A New Diagram For Vision

Let's recap. Remember Figure 5.1, the diagram that opens this chapter, with my friend Mike screaming at the camera. As we discussed, that is not a good representation of what really happens in the brain. **Figure 5.12** offers a more accurate alternative.

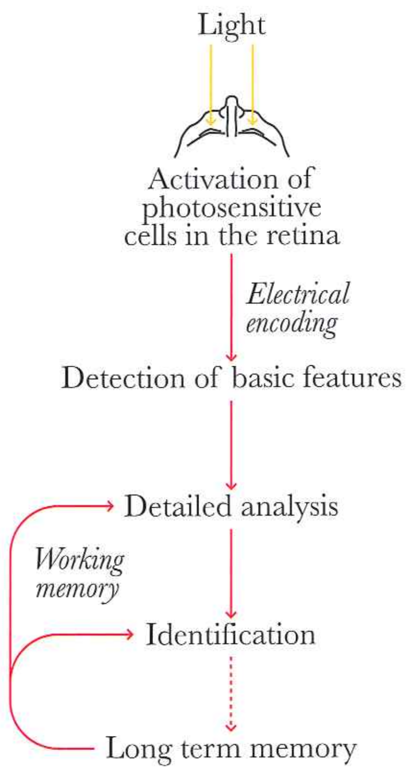


Figure 5.12 How perception really works.

Once the retina has encoded the patterns of light into electrical signals, the brain proceeds to discriminate basic object features, such as gross shapes, patches of color, and others I'll explain in the next two chapters. Only after this happens does the brain proceed to a much deeper analysis of what is being seen and to consciously identify it, based on a great deal of content that is retrieved from our memories.

But I am putting the cart in front of the horse. **Now that I've explained how the eye, the brain, light, and memory work together, I can explain how important all this is to our jobs as designers.**

6

Visualizing for the Mind

Perception is a fantasy that coincides with reality.

—Chris 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

1 If you want to dig deeper into the contents of this chapter, take a look at the work of Ware (2004), Malamed (2009), Few (2004), and Maceachren (2004), all listed in the bibliography at the end of this book.

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.

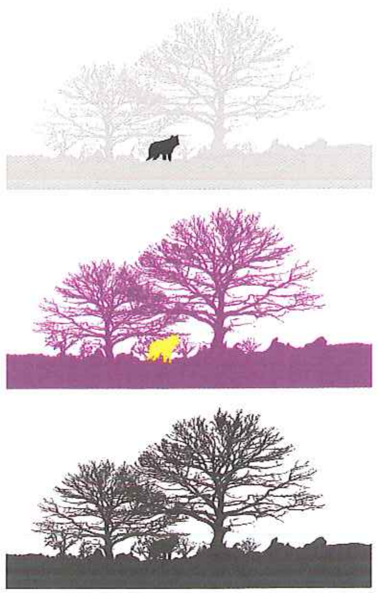


Figure 6.1 How quickly can you see the wolf in the trees in each of these illustrations?

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.

43679812551156115813415915	43**6**7981255115**6**115813415915
15345115251319251218914116	1534511525131925121891411**6**
52161161241816158241415191	521**6**11**6**124181**6**158241415191
14181951281911511516182612	1418195128191151151**6**182**6**12
26191512214118214124411912	2**6**191512214118214124411912
31251161531821381181413161	312511**6**15318213811814131**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.

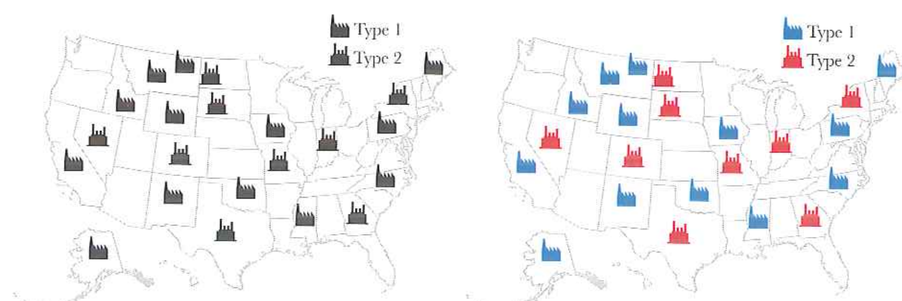


Figure 6.3 On which of these maps is it easier to identify the number of factories of each kind?

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.

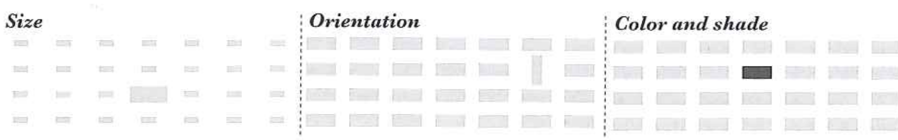


Figure 6.4 Some features that the brain is able to detect preattentively.

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.

