Designing for the Mind: Five Psychological Principles of Articulate Graphics

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Introduction

Multimedia technology can deliver information like a fire hose delivers water. Just as drinking from a fire hose is not an efficient way to quench one's thirst, high-powered multimedia presentations can overload the senses and fail to communicate information effectively. Multimedia relies on the essential truth in the Chinese proverb that tells us a picture is "worth more than a thousand words." Unfortunately, some pictures do not help to control the flood of information, and actually make it worse. Instead of packaging information in concise, easily swallowed sips, they splatter it at us in the form of puzzles that can be decoded only with considerable effort by a highly motivated viewer.

We cannot exploit multimedia technology to manage information overload unless we know how to use it properly. Visual displays must be *articulate graphics* to succeed. Like effective speeches, they must transmit clear, compelling, and memorable messages, but in the infinitely rich language of our visual sense. Articulate graphics exploit the remarkable power of the human visual system to communicate complex patterns of information effectively. Articulate graphics will be the foundation of multimedia's future; as Apple Computer CEO John Sculley put it at the 1988 Microsoft CD-ROM conference, the next generation of computers must "deliver information in forms that correspond to the natural patterns of human thought" (as quoted on page 7 of *Multimedia Review,* Volume 1, Number 1, Spring 1990).

Articulate graphics are essential because poor visual displays do not merely look bad. When displays confuse, mislead, or misrepresent, they forfeit every advantage multimedia promises. Few people would deny that all forms of information presentation, computerized or otherwise, should respect the characteristics of their audiences. Just as one would not address a group of engineers with the jargon of the art world, or vice-versa, one should not create visual displays that could only be understood by omniscient, superhuman viewers. To use multimedia presentations effectively, we must discover and understand the "patterns" of mental function that information delivery should follow.

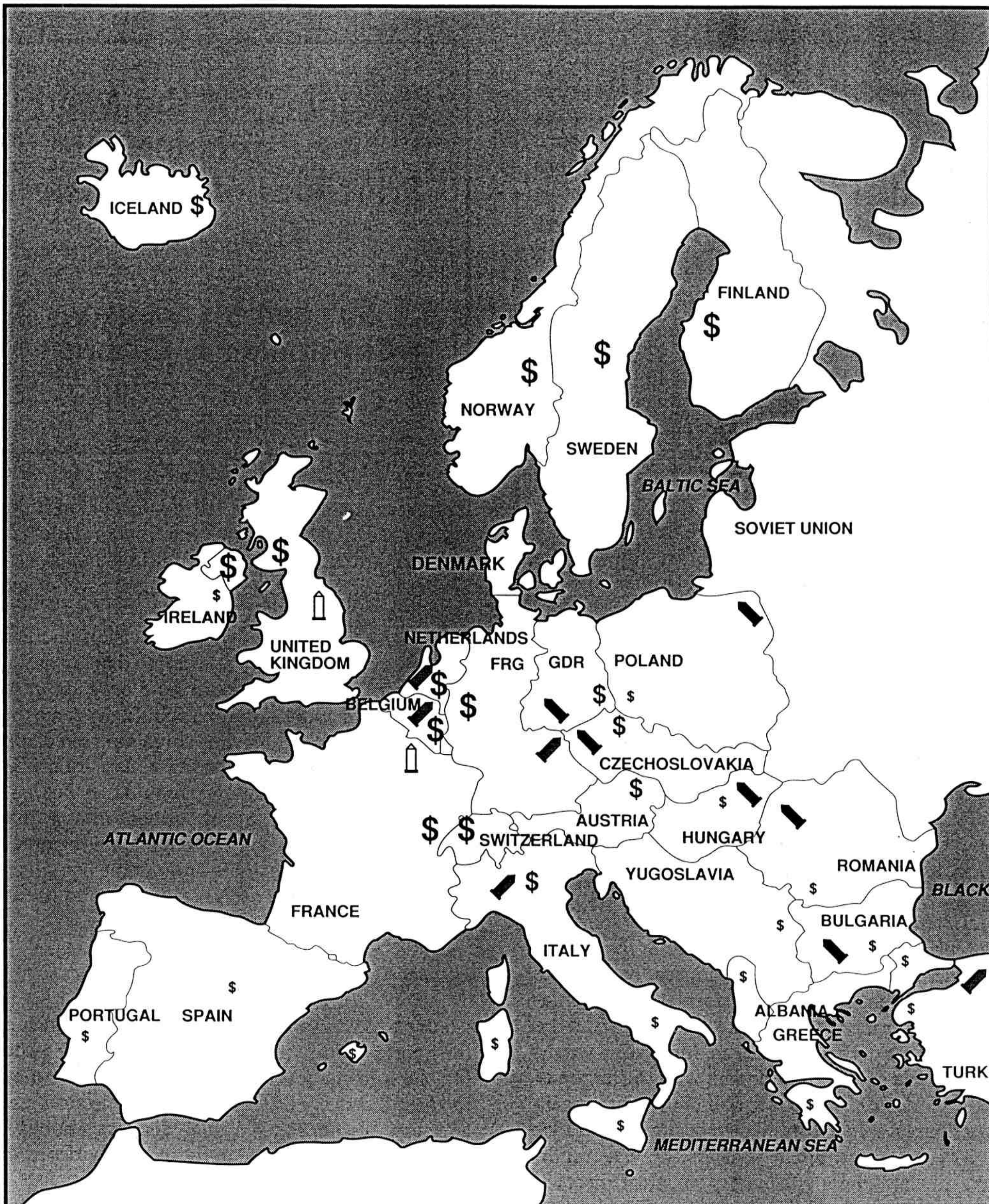
Cognitive science, the analytic study of perception, memory, thought, and action, will provide the solution. We might best view new technologies of information delivery such as CD-ROM, hypertext, and multimedia as *cognitive prostheses.* Just as a good prosthetic feels and works similar to the natural limb it replaces, an external source of information should behave like our own internal information processes. In short, articulate graphics are visual displays that are designed for the mind according to psychological principles.

