2. Forms and Functions: Visualization as a Technology

> The usefulness of a graph can be evaluated only in the context of the type of data, the questions the designer wants the readers to answer, and the nature of the audience.
>
> —**Stephen M. Kosslyn, from *Graph Design for the Eye and Mind***

The fact that an information graphic is designed to help us complete certain intellectual tasks is what distinguishes it from fine art. Rather than serving as a means for the artist to express her inner world and feelings, an infographic or visualization strives for objectivity, precision, and functionality, as well as beauty. In short:

The function constrains the form.

In this chapter I will explore this idea and its usefulness for infographics and visualization, starting with the original phrase “form follows function,” and the critiques and iterations it has undergone over time. The original idea remains the same, but these iterations contribute to a more nuanced understanding of what the relationship between forms and functions entails.

An Information Graphic on Defense

Let’s start with a real-life example to illustrate what I mean. Although Brazil is a huge country and the main power in South America, its armed forces are not on par with its status as the sixth-largest economy in the world. Proportionally, some of Brazil’s neighbors, such as Venezuela and Chile, invest much more each year in keeping their armies, naval fleets, and air forces up to date. And that’s an issue: Brazilians are proud of their newly earned status as an almost-developed nation, and they want the world to know about it. So, in August 2008, the Brazilian government announced a new strategic defense plan, the culmination of a public discussion that had begun many years before.

Brazil’s main newspaper is *Folha de São Paulo*. It has the biggest information graphics staff in the country, full of great talent. *Folha* dedicated an entire page to then-President Lula da Silva’s new strategic plan. It was a critical story, explaining that some of the defense investments were not well planned, and that some of Brazil’s rivals in the region were better focused on what was really needed to defend their territories and offshore waters.

Two information graphics accompanied the story. The first detailed the Brazilian defense budget for 2009. The second, which was the source for Figure 2.1, was titled “The Defense of the Neighbors: An overview of the armed forces of countries surrounding Brazil.”

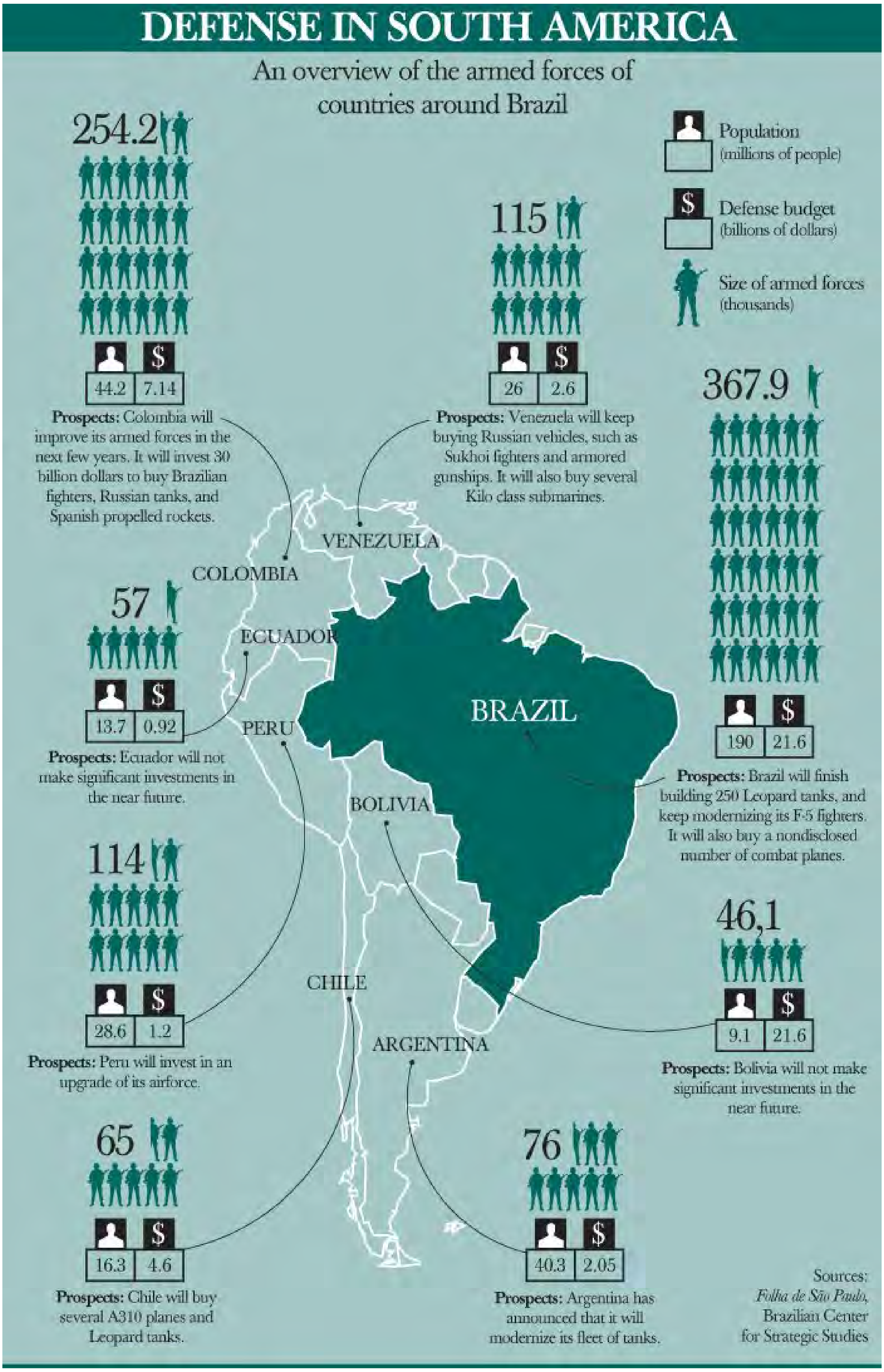

Figure 2.1. A portrait of the power balance in South America.

I will use Figure 2.1 to demonstrate an exercise I recommend you try whenever you see an information graphic in a newspaper, magazine, book, or website. Practice this exercise and it will help you become an infographics and visualization expert. The first part is simple. Ask yourself:

What does the designer want me to do with this graphic?

In other words: **If we accept that an infographic is, at its core, a tool, what tasks is this one intended to help me with?** Here is my personal list for the Brazilian defense graphic:

1. The graphic must ***present*** several variables—armed forces personnel, population to be defended, defense budget, and so forth—so that I have the proper information in front of me.
2. It should allow ***comparisons***. At a glance, I should be able to tell which country has the biggest and the smallest army, is more or less populated, or invests more heavily or lightly in its military.
3. It should help me ***organize*** countries, from the biggest to the smallest, based on the variables and the comparisons.
4. It should make ***correlations or relationships*** evident to me. For instance, are population and size of defense forces directly and perfectly proportional?

Of those four possible tasks—present, compare, organize, correlate—the graphic accomplishes *just one* satisfactorily. It presents tons of variables and values. But it doesn't show them in proportion to one another. This makes it impossible for readers to dig into the data.

Imagine you're a concerned Brazilian patriot. Your first impulse will probably be to compare your country with Venezuela and Argentina, Brazil's main commercial and strategic rivals in the region. See how difficult this operation is? If you want to compare, say, population, you will have to read all the numbers, memorize them, and then organize them in your head. The same thing happens when you try to compare the countries' defense budgets.

You need a pretty powerful memory to do that. From a functional standpoint, there's little difference between this graphic and a simple table. The graphic may be prettier, but it still makes you work too hard to extract basic meanings.

There's something else: Does the map need to be the main visual element in the composition? I doubt it. Using so much real estate for the map suggests that the main goal of the graphic is to show where Brazil's neighboring countries are—and likely most or all of *Folha de São Paulo*'s readers know that already.

To be fair in my remarks, I know that a single *Folha de São Paulo* designer had just two hours to produce this infographic after obtaining the data from a reporter. That's how things work in newspapers. Turnaround times for breaking-news projects are tight. Still, I believe that the graphic could have been greatly improved with 10 or 15 minutes of planning.

Here's where the second part of our exercise begins.

What Shape Should My Data Have?

Once we have listed the goals our graphic should help accomplish, it's time to consider what shape the numbers should adopt.

Let's start with the comparison. As originally published, the infographic doesn't make our lives easy. The numbers are there, but populations and budgets are not visually represented. Comparing the figures mentally—which is what we are forcing readers to do if they want to get an idea of the proportional sizes of those variables in different countries—is too hard.

Military personnel are represented by tiny silhouettes, each equivalent to 1,000 soldiers. But in the original, the symbols are useless because the bars formed by the little soldiers do not sit on the same horizontal axis. This makes comparisons more difficult than they should be. See how much easier things are if we place the columns of soldiers side by side, as shown in **Figure 2.2**.

Figure 2.2. Simply placing the bars on the same horizontal axis allows you to make more accurate comparisons.

If you accept that bars facilitate comparison better than other ways of encoding the variables, let's represent the countries' military personnel as bars and organize them from biggest to smallest amounts. In **Figure 2.3** you can see the result: Readers can now easily identify the winners and losers in the South American arms race (I'm being a bit hyperbolic), a task that required far more cognitive energy in the original *Folha de São Paulo* graphic.

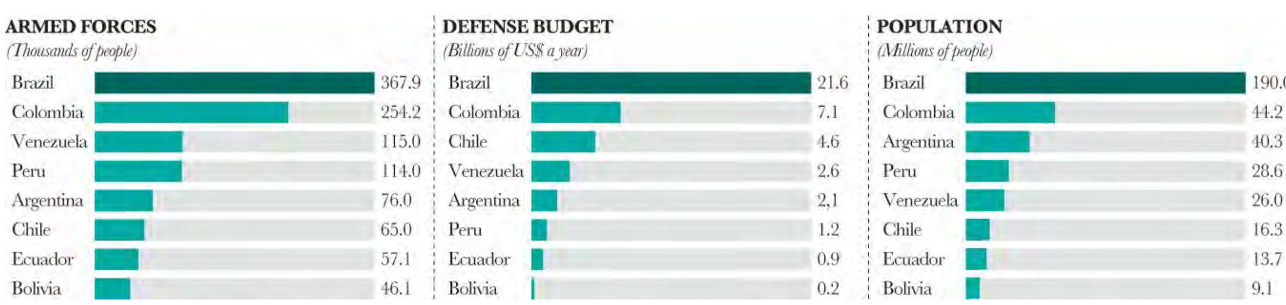

Figure 2.3. Let's get rid of the pictograms and use a traditional bar chart.

At this point we face a challenge. It would seem Brazil will be the winner in all of the rankings, because the bigger the population a country has, the bigger its military forces and heftier its defense budget will be. But is this relationship perfectly proportional? In other words, if population is *n* times bigger in one country than in another, will armed forces also be *n* times larger?

This question is related to the fourth task, *correlation* among variables. The bars in the previous figure don't address that goal. That is because they encode *absolute* figures.

Think about it this way: What if you want to compare violent crime in Detroit, Michigan, against figures in Poughkeepsie, New York? You would never use an absolute variable, such as the *total* number of people killed, because Detroit is much bigger than Poughkeepsie, so the total number of crimes will also be enormous.

Instead, you would choose a *derived* variable; that is, you would obtain the number of homicides in each city, divide it by the population, and then multiply the result by 100,000. You would then get the *homicides per 100,000 people*.

The same can be applied to our Brazilian defense graphic. See what happens when we control the armed forces sizes by population, or when we calculate per capita spending in defense? The rankings look much different. Compared with Figure 2.3, **Figure 2.4** gives readers an additional and useful level of depth and understanding: The biggest armies in *absolute* terms may not be the biggest ones in *relative* terms. In relative terms, our Brazilian patriot would surely be alarmed, because her country ranks second *from the bottom*. Countries like Venezuela and Bolivia are more militarized, and Colombia is far ahead because of its war on narco-guerrillas.

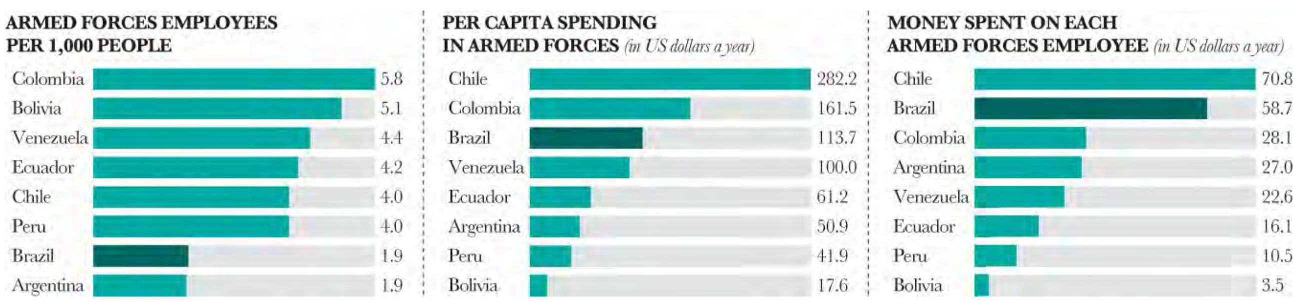

Figure 2.4. The country rankings change quite a bit when you encode secondary variables instead of absolute numbers.

Are there ways of representing correlations using absolute variables? Sure. You could design a scatter-plot, a type of chart mentioned in Chapter 1. In the redesign I put together after thinking about *Folha de São Paulo's* original graphic (**Figure 2.5**), I included another version titled, "A different look at the data." If this were a real project, I would not have done this because it tells essentially the same story as the two sets of bar charts, but it illustrates an important point: **In most cases, there is not just one way of encoding a particular set of data properly.** You may have more than one option, but your goal must be always to think first about what kinds of questions readers are more likely to want answered by your infographic.

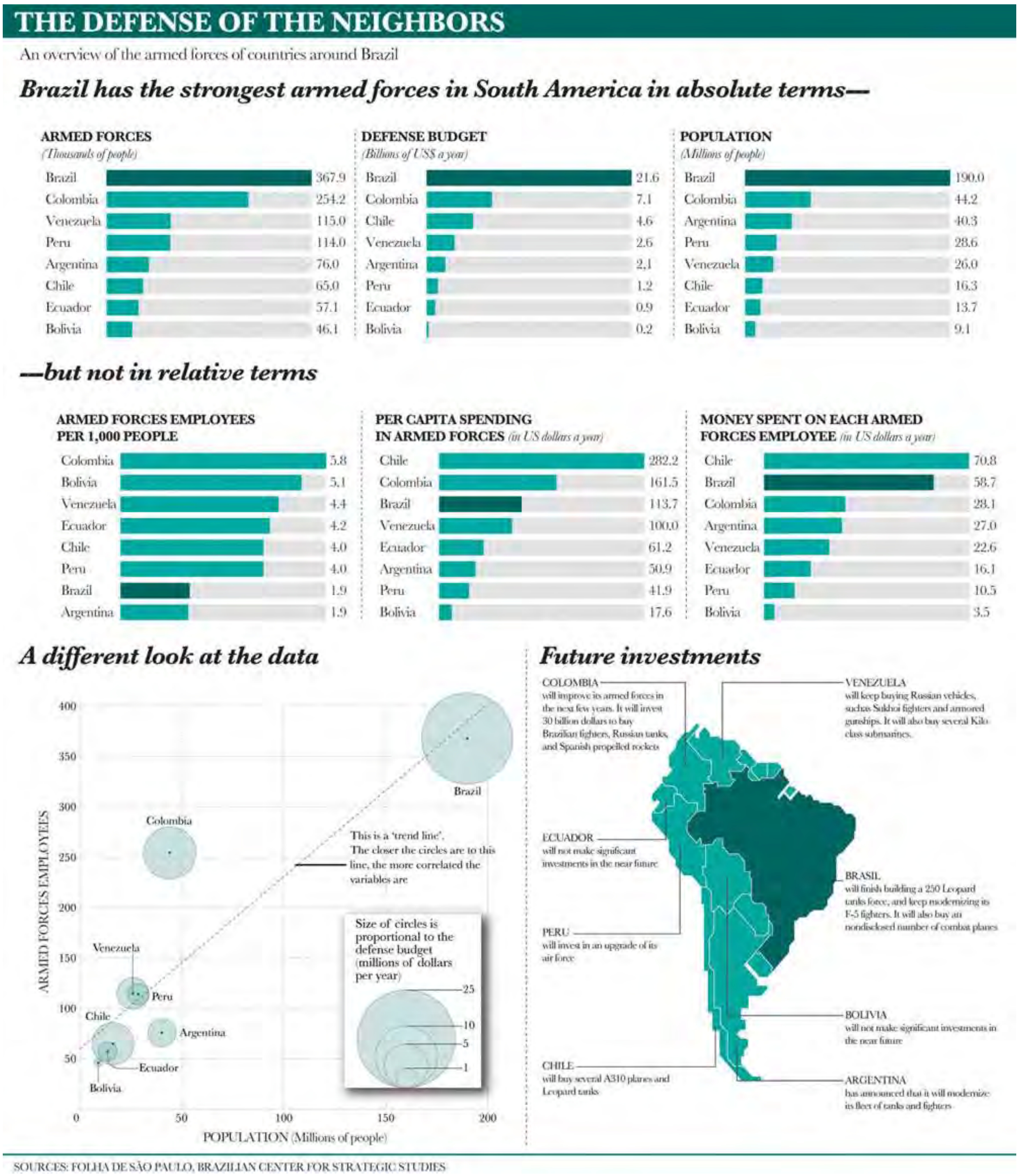

Figure 2.5. A different take on the defense infographic.

The Origins of "Form Follows Function"

The maxim "form follows function" was born in 1896 when the American architect Louis Sullivan wrote an article titled, "The Tall Office Building Artistically Considered." In it, Sullivan discussed the needs of the occupants of big office buildings, which had begun to proliferate at the end of the nineteenth century. The most widely cited paragraph is:

> All things in nature have a shape, that is to say, a form, an outward semblance, that tells us what they are, that distinguishes them from ourselves and from each other. Unfailing in nature these shapes express the inner life, the native quality of the animal, tree, bird, fish, that they present to us; they are so characteristic, so recognizable, that we say, simply, it is "natural" it should be so (...) It is the pervading law of all things organic and inorganic, of all things physical and metaphysical, of all things human and all things superhuman, of all true manifestations of the head, of the heart, of the soul, that the life is recognizable in its expression, that **form ever follows**

> **function**. This is the law.[1]

Those highlighted words were defining for twentieth-century architecture and had an enormous influence on contemporary masters, either because they embraced them (the Bauhaus school), or because they rejected them or introduced their own nuances (Frank Lloyd Wright). Some of the most renowned ideas of luminaries like Le Corbusier, who defined a house as “a machine for living in,” connect directly to Sullivan.

Today, we interpret Sullivan’s idea as a call to center any design, regardless of its nature—a building, a tool, a software program—on the user. However, that was not exactly what Sullivan had in mind when he wrote his article. His “function” is not a goal in the sense of a task that the tool is designed to help achieve, but rather, an intrinsic property of both artificial and natural entities, a kind of essence. According to Sullivan, the form of a thing is a clue to its nature.

The fact that we misinterpret Sullivan is one of those fortunate paradoxes that make history colorful. Taken in a literal sense, the original paragraph includes several fallacies worth discussing before we can understand the relationship between form and function in visualization.

Consider this:

> All things in nature have a shape ..., an outward semblance, that tells us what they are .... Unfailing in nature these shapes express the inner life, the native quality of the animal, tree, bird, fish, that they present to us.

If you remember something from your high school biology classes, you’ll understand why this is appealing at first but ultimately absurd. If we follow Sullivan’s rationale, we could hypothesize, as pre-modern thinkers did, that fishes and dolphins belong to the same animal order, because the shapes of their bodies are pretty much identical. Or we could say that hippopotami are cousins of elephants and rhinoceros, since all three share features such as thick legs and bodies, and tons of body fat under hard skins. But, as always happens in science, evidence (in this case, genetics) contradicts appearances. The hippopotamus descended from whales that evolved to return from the sea to the land.[2] Never trust your intuitions without testing them.

Even in the world of technology, the idea that the shape of an object is unequivocally connected to its functions is not valid. True, a spoon is concave and solid so no liquid can fall through it, so one can deduce that we can use it to bring liquid food to our mouths. But what about an iPod? Does the shape of its central wheel naturally suggest the way it should be used? Hardly. In this case, the connection between form and function must be learned. It is in reflections such as these that we see that Sullivan’s law cannot be strictly applied.

More about Functions in Nature

Another problem with Sullivan’s law is that the sentence “form follows function” indicates that the relationship between the two components is unidirectional. At first this seems intuitive. After all, what are a couple of feather-covered wings for, if not for flying? If wings have evolved, it must be because some animals felt the need to flee from predators or to reach fruits growing on treetops.

The problem is that the world doesn’t work that way. A species doesn’t *feel* a need first (the *function*) and then develops an organ to fulfill it (the *form*). If you’ve ever had this kind of thought—some people still do—you’ve fallen prey to what is known as the *Lamarckian Fallacy*.

Jean-Baptiste Lamarck, who lived between the nineteenth and twentieth centuries, was one of the first scientists to describe the mechanism that guides evolution. In his time, evidence existed linking living species to usually extinct ancestors, who in turn were heirs of even older ancestors, and so on, in a chain dating to the beginning of time. What Lamarck and other scientists had not discovered was the hidden logic of this phenomenon, the underlying force that leads one animal or vegetable to become a completely different one given enough time.

Lamarck proposed a scientific theory called “inheritance of acquired characteristics.” To understand it, let’s consider giraffes, a descendant of ancient creatures that supposedly were similar to modern antelopes. How did the giraffe evolve its long neck?

According to Lamarckian logic, thousands and thousands of years ago, some antelopes felt the need to feed on tree leaves beyond the reach of their mandibles. They began stretching their necks to get them. As a consequence, they were born with slightly longer necks than the previous generation. But this is like saying that if I start doing heavy bodybuilding today and become a clone of Sylvester Stallone, my kids will be born with steel muscles. To the followers of Lamarckism, form *literally* follows function. The former pushes the latter.

Thanks to Charles Darwin, though, we now know that evolution doesn’t work that way. Darwin’s *On the Origin of Species* was published in 1859 and offered an alternative to Lamarck’s hypothesis. The force that moves evolution forward is not the acquisition of characteristics and skills inherited by kin, but the natural selection of traits that help an organism survive in its environment. What Darwin did was to invert Lamarck’s logic: Function doesn’t *determine* form. In fact, in many cases, the opposite is true.

First, let’s be clear about what Darwin meant by *natural selection*. Back to our friend the giraffe, a Darwinian narrative of its origin might run like this:[3] Many generations ago, the ancestors of the giraffe lived in grasslands and forests and fed on vegetation. Every time a new calf was born, it could have a neck that was slightly longer or shorter than its parents because of tiny mutations in its DNA (Darwin didn’t know about DNA, but it doesn’t matter; he did know that children look very much like their parents.) This is called *variation*.

In a particular moment in time—maybe because a drought made grass scarce, or because some pre-giraffe families moved to savannahs where food was difficult to find—having a slightly longer neck than your kin suddenly became an advantage. You could feed on tree leaves that were far from the ground.

The pre-giraffes that had longer necks tended to live longer and have better health (on average) than their congeners. They also reproduced more and passed the longer-neck gene mutations to their offspring. Successive mutations leading to even longer necks may have given subsequent generations an even bigger competitive advantage, in a fortuitous circle.

In other words, the need to reach higher every day (the *function*) didn’t force the development of longer necks (the *form*). Longer necks were the result of random genetic mutations that were *nonrandomly* filtered (that is, selected) by the environment. In nature, then, relationships between forms and functions are much more complex than what Sullivan thought.

Another factor also counters the idea of a cause-effect relationship between functions and forms. Remember our question, “What are a couple of feather-covered wings for, if not for flying?” Well, wings were certainly not for flying at first. Birds descended from dinosaurs that began to evolve feathers not for flight, but for maintaining body temperature and attracting mates. The functions of feathers—that is, their competitive advantages—were to keep their owner warm and make the creature more handsome.

But evolution eventually crossed paths with another possible function: to control the movement of air around the feathered extremities, which allowed a primitive form of gliding. This is an example of what paleontologist Stephen Jay Gould called *exaptation*, by which a trait that evolves in response to an environmental challenge is used for an entirely different purpose (flying).[4]

Exaptations are common in technology as well. The Internet could be analyzed as an exaptation. Designed to enhance communication between scientists, it ended up being adopted by the public as a virtual world that facilitates many kinds of human sharing. Guttenberg’s printing press was based on technologies previously used to crush grapes and make wine. The original function of presses was to crush grapes, and their form was well suited to that function. It just happened that someone eventually saw that the form of those machines could have an entirely different function.[5]

Cases such as these help us understand that the relationship between forms and functions is *bidirectional*. Form doesn’t *always* follow function; in many cases, the function follows a form that previously followed another unrelated function. It is easy to imagine one of our ancestors, hundreds of thousands of years ago, walking through the woods and finding a sharp triangular rock. Our ancestor picks up the rock and notices that it perfectly fits the palm of his hand. What is the function of that form? None, until our ancestor sees a goal that matches what the rock’s shape suggests: *It may be used for cutting fur, flesh, and bone*. Nature becomes technology through the eyes and mind of an intelligent agent.