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

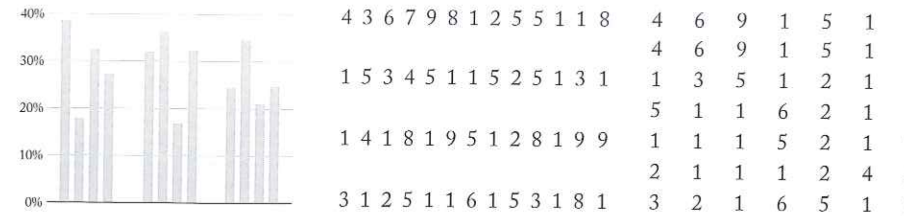


Figure 6.5 Objects close to each other will be perceived as belonging to a group.

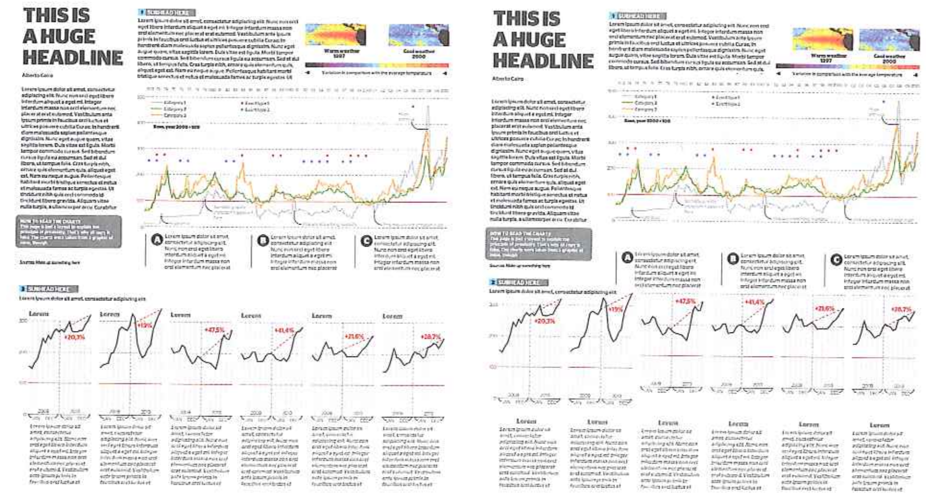


Figure 6.6 If you have several sections in your infographic, make sure that the objects that belong to them are near one another. The graphic on the left looks neat and organized, as you can clearly see the separation between its different sections. The graphic on the right does not.

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.

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.

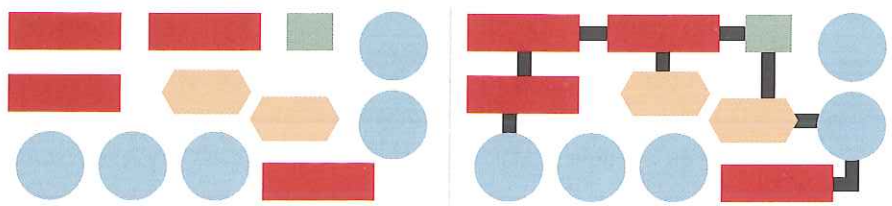


Figure 6.8 Lines are powerful clues the brain can use to perceive whether objects are related.

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.

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.

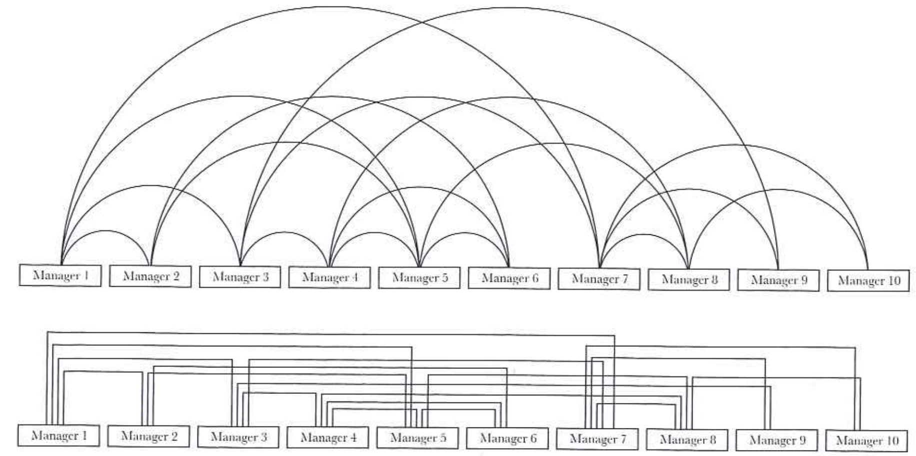


Figure 6.9 Continuity is better perceived in curves than in lines with sharp angles.