Much of what is known about vision, memory, and reasoning is directly relevant to display design. For example, because we can hold only about five items in mind at once, graphs should not force their viewers to remember legends containing ten distinct symbols. Similarly, if regions of a map are marked by different patterns, not only should they be clearly discriminable, but the similarities among them should reflect the similarities among the regions. In this article, we will illustrate and outline five specific principles of cognitive science that can be used to create articulate graphics.

Display Elements Are Organized Automatically

Contrary to what we might introspectively conclude, the mind is not like a video camera, passively recording the information it gets from the environment. Instead, it actively filters and groups it in systematic and predictable ways. Visual displays should be drawn to take advantage of these proclivities of our perceptual systems.

Consider the map in Figure 1. It is confusing because its designers failed to respect the Gestalt laws of *perceptual organization* that describe how display elements are visually grouped. Many of these laws were discovered as long ago as the 1930s, but only now are they being systematically quantified and applied. For example, elements that are nearby, collinear, or look alike tend to be percep-



NUCLEAR CAPABILITY

- Independent Nuclear Capability
- Nuclear-capable delivery systems with warheads in custody of the USA
- Nuclear-capable delivery systems with warheads in custody of the USSR

ECONOMIC LEVEL

- $ Poor
- $ Middle Income
- $ Rich

Figure 1. A map of Europe showing various political, military, and economic information.

tually grouped (via the Laws of Proximity, Good Continuation, and Similarity, respectively) and seen as a single unit. Viewers of Figure 1 are supposed to associate a dollar sign and missile symbol immediately with each country on the map. This is difficult because the laws of perceptual organization not only fail to group the names and symbols properly, but also produce spurious groupings (e.g., the two dollar signs in France and Switzerland form a single perceptual unit even though they are unrelated). Failure to respect the Gestalt Laws also results in cluttered displays, which are not only difficult to use, but also visually unappealing.