Functions Constrain Forms

The fact that Louis Sullivan was misguided in his coarse essentialism doesn’t disprove the idea that forms and functions are and must be closely related. It is true, as we just have seen, that function doesn’t necessarily determine form. But it is also true that **the form of a technological object must depend on the tasks it should help with**. This is one of the most important principles to remember when dealing with infographics and visualizations: **The form should be constrained by the functions of your presentation.** There may be more than one form a data set can adopt so that readers can perform operations with it and extract meanings, but the data cannot adopt *any* form. Choosing visual shapes to encode information should not be based on aesthetics and personal tastes alone.

In general, **the better defined the goals of an artifact, the narrower the variety of forms it can adopt**. Let me illustrate this principle with several real-world examples.

More than a decade ago, I worked for several print newspapers in Spain and became familiar with the templates used for stories that repeat on a regular basis. This is common practice in news media: If you know that you will publish, say, an infographic on the unemployment rate every month, or a weather page every day, why would you design a new graphic for each occasion? Using templates saves time. Unfortunately, it also encourages inertia. Bringing up the template file over and over again invites you not to think deeply about its structure and appropriateness. Just open it, update it with the new data, save it, and move on to more interesting stuff.

The infographic in [Figure 2.6] is similar to the template many newspapers in Spain use to publish monthly government data on unemployment. It presents all the numbers and includes a layer of information that aggregates them, offering a quick overview of the data. Three different tones of gray represent the higher-than-average, on-average, and below-average employment regions. But let's apply a little question-based critique to test it. Try to answer these questions in less than five seconds each:

1. In which region has unemployment grown the most?
2. In which one has it dropped the most?
3. Has the unemployment change been bigger in Madrid, La Rioja, or Canarias?
4. Has unemployment dropped more in Extremadura, Andalucía, or Baleares?

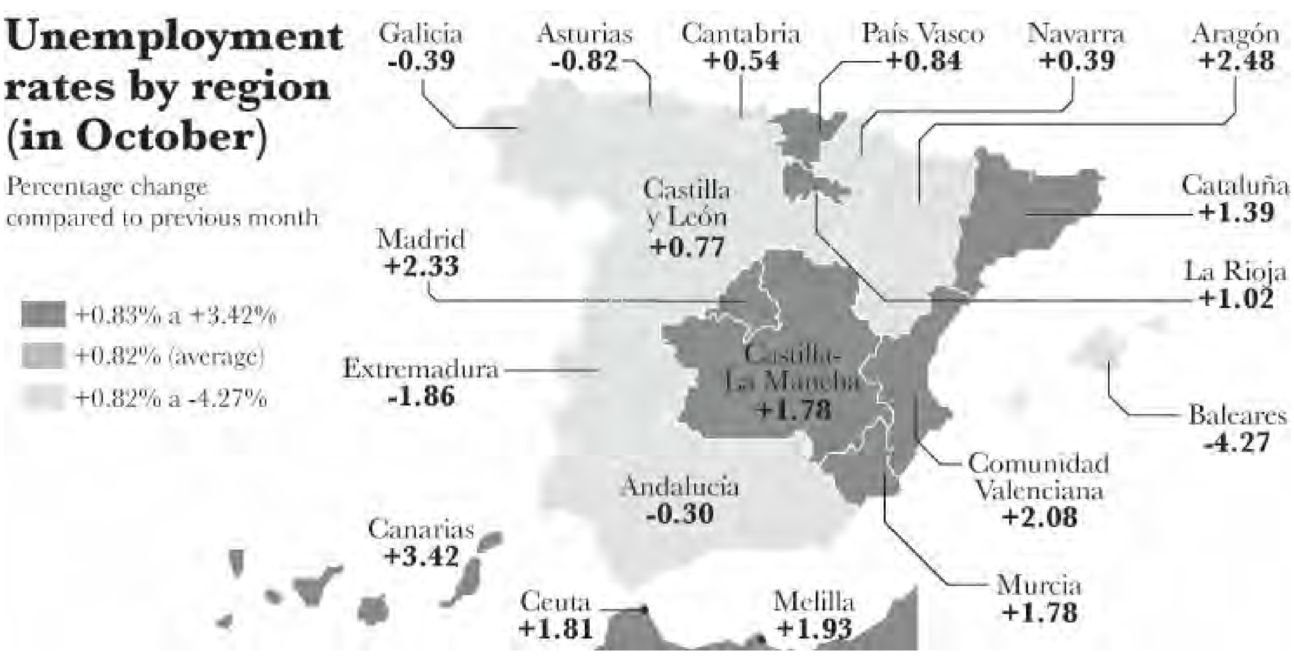

Figure 2.6. A type of graphic very common in Spanish newspapers: the monthly unemployment rate change.

Likely, you can't do it. I did not ask myself such questions when I was designing these kinds of graphics, but I do now. My perspective has changed. I no longer think like a designer, but like a reader. And, as a reader, those are the kinds of answers that I want to get using this kind of tool.

The challenge of this graphic is similar to the one we analyzed in the first pages of this chapter. Here's what happens when you try to complete any of the operations above:

1. Your eyes look for the numbers mentioned in the question.
2. Your brain memorizes them.
3. Your brain organizes the numbers from biggest to smallest (or vice versa).
4. Your brain compares the reorganized numbers.

That's too much work. If we know that readers are likely to look for how their own region fits into the big picture, *why not anticipate it*? [Figure 2.7] represents exactly the same data, but offers more options to explore them.

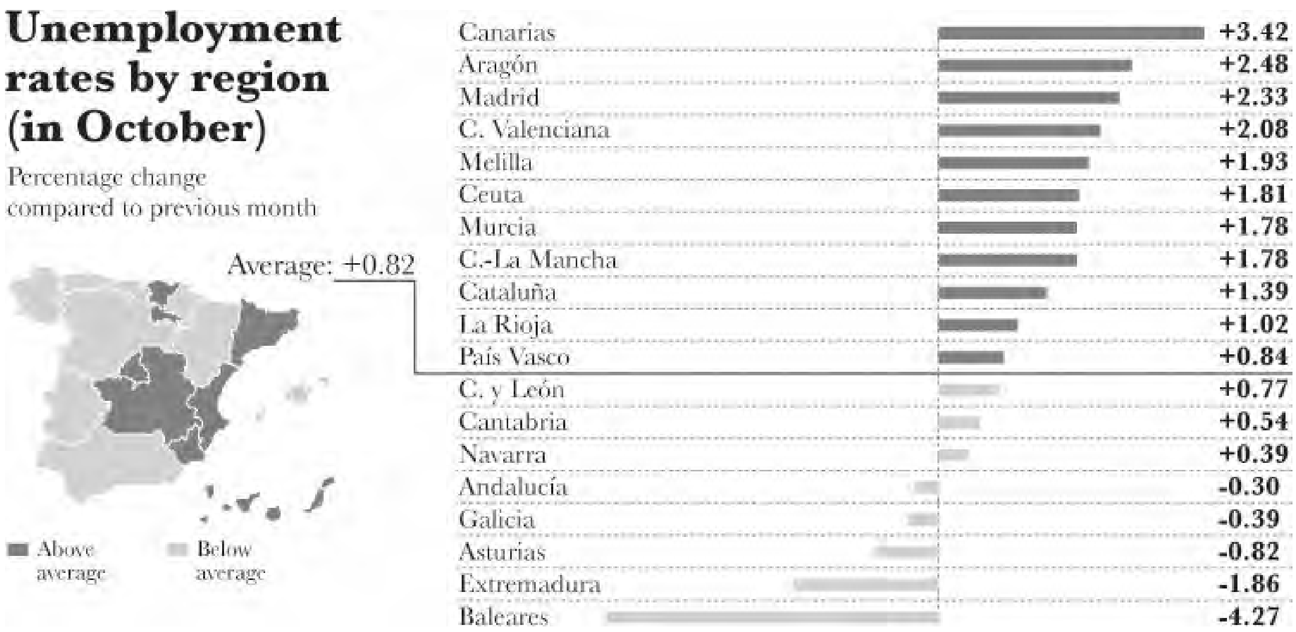

Figure 2.7. This variation of the unemployment rate graphic allows you to compare and rank Spain's regions.

Again, the map: Is it necessary? Perhaps. In this case, the geographical location of the regions may be relevant, as it shows that unemployment is getting worse in the southeast of Spain.

In an interview with *Technical Communication Quarterly* in 2004, Edward Tufte, arguably the most influential theoretician in visualization and information design (which he prefers to call *analytical design*), defined the relationship between form and function succinctly:

> Effective analytic designs entail turning thinking principles into seeing principles. So, if the thinking task is to understand causality, the task calls for a design principle: "Show causality." If a thinking task is to answer a question and compare it with alternatives, the design principle is: "Show comparisons." The point is that analytical designs are not to be decided on their convenience to the user or necessarily their readability or what psychologists or decorators think about them; rather, design architectures should be decided on how the architecture assists analytical thinking about evidence.[6]

Clear enough. But this idea is not as obvious as it should be, as the previous examples prove. A simple Google search on *infographic*s will return thousands of links to projects in which the designer didn't choose graphic forms according to how well they assist thinking, but because they looked cool, innovative, or funny. Designers who don't develop the crucial skill of asking themselves, "What is my graphic for?" are easy victims of fashion. No fashion plague is more prevalent as I write this book than the bubble.

The Bubble Plague

The overuse of bubble charts in news media is a good example of how infographics departments can become more worried about how their projects look than with how they work. When I give presentations, I often use charts like the one in **Figure 2.8**, which I made up based on a real project by *Bloomberg News*.

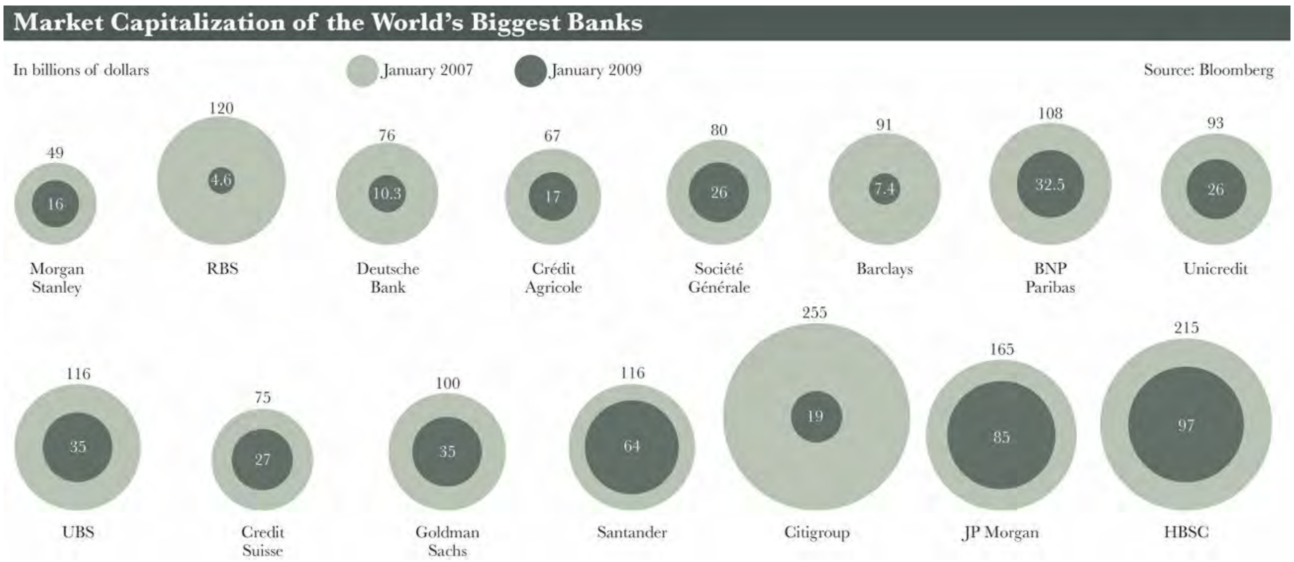

Figure 2.8. Banks as shrinking bubbles. How appropriate. This example is inspired by an article by Stephen Few: "Our Irresistible Fascination with All Things Circular": http://www.perceptualedge.com/articles/visual_business_intelligence/our_fas

When I ask the audience for their reaction to the graphic, the answer usually is, "I don't see a problem. It is clear that the value of all banks in the chart fell dramatically during the 2007–2008 economic meltdown." I agree; that's what I see as well. Immediately, I show a different slide, **Figure 2.9**, and ask, "If you know that Société Générale's market capitalization was $80 billion in 2007, how much was it in 2009?" (Try to answer the question without looking at Figure 2.8.)

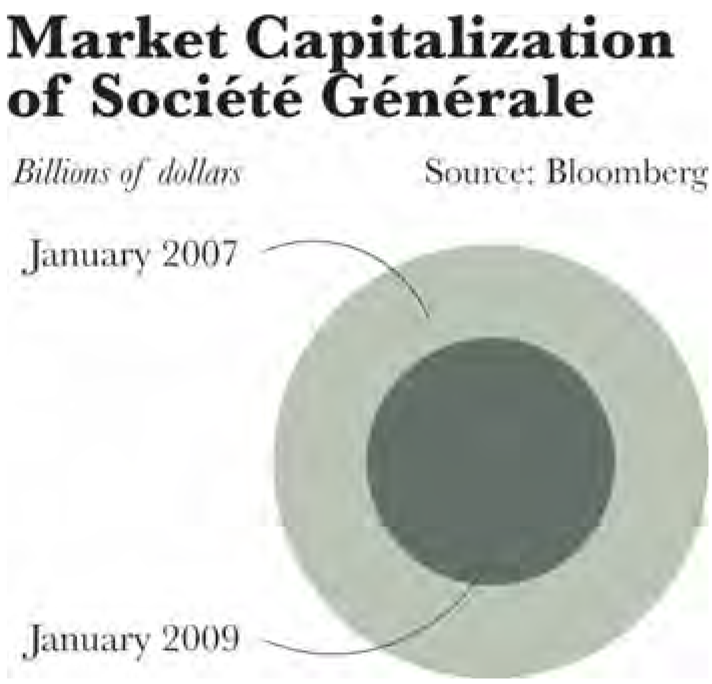

Figure 2.9. The first bubble represents $80 billion. What percentage of that does the second bubble represents? Half, perhaps?

According to my informal records, more than 70 percent of attendees guess that the answer is slightly more than $40 billion. In other words, they see the smaller bubble as being *half* the size of the bigger one.

Then I switch to **Figure 2.10** and tell them that the length of the bars display *exactly* the same numbers as the areas of the bubbles. This figure makes it clear that the value of Société Générale in 2009 was around *one third* of what it was in 2007. The surprised looks I get when they see this are a lot of fun.

Figure 2.10. Our friend, the bar chart, comes to the rescue.

Why do so many people overestimate the number for 2009 in the bubble chart? Because the human brain is not good at calculating surface sizes. It is much better at comparing *a single dimension* such as length *or* height. As we'll see in the second section of this book, the brain is also a hopelessly lazy machine. When faced with the question of whether that bear running toward you is big enough to pose a threat, the brain doesn't waste time or energy analyzing if the bear is tall *and* wide. Seeing if it's *just tall* is good enough. In **Figure 2.11**, what you want your readers to compare (the areas) is on the left; what they *actually* compare (the diameters) is on the right.

Figure 2.11. You want readers to compare areas, but they tend to compare heights.

The objection I usually hear when I build my case against bubbles as a means to facilitate *precise* comparisons between magnitudes is, "I understand your point, but you're cheating. You've hidden all the values. If you hadn't done so, there'd be no problem." Granted, but in that case, *what do you need the bubbles for*? Bubbles are misleading. They make you underestimate differences. In Figure 2.8, consider Santander Bank. Can you tell without reading the numbers that its value in 2009 was *half* what it was in 2007? I'll bet you can't. If you are as absent-minded as I am and don't pay close attention to the graphic, you may walk away with the idea that Santander didn't suffer much during the crisis.

If the bubbles have no functional purpose, why not design a simple and honest table? Because circles *look good*. They are decorative.

Are there other ways to design this chart respecting Edward Tufte's principle of transforming thinking principles into design principles? Certainly. As we discussed earlier, function doesn't dictate form. It constrains your options, but you still *have* options. You can design a chart that not only allows comparisons, but also focuses on changes that occurred between the two years. (See **Figure 2.12**.)

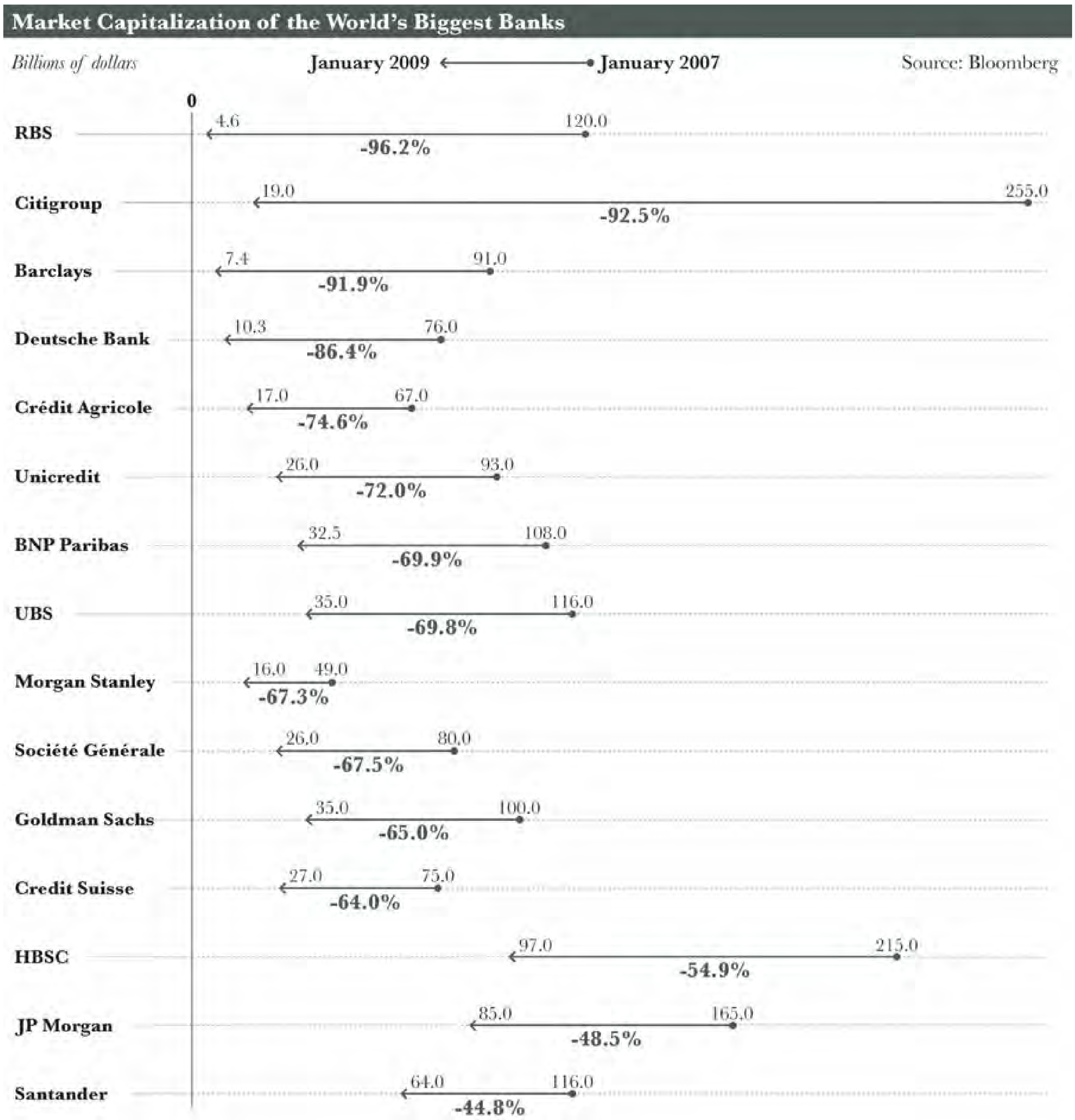

Figure 2.12. A chart that represents change.

Is it always wrong to represent numbers with bubbles? No. Let's return to our most cherished principle of the infographic as a tool whose shapes should be chosen according to intended goals. The banks infographic is supposed to help us make precise comparisons between values. But see the map in Figure 2.13, published by *The New York Times* after the 2004 presidential elections. Each circle represents the margin of votes in those counties won by John Kerry (blue) or by George W. Bush (red). In cartography, this kind of map is called a proportional symbol map.

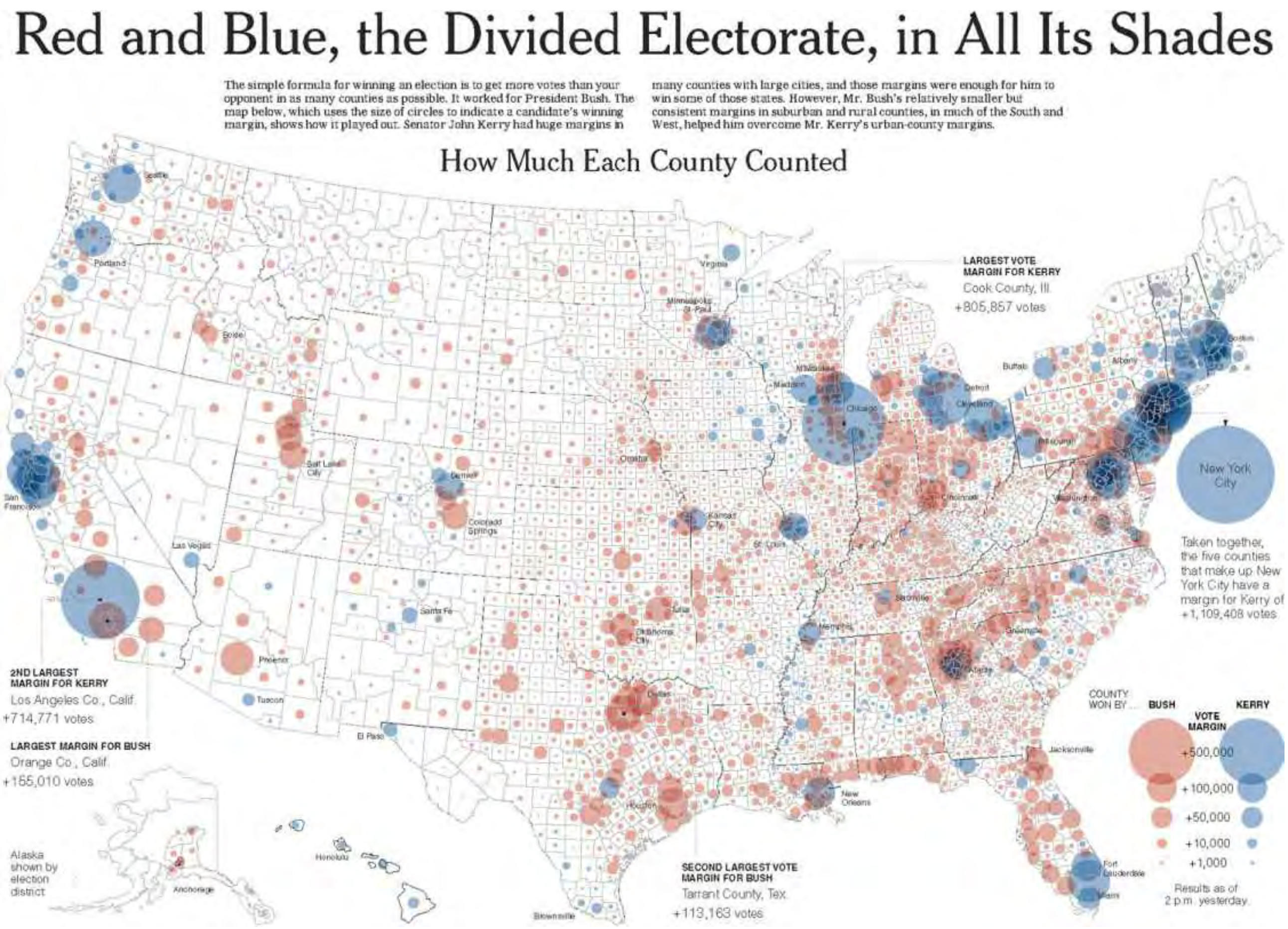

Figure 2.13. A proportional symbol map is appropriate when your goal is to visualize the big picture. It allows you to perceive general patterns and trends.