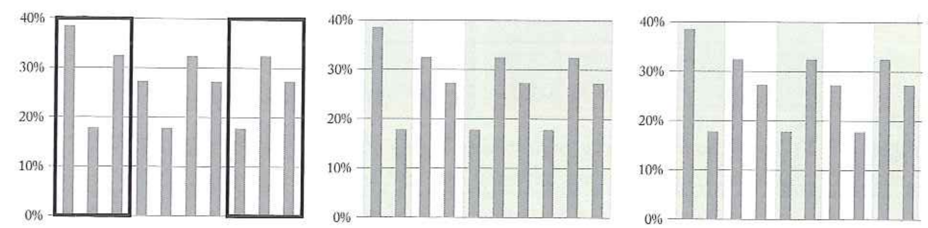


Figure 6.10 Boxing bars helps readers identify groups.

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.

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.

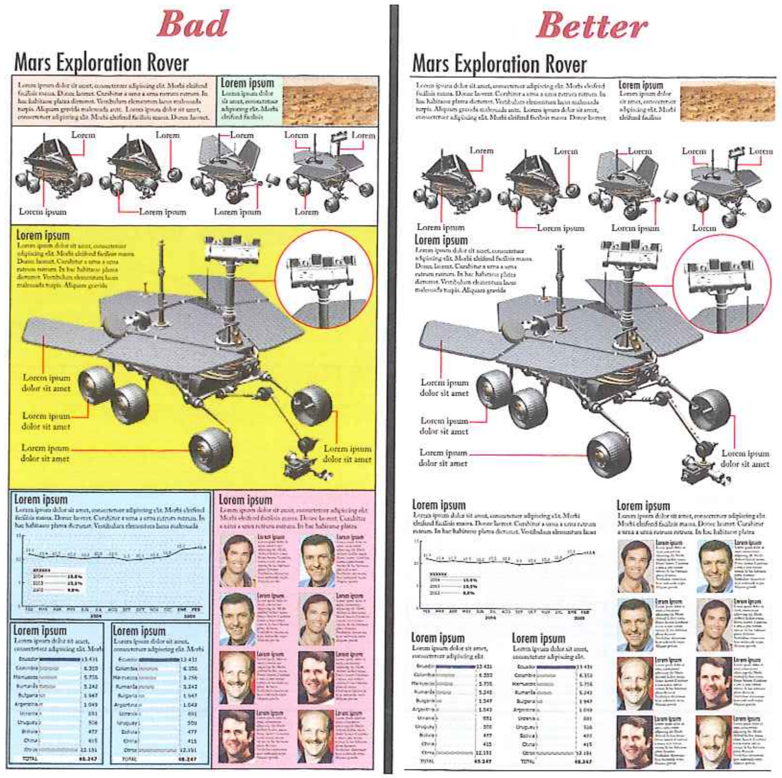


Figure 6.11 Don't overuse background boxes. Doing so will make your graphic look cluttered. If you need to differentiate between different sections, use white space.

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

2 Today, William S. Cleveland is a professor of statistics at Purdue University. His books *The Elements of Graphing Data* (1985) and *Visualizing Data* (1993) are must-reads for anyone interested in statistical charts.

