routine tasks, thereby making the decisions once and for all. Kevin Mullet and Darrel Sano beautifully express the benefits of a good set of standards:

> *Without minimizing the value of intuition as a problem solving tool, we propose that systematic design programs are more valuable from a communication standpoint than are ad hoc solutions; that intention is preferable to accident; that principled rationale provides a more compelling basis for design decisions than personal creative impulse.*[2]

2. Kevin Mullet and Darrel Sano (1995) *Designing Visual Interfaces.* Sun Microsystems, Inc., page 15.

You will have plenty of worthwhile opportunities for creativity as you work to understand numbers and present their message in a way that leads your readers to insight and action. "Design professionals learn quickly that constraints free the designer to focus . . . resources on those portions of the problem where innovation is most likely to lead to a successful product."[3] Your time is too valuable to waste. Keep your mind alert with challenging and productive activity. Don't dull it with redundant, meaningless choices.

Not only do wise consistencies save you time and effort, they do the same for your readers. Rather than calling readers' attention to ever-changing diversity in the design of tables and graphs, you can consistently use best practices to create a familiar form that invites the information to tell its story and engage their interest.

Think for a moment about standards that you've encountered in your own work. When have they worked? When have you ignored them and why? Here are some of the qualities that design standards for tables and graphs should exhibit:

- They should grow out of real needs and never grow beyond them.
- They should represent the most effective design practices.
- They should have effective communication as their primary objective.
- They should evolve freely as conditions change, or new insights are gained.
- They should be easy to learn and remember.
- They should save time.
- They should be applied to the software that is used to produce tables and graphs in the form of specific instructions and design templates.
- They should never inhibit creativity that actually improves communication.

I won't write your design standards for you. If I did, they would likely end up gathering dust on that shelf with all the others. The standards that will actually get used will be your own, the product of your own sweat, the rewards of your own labor. Whatever you do is worth doing well. Give a clear voice to the numbers that tell the story of your organization and clear visibility to the opportunities those numbers reveal. Produce tables and graphs that communicate.

3. Kevin Mullet and Darrel Sano (1995) *Designing Visual Interfaces.* Sun Microsystems, Inc., page 227.

Appendix A TABLE AND GRAPH DESIGN AT A GLANCE

Fundamental Steps in the Design Process

1. Determine your message.
2. Select the best means to display your message.
3. Design the display to show the information simply, clearly, and accurately.
   - Make the data (versus non-data) prominent and clear.
   - Remove all components that aren't necessary (both data and non-data components).
   - Reduce the visual salience of the remaining non-data components in comparison to the data.
   - Highlight the information that's most important to your message.

When to Use Tables vs. Graphs

Use Tables When	Use Graphs When
1. The display will be used to look up individual values 2. The display will be only be used to compare individual values rather than whole series of values 3. Precise values are required 4. Values involve more than one unit of measure 5. Values must be presented at various levels of aggregation (i.e., summary and detail)	1. The message is contained in patterns, trends, and exceptions 2. Entire series of values must be seen as a whole and/or compared

Tables: Matching Relationships and Structural Types

Quantitative-to-Categorical Relationships

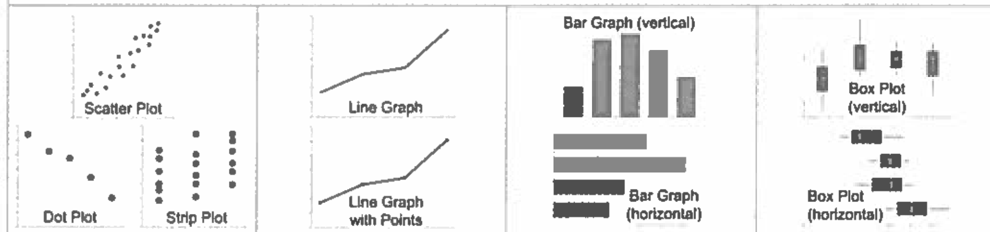
	Structural Type	
Relationship	**Unidirectional**	**Bidirectional**
Between a single set of quantitative values and a single set of categorical items	Yes	Not applicable because there is only one set of categorical items
Between a single set of quantitative values and the intersection of multiple categories	Yes. Sometimes this structure is preferable because of convention.	Yes. This structure saves space.
Between a single set of quantitative values and the intersection of multiple hierarchical categories	Yes. This structure can clearly display the hierarchical relationship by placing the separate levels of the hierarchy side by side in adjacent columns.	Yes. However, this structure does not display the hierarchy as clearly if its separate levels are split between the columns and rows.