Why was the bank infographic ineffective, whereas this map works? The reason lies in their goals. The goal of the election map is not that readers should be able to accurately compare Manhattan's bubble with Houston's. It would take a different kind of chart to facilitate that task. The goal here is to help readers *identify general patterns of concentration* of Democratic and Republican votes.

More Flexible Than It Seems

I don't want you to leave this chapter with the impression that choosing the right graphic forms for each story is an easy task. It is tempting to propose rock-solid rules—if you want to show change through time, use a time-series chart; if you need to compare, use a bar chart; or to display correlation, use a scatter-plot—because some of these rules make good common sense. There is even evidence supporting the use of certain kinds of charts for particular goals. (See **Figure 2.14**.)

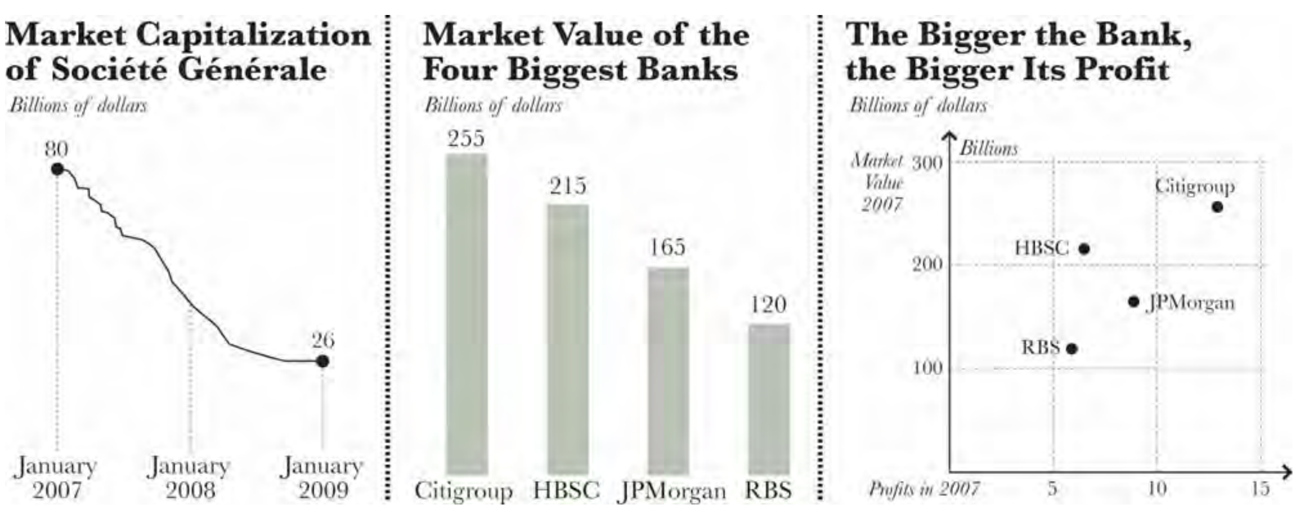

Figure 2.14. Three very common kinds of charts: (from left to right, time series chart, bar chart, and scatter-plot chart.

But reality is complex, and hard-and-fast rules can transform sound advice into immovable law. Exceptions and nuances can arise with the particularities of each project. What is really important is to remember that no matter how creative and innovative you wish to be in your graphics and visualizations, the first thing you must do, before you put a finger on the computer keyboard, is **ask yourself what users are likely to try to do with your tool**.

3. The Beauty Paradox: Art and Communication

> No one can write decently who is distrustful of the reader's intelligence, or whose attitude is patronizing.
>
> **—E. B. White, from *The Elements of Style***

Learning to deal with frustration is part of professional life. So is being able to explain what you do and why you do it. I kept repeating those maxims to myself on November 1, 2010, after the weekly news magazine I worked for, *Época*, published what I considered a decent graphic about the prison population in Brazil.

It all began two weeks before. As the magazine's infographics director, one of my responsibilities was to coordinate a two-page section called "Diagram," a news story told through short pieces of text, statistical charts, maps, and illustrations. "Diagram" was our big infographic of the week, and we put a lot of effort and resources into it.

From January 2010, when I was hired, to that moment in November, we had published more than 30 "Diagrams," each a detailed visual description of subjects as diverse as demographics; spaceships; boats made of thousands of recycled plastic bottles (its name is *Plastiki*); *and* election results, with a wide assortment of other data-based stories besides.

Part of my job was to dream up potential stories for "Diagrams," so I read several newspapers a day looking for inspiration. An item published by *Estado de São Paulo*, one of Brazil's three largest newspapers, caught my eye. It contained data recently released by the Ministry of Justice revealing a surge in the number of prison inmates over the previous four years. Surprisingly, although *Estado* cited the ministry's exhaustive database, it did not include a chart.

Stories about packed prisons in Brazil are nothing new. The problem dates to a military dictatorship that ruled the country between 1964 and 1985, and, paradoxically, it has only gotten worse as the police and judiciary have become more efficient. More efficiency leads to more criminals behind bars, which is good, but it also pressures federal and state governments to keep up by building more facilities. There's never enough money for that.

When dealing with a story that people are already familiar with, what you lack in novelty must be compensated for with depth. After all, **journalism is not just about covering the news, but also about providing context for the news**.

Building a Narrative Structure

As I was downloading and organizing the data from the Brazilian Ministry of Justice, Humberto Maia, a talented young reporter, telephoned sources who could explain what the numbers meant. He spoke with public officials, sociologists, and human rights advocates.

We decided to create a stand-alone graphic with four parts:

1. A comparison of Brazil's prison system and those of other countries between 1997 and 2007. We had found a United Nations report showing that Brazil ranked fifth in prison population growth over those years and first in the Americas. Its number of inmates grew 150 percent in that

decade.

2. A list of the Brazilian states with the most drastic inmate increases between 2007 and 2010, based on the Ministry of Justice data. We decided to calculate the number of inmates per 100,000 people in each state, as this measure allows a fair comparison of regions with different-sized populations. Had we used absolute numbers, the states with more inhabitants, such as São Paulo and Rio de Janeiro, would always rank first.
3. A graphic that showed the imbalance between the number of prison inmates and the number of spaces for them in jails. In the worst cases, like the state of Acre, there were more than two prisoners per space. We included those figures.
4. Explanations highlighting the most surprising numbers. Designers sometimes forget that in many cases an infographic is a narrative based on charts, maps, and diagrams, in which text is crucial.

Our next step was to devise a structure that would make sense of the data. We decided to use headlines to guide readers through the information:

1. Between 1997 and 2007, Brazil experienced the fifth-largest increase in prison population in the world;
2. The trend has continued since 2007; and
3. Government has not kept pace with the growing prison population by building sufficient accommodations.

Figure 3.1 shows the infographic we published.

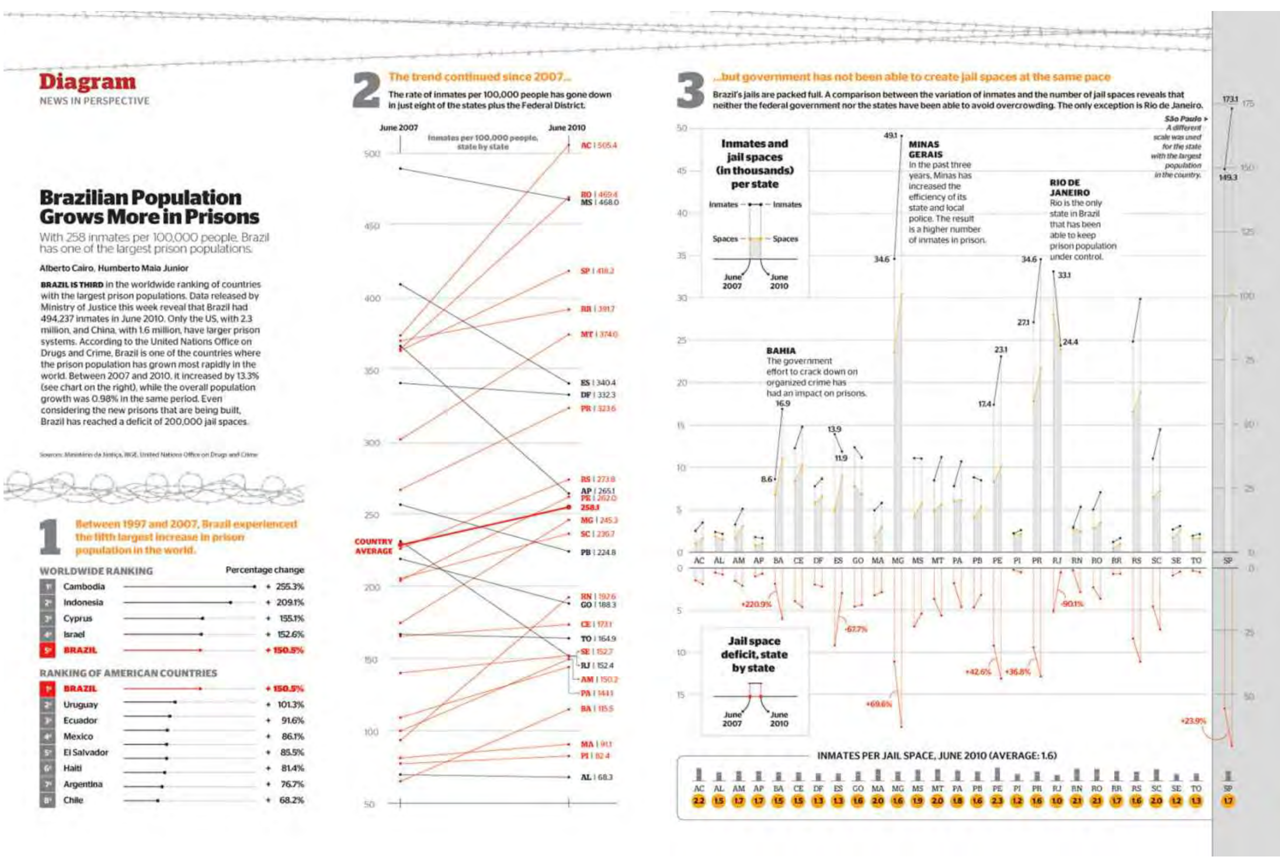

Figure 3.1. *Época* magazine (São Paulo, Brazil). Originally published in Portuguese on November 1, 2010.

We ended up with a two-page, graphics-based story told in several layers of increasing depth and complexity that readers could explore at their leisure. While we could have restrained ourselves and merely summarized the data, I reasoned that readers living in Rio Grande do Norte, Tocantins, or Amazonas would want to analyze how their home states compared with others and with the country averages. They would want details in terms of granular data. On seeing the story in print, I believed we had created an acceptable and interesting graphic.

Not everyone agreed.

An Unexpectedly Controversial Chart

The *Época* newsroom finishes working on each issue by Friday evening. The magazine hits the newsstands Saturday morning. That gives executive editors—myself among them at the time—a chance to look over the stories and prepare for a critique meeting that takes place every Monday morning before the next edition is planned.

On Monday, November 1, 2010, I arrived in the newsroom five minutes before the meeting started. Anticipating a routine critique, I basked in the lingering feeling of peaceful drowsiness after a particularly nice, quiet weekend. **Nothing prepared me for what happened next.**

"I feel compelled to say that this week's 'Diagram' is horrible," said one of the executive editors. "We should strive to become more popular. Our average reader is not going to be able to understand something as complex as this."

The comment unleashed a firestorm. "I think this graphic is not friendly enough. No one will read it," said another colleague.

The director took a turn: "The problem is not complexity. The infographic is not hard to understand. The problem is that it is ugly."

"In my opinion, it has too much information," another colleague said.

Holy *crap*! I was flabbergasted. Patiently, I waited for everyone to finish tearing our project down, giving myself a chance to cool off. Then, I explained the reasoning behind the piece: the gathering of the data, the structure, the narrative, the depth. No one was convinced. It really wasn't my goal to convince them. The critique meeting is not the place to persuade others of how good your work is, but to hear suggestions for how to improve it.

Even if I disagreed with the objections, and even if, one year later, the graphic would go on to win a Malofiej Infographics award, the highest honor in the infographics field, I took the comments to heart. In fact, they led me to revisit a question that generations of designers have pondered:

What does "ugly" mean when used to describe an infographic?

That is, what did my colleagues, whose combined journalism experience totaled more than 100 years, really mean when they said that the graphic was *horrible*, *too complex*, and that *it could scare readers away*?

The Visualization Wheel

After the meeting, I took a couple of hours off to reflect. I grabbed a pen and paper and began sketching and taking notes, which helps me think. I listed my colleagues' opinions. According to them, our graphic was:

1. Too complex
2. Too abstract
3. Too far from the aesthetics a majority of our readers expect ("ugly")
4. Too dense

I discovered their critique could be summarized using a conceptual device I had developed while writing my first book, *Infografía 2.0* (2008, no English version available): **the visualization wheel**. See **Figure 3.2**.

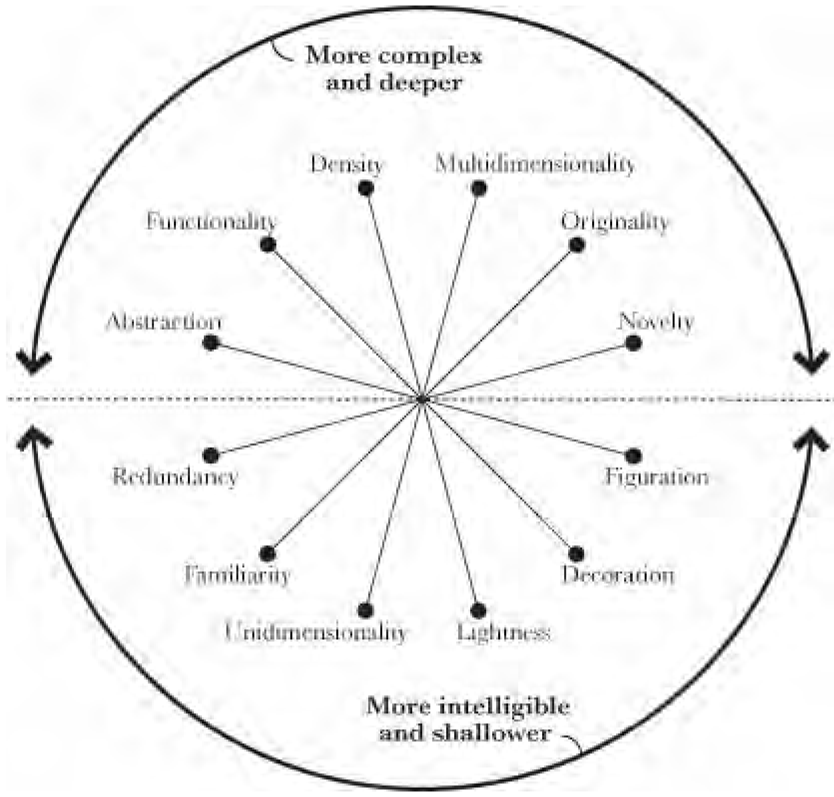

Figure 3.2. The visualization wheel.

The visualization wheel's axes correspond to the main features you need to balance when you design an information graphic. For this reason, I also refer to it as the *tension wheel*. The idea isn't so original: It's based on a similar wheel in Chapter 1 of Joan Costa's *La Esquemática* (see bibliography). My wheel includes several changes and more axes.

A word of warning before we move on: The visualization wheel is an aid I use for thinking about my own graphics. The position along each axis is therefore very subjective, so it is unlikely you'll be able to use it for academic or quantitative analyses. It is an exercise in meta-visualization: *a visualization for planning visualizations*.

Let's see how the wheel works.

The outer layer is divided into two hemispheres, each with six features. The upper hemisphere's features define graphics that are deeper and more complex. By complex I mean the amount of effort readers have to invest in deciphering a particular graphic. Depth is the number of layers of information a graphic includes.

It is possible for a graphic to be complex *and* shallow if you use a funky graphic form to encode irrelevant data, or simple *and* deep if you encode tons of data with common graphic forms. But, in general, complexity and depth are related variables in information graphics and visualizations. Graphics containing a good amount of data tend to be more difficult to read, but are also more rewarding and enlightening.

Let's look at the axes.

Abstraction-Figuration

An information graphic (or a portion of it) is completely *figurative* when the relationship between the referent and its representation is perfectly mimetic. The more distant the representation and its referent are, the more abstract the infographic will be: For example, a realistic illustration of a person is more figurative than a pictorial symbol of the person. In extreme cases, there will be no natural relationship between the two, and in those cases we would say that the connection between referent and representation is *conventional*.

You can see this axis at work in two scenes of a single interactive graphic of mine about the NASA Cassini-Huygens Mission to Saturn. See [Figure 3.3](#).

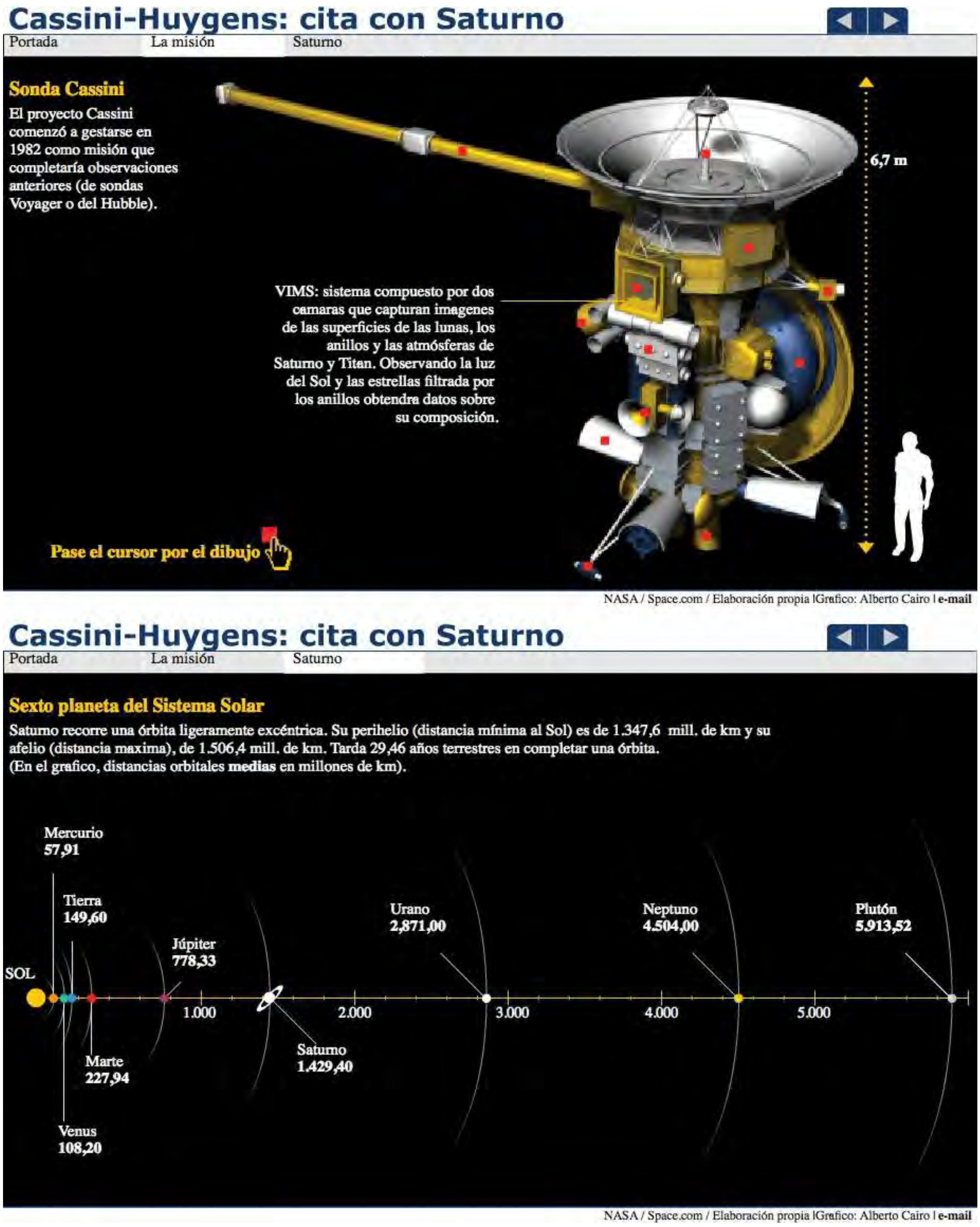

Figure 3.3. Cassini-Huygens Mission:
http://www.elmundo.es/elmundo/2004/graficos/jun/s4/cassini.html.

The graphic in the top image is more figurative. The illustration resembles the object it intends to explain. The graphic at the bottom displaying the distances between planets in the solar system is much more abstract. In general, the more closely a graphic reproduces a material reality, the more figurative it will be.

On the other hand, if the representation involves significant conceptual manipulation on the part of the designer, it will tend to be more abstract. In the case of the Saturn mission graphic, I consciously reduced the realism of the planets to transform them into simple color circles, and I placed them on top of a distance scale—another conceptual item device.

Functionality-Decoration

A graphic can be functional and visually pleasing, obviously, but here I am not considering stylistic elements that improve readability, such as the correct use of elegant fonts and carefully crafted color palettes. This axis refers to the inclusion of visual elements that are not directly used to enhance the comprehension of the material.

Take another look at the Brazilian prison graphic (Figure 3.1). Do you see the barbed wire? That's what I would call a non-functional visual element. It's decoration. Decoration is not bad per se, but it can interfere with the information in a chart if not handled well.

Density-Lightness

The position an infographic occupies on this axis is related to the amount of data it displays in relation to the space it uses. See the two graphics in **Figure 3.4**, which my colleagues and I created at *Época* magazine. Although almost equal in size, the graphics offer very different amounts of information. The first graphic is very dense; the second, very light, although still informative.

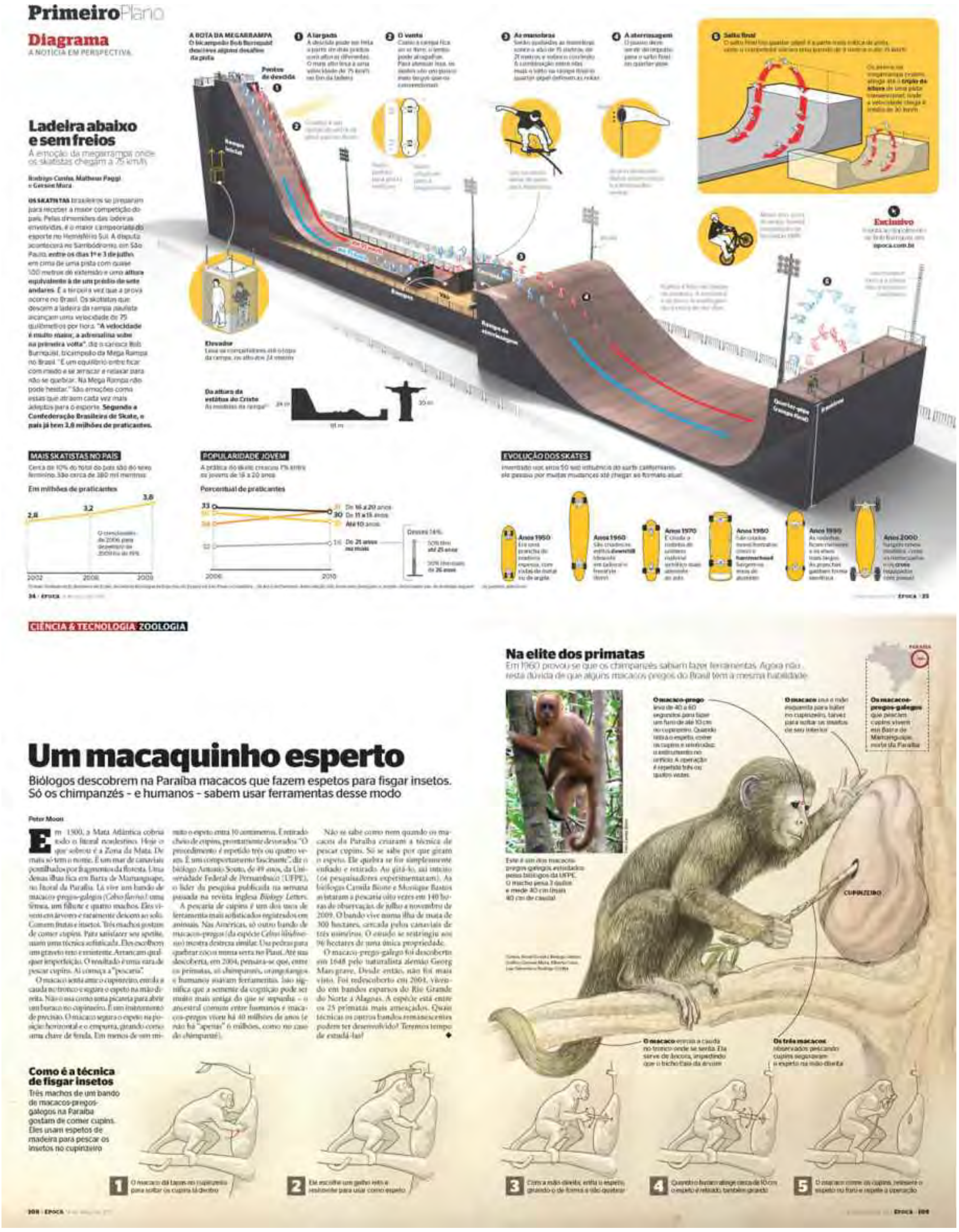

Figure 3.4. “Megaramp: Skate Boarding Competition in São Paulo,” and “How the Brown Capuchine Macaque Hunts Termites.”