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

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

3 Robbins's *Creating More Effective Graphs* (2004) is excellent and as Clevelandesque a manual as it gets.

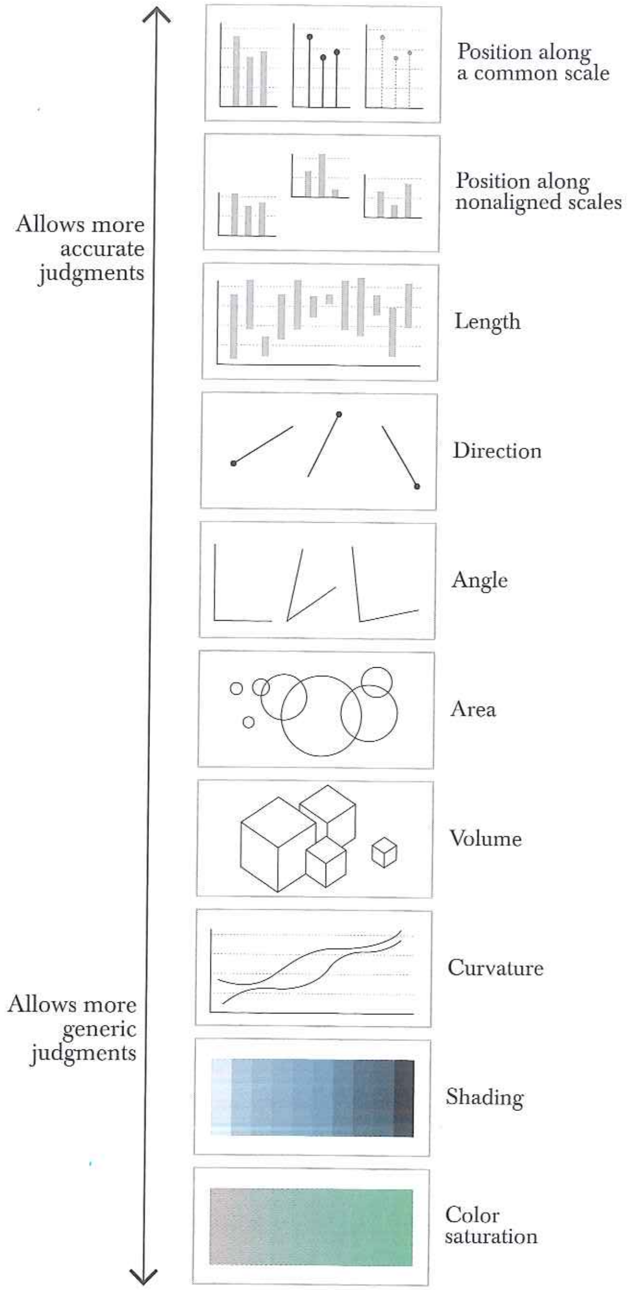


Figure 6.12 Cleveland and McGill's elementary perceptual tasks. The higher an encoding method on the scale, the more accurate the comparisons it facilitates.

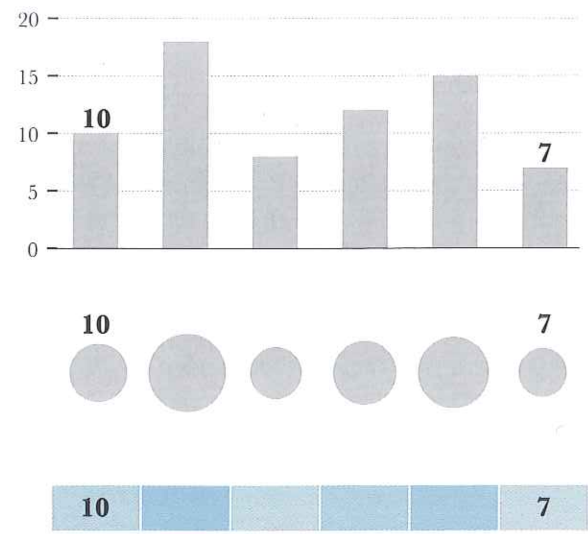


Figure 6.13 When the goal is to allow readers to make accurate comparisons, a chart based on bars or lines sitting on a single horizontal or vertical axis beats other forms of representation.

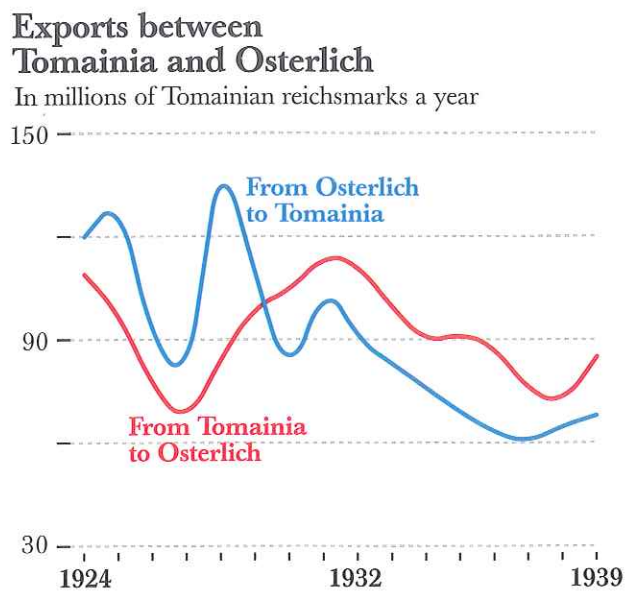
height of the first one, but the second bubble does not *preattentively* appear to be double the size of the first one.

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*.)

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



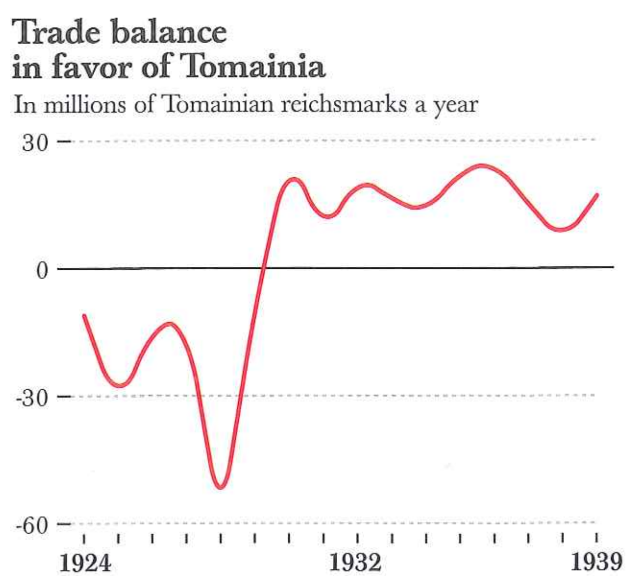


Figure 6.14 Trade balance between Tomainia and Osterlich, two of the imaginary countries in Charlie Chaplin's *The Great Dictator*. Of course, the data I used for the charts is also imaginary.

