Despite these reservations, Gibson's theories influence much of this book. The concept of affordances, loosely construed, can be extremely useful from a design perspective. The idea suggests that we build interfaces that beg to be operated in appropriate and useful ways. We should make virtual handles for turning, virtual buttons for pressing. If components are designed to work together, this should be made perceptually evident, perhaps by creating shaped sockets that afford the attachment of one object to another. This is the kind of design approach advocated by Norman in his famous book, *The Psychology of Everyday Things* (1988). Nevertheless, on-screen widgets present affordances only in an indirect sense. They borrow their power from our ability to represent pictorially, or otherwise, the affordances of the everyday world. Therefore, we can be inspired by affordance theory to produce good designs, but we cannot expect much help from that theory in building an applied science of visualization.

A Model of Perceptual Processing

In this section, we introduce a simplified information processing model of human visual perception. As Figure 1.5 shows, there are many subsystems in vision, and we should always be wary of overgeneralization. Still, an overall conceptual framework is useful in providing a starting point for more detailed analysis. Figure 1.11 gives a broad schematic overview of a three-stage model of perception. In Stage 1, information is processed in parallel to extract basic features of the environment.

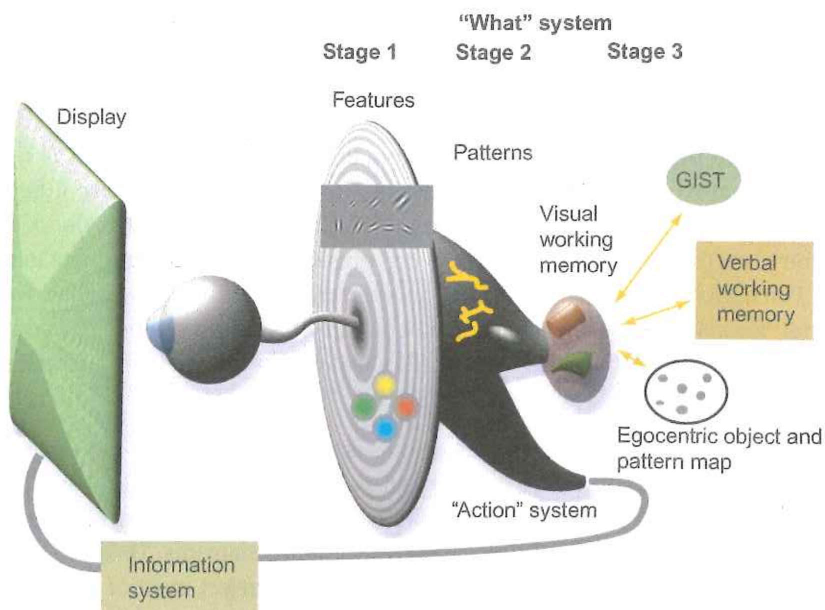


Figure 1.11 A three-stage model of visual information processing.

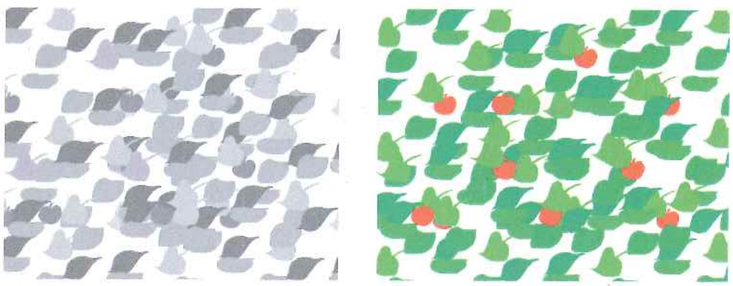


Figure 4.1 Finding the cherries is much easier with color vision.

becomes much harder. Color also tells us much that is useful about the material properties of objects. This is crucial in judging the condition of our food. Is this fruit ripe or not? It this meat fresh or putrid? What kind of mushroom is this? It is also useful if we are making tools. What kind of stone is this? Clearly, these can be life-or-death decisions. In modern hunter–gatherer societies, men are the hunters and women are the gatherers. This may have been true for long periods of human evolution, which could explain why it is mostly men who are color blind. If they had been gatherers, they would have been more than likely to eat poison berries—a selective disadvantage. In the modern age of supermarkets, these skills are much less valuable; this is perhaps why color deficiencies so often go unnoticed.

The role that color plays ecologically suggests ways that it can be used in information display. It is useful to think of color as an attribute of an object rather than as its primary characteristic. It is excellent for labeling and categorization, but poor for displaying shape, detail, or spatial layout. These points are elaborated in this chapter. We begin with an introduction to the basic theory of color vision to provide a foundation for the applications. The latter half of the chapter consists of a set of four visualization problems requiring the effective use of color; these have to do with color selection interfaces, color labeling, pseudocolor sequences for mapping, color reproduction