Multidimensionality-Unidimensionality

This axis is a measure of two related variables: the number of layers of depth a graphic lets readers navigate, and the different forms it uses to encode the data.

Consider our prison graphic. I believe that this one leans toward the *multidimensionality* side of the wheel, because it gives readers the opportunity to dig into the data quite deeply. Also, in the case of the relationship between number of inmates and jail spaces in different states, it lets them see the same data in different ways.

Another example of multidimensional infographics is Figure 3.5, published by *The New York Times* right after the 2004 U.S. presidential elections. The popular vote is represented by county and by population density. The electoral vote is shown state by state in a standard *choropleth map* (a map that uses different colors and shades) and in a *cartogram* (a map that distorts the relative size of regions proportionally to a variable—in this case, the number of electoral votes each state has). On top of the composition is the proportional symbol map I discussed at the end of Chapter 2, "Forms and Functions: Visualization as a Technology."

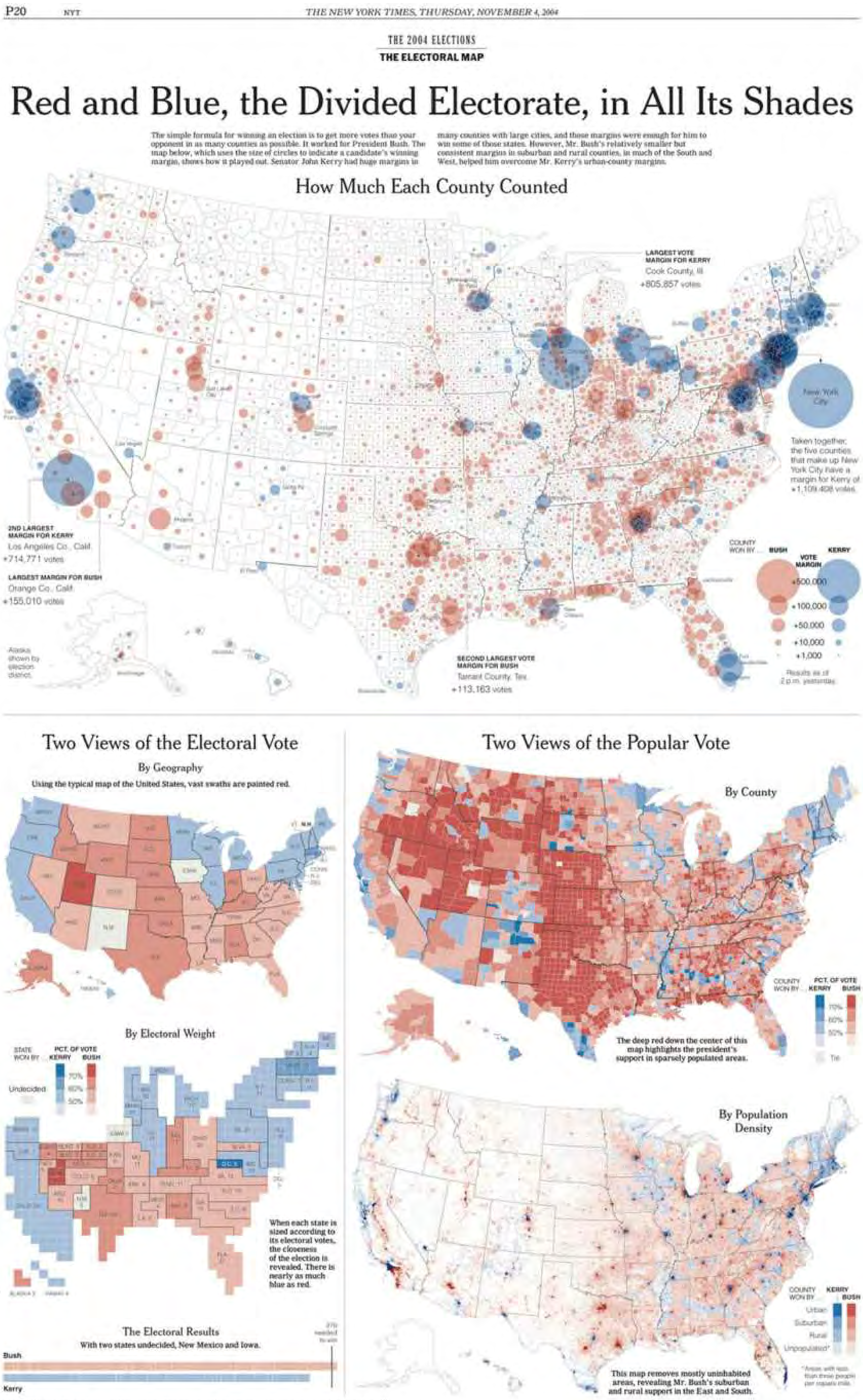

Figure 3.5. *The New York Times*. Reproduced with permission.

Originality-Familiarity

Some graphic forms have become so common that they are almost as readable as text. Think of bar charts, line charts, and pie charts. This has not always been so, of course. In the late eighteenth century, when the use of such charts was first systematized and theorized by polymath William Playfair, they were considered revolutionary, albeit understandable.

However, the explosion of the use of information graphics and visualization in many areas—from academic computer science departments to PR and marketing companies and more—has fueled a desire to innovate new graphical forms. An example of a form that today some people would find new or challenging is *theme rivers* (also called stream graphs), for instance. See one in **Figure 3.6**, made by Periscopic, an information visualization firm, for Yahoo!. It shows the keywords processed by Yahoo! Mail over a 30-second period. Word size and line width denote volume of occurrence. Spam keywords are shown in gray.

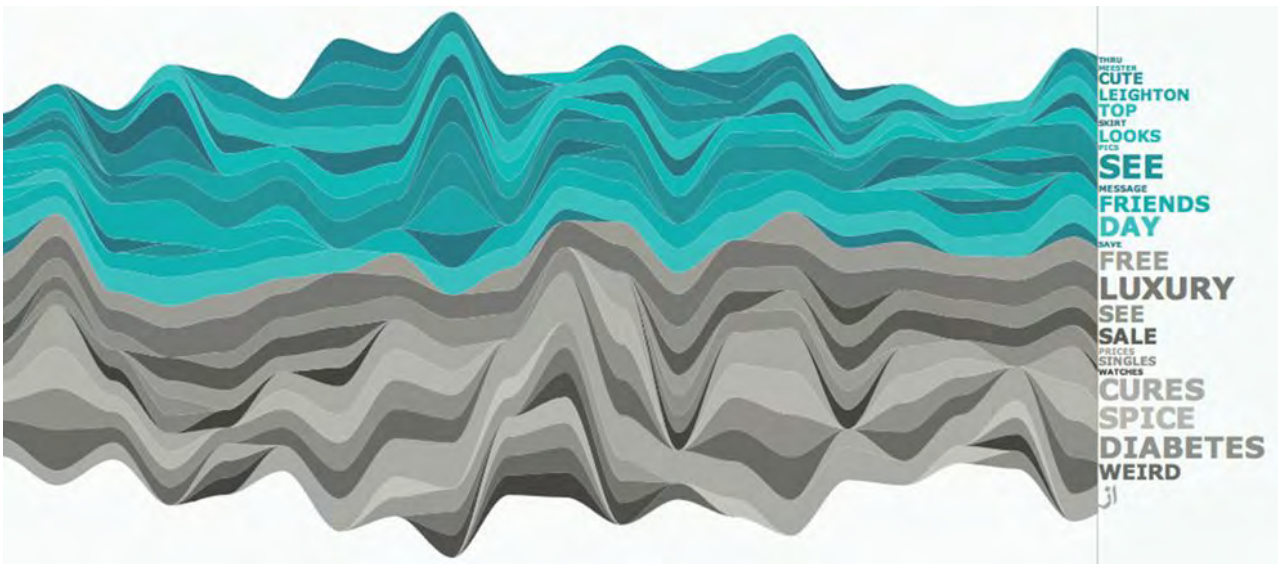

Figure 3.6. An example of a stream graph. ©2011 Yahoo! Designed by Periscopic (http://periscopic.com/).

Novelty-Redundancy

An information graphic can explain many different things once (novelty) or it can explain the same things several times, by different means (redundancy). Striking a balance between novelty and redundancy is critical. Novelty is important to avoid boring your readers, but a certain level of redundancy is necessary if you want to be understood.

See **Figure 3.7**, which shows a portion of an infographic about giant waves that I'll discuss later on in this book. The copy accompanying each step of the explanation repeats some of the information encoded in the illustration. In this case, the text not only complements the image (or vice versa), it also *strengthens* the message by clarifying what the image shows. Another example: In a complex statistical chart, you could add necessary redundancy by highlighting relevant data points.

Figure 3.7. Realistic illustrations accompanied by redundant copy.

If I had to visualize my Brazilian prisons infographic using the visualization wheel, the result would be [Figure 3.8](#). I consider the graphic more abstract than figurative, for an obvious reason: The charts don't resemble physical reality but are conceptual tools that allow me to encode quantitative data.

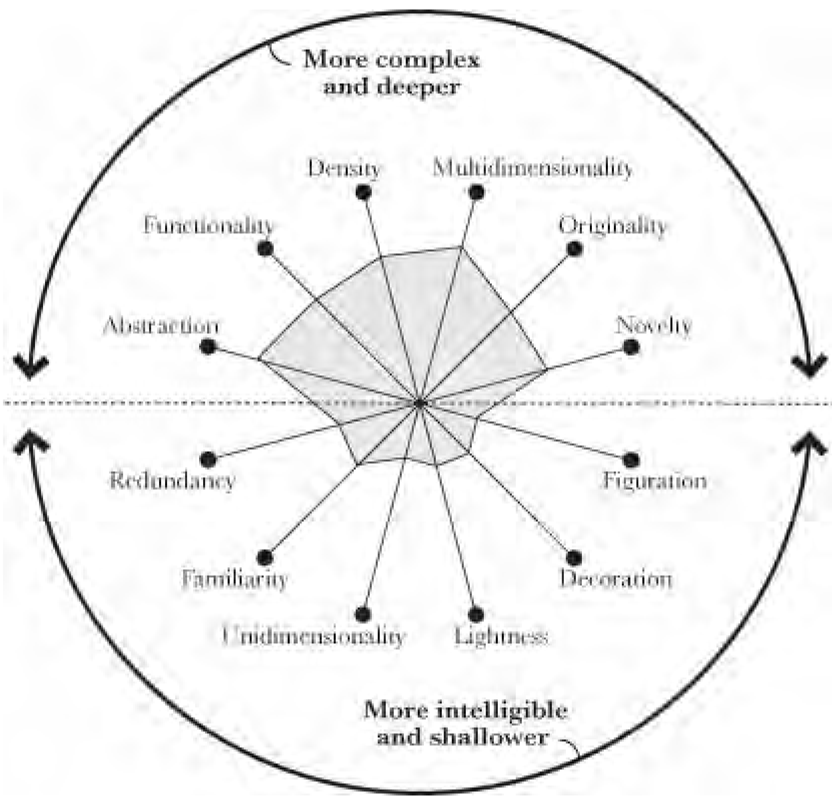

Figure 3.8. Visualization wheel of the Brazilian prisons infographic.

In a conventional sense, the chart is more functional than beautiful. It contains almost no decoration, although we paid attention to color palettes and the consistency of typographical style.

The chart is multidimensional: It has at least five layers of information that readers can explore.

It's not very original. All of the graphic forms are in common use—the bar chart, the slopegraph (used for the second part), the tables, and so on.

The charts contain quite a bit of redundancy. Notice on the second page, where the number of inmates is compared to jail spaces, that the same data is encoded in different formats. It also includes explanatory text to clarify the most striking figures.

Is this an adequate combination of factors? I believe it is. Despite the comments from my colleagues, I don’t think that this information graphic is overloaded or excessively difficult to read. It’s not the prettiest thing in the world, I concede. But it’s not very ugly, either. (I’ve done worse!)

It is true that, according to my own terms, the Brazilian prisons project leans toward the upper half of the visualization wheel: It is complex and deep. This should be no obstacle for readers of a quality publication such as *Época*. If we assume that our audience is willing to read 8,000-word stories about convoluted corruption schemes in the upper echelons of government, why not apply the same expectation to graphics? It would be strange to publish stories for adults illustrated with graphics for kids, which is what happens when publications underestimate what their readers can absorb.

Identifying your audience

The complexity of a graphic should be adapted to the nature of your average reader. This sounds easier than it really is. Figure 3.9 explains that at least two factors influence the communication between a designer and an audience through information graphics and visualizations: first, how well the visual forms used to encode the information are adapted to the nature of the story the graphic should tell; and second, the previous knowledge the user has about the topic and about how those visual forms work (e.g., bar charts are more common than scatter-plots).

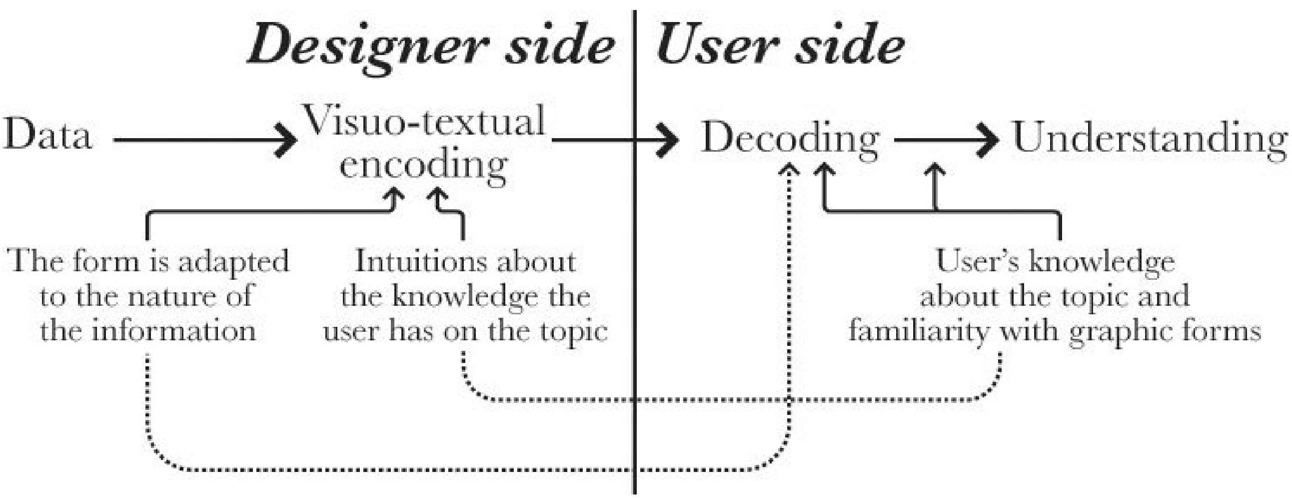

Figure 3.9. Designers encode, users decode.

The more specialized your audience niche, the more you can take for granted, and the more you can rely on what your users presumably already know.

Consider the charts in Figure 3.10. They display the co-occurrence of neuropsychiatric disorders within families, drawn from an academic paper published in the online magazine *PlosOne*.[1] Do you know what it all means? I don’t (well, actually, only to a point). That is not criticism of the charts: It’s just that the researchers didn’t have me in mind when they plotted their graphics. They were thinking of their peers, people with so much knowledge of psychiatry and neuroscience that they can decode these graphics in the blink of an eye. They don’t need extra explainers, legends, or any other artifice that designers ordinarily employ to make readers’ lives easier.

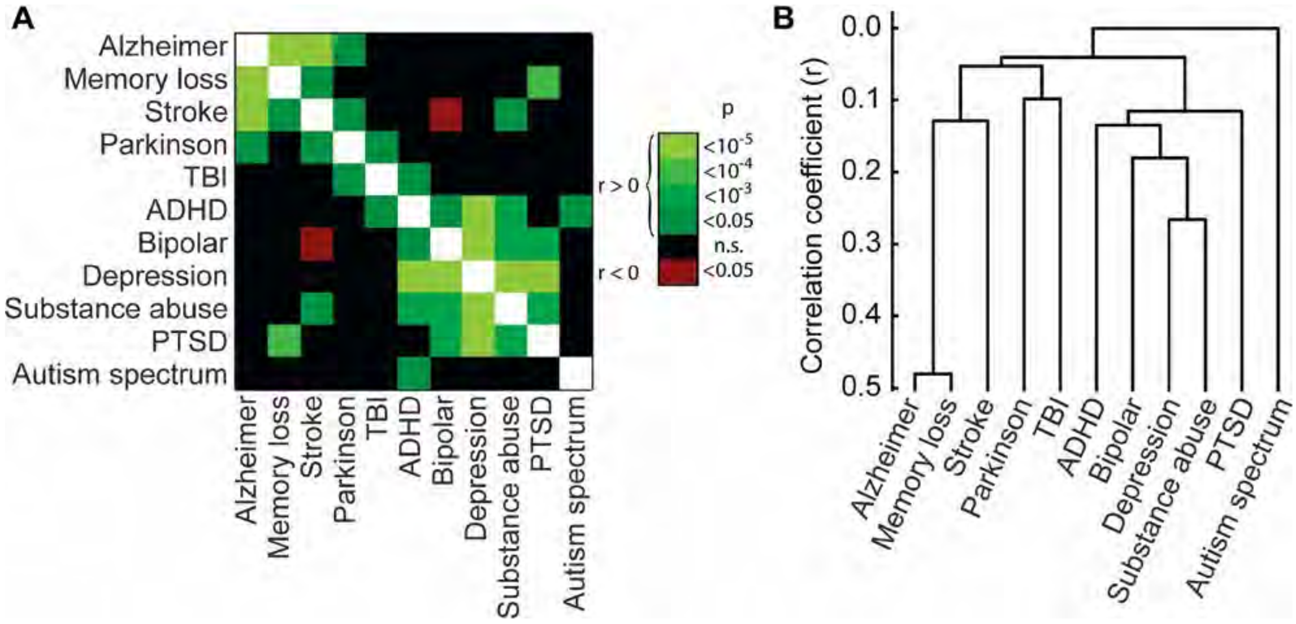

Figure 3.10. Try to figure out what these charts mean. It's not easy, is it?

Few designers have the privilege of working for scientific publications, where it is easy to base decisions on assumptions about one's audience. Most of us work for general publications and face questions such as, "Is this graphic too complex for the majority of our readers?" or "Will our readers feel overwhelmed by the amount of data we've given them, or by the way we've presented it?"

Sadly, when faced with these challenges, **too many communicators dumb down the data**, simplifying it rather than *clarifying* it, and they add cutesy illustrations and icons that, to their way of thinking, will make the graphic presentations less dry.

The mind-set behind this approach is captured in a statement that I've heard, with minor variations, in three different newsrooms from three different managers who didn't know one another: "Our readers are idiots." The quote that opens this chapter, taken from E. B. White's great classic on writing, *The Elements of Style*, is the perfect antidote against this deleterious nihilism:

> No one can write decently who is distrustful of the reader's intelligence, or whose attitude is patronizing.

Do you respect your audience's intelligence? How do you know if you are overestimating it (not likely) or underestimating it (most common)?

Engineers vs. Designers: Edward Tufte and Nigel Holmes

There has always been a fundamental clash in information graphics and visualization between those who favor a rational, scientific approach to the profession, emphasizing functionality, and those who consider themselves "artists," placing emphasis on emotion and aesthetics.

There is a middle ground between the two groups, and the boundary between the two philosophies is blurry. But, in general, it is my perception that those in the first group typically come from technical backgrounds (statistics, cartography, computer science, and engineering), while those in the second group are graduates of graphic design, art, and journalism programs. The first group would be drawn to visualization wheels like the one shown on the left in Figure 3.11. The second group would prefer to deliver graphics similar to the wheel on the right.

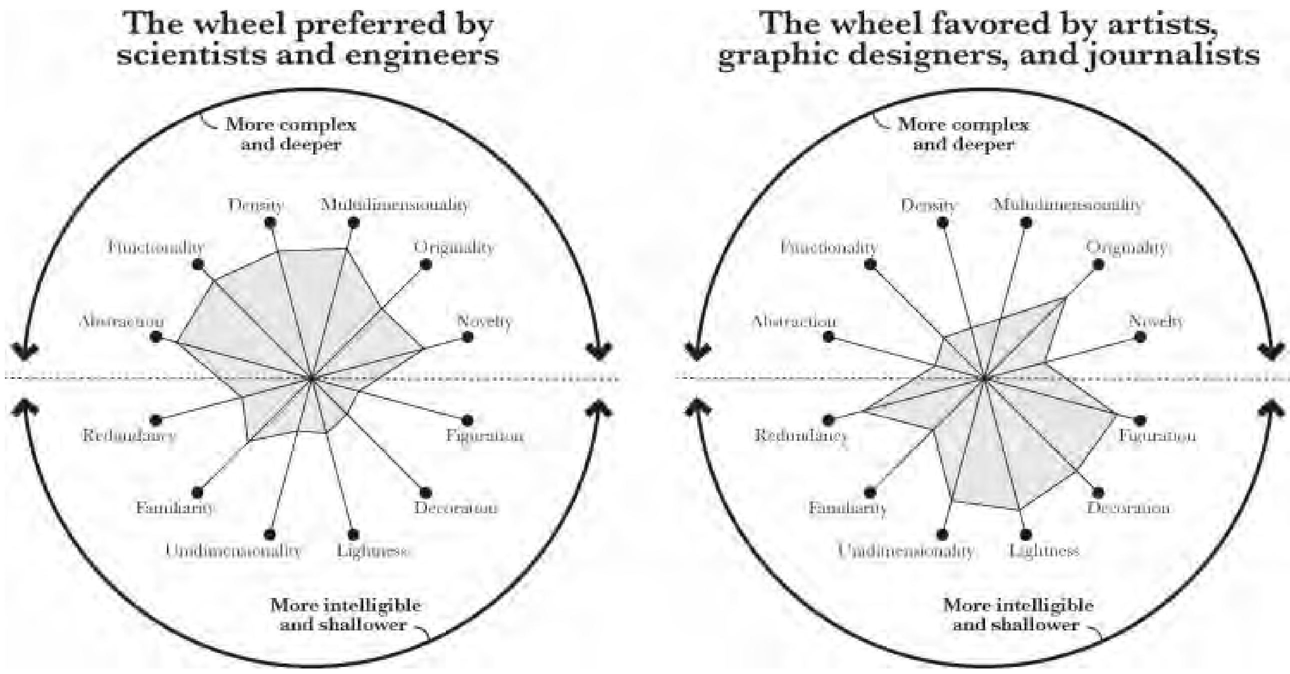

Figure 3.11. Different professional backgrounds, different ways of facing projects.

War between the factions was more or less formally declared by Edward R. Tufte in 1990. A professor emeritus of political science and statistics at Yale University, Tufte is arguably the most influential theoretician in information design and visualization, and deservedly so. His books *The Visual Display of Quantitative Information* (1983), *Envisioning Information* (1990), *Visual Explanations* (1997), and *Beautiful Evidence* (2006) are must-reads in our field.

In *Envisioning Information*, Tufte attacked an infographics tradition that took shape in the United States in the late 1980s and early 1990s. Thanks to the success of the visual style of *USA Today* (launched in 1982) and *Time* magazine, illustrated charts and pictorial maps became very popular.

Tufte coined a term to define pictograms and illustrations within charts and maps: *chartjunk*. To make his case, he chose a *Time* chart (**Figure 3.12**) designed by renowned artist Nigel Holmes, the magazine's art director at the time. Holmes himself recognizes that this is not one of his most inspired works, but also contends that Tufte picked just one graphic among hundreds and elevated an isolated anecdote to a category level to make his case.