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

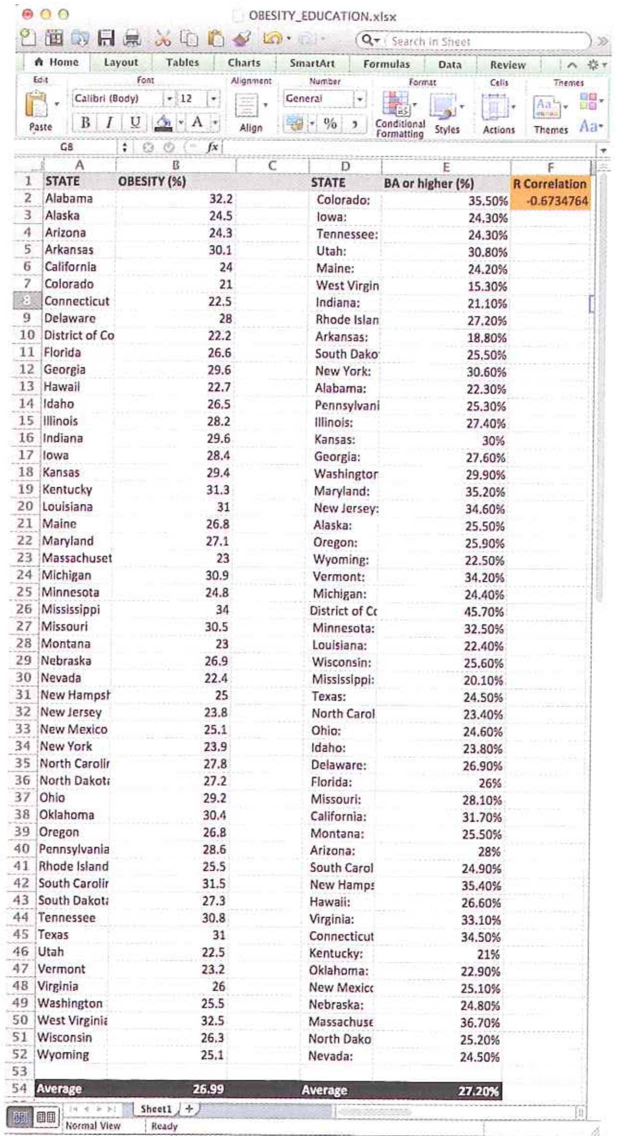
Rather than limit our discussion to abstractions, let me come down to Earth and show you how to use Cleveland and McGill's scale to orient your design decisions in a flexible manner.

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

4 From Chapter 2 of William Cleveland's *The Elements of Graphing Data*.



	A	B	C	D	E	F
1	STATE	OBESITY (%)		STATE	BA or higher (%)	R Correlation
2	Alabama	32.2		Colorado:	35.50%	-0.6734764
3	Alaska	24.5		Iowa:	24.30%	
4	Arizona	24.3		Tennessee:	24.30%	
5	Arkansas	30.1		Utah:	30.80%	
6	California	24		Maine:	24.20%	
7	Colorado	21		West Virgin	15.30%	
8	Connecticut	22.5		Indiana:	21.10%	
9	Delaware	28		Rhode Islan	27.20%	
10	District of Co	22.2		Arkansas:	18.80%	
11	Florida	26.6		South Dako	25.50%	
12	Georgia	29.6		New York:	30.60%	
13	Hawaii	22.7		Alabama:	22.30%	
14	Idaho	26.5		Pennsylvani	25.30%	
15	Illinois	28.2		Illinois:	27.40%	
16	Indiana	29.6		Kansas:	30%	
17	Iowa	28.4		Georgia:	27.60%	
18	Kansas	29.4		Washingtor	29.90%	
19	Kentucky	31.3		Maryland:	35.20%	
20	Louisiana	31		New Jersey:	34.60%	
21	Maine	26.8		Alaska:	25.50%	
22	Maryland	27.1		Oregon:	25.90%	
23	Massachuset	23		Wyoming:	22.50%	
24	Michigan	30.9		Vermont:	34.20%	
25	Minnesota	24.8		Michigan:	24.40%	
26	Mississippi	34		District of Cc	45.70%	
27	Missouri	30.5		Minnesota:	32.50%	
28	Montana	23		Louisiana:	22.40%	
29	Nebraska	26.9		Wisconsin:	25.60%	
30	Nevada	22.4		Mississippi:	20.10%	
31	New Hampsh	25		Texas:	24.50%	
32	New Jersey	23.8		North Carol	23.40%	
33	New Mexico	25.1		Ohio:	24.60%	
34	New York	23.9		Idaho:	23.80%	
35	North Carolir	27.8		Delaware:	26.90%	
36	North Dakota	27.2		Florida:	26%	
37	Ohio	29.2		Missouri:	28.10%	
38	Oklahoma	30.4		California:	31.70%	
39	Oregon	26.8		Montana:	25.50%	
40	Pennsylvania	28.6		Arizona:	28%	
41	Rhode Island	25.5		South Carol	24.90%	
42	South Carolir	31.5		New Hamps	35.40%	
43	South Dakota	27.3		Hawaii:	26.60%	
44	Tennessee	30.8		Virginia:	33.10%	
45	Texas	31		Connecticut	34.50%	
46	Utah	22.5		Kentucky:	21%	
47	Vermont	23.2		Oklahoma:	22.90%	
48	Virginia	26		New Mexicc	25.10%	
49	Washington	25.5		Nebraska:	24.80%	
50	West Virginia	32.5		Massachuse	36.70%	
51	Wisconsin	26.3		North Dako	25.20%	
52	Wyoming	25.1		Nevada:	24.50%	
53						
54	Average	26.99		Average	27.20%	

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

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.