Perceptual Organization Is Influenced by Knowledge

Consider the display in Figure 2. It uses several types of symbols that vary in shade and shape, have no legend to identify them, and are not grouped together in any obvious way. How are we to know what it means?

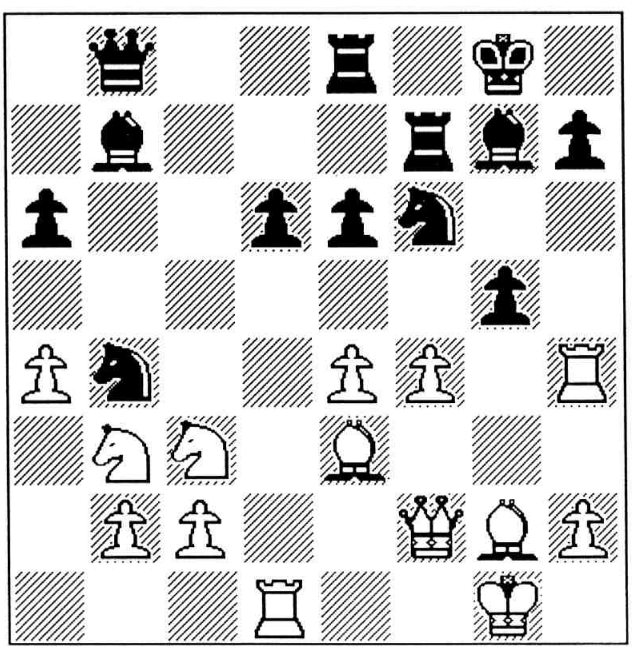


Figure 2. A visual display that is impossible for most people to understand, but nevertheless conforms to psychological principles.

The answer is that most people are neither expected nor even able to understand it. It is a diagram of a chess position, and an experienced chess master would need only a second to recognize it as such and a few seconds more to appreciate what it depicts and begin to consider which side is winning, what move is best, and so on.

Now try looking away and remembering what the diagram looked like, including the exact locations of each symbol. You can probably recall only a couple of pieces, but a chess master asked the same question would be able to reconstruct the entire position with relative ease. This is puzzling because experts do not have greater overall memory capacities than laymen. The difference is that experienced viewers can use an ability called *chunking* to impose a new perceptual organization on display types with which they are familiar—they group the display's elements into a small set of chunks, or meaningful patterns. This is important because our memory limitations are determined primarily by the sheer number of groups, not the complexity of the groups themselves.

Thus, as one's expertise in a domain increases, one can be presented with more and more complex displays without overloading one's cognitive systems. However, it is important to note that chunking abilities are highly domain-specific. For example, an expert electrician who can understand circuit diagrams in an instant will have no special advantage in using power plant schematics or star maps.

Images Are Transformed Incrementally

In the physical world, an object cannot disappear and suddenly reappear in another location; it must traverse the intervening space to get from here to there. Mental images, the internal "pictures" the mind uses to remember, plan, and solve some sorts of problems, are constrained in a similar way.

Try to decide whether the object shown in Figure 3a is identical to the object in Figure 3b. You probably imagined one of the objects rotating until the two came into alignment and the correct answer became apparent. In this case, the objects are identical; however, the object in Figure 3c is different from the one in Figure 3a. Laboratory studies have shown that the time needed to solve a problem with such mental rotation is proportional to how far the objects would have to be rotated through physical space to become aligned. In general, objects in mental images are transformed incrementally, a small amount at a time, until the change is complete.

All else being equal, interactive visual displays should also change incrementally if they are to act as natural extensions of cognitive processes. CAD systems should not only allow their users to rotate objects freely (instead of forcing them to type in the new angle or the amount of displacement), but also provide them with continuous feedback by displaying the intermediate positions along movement paths. Likewise, pictorial databases with magnification features should zoom in and out smoothly between lower and higher levels of detail.