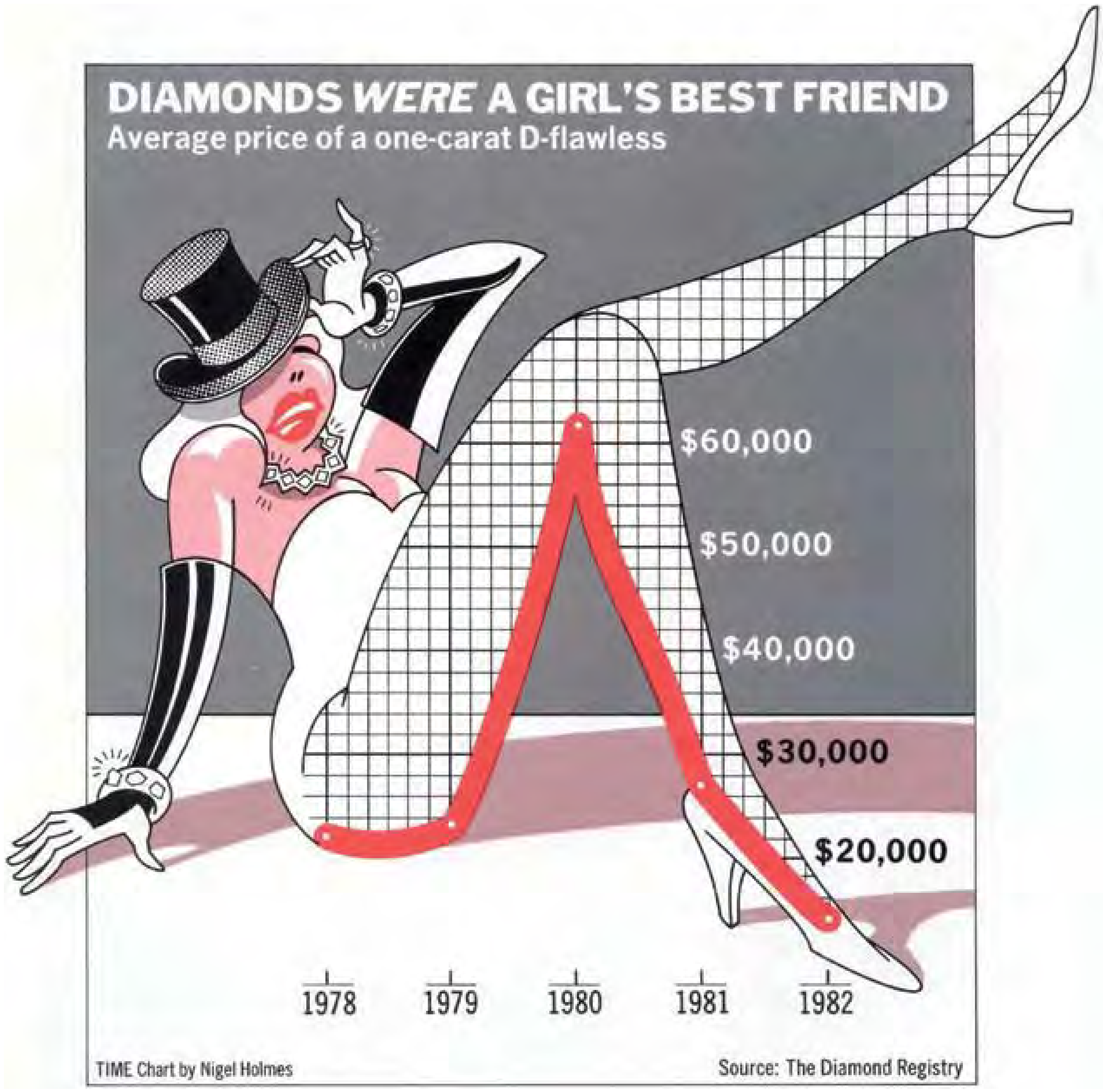

Figure 3.12. Chart by Nigel Holmes for Time magazine. (Reproduced with permission.)

Tufte explained why he despised decorative ideology represented by the graphic this way:

> Lurking behind chartjunk is contempt both for information and for the audience. Chartjunk promoters imagine that numbers and details are boring, dull, and tedious, requiring ornament to enliven. Cosmetic decoration, which frequently distorts the data, will never salvage an underlying lack of content. If the numbers are boring, then you've got the wrong numbers (...) Worse is contempt for our audience, designing as if readers were obtuse and uncaring. In fact, consumers of graphics are often more intelligent about the information at hand than those who fabricate the data decoration (...) The operating moral premise of information design should be that our readers are alert and caring; they may be busy, eager to get on with it, but they are not stupid.[2]

Minimalism and Efficiency

A cherished notion of Tufte's is a principle of efficiency: **A visual design project is good if it communicates a lot with little**. In his own words, in his principles of graphic excellence:

> • Graphical excellence is the well-designed presentation of interesting data —a matter of substance, of statistics, and of design.

- Graphical excellence consists of complex ideas communicated with clarity, precision, and efficiency.
- Graphical excellence is that which gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space.[3]

This efficiency principle is defined with more precision by Tufte as the *data-ink ratio*: a measurement of the amount of ink that is used to represent data in a chart. Tufte defines data-ink elements as those that cannot be removed without destroying the integrity of the presentation. The other items, those that amount to decoration, can be eliminated because they are either redundant or they distract the reader from what really matters. Tufte even proposed a little formula:

> Data-ink ratio = Ink that encodes data / Total amount of ink used to print the graphic

Nigel Holmes's diamonds graphic scores low in this formula. Let's say that 1,000 drops of color ink were used to print it. Of those, around 150 are the ones that define the line, the headline and subtitle, the scale, and the specific values. Those are the elements that encode data. The woman illustration is non-data ink. So:

> Data-ink ratio = 150 / 1,000 = 0.15

According to Tufte, the closer the data-ink ratio is to 1.0, the better the graphic is. The less ink you use for ornamental effects, the better. Tufte doesn't just consider mere decoration erasable. In his first book, he also proposed removing gridlines and even portions of bars in a bar chart. See **Figure 3.13**.

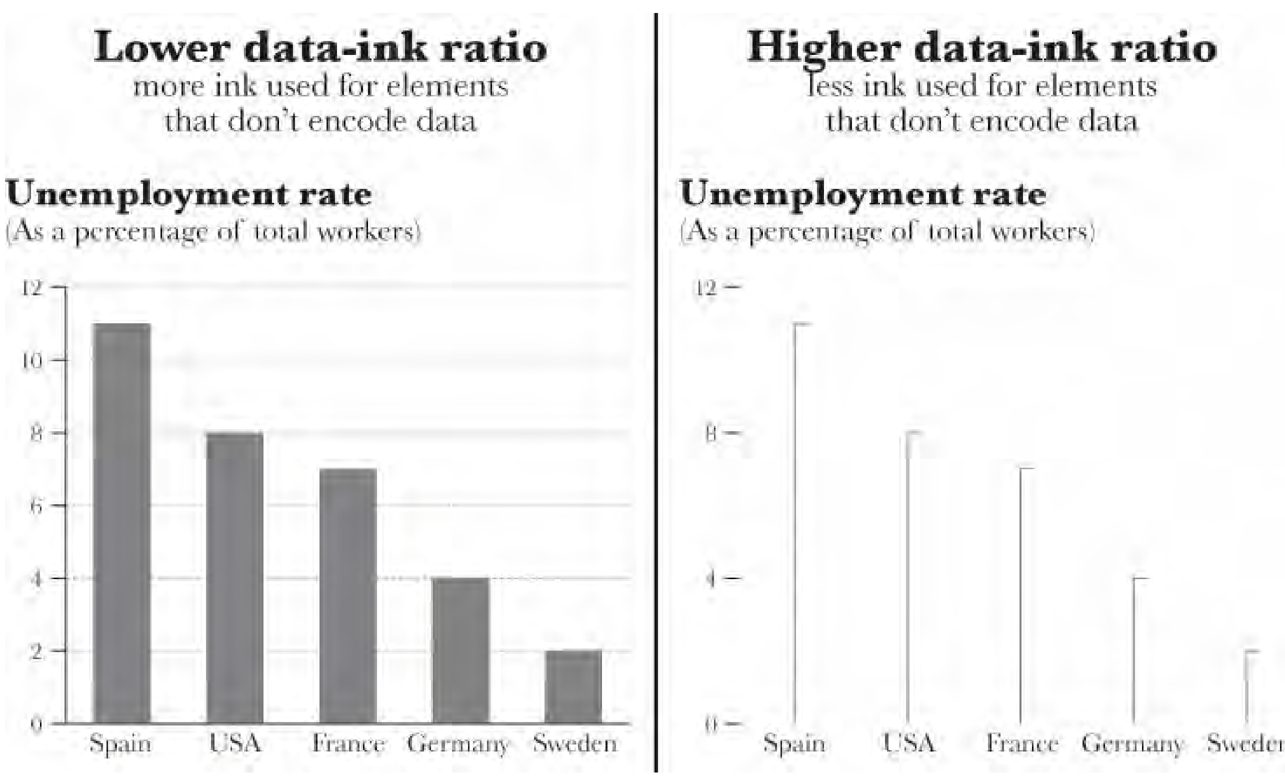

Figure 3.13. A traditional bar chart and its minimalist version.

Tufte's books imposed sanity at a time when flashy prevailed over functional, when pictorial and fun presided over abstract and intellectual. His writing style is as austere and economical as the graphics he favors, and many of his best quotes and soundbites (including "chartjunk" and "chartoon") became conceptual weapons in many discussions on what is appropriate in information graphics and visualization. But are Tufte's rants against *redundant* and *unnecessary* visual junk always right?

Is All "Chartjunk" Junk?

The problem with Tufte is that he tends to write in aphorisms and epigrams rather than building a continuous argument cover to cover. John Grady, a Wheaton College professor, observed in 2006 that Tufte's books are neither guides nor analytical texts, but "meditations" or essays: "Each chapter of his books consists of loosely integrated discussions of the merit of particular displays."[4] **That is why so many readers of Tufte's work** (in the past, myself among them) **feel a bit disoriented when they try to transfer his abstract principles to the real world.**

Another challenge of Tufte's writing is that he doesn't indicate whether an opinion is based on research or derived from personal views. The writing is matter-of-fact, as if the ideas are self-evident and grounded in reason. There are no cracks in the armor that would allow you to sense whether the author has any doubts. This minimalism is not purely a rational choice, it is also an aesthetic one. As much as I agree with Tufte on being serious about the data you handle, respecting the reader's intelligence, and reducing clutter and increasing elegance, his lack of differentiation between evidence-based assertions and personally informed intuitions is a weakness.

The data-ink ratio is paradigmatic. His assertion that a higher efficiency—the lowest amount of visual resources to communicate the highest possible amount of content—*always* facilitates understanding is dubious. This doesn't mean that designers should feel free to start cramming charts with cartoons and illustrations, but it does mean that resources considered by Tufte to be non-data ink—for instance, gridlines in a time-series chart, or unobtrusive and subtle icons that identify the topic the chart discusses—might not be junk at all. Far from obstacles to understanding, they may *enhance* understanding.

In the past decade, academic papers have tested Tufte's hypotheses with mixed results. A 2007 study from Ben-Gurion University presented 87 students with traditional bar charts and maximized data-ink ratio charts similar to those in **Figure 3.14**. The minimalist version was rejected by many of the participants, perhaps because the bar chart is such a common graphical form. More importantly, when researchers tested to see if readers interpreted the minimalist chart better and faster than the more cluttered one, they found no significant difference. In this case, radically reducing the bar chart to its main constituents was not a matter of functionality, but of visual style.[5]

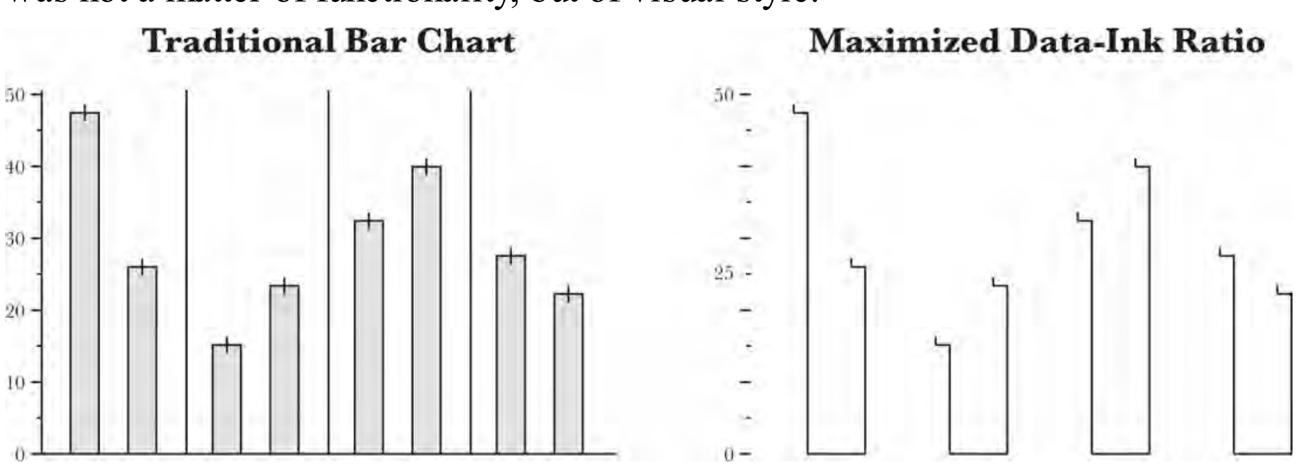

Figure 3.14. Which chart would you prefer?

In another study at the University of Saskatchewan (Canada),[6] 20 students read four old Nigel Holmes graphics and their corresponding minimalist versions designed by the researchers. One was our well-known diamonds chart in Figure 3.15.

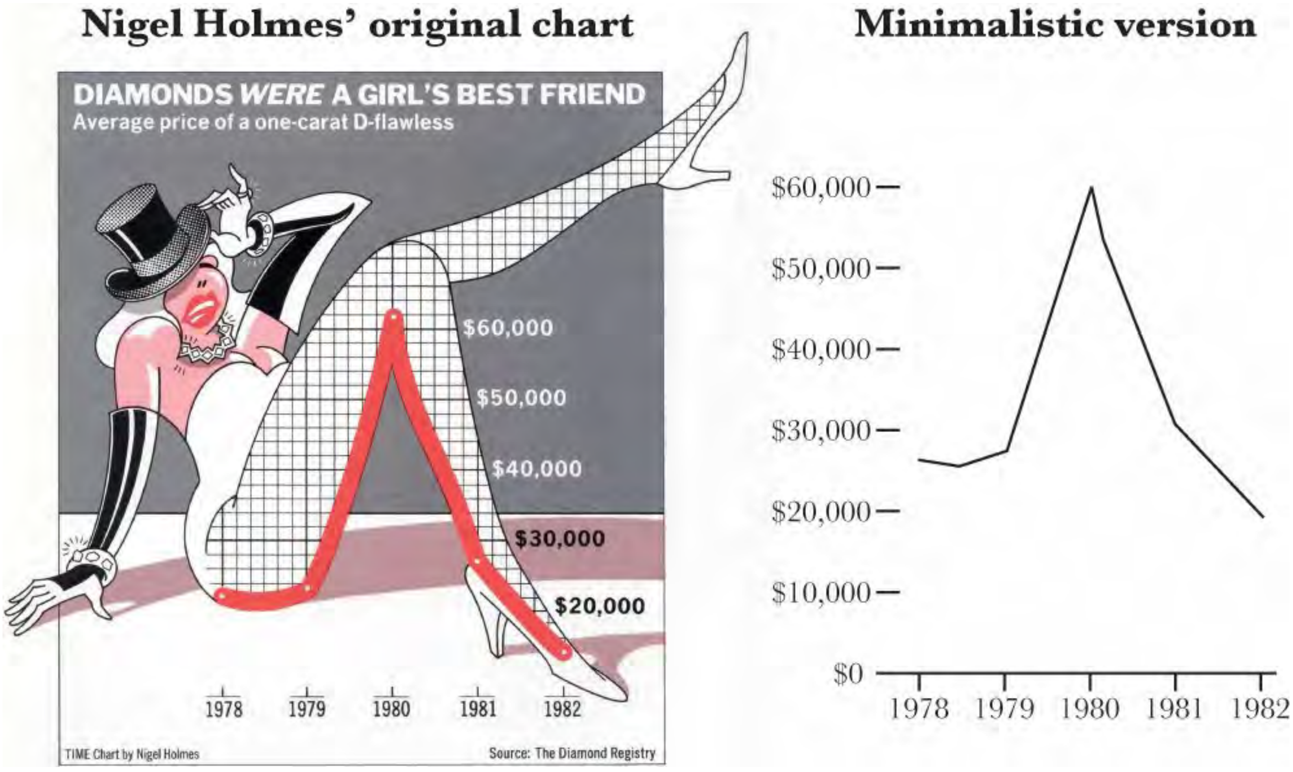

Figure 3.15. The original graphic is not very appealing, but the stripped-down version was not easily remembered.

The study was divided into three stages. First, the researchers used eye-tracking devices to register eye movements as each participant read each pair of graphics.

In the second phase, each subject answered a questionnaire about the charts' contents, answering questions such as:

1. What is its central topic?
2. What phenomena and variables does the graphic show?
3. What changes does the graphic highlight in the data it represents?
4. Does the graphic present information in an objective manner, or does the author editorialize about the content?

As in the Ben-Gurion University paper, the researchers detected no significant differences in the effectiveness of the embellished and minimalist graphics. The components of each pair of charts conveyed the message equally well.

The most interesting part of the study was the third phase, in which the researchers tested the level of short- and long-term recall for each graphic. The participants were divided into two groups of equal size. They were not informed that they would be questioned about the graphics later on. The first group was tested five minutes after phase two questioning was completed, while the second group was asked to return to the lab three weeks later.

In all cases, the participants were better able to recall the topics and contents of the chartjunk-filled graphics. Apparently, their coarse humor ("coarse" is the adjective Tufte used to refer to Holmes's work) enhanced memory.

Fun and Functionality

To call these two studies conclusive would be a mistake. Both have been justly criticized by experts such as Stephen Few, author of two essential books on statistical charts,[7] for their methodologies, for the small number of subjects tested, and for the lack of socioeconomic and cultural diversity among subjects.

While it would be risky to extract general lessons from the papers, I personally believe they suggest compelling reasons to doubt that always reducing charts to their barest bones facilitates comprehension and memorability. It depends on the audience's nature, knowledge, tastes, and expectations.

This idea coincides with what other critics of Tufte's approach, including Nigel Holmes, have observed: Tufte's influence in the visualization and information graphics communities has led many publications to adopt a style that is serious, cold, and stripped bare of aesthetic attributes that may be gratuitous to the statistician but that are useful for readers. This is not to say that we should not strive for economy of style and respect the integrity of the data, but that, as Donald A. Norman pointed out in *Emotional Design* (2003), beautiful things are more functional, and beauty is as much in the eye of the designer as it is in the eye of the beholder. Feeling good about an artifact makes us better at using it to accomplish a goal.

Holmes anticipated a similar idea in his early writings. He has always been an advocate of humanizing information graphics and using humor to instill affection in readers for numbers and charts. In *Designer's Guide to Creating Charts and Diagrams* (1984), he wrote in what appears to be a direct reference to Tufte's *Visual Display of Quantitative Information*, published the year before:

> If you belong to the school of people who believe that charts should only present statistics in the most straightforward, plain way, with no other visual help to the reader, for example, than the bar of the bar chart, the line of the fever graph, the circle of the pie chart, or the rules of the table, then move on to another part of the book. As long as the artist understands that the primary function is to convey statistics and respects that duty, then you can have fun (or be serious) with the image; that is, the form in which those statistics appear.[8]

Holmes also referenced this passage from *A Primer of Visual Literacy* (1973), a classic book by Donis A. Dondis:

> Boredom is as much a threat in visual design as it is elsewhere in art and communication. The mind and eye demand stimulation and surprise.

And Holmes praised the power of humor:

> Humor is a great weapon in your visual arsenal. As long as it is not malicious, making people laugh with you will usually help them remember your image and therefore the point of the chart. Even a smile will encourage a reader to look into the statistics if he or she might not have thought of reading in a less-embellished chart.

Many of the examples Holmes includes in his book are problematic from a structural standpoint because, as in **Figure 3.16**, integrating lines and bars with illustrations sometimes leads to misleading distortions. But they do use humor, and they are memorable. Most of the graphics would not be publishable today, as Holmes himself acknowledges, but we must remember that *Designer's Guide to Creating Charts and Diagrams* was marketed almost 30 years ago and is a product of its times.

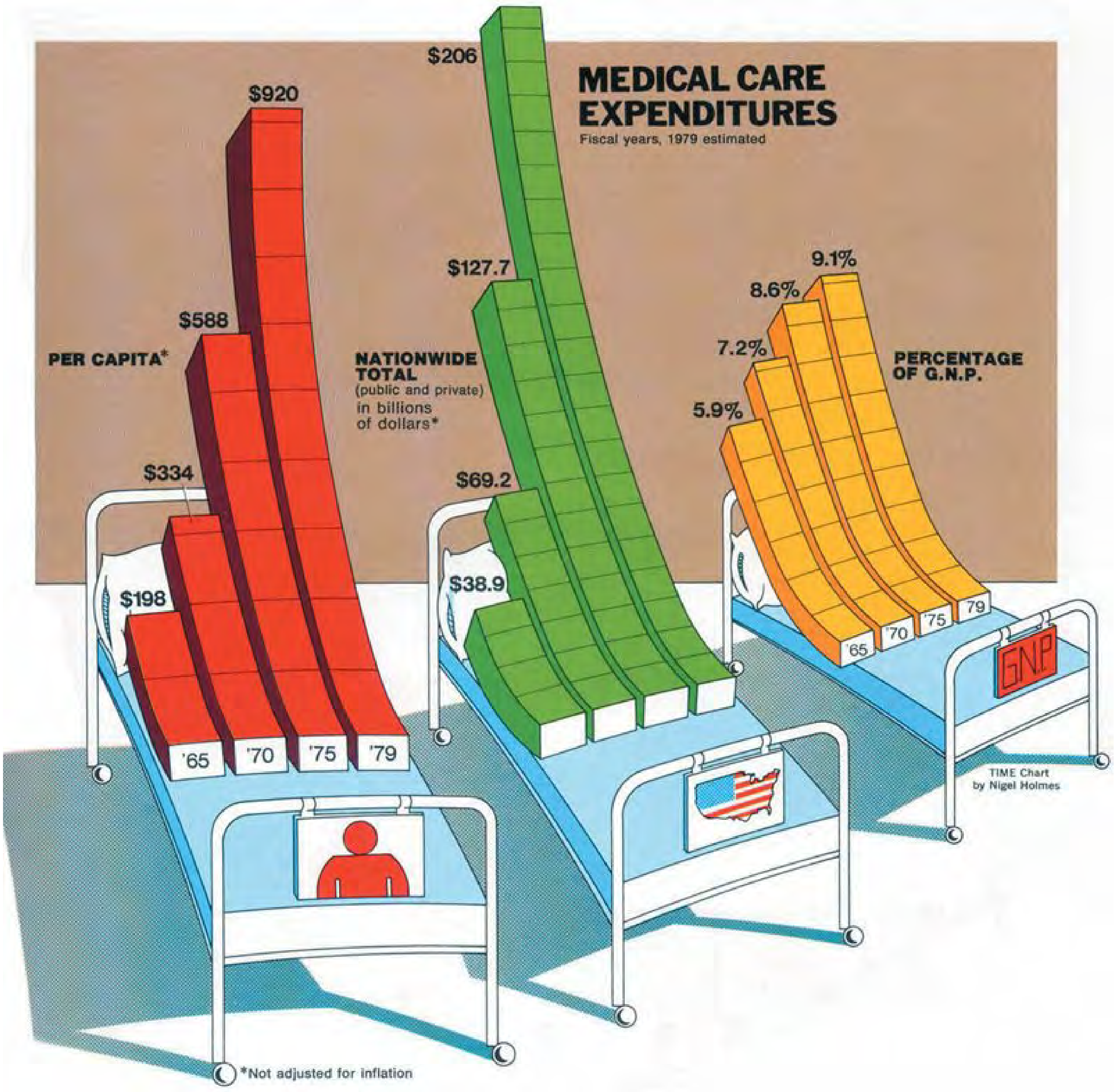

Figure 3.16. Too much expense on medical care makes bars feel sick. Chart by Nigel Holmes for *Time* magazine, 1979.