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.

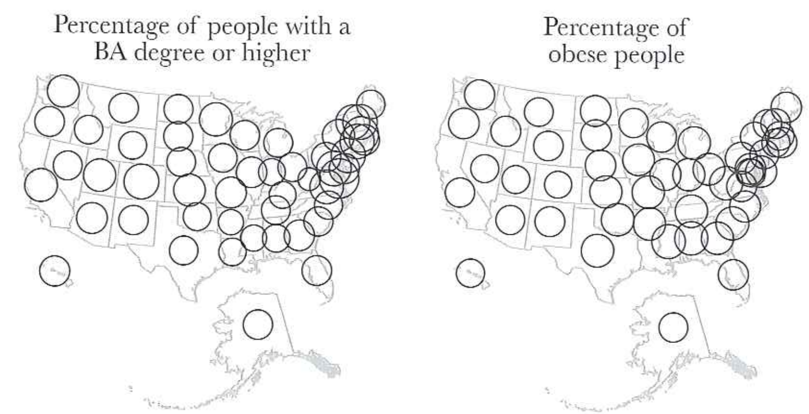


Figure 6.16 Proportional symbol maps are not the best way to represent these data sets.

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

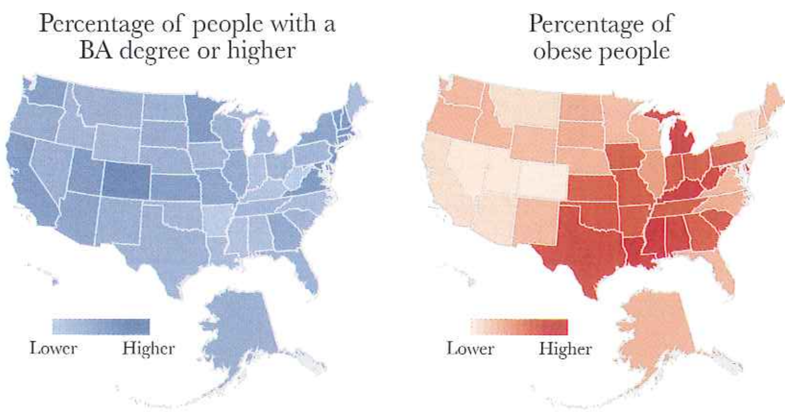


Figure 6.17 My second choice was a choropleth map. I was not very fond of it.

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.

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.

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.