Different Visual Dimensions Are Processed by Separate Channels

Any element of a display can be described along several visual dimensions, such as shape, color, position, orientation, and so on. The mind analyzes and interprets many of these different features with separate processing channels, which often correspond to distinct neural pathways in the brain.

The graph in Figure 4a is a scatterplot whose data points are drawn as gray and white geometric shapes. Try to use the key to find the information for British banks in 1989. You probably had to go through the symbols one by one to find the ones you wanted. Now try using the version of the graph in Figure 4b, where the 1989 British data points are colored black instead of gray. The important elements of the display should now "pop out" as soon as you look at it. This obviously desirable effect occurs because the brain processes many individual dimensions in parallel over the entire visual field at once, but can only deal with multiple dimensions in sequence. Therefore, whereas the visual system will notice all the black objects instantaneously in Figure 4b, it must first find all the gray objects and then select those that are diamond-shaped (a two-step process) in Figure 4a.

Keep in mind, however, that some dimensions that might seem separate are nevertheless processed together by the brain. Forcing users to separately evaluate such *integrable* dimensions, such as height and width, which are subdimensions of shape, will probably cause confusion and misunderstanding.

Color Is Not Perceived as a Continuum

Using color to represent a set of continuous values can simultaneously beautify a display and destroy its effectiveness. Designers are fond of such conventional practices as making "hot" areas of a diagram red, "cold" areas blue, and showing intermediate temperatures with intermediate wavelengths of the visible light spectrum.

The problem is that our visual systems do not see colors as lined up along a single dimension, because they do not register wavelength per se. The light-sensitive cells of the retina (the extruded part of the brain that lies at the back of the eye) are of two types: rods and cones. Rod cells respond to all wavelengths of light and do so approximately in proportion to the intensity of the light that hits them, whereas cone cells respond selectively to certain wavelength ranges, which correspond roughly to red, green, and blue light. The brain "sees" colors by combining the responses of the three types of cones, so the psychological proximity of one color to another depends on their positions on not one but several distinct dimensions. Although there are some local continuous regions, such as red-orange-yellow, there is no clear progression through the entire spectrum.

Varying intensity by itself is almost always the best way to display data that is spatially distributed,