Holmes's style has evolved. Without losing its humorous appeal, it has become more restrained, as is evident in his wonderfully illustrated *Wordless Diagrams* (2004), which is witty, funny, and informative. (See Figure 3.17.) His work has become closer to the man he calls his main inspiration, Otto Neurath, one of the great thinkers of the twentieth century.

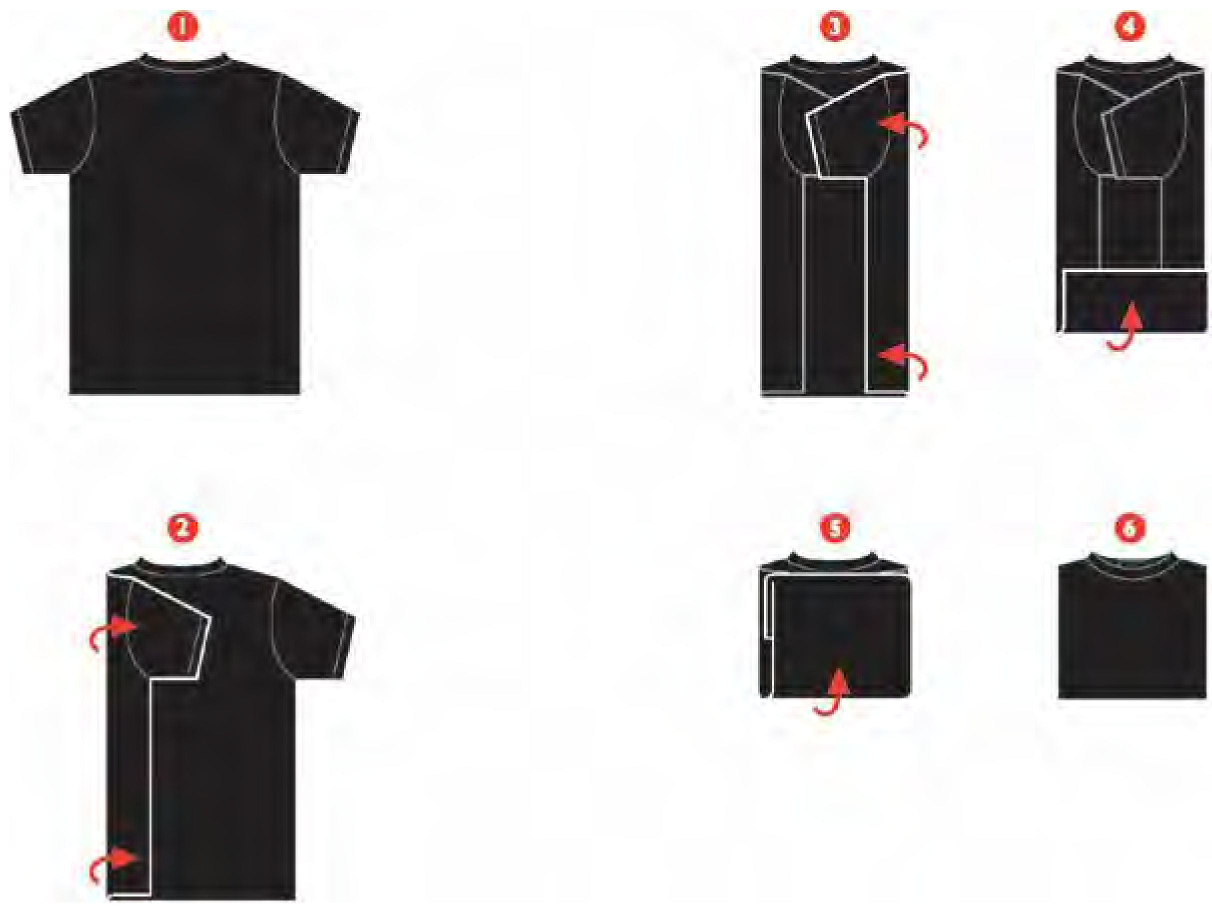

Figure 3.17. My mother was very happy after I read *Wordless Diagrams* (2005) by Nigel Holmes. After more than 30 years, I finally learned how to properly fold a T-shirt.

Otto Neurath and the Visual Education of the Masses

Otto Neurath was an Austrian philosopher, mathematician, sociologist, and political scientist born in 1882. He forged his fame in the world of information graphics in the Vienna of the first quarter of the twentieth century.

At the time, the capital city of Austria was a scientific and philosophical powerhouse. Besides Neurath, geniuses like Karl Popper, Niels Böhr, and Kurt Gödel walked Vienna's streets. Together, these intellectuals would be known as The Circle of Vienna, and their ideas gave rise to the philosophical tradition of logical empiricism.

Neurath combined the virtues of a rigorous, rational, and logical mind with the humanitarian concerns that emerged from his leftist leaning. He was a democratic socialist, a rare species in a time of ideological extremes. Neurath didn't want to communicate solely with his peers. He wanted to promote mass education. He defended the idea that abstract and mathematical thought could be conveyed with clarity and ease to people regardless of their social, cultural, and economic backgrounds.

Around 1925, as director of the Museum of Society and Economy in Vienna, Neurath devised *Isotype* (International System of Typographic Picture Education), a universal language based on pictograms whose goal was the "humanization of knowledge" and the overcoming of cultural barriers. Over many years, he worked with Gerd Arntz, a German graphic designer, and Marie Reidemeister (who would become Mrs. Neurath in the 1940s) to create many displays of information, charts, and maps of beautiful simplicity and clarity. See Figure 3.18 representing the amount of fabric produced in Britain between 1820 and 1880. The chart shows a paradigm change: At the beginning of the century, production was small and mainly a family venture; later, it became industrialized.

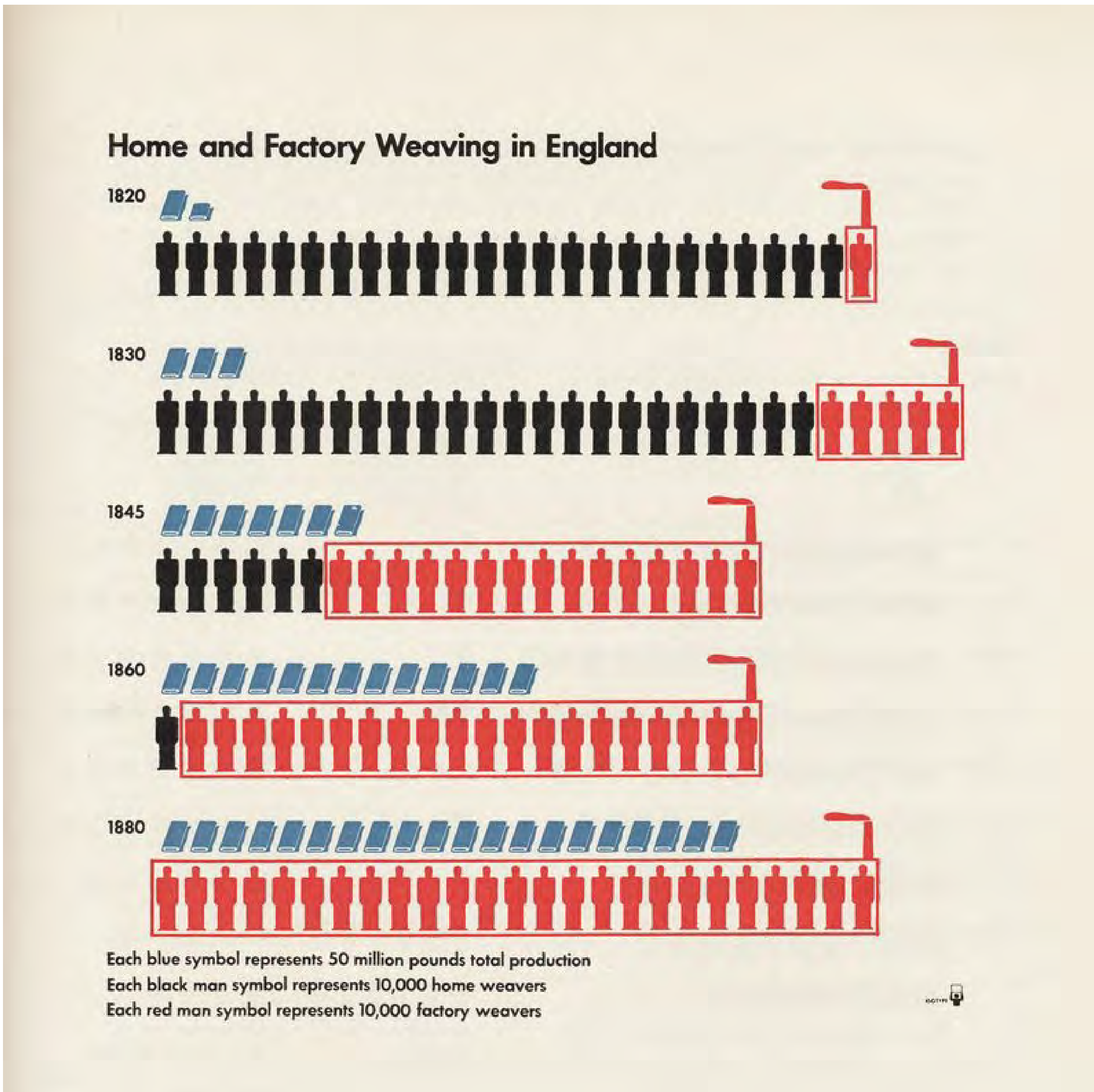

Figure 3.18. Otto & Marie Neurath Isotype Collection, University of Reading.

In his professional autobiography, written between 1943 and 1945 and titled *From Hieroglyphics to Isotype* (2010 edition), Neurath explained what his pictographic language was intended to achieve:

> We started our visualization in adult education by making exhibitions for museums and preparing sheets for classes and diagrammatic films in the Isotype style. We tried to evolve a new type of exhibition to attract the masses immediately. The subject of the exhibition should be serious but it should be combined with a charm and direct appeal to everybody. As many people should be persuaded to visit it as would go to some public show of purely entertainment value. Education has to compete with entertainment (...) It would be dangerous if education were to become a purely occupational matter and something boring in itself.[9]

Charm and direct appeal. Those words resonate deeply in Nigel Holmes's work, which, like Neurath's, tends to be tightly edited and to convey a few ideas with clarity and power. That goal is not opposite to Tufte's approach, but it is different. Tufte favors highly detailed, multivariate presentations that allow careful exploration on the part of the reader.

So who is right—Tufte in his defense of dense graphics, bereft of trivial "junk"? Or Holmes and Neurath and their populist graphics, encoding just a few easily digestible messages with friendly looking pictograms and humorous illustrations? Is it possible to reach a synthesis between the two approaches, or at least to choose one of them without despising the other? I believe it is. After all, even if it may seem otherwise, Tufte's and Holmes's *ideologies* are more similar than different. This is the focus of the next chapter.

6. Visualizing for the Mind

> Perception is a fantasy that coincides with reality.
>
> —**Christ Firth, from** ***Making Up the Mind: How the Brain Creates Our Mental World***

If you know what tricks and shortcuts the brain uses to make sense of the information gathered from the senses, you can use that knowledge to your advantage. In this chapter, I will focus on the mechanisms of detecting basic features, also called **preattentive features**. The ability to anticipate what the brain wants to do can greatly improve your information graphics and visualizations.[1]

The Brain Loves a Difference

When you open your eyes to the world, one of the first things your brain does is discriminate between background and foreground. That is, it identifies the boundaries of the objects and creatures in your vision field: where the lion ends and the grass begins, and where the grass ends and the sky begins. Evolution has fine-tuned our vision to be quite good at accomplishing this feat, but it has also given other organisms the ability to impede it by using such tricks as camouflage.

The detection of object boundaries is based on variations of light intensity and color, and on how well the edges of the things you see are defined. The higher the contrast between two adjacent patches of color, the more likely they will be identified as belonging to different entities. The lower the contrast (or the blurrier the edges), the harder the brain must work to distinguish between them.

Compare the illustrations in **Figure 6.1**. The first has a high contrast, so we immediately perceive something *different* (identifying the wolf takes just an extra fraction of a second). We experience the second picture similarly, except that here the contrast is due less to light intensity than to hue. In the third illustration, the threat is more difficult to make out unless you invest considerable cognitive energy figuring out the scene and identifying the creature by its shape.

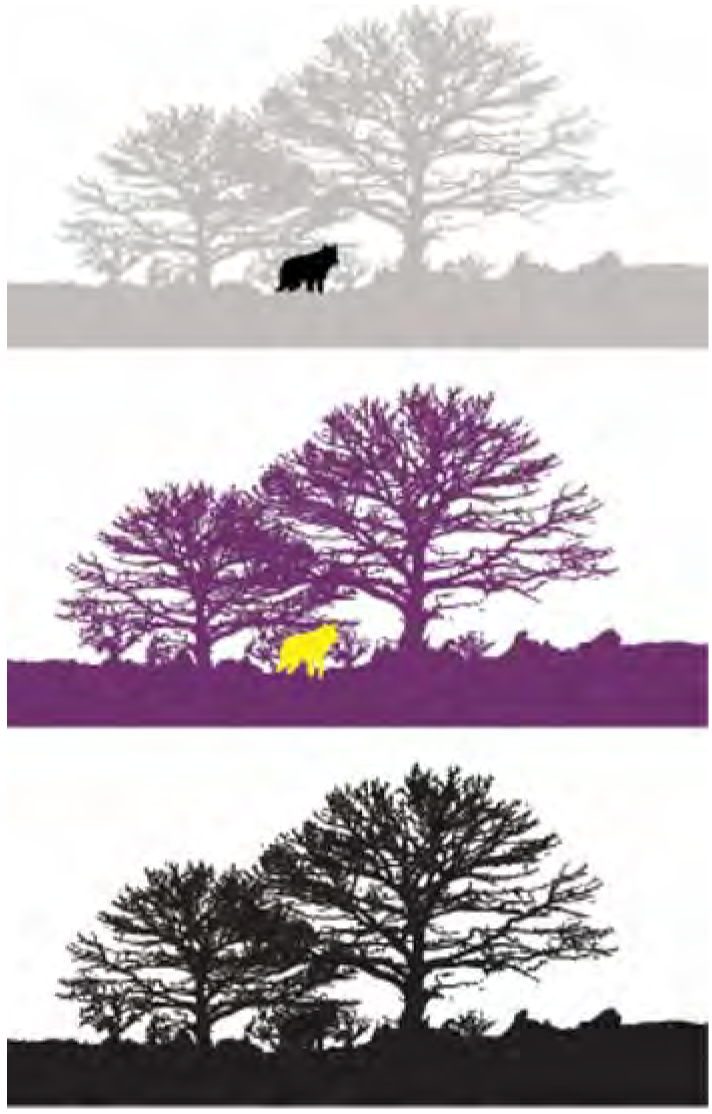

Figure 6.1. How quickly can you see the wolf in the trees in each of these illustrations?

In the first two illustrations, the differences between object (foreground) and background are sensed before attention and reason come into play. You don't know it's a wolf. You see something that may be relevant for your survival and unconsciously fix your gaze on it.

The brain is much better at quickly detecting *shade variations* than *shape differences*. Take a look at **Figure 6.2**, inspired by a picture made by Stephen Few. Suppose you are creating a table whose goal is to allow readers to quickly estimate the number of sixes in that sequence. It's hard to see the number 6 in the table on the left, but much easier in the one on the right. Assuming this is a visualization with a *function*—facilitate the identification of the number 6—the second picture is a better *tool* than the first because it was designed for what the brain is good at doing.

4 3 6 7 9 8 1 2 5 5 1 1 5 6 1 1 5 8 1 3 4 1 5 9 1 5	4 3 6 7 9 8 1 2 5 5 1 1 5 6 1 1 5 8 1 3 4 1 5 9 1 5
1 5 3 4 5 1 1 5 2 5 1 3 1 9 2 5 1 2 1 8 9 1 4 1 1 6	1 5 3 4 5 1 1 5 2 5 1 3 1 9 2 5 1 2 1 8 9 1 4 1 1 6
5 2 1 6 1 1 6 1 2 4 1 8 1 6 1 5 8 2 4 1 4 1 5 1 9 1	5 2 1 6 1 1 6 1 2 4 1 8 1 6 1 5 8 2 4 1 4 1 5 1 9 1
1 4 1 8 1 9 5 1 2 8 1 9 1 1 5 1 1 5 1 6 1 8 2 6 1 2	1 4 1 8 1 9 5 1 2 8 1 9 1 1 5 1 1 5 1 6 1 8 2 6 1 2
2 6 1 9 1 5 1 2 2 1 4 1 1 8 2 1 4 1 2 4 4 1 1 9 1 2	2 6 1 9 1 5 1 2 2 1 4 1 1 8 2 1 4 1 2 4 4 1 1 9 1 2
3 1 2 5 1 1 6 1 5 3 1 8 2 1 3 8 1 1 8 1 4 1 3 1 6 1	3 1 2 5 1 1 6 1 5 3 1 8 2 1 3 8 1 1 8 1 4 1 3 1 6 1

Figure 6.2. It is easier to spot the numeral 6 in the number sequences when we highlight it with a different shade.

Transforming a perceptual feature into a design principle is not hard in this case. If you are creating a map locating two different kinds of factories in the United States (**Figure 6.3**), you could certainly identify them with pictograms. But if you want your readers to *preattentively* detect the factories and estimate their numbers, using two different colors is a much better way to accomplish your goal.

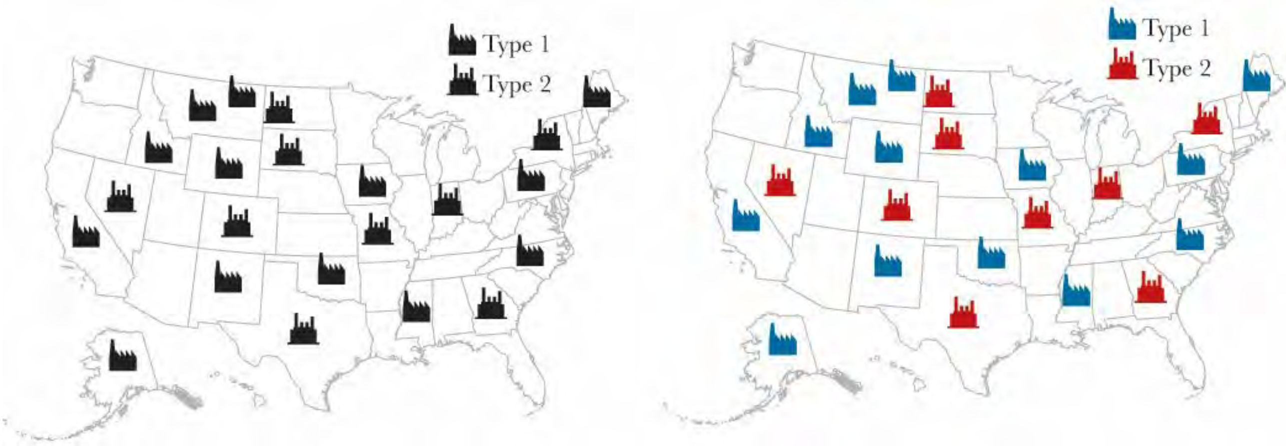

Figure 6.3. On which of these maps is it easier to identify the number of factories of each kind?

The Gestalt School of Thought and Pattern Recognition

At its core, **the visual brain is a device that evolved to detect patterns**: regions in the vision field that share a nature or that belong to different entities. In Figure 6.4, you will find several factors the brain uses effortlessly to discriminate between objects. With the goal of saving processing time, the brain groups similar objects (the rectangles of same size and tone) and separates them from those that look different. Then, it focuses on the different shapes. This preattentive detection feature—the instant sorting of differences and similarities—is one of the most powerful weapons in the designer's arsenal.

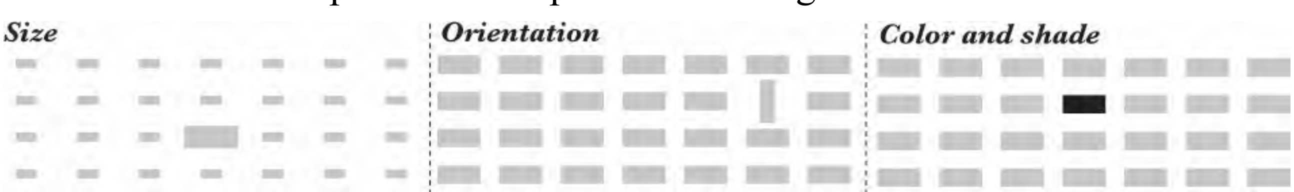

Figure 6.4. Some features that the brain is able to detect preattentively.

Originating in Germany at the beginning of the twentieth century, the Gestalt school of thought studied these mechanisms in depth. The main principle behind Gestalt theory is that brains don't see patches of color and shapes as individual entities, but as aggregates. In fact, the word *gestalt* means *pattern*. Striving for efficiency in how it invests its energy, the brain follows certain principles of perceptual organization. Let's take a look at some of them and learn how they can be applied to information graphics.

Proximity

This principle notes that objects that are close to each other tend to be perceived as natural groups.

Notice how hard it is not to see groups in Figure 6.5. It's almost impossible not to. That's because your brain is telling you that the disposition of those bars and numbers, however different they may appear in shape and size, *is not random.* They have an underlying logic, a pattern.

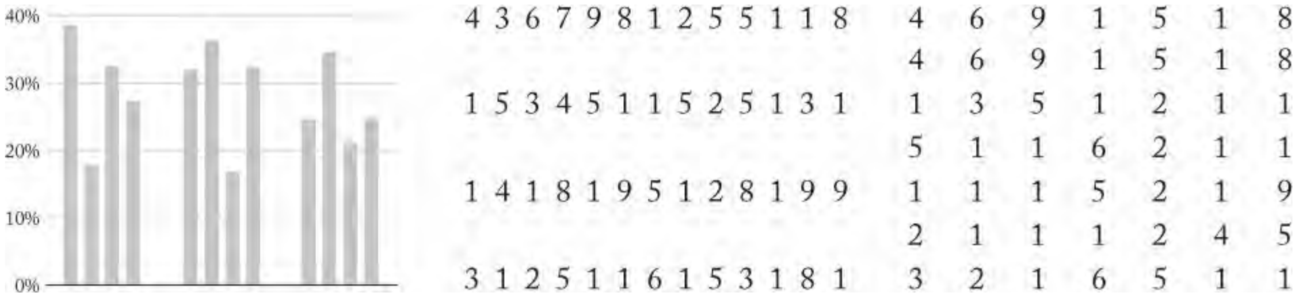

Figure 6.5. Objects close to each other will be perceived as belonging to a group.

Applying this perception principle to an information graphic is easy: Objects that are related should be near one another in your composition, and aligned on the vertical or horizontal axis. Look at the first infographic in [Figure 6.6](#). (The data is fabricated.) White strips help separate the different sections and portions. The second graphic appears chaotic because it wasn't designed with attention to the proximity principle. Your brain must make an effort to tell what goes with what.

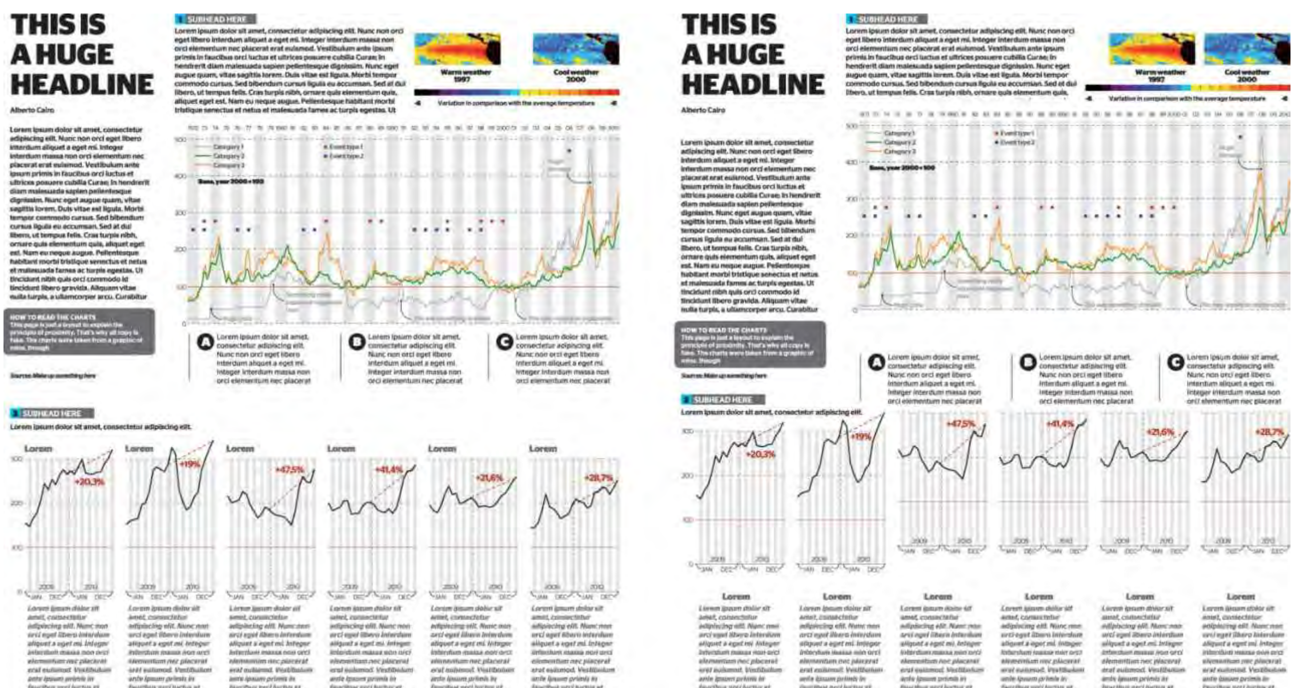

Figure 6.6. If you have several sections in your infographic, make sure that the objects that belong to them are near one another. The graphic on the left looks neat and organized, as you can clearly see the separation between its different sections. The graphic on the right does not.