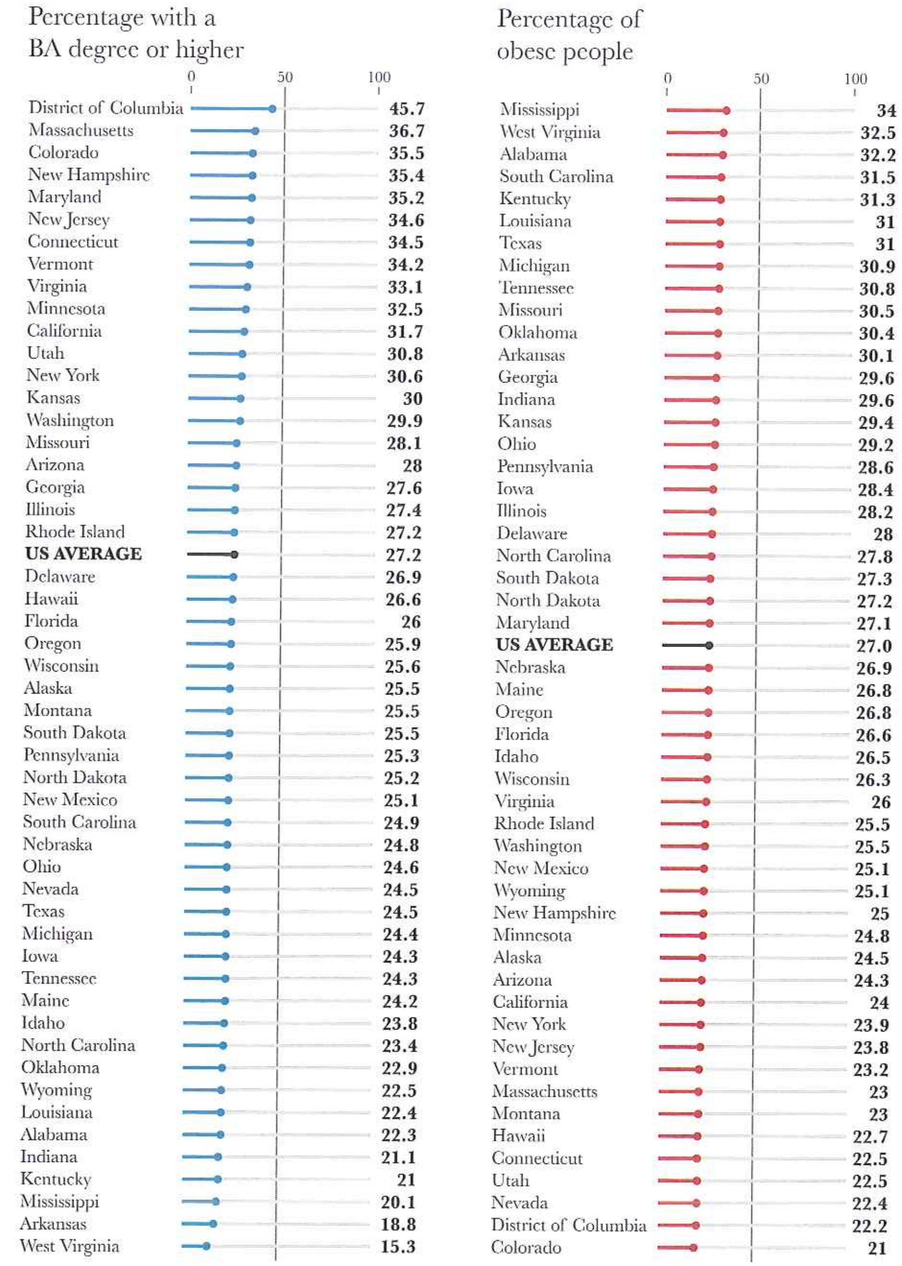


Figure 6.18 A dot chart is equal to a bar chart when it comes to estimating proportions.

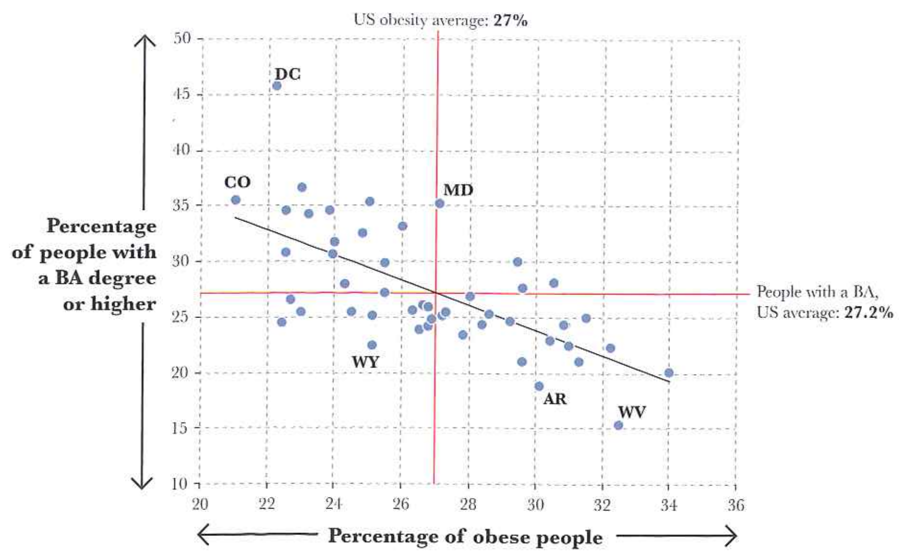


Figure 6.19 A scatter-plot.

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.