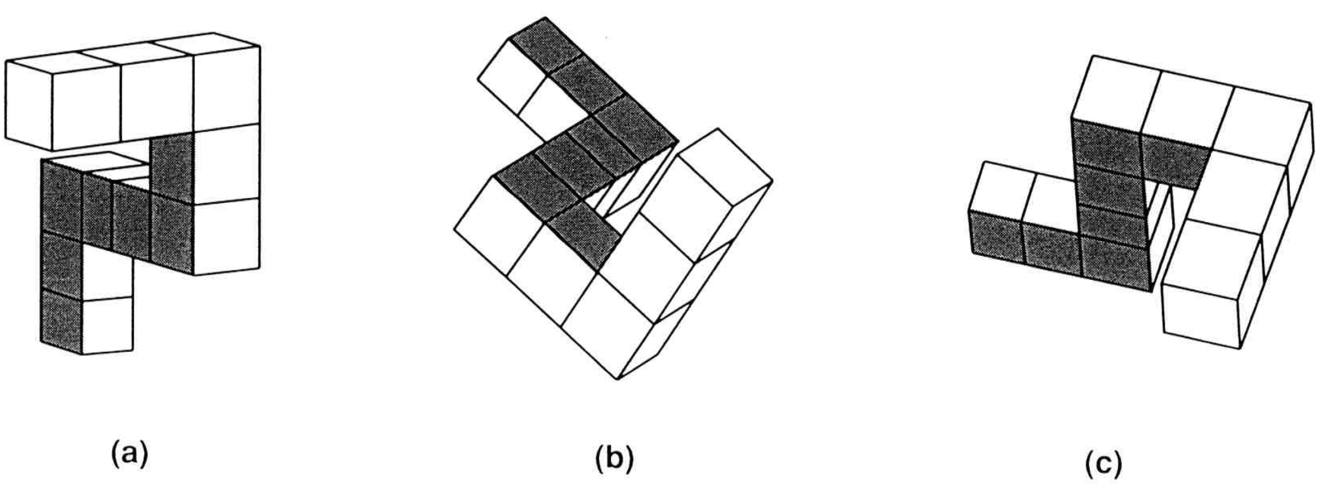
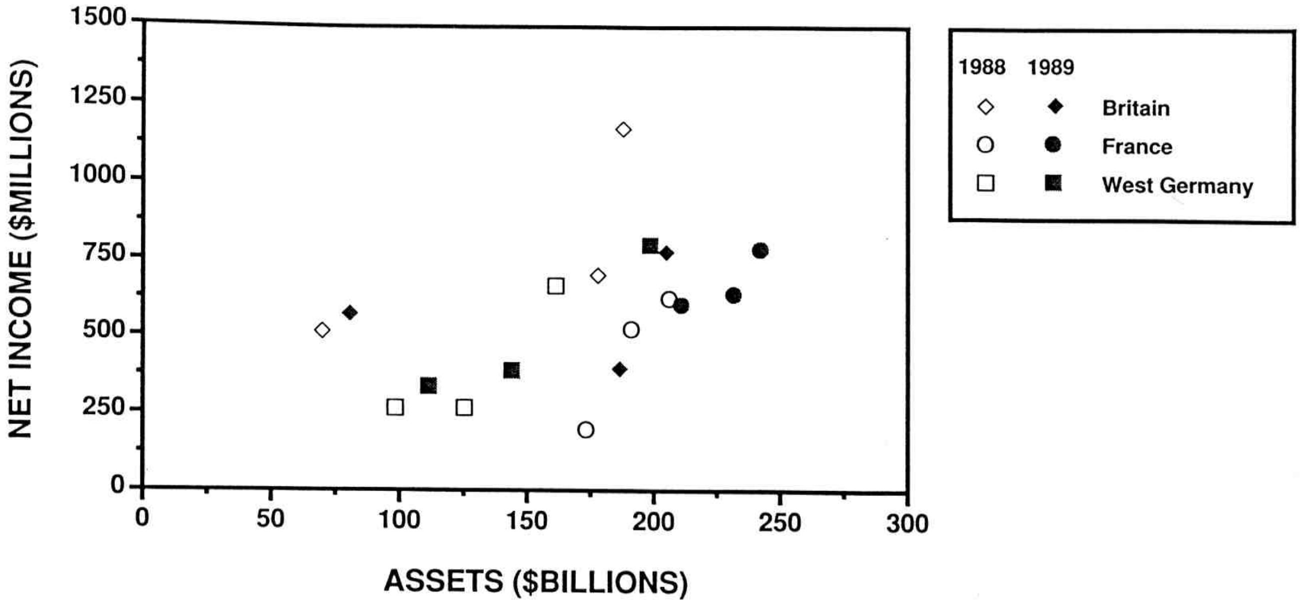


Figure 3. Three dimensional objects. Are objects (b) and (c) identical to object (a)?