Quantitative-to-Quantitative Relationships

	Structural Type	
Relationship	**Unidirectional**	**Bidirectional**
Among a single set of quantitative values associated with multiple categorical items	Yes	Yes. This structure works especially well because the quantitative values are arranged closely together for easy comparison.
Among distinct sets of quantitative values associated with a single categorical item	Yes	Yes. However, this structure tends to get messy as you add multiple sets of quantitative values.

Graph Selection Matrix

Value-Encoding Objects



Featured Relationship	Points	Lines	Bars	Boxes
Time Series Values display how something changed through time (yearly, monthly, etc.)	Yes (as a *dot plot*, when you don't have a value for every interval of time)	Yes (to feature overall trends and patterns and support their comparisons)	Yes (vertical bars only, to feature individual values and to support their comparisons)	Yes (vertical boxes only, to display how a distribution changes through time)
Ranking Values are ordered by size (descending or ascending)	Yes (as a *dot plot*, especially when the quantitative scale does not begin at zero)	No	Yes	Yes (to display a ranked set of distributions)
Part-to-Whole Values represent parts (proportions) of a whole (for example, regional portions of total sales)	No	Yes (to display how parts of a whole have changed through time)	Yes	No
Deviation The difference between two sets of values (for example, the variance between actual and budgeted expenses)	Yes (as a *dot plot*, especially when the quantitative scale does not begin at zero)	Yes (when also featuring a time series)	Yes	No
Distribution Counts of values per interval from lowest to highest (for example, counts of people by age intervals of 10 years each)	Yes (as a *strip plot* to feature individual values)	Yes (as a *frequency polygon*, to feature the overall shape of the distribution)	Yes	Yes (when comparing multiple distributions)
Correlation Comparison of two paired sets of values (for example, the heights and weights of several people) to determine if there is a relationship between them	Yes (as a *scatter plot*)	No	Yes (as a *table lens*, especially when your audience is not familiar with *scatter plots*)	No
Geospatial Values are displayed on a map to show their location	Yes (as bubbles of various sizes on a map)	Yes (to display routes on a map)	No	No
Nominal Comparison A simple comparison of values for a set of unordered items (for example, products, or regions)	Yes (as a *dot plot*, especially when the quantitative scale does not begin at zero)	No	Yes	No

Appendix B RECOMMENDED READING

The following books are some of the best that have been written about data visualization:

Edward Tufte is one of the world's leading theorists in the field of data visualization. All four of his books are filled with marvelous insights.

The Visual Display of Quantitative Information, Second Edition (2001), Graphics Press.

Envisioning Information (1990), Graphics Press.

Visual Explanations (1997), Graphics Press.

Beautiful Evidence (2006), Graphics Press.

William Cleveland has written two of the best guidelines for sophisticated graphing techniques, especially for statisticians.

The Elements of Graphing Data (1994), Hobart Press.

Visualizing Data (1993), Hobart Press.

Naomi Robbins has written a simple and practical book that makes many of the principles taught by Cleveland accessible to non-statisticians.

Creating More Effective Graphs (2005), John Wiley & Sons, Inc.

Robert Harris has written a comprehensive encyclopedia of charts in their many forms. This is a great reference to keep handy.

Information Graphics: A Comprehensive Illustrated Reference (1999), Oxford University Press.

Colin Ware has written the most accessible and comprehensive explanations that I've found about visual perception and how our current understanding of it can be applied to the presentation of information.

Visual Thinking for Design (2008), Elsevier, Inc.

Information Visualization: Perception for Design, Second Edition (2004), Morgan Kaufmann Publishers.

Robert Horn tackles the entire realm of visual thinking and asserts that a completely new visual language has emerged.

Visual Language Global Communication for the 21st Century (1998), MacroVU Press.

Stuart Card, Jock Mackinlay, and Ben Shneiderman provide the best introduction to research in the field of information visualization.

Readings in Information Visualization: Using Vision to Think (1999), Morgan Kaufmann.

My other two books teach principles and practices for presenting data in the form of dashboards and graphical techniques for exploring and analyzing data.

Information Dashboard Design: The Effective Visual Communication of Data (2006), O'Reilly Media, Inc.

Now You See It: Simple Visualization Techniques for Quantitative Analysis (2009), Analytics Press.