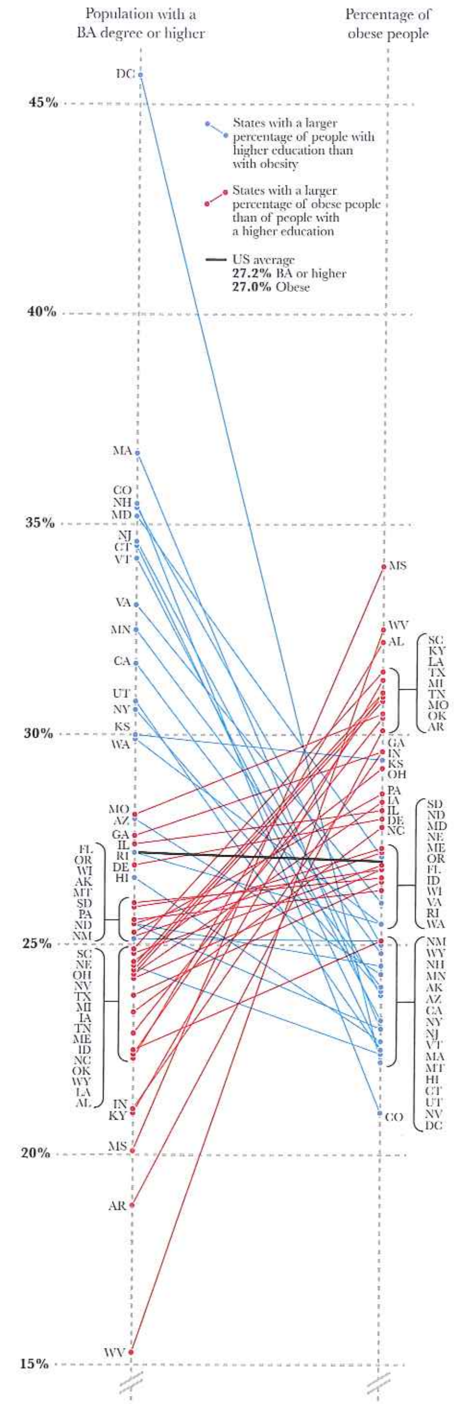


Figure 6.20 A slopegraph.

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.

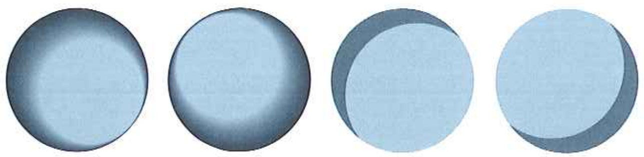


Fig 6.21 Our brains define concave and convex objects by how light hits them.

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**.

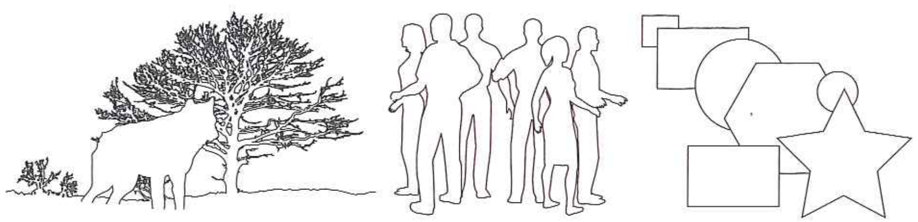


Figure 6.22 Interposition is a powerful tool for building the illusion of depth.

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.

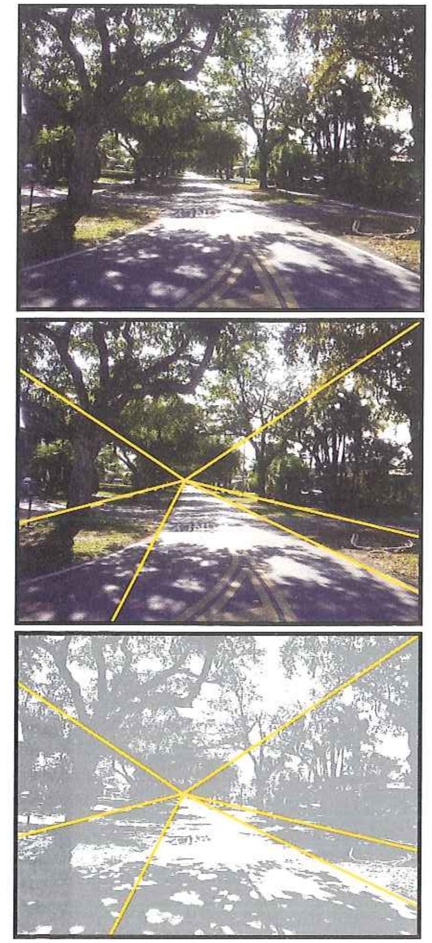


Figure 6.23 Seeing in perspective.

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]

5 Fron the book, *The Man Who Mistook His Wife for a Hat and Other Clinical Tales*, by Oliver Sacks, (1985). The book's title is based on the case of a patient who suffered from visual agnosia.

7

Images in the Head

In order to understand perception, you need first to get rid of the notion that the image at the back of your eye simply gets "relayed" back to your brain to be displayed on a screen. Instead, you must understand that as soon as the rays of light are converted into neural impulses at the back of your eye, it no longer makes sense to think of the visual information as being an image. We must think, instead, of symbolic descriptions that represent the scenes and objects that had been in the image.

—V.S. Ramachandran, from *The Tell-Tale Brain: A Neuroscientist's Quest for What Makes Us Human*

Evolution influences us to be attracted to what increases our chances of survival and reproduction and to be repelled by what harms us. If bananas were poisonous, their smell would be as repulsive to us as the stench of fresh excrement. Likewise, if feces were not a source for infections and our digestive system had evolved to extract nutrients from them, we would perceive their smell as a mouth-watering fragrance. What a dung beetle would consider a delicacy is for us the epitome of revulsion.

In other words, sensory properties are not intrinsic to objects, plants, and animals, but attributes our brains assign to them depending on how they relate to us as organisms. As I've said in previous chapters, perception is an active process. So is cognition, the ensemble of processes that identifies our environment and