Similarity

Identical objects will be perceived as belonging to a group. You can see this principle at work in [Figure 6.7](#). In the case of the bar chart, you can also see the principles of Similarity and Proximity combined. These principles help the brain identify two different levels of grouping: one by the common nature of the objects, and the other based on how close the bars are.

Figure 6.7. Objects that look alike will be identified as parts of a group.

Connectedness

Objects linked by means of a graphic artifice, such as a line, will be perceived as members of a natural group. Take a look at Figure 6.8. When you present only the geometric shapes, the brain groups them by shade and shape. But when you add a thick black line behind some of them, connectedness overrules the previous clues for grouping. A much more powerful pattern appears.

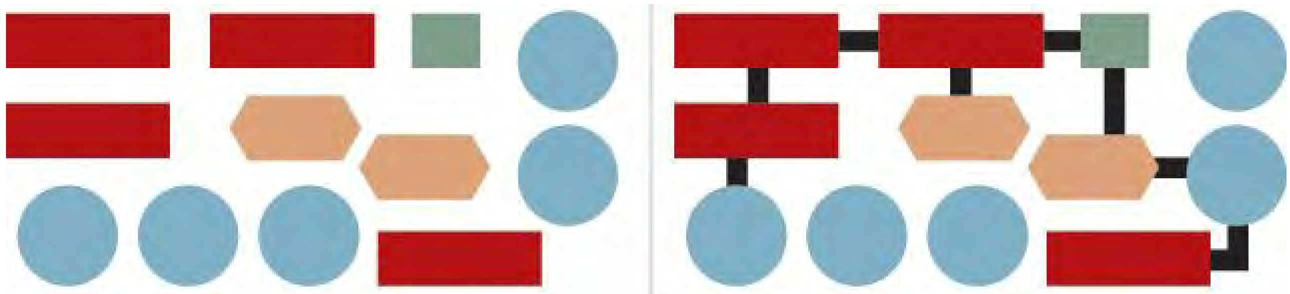

Figure 6.8. Lines are powerful clues the brain can use to perceive whether objects are related.

Continuity

The continuity principle holds that it is easier to perceive the gross shape of an object as a coherent whole when its contours are smooth and rounded than when they are angular and sharp. See Figure 6.9, where two node diagrams represent the connections between the mid-level managers within a company. The brain sees the connections better in the diagram on top. In the second visualization, as the straight, right-angled lines cross one another, it is much harder to complete the task.

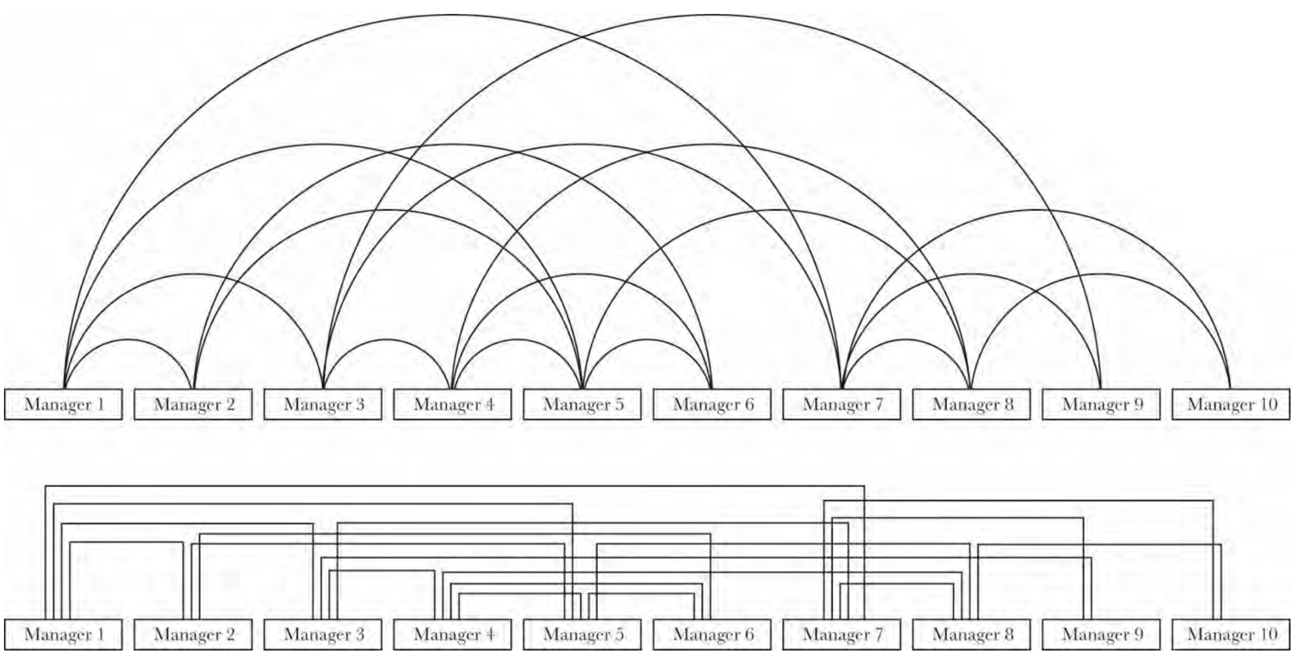

Figure 6.9. Continuity is better perceived in curves than in lines with sharp angles.

Closure

Objects inside an area with crisp, clear boundaries will be perceived as belonging to a group. In Figure 6.10, even if the distance between the bars is constant among the three charts, and all are the same shade, the brain sees them as different sections of a single set of data when they are enclosed.

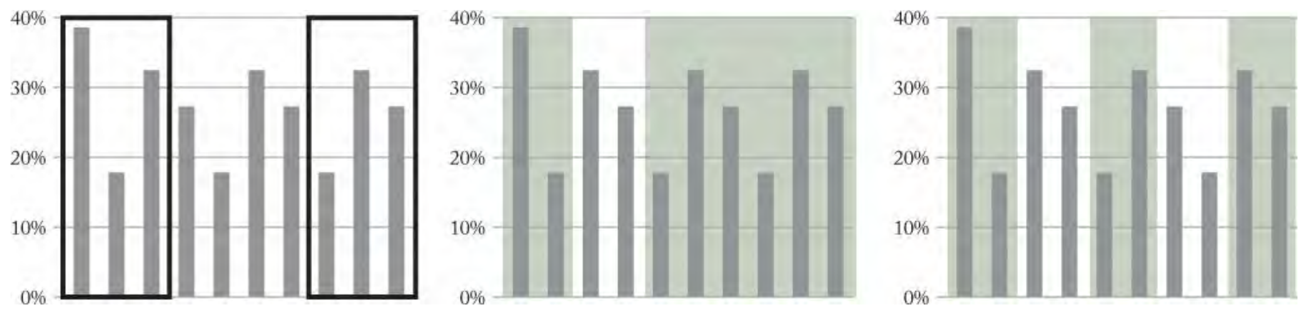

Figure 6.10. Boxing bars helps readers identify groups.

The principle of Closure is helpful when you create a multisectioned infographic, but only if applied with common sense and combined with the principle of Proximity. See the two examples in Figure 6.11. The one on the left looks sloppy because it's overloaded with boxes. Although the boxes are meant to aid your eye in distinguishing the parts of the composition, they are redundant. In the example on the right, I used Proximity to separate the background data (the sections at the bottom) and white spaces to define the shapes of the other portions.

Figure 6.11. Don't overuse background boxes. Doing so will make your graphic look cluttered. If you need to differentiate between different sections, use white space.

So far we've looked at principles that can help us make our information graphics more functional through their organization, composition, and layout. But can a slight knowledge of visual perception also help us decide what graphical form is best suited to the tasks our graphic must help readers with? Yes, it can.

Choosing Graphic Forms Based on How Vision Works

In 1984, William S. Cleveland and Robert McGill, statisticians working for AT&T Bell Labs, published a groundbreaking paper in the *Journal of the American Statistical Association*. It was titled “Graphical perception: theory, experimentation, and application to the development of graphical methods.” Thirty years after publication, many of its contents are still relevant to a rational understanding of information graphics and visualization.

Sadly, Cleveland’s and McGill’s work is not widely known among journalists and graphic designers.[2] It is revered in other circles, particularly those related to business and scientific visualization. Authors such as Stephen Few and Naomi Robbins have followed Cleveland’s steps and delivered superb books partially inspired by them.[3]

What is important about Cleveland’s and McGill’s paper is that it proposes basic guidelines for choosing the best graphic form to encode data depending on the function of the display. The authors designed a list of **10 elementary perceptual tasks**, each one a method to represent data, and ranked them according to how accurately the human brain can detect differences and make comparisons between them.

Figure 6.12 shows the elementary perceptual tasks from highest to lowest accuracy. The tasks are grouped according to how well you can perceive differences in the data by using them. In other words, if two tasks are in the same bullet point, the accuracy is equivalent. The tasks include:

- Position along a common scale
- Position along nonaligned scales
- Length, direction, angle
- Area
- Volume, curvature
- Shading, color saturation

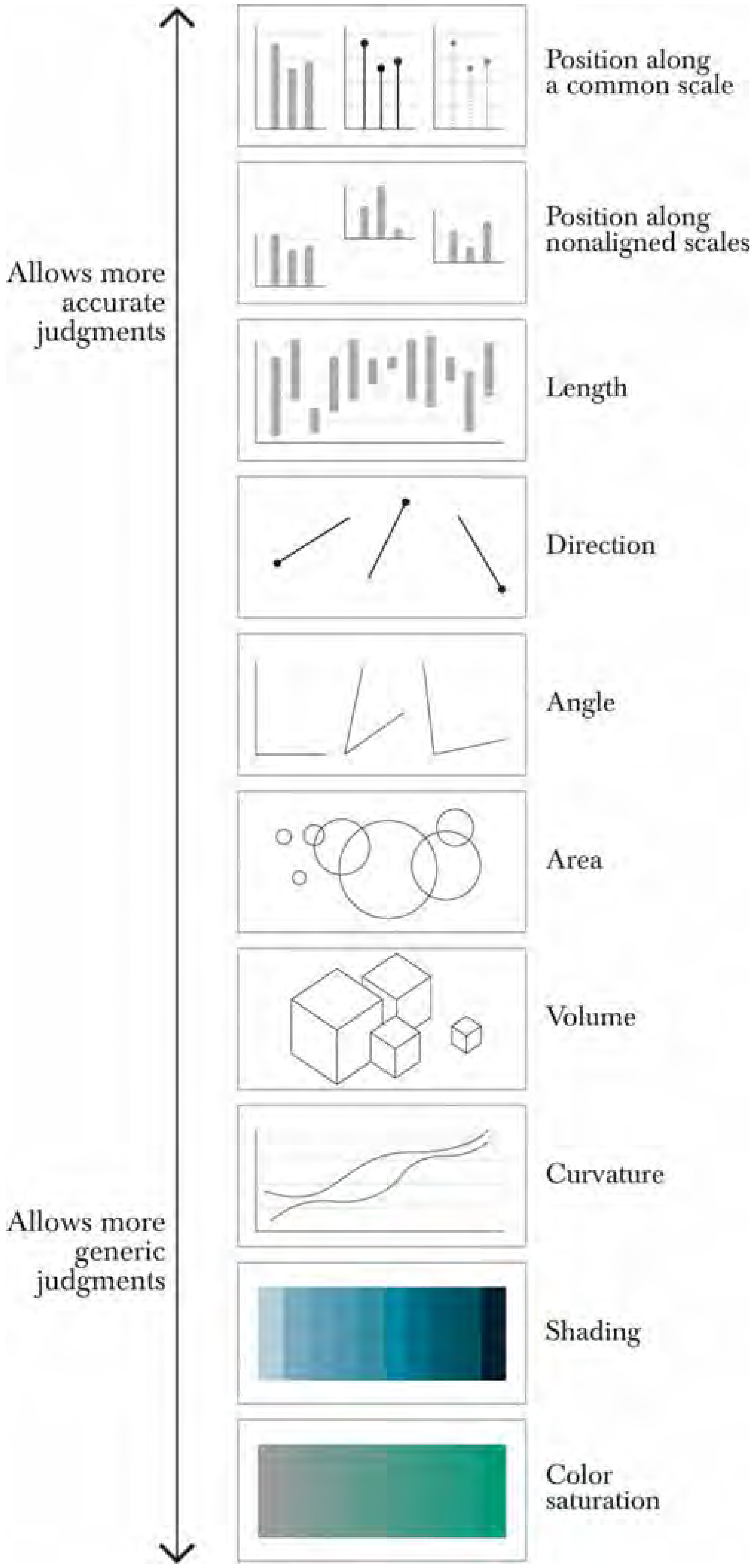

Figure 6.12. Cleveland and McGill's elementary perceptual tasks. The higher an encoding method on the scale, the more accurate the comparisons it facilitates.

The authors based their ranking not on personal preferences or tastes, but on experiments and a careful reading of academic literature about human visual perception. They pointed out:

> A graphical form that involves elementary perceptual tasks that lead to more accurate judgments than another graphical form (with the same quantitative information) will result in a better organization and increase the chances of a correct perception of patterns and behavior.

In other words, the more accurate the judgment readers must make about the data, the higher on the scale the graphical form must be. A bar chart is *always* superior to a bubble chart or a heat map *if the goal of the graphic is to facilitate precise comparisons*, as shown in [Figure 6.13](). Here, identical quantities are encoded using three techniques: bars, areas, and color saturation. Notice that we underestimate differences when forced to compare areas. The second bar is almost double the height of the first one, but the second bubble does not *preattentively* appear to be double the size of the first one.

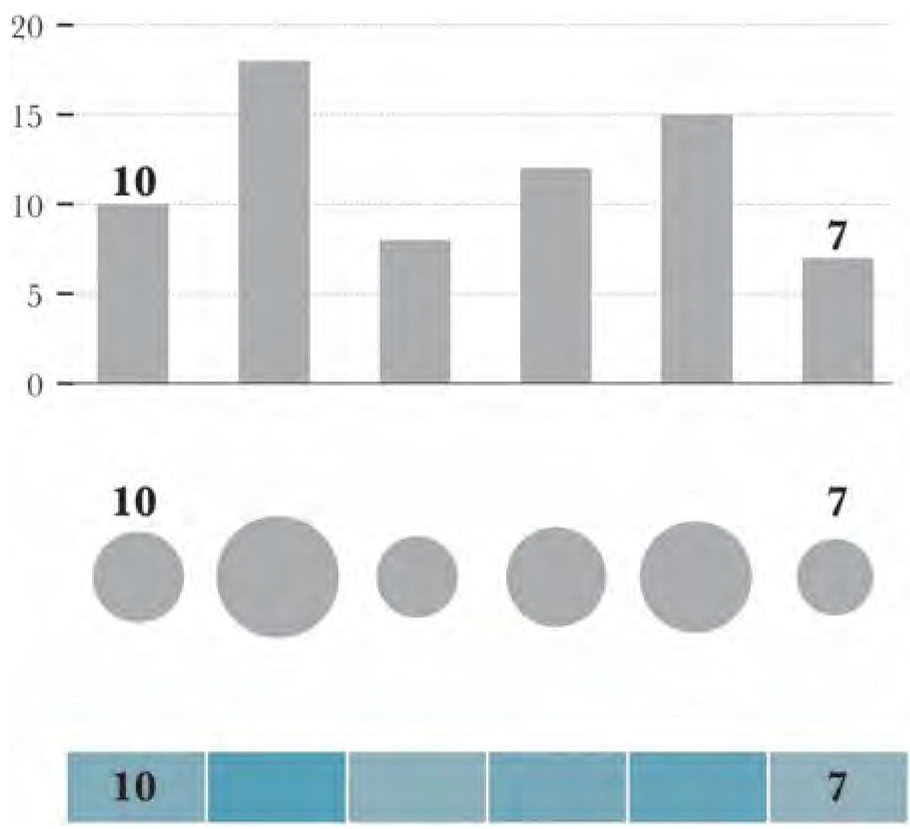

Figure 6.13. When the goal is to allow readers to make accurate comparisons, a chart based on bars or lines sitting on a single horizontal or vertical axis beats other forms of representation.

Another example, inspired by one included in Cleveland's and McGill's paper: Suppose that you want to plot the exports between two countries. If the goal of your chart is to allow readers to see how much each nation exports to the other, a chart with two lines will be fine.

But if the goal is to display the trade balance between the two nations, the line chart is not the best way. Why? Because the human brain has difficulty comparing angles, directions, and curvatures. Better to do some subtractions, calculate the balance in favor of one of the nations, and plot the derived variable instead. You can see both examples in [Figure 6.14](). (If you don't know where Tomainia and Osterlich are, watch Charlie Chaplin's *The Great Dictator*.)

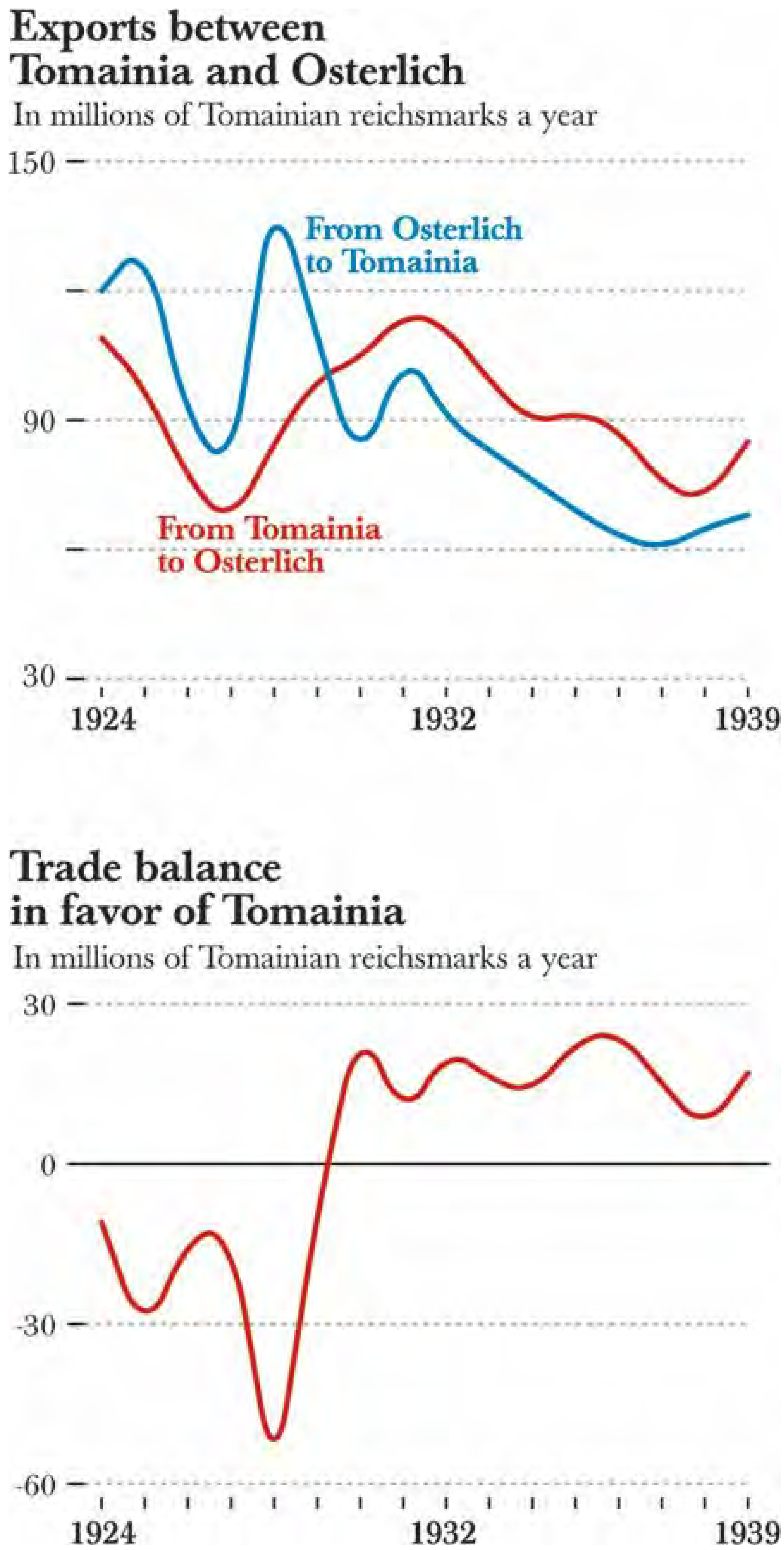

Figure 6.14. Trade balance between Tomainia and Osterlich, two of the imaginary countries in Charlie Chaplin's *The Great Dictator*. Of course, the data I used for the charts is also imaginary.

To summarize what we've discovered so far: The higher you move on Cleveland's and McGill's scale, the more accurate the judgments your readers will be able to make based on your charts. But there's another side to the story. Sometimes your goal is not to allow precise comparisons or to rank values, but to facilitate the perception of larger patterns, or the relationship of a variable with its geographical location.

In that case, it may be fine to pull from the bottom of the list and encode lots of values as shades of color on a map, or dozens of bubbles on top of the same map. Cleveland's and McGill's perceptual task ranking is an invaluable tool for grounding decisions in fact and reason, rather than aesthetic taste alone, but like all conceptual tools, there are nuances and exceptions depending on the context and circumstances.

As an aside, William Cleveland expanded his ideas about charts in several more articles and books. I offer one of his insights in *The Elements of Graphing Data* especially for journalists and marketing and PR managers to keep in mind when designing infographics:

> While there is a place for rapidly understood graphs, it is too limiting to make speed a requirement in science and technology, where the use of graphs ranges from detailed in-depth data analysis to quick presentation (...). The important criterion for a graph is not simply how fast we can see a result; rather it is whether through the use of the graph we can see something that would have been harder to see otherwise or that could not have been seen at all.[4]

I would not limit that rule to science and technology. It can be applied to any infographic created to enlighten.

The Perceptual Tasks Scale as a Guide for Graphics

Rather than limit our discussion to abstractions, let me come down to Earth and show you how to use Cleveland and McGill's scale to orient your design decisions in a flexible manner.

Not long ago I read a news story about the connection between education and obesity. It highlighted several studies that found, on average, that better educated people are less likely to be obese. The problem with the story was that it didn't include a chart to prove its main point. As you saw in Chapter 1, assertions like this one tempt me to do a graphic myself. And so I did.

First, I gathered numbers: the percentage of people holding BA degrees (or higher) per state, and the percentage of people who are obese. I culled the numbers from the U.S. Census Bureau and Centers for Disease Control and Prevention. The figures may be dated—for a real infographic I would double-check them—but this is an exercise, after all.

You can see my Excel spreadsheet in **Figure 6.15**. After I entered the figures in it, I calculated the correlation between the two data series: –0.67. The *correlation coefficient*, also called *Pearson product-moment correlation coefficient*, or "r," is a measure of how related two variables are. If *r* is close to 1, the two variables are *directly* proportional: the higher the first is, the higher the second will be. If *r*'s value is close to –1, the variables are *inversely* proportional: the higher one is, the smaller the other.