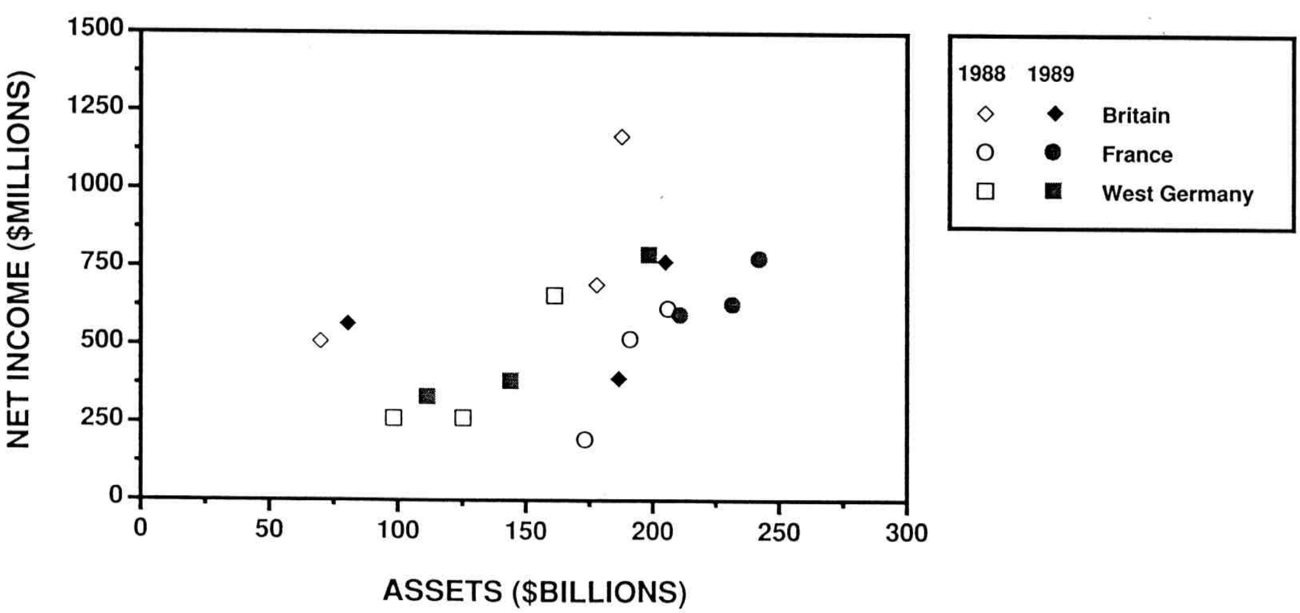


Figure 4. Two versions of a scatterplot comparing assets and net income for various banks in 1988 and 1989.

as Figure 5 demonstrates. But if other design considerations dictate the use of color, then hue should covary with either intensity or saturation (the purity of the color, or how free it is from dilution with white light), since both of these color subdimensions are perceived as continua.

Conclusion

One of the great strengths of interactive displays is that their information content can change as the needs of their users change. An effective display must be designed to answer the questions the users bring with them, and should never surprise them or keep them in suspense. Surprise and suspense make for effective horror and mystery stories, but for distracting information designs. For example, if an animated sequence is illustrating the components of a piece of machinery, it typically should move smoothly from the assembly level to the subassembly and individual part levels, not jump back and forth in two-second segments like a music video. Users should be able to anticipate what will happen next so that they can construct logical trains of thought as they interact with the information before them.

What one can anticipate depends in part on one's level of expertise. When one becomes an expert in a certain domain, one can anticipate even large jumps—in which case one can forget an initial image and form a new one in the transformed position or shape. So too with externalized "mental" images; interactive technology can allow a display to adapt