OBESITY_EDUCATION.xlsx

STATE	OBESITY (%)		STATE	BA or higher (%)	R Correlation
Alabama	32.2		Colorado:	35.50%	-0.6734764
Alaska	24.5		Iowa:	24.30%	
Arizona	24.3		Tennessee:	24.30%	
Arkansas	30.1		Utah:	30.80%	
California	24		Maine:	24.20%	
Colorado	21		West Virgin	15.30%	
Connecticut	22.5		Indiana:	21.10%	
Delaware	28		Rhode Islan	27.20%	
District of Co	22.2		Arkansas:	18.80%	
Florida	26.6		South Dako	25.50%	
Georgia	29.6		New York:	30.60%	
Hawaii	22.7		Alabama:	22.30%	
Idaho	26.5		Pennsylvani	25.30%	
Illinois	28.2		Illinois:	27.40%	
Indiana	29.6		Kansas:	30%	
Iowa	28.4		Georgia:	27.60%	
Kansas	29.4		Washingtor	29.90%	
Kentucky	31.3		Maryland:	35.20%	
Louisiana	31		New Jersey:	34.60%	
Maine	26.8		Alaska:	25.50%	
Maryland	27.1		Oregon:	25.90%	
Massachuset	23		Wyoming:	22.50%	
Michigan	30.9		Vermont:	34.20%	
Minnesota	24.8		Michigan:	24.40%	
Mississippi	34		District of Cc	45.70%	
Missouri	30.5		Minnesota:	32.50%	
Montana	23		Louisiana:	22.40%	
Nebraska	26.9		Wisconsin:	25.60%	
Nevada	22.4		Mississippi:	20.10%	
New Hampsh	25		Texas:	24.50%	
New Jersey	23.8		North Carol	23.40%	
New Mexico	25.1		Ohio:	24.60%	
New York	23.9		Idaho:	23.80%	
North Carolir	27.8		Delaware:	26.90%	
North Dakot	27.2		Florida:	26%	
Ohio	29.2		Missouri:	28.10%	
Oklahoma	30.4		California:	31.70%	
Oregon	26.8		Montana:	25.50%	
Pennsylvania	28.6		Arizona:	28%	
Rhode Island	25.5		South Carol	24.90%	
South Carolir	31.5		New Hamps	35.40%	
South Dakot	27.3		Hawaii:	26.60%	
Tennessee	30.8		Virginia:	33.10%	
Texas	31		Connecticut	34.50%	
Utah	22.5		Kentucky:	21%	
Vermont	23.2		Oklahoma:	22.90%	
Virginia	26		New Mexicc	25.10%	
Washington	25.5		Nebraska:	24.80%	
West Virginia	32.5		Massachuse	36.70%	
Wisconsin	26.3		North Dako	25.20%	
Wyoming	25.1		Nevada:	24.50%	
Average	**26.99**		**Average**	**27.20%**	

Sheet1

Normal View Ready

Figure 6.15. A screenshot of the spreadsheet used for this exercise.

Based on this, a result of –0.67 indicates a solid negative correlation. I thought I had something interesting on my hands.

How would you encode the data so readers can see the relationship, or lack thereof, between your two variables? A table is not an efficient way to help them understand. Nor is telling them, “Hey, *r* is –0.67! That helps prove my point!” After all, how many newspaper readers do you suppose know what *r* is? We need to display the evidence visually.

How do designers proceed when they see data linked to geographical locations? Most don’t bother to stop for a minute. They rush to produce a map. After all, a nice map looks good, and bubbles are trendy, so let’s give them a try in a *proportional symbol map*. The results are in **Figure 6.16**. Bubble size is proportional to the encoded numbers.

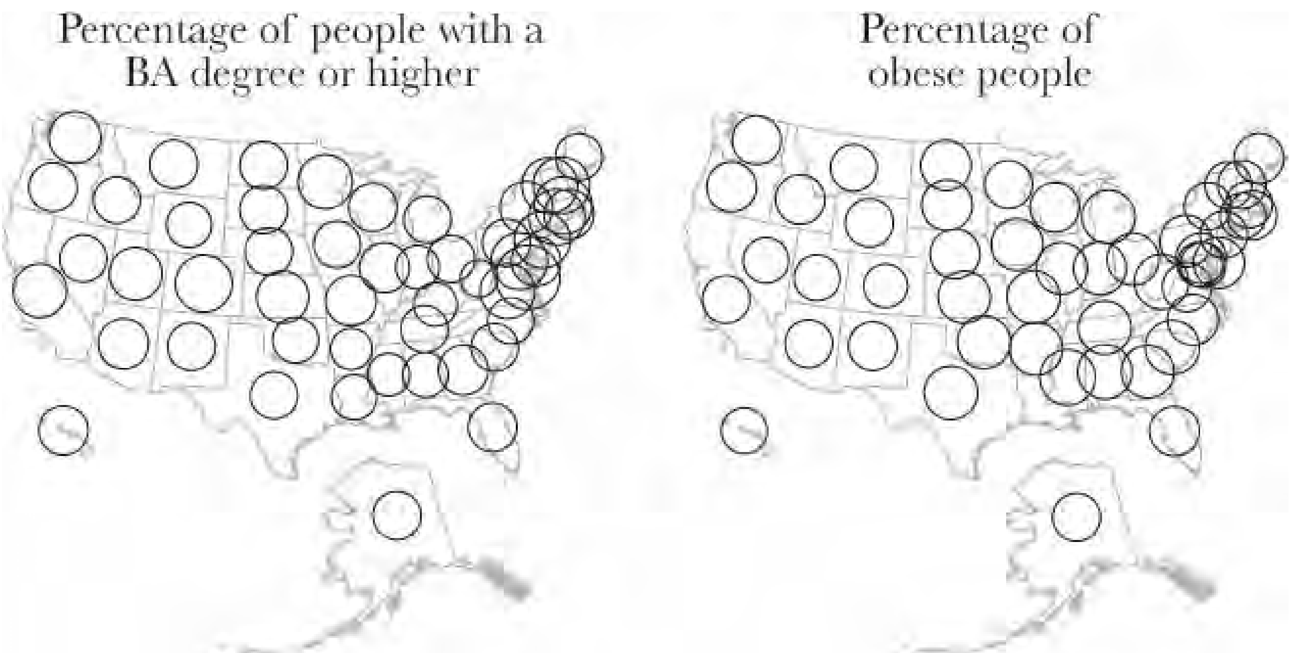

Figure 6.16. Proportional symbol maps are not the best way to represent these data sets.

It doesn’t convey much, does it? The reason is that the task of area comparison is low on the Cleveland-McGill scale, and areas tend to minimize differences between values. Since the value range was not that wide in the first place, the United States looks like an ocean of almost equal-sized circles.

Proportional symbol maps can also be misleading if the regions displayed vary too much in size. Notice the dense cluster of bubbles in the northeast United States, indirectly suggesting a high concentration of people with college degrees *and* obesity in the region.

Would a *choropleth map* be more effective? A choropleth map encodes values by means of shades and colors. I tried that, too, in **Figure 6.17**. It doesn’t work very well either. Shading is low on our scale, indicating that it’s not that great for comparisons, although it might be appropriate if you just want to offer an overview of the data. Can you tell how much higher the obesity rate is in Texas than in California? Not likely.

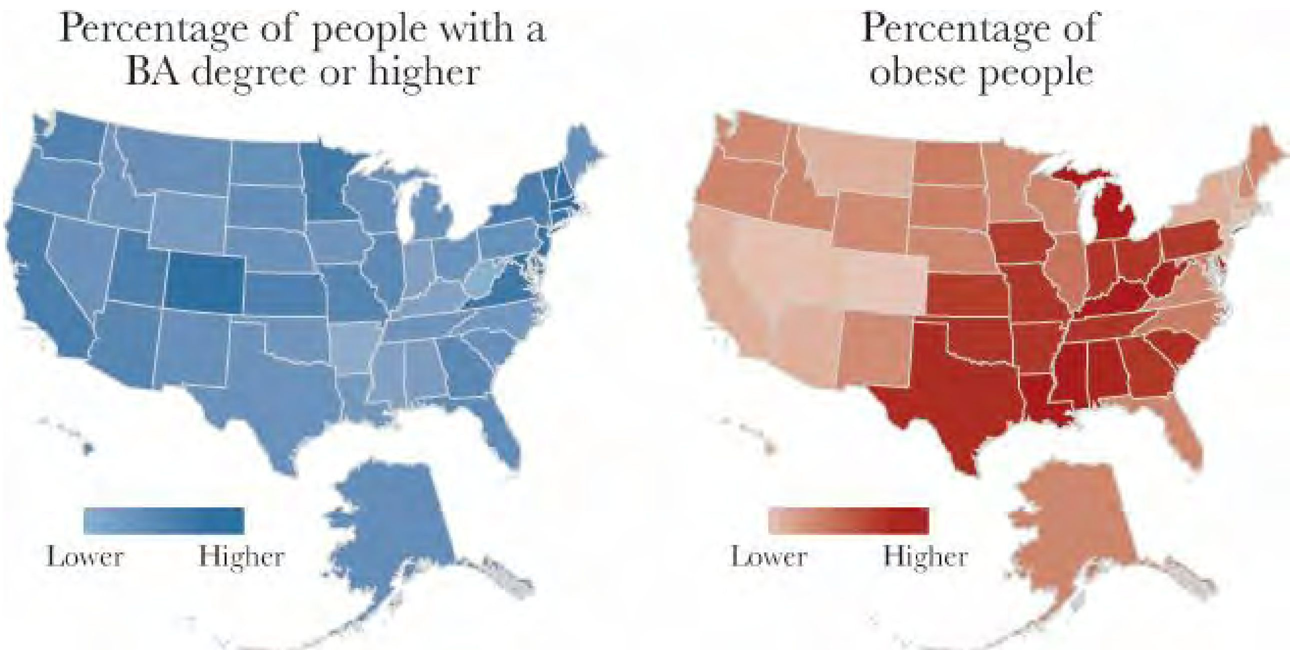

Figure 6.17. My second choice was a choropleth map. I was not very fond of it.

If I wish readers to be able to rank and compare, a bar chart or *dot chart* would be good options. You can see the data encoded as a dot chart in **Figure 6.18**. I'm sure you'll notice the big differences between states.

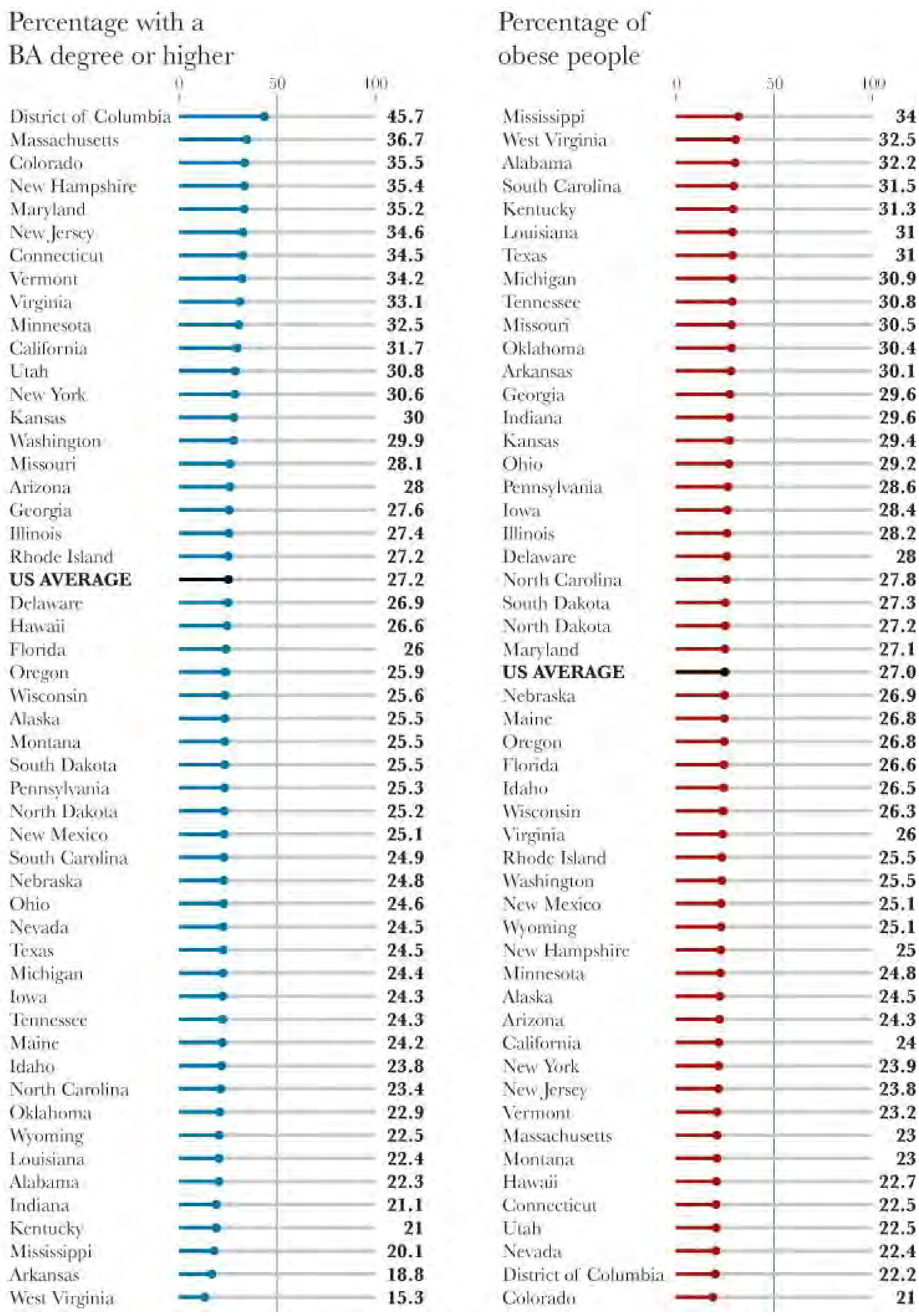

Figure 6.18. A dot chart is equal to a bar chart when it comes to estimating proportions.

Are there other kinds of charts that would rank high in Cleveland and McGill's scale and, besides allowing comparisons between the values, also facilitate the visualization of the relationship between them? Yes. The first is the *scatter-plot,* shown in Figure 6.19. The other, a favorite of mine, is the *slopegraph* (Figure 6.20). Although the examples would need to be tweaked and refined to be publishable in a newspaper or magazine, they accomplish both the goals of comparing values and seeing relationships.

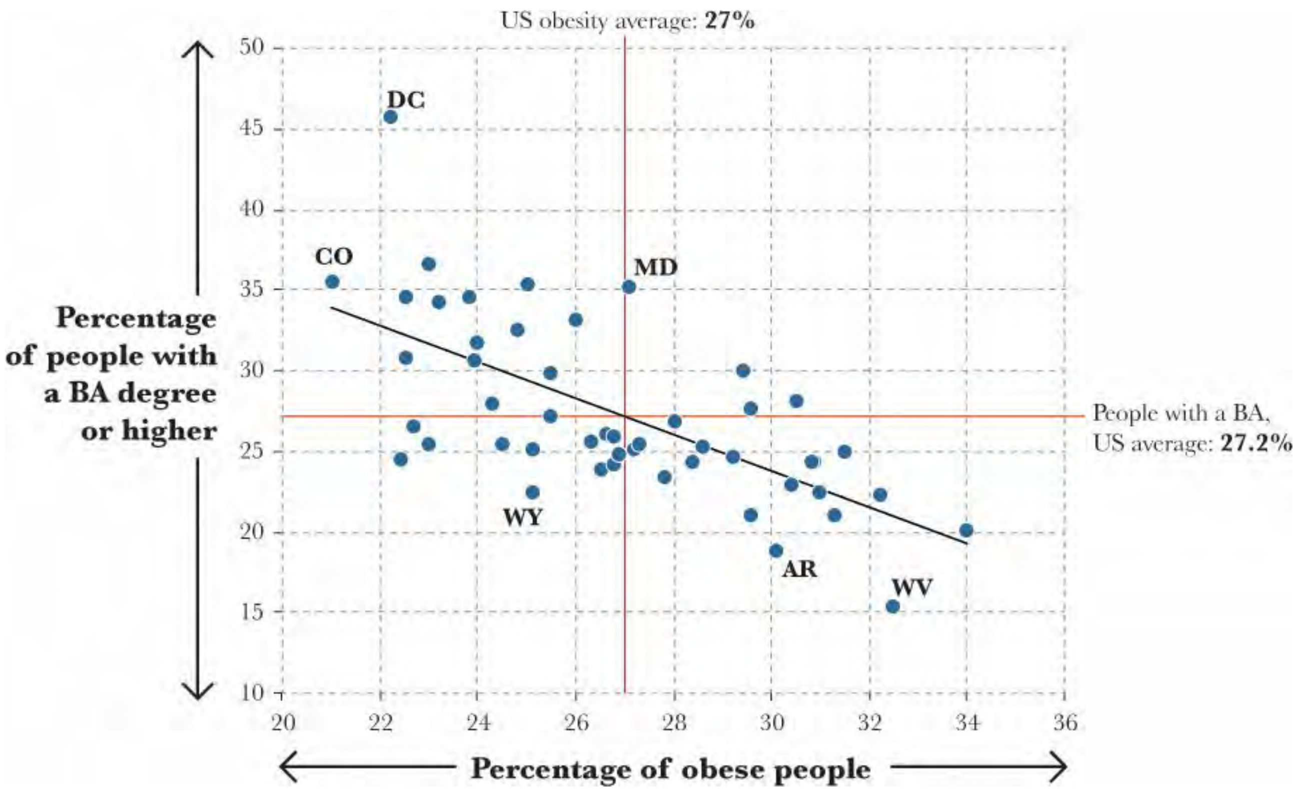

Figure 6.19. A scatter-plot.

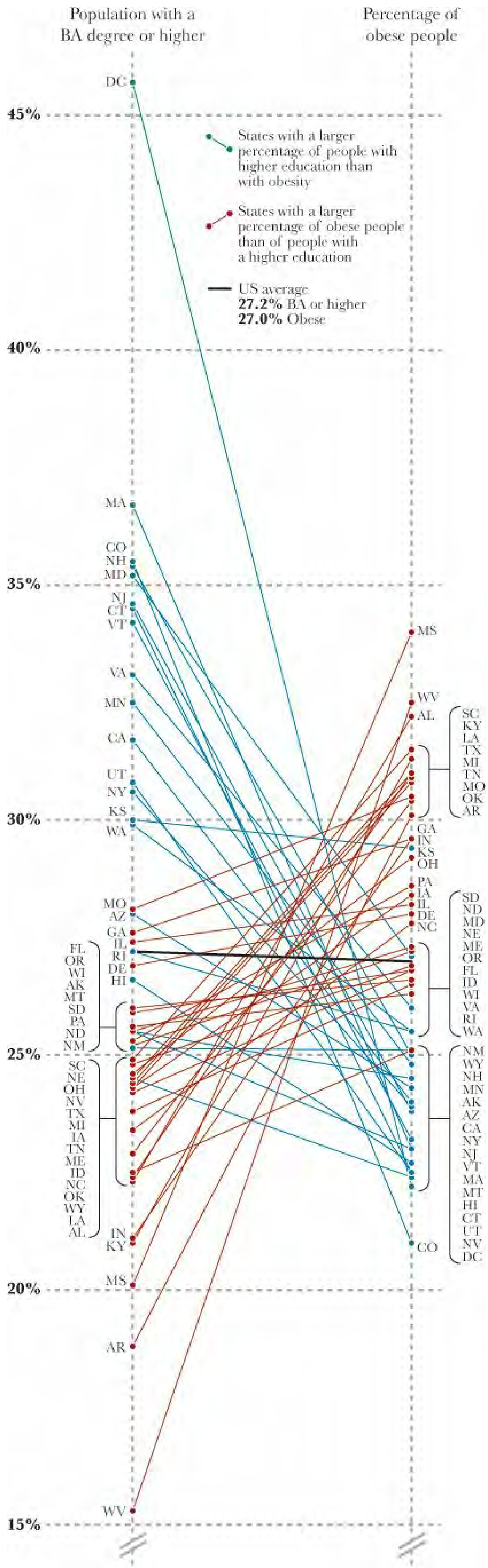
Population with a BA degree or higher
Percentage of obese people
45%
40%
35%
30%
25%
20%
15%
States with a larger percentage of people with higher education than with obesity
States with a larger percentage of obese people than of people with a higher education
US average
27.2% BA or higher
27.0% Obese
DC
MA
CO
NH
MD
NJ
CT
VT
VA
MN
CA
UT
NY
KS
WA
MO
AZ
GA
IL
RI
DE
HI
FL OR WI AK MT SD PA ND NM
SC NE OH NV TX MI IA TN ME ID NC OK WY LA AL
IN
KY
MS
AR
WV
MS
WV
AL
SC KY LA TX MI TN MO OK AR
GA
IN
KS
OH
PA
IA
IL
DE
NC
SD ND MD NE ME OR FL ID WI VA RI WA
NM WY NH MN AK AZ CA NY NJ VT MA MT HI CT UT NV DC
CO

Figure 6.20. A slopegraph.

Other Preattentive Features: Seeing in Depth

There are other features our brain detects preattentively and with ease. Consider three-dimensional vision. Why are we able to see in depth when visual perception starts with the stimulation of cells attached to a flat surface, the retina? How do we translate 2D into 3D?

We see in 3D, first, because we have two eyes. What your right eye sees is not exactly what your left eye does. You can test this easily if you put a pencil a few inches in front of your head. If you close your right eye, the pencil will appear to move slightly to the right; if you close your left eye, the pencil will move to the left. The image of the world your brain generates is a composite of the slightly different inputs it receives from both eyes.

This phenomenon, called *stereoscopic depth perception*, is not the only way to see in 3D. If it were, we would be in serious trouble when closing (or losing) one eye. Fortunately, the brain also receives tons of still images per second from each eye, thanks to the fact that it constantly scans the scene. Remember saccades, that rapid, intermittent movements of the eye as it takes in any scene? I explained those in Chapter 5.

The brain uses other tricks to build the illusion of depth. Interestingly, the hints our mind extracts from our surroundings to accomplish this task are very similar to the techniques traditional artists use to simulate perspective in works of art.

For instance, the brain assumes that light comes from above. In the natural world, circumstances in which the light comes from below an object are extremely rare. Therefore, as a timesaving strategy, the brain learned to infer that if an object looks more or less like the first circle in **Figure 6.21**, it is probably concave, and if it looks like the second circle, it is convex. The illusion remains even if we simplify the circles and their shades. Keep it in mind when you design buttons for your interactive graphics. As we'll see in Chapter 9, it is important that readers are able to recognize interface elements at a glance.

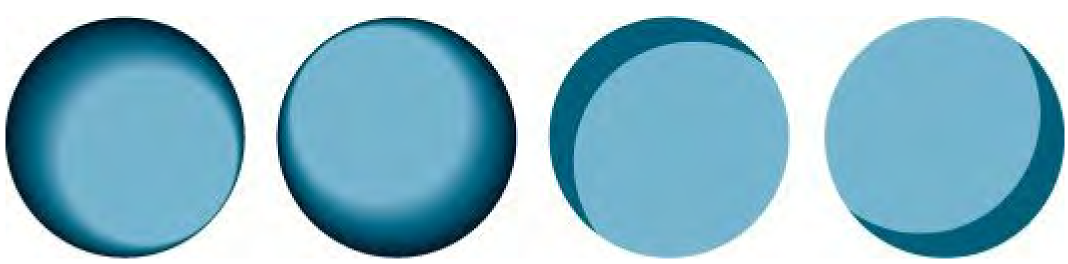

Fig 6.21. Our brains define concave and convex objects by how light hits them.

The relative sizes of objects in a scene and their interposition are also powerful clues for depth perception. Notice how hard it is not to perceive objects closer to us and in front of each other in **Figure 6.22**.

Figure 6.22. Interposition is a powerful tool for building the illusion of depth.

Finally, if you remember the beginning of this chapter—I love circular structures when I write—I began with the assertion that one of the first steps in visual perception is to discriminate foreground from background; that is, to identify the edges of objects and creatures in order to know their boundaries. This feature is enlisted for depth perception as well. In **Figure 6.23**, the brain perceives *lines* that recede toward the horizon until they converge in a vanishing point, even if no real lines are present, just blurry edges. The illusion persists when we substitute the photograph with more abstract representations of the same landscape. Making the edges sharper, in fact, only strengthens this illusion.

Figure 6.23. Seeing in perspective.

So far, we've covered what it is known as *low-level visual perception*, including the most basic tasks of foreground-background differentiation, the estimation of the relative sizes of things, the extraction of simple patterns from our surroundings, and so on. I hope I've convinced you that learning about how the brain performs these tasks will help you design better information graphics and visualizations.

We are about to enter an even more fascinating territory, that of *high-level perception*, which involves the identification of what we see. These perceptual tasks answer the intriguing question suggested by renowned neurologist Oliver Sacks back in 1985:

How the hell do I know that this moving and talkative object standing in front of me is my wife, and not a hat?[5]