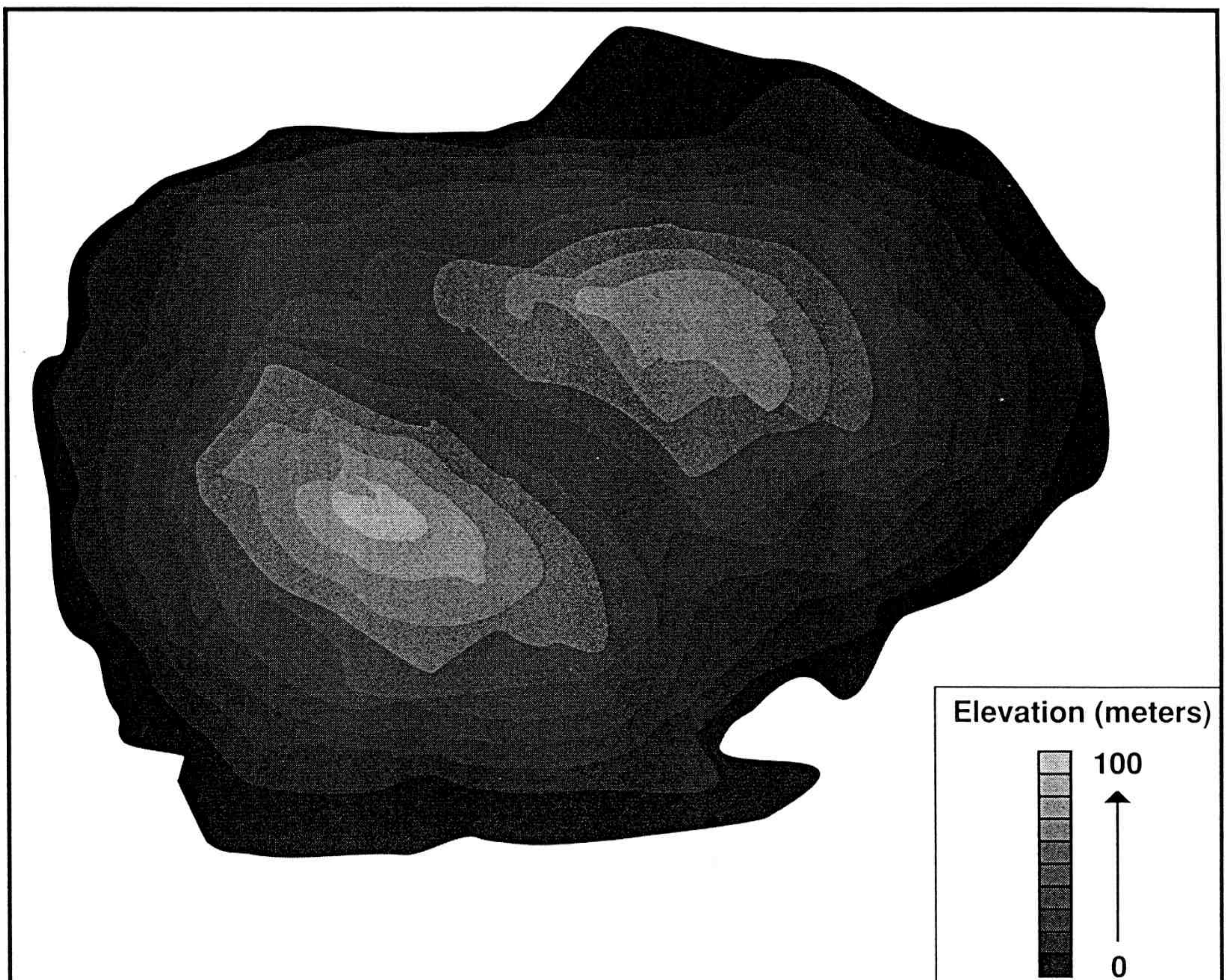


Figure 5. Elevation data presented in a contour map by varying intensity only. Note that it is easy to compare two regions without referring to the key.

to the user, mirroring his or her mental processes as he or she gains expertise in a domain. In short, any time a picture on a screen changes, it should do so just as the user's mental image would.

In this article we have only scratched the surface of what is known about designing for the mind. For example, we have developed a complete system for designing and evaluating information graphics (graphs, charts, maps, tables, and diagrams) that includes over fifty specific rules. And as we have seen, the approach and general principles can be applied to virtually any type of static or dynamic system that relies on visual displays.

The danger of multimedia technology comes from its unprecedented power to combine and package information into new and exciting presentations. We may be seduced by clever software features into "letting multimedia become the message." Understanding the human perceptual and cognitive systems will enable us to overcome the temptation to drown our real messages in a digital sea of superfluous special effects. With psychological principles, we can strike a design balance between aesthetics and information that will make our graphics truly *articulate graphics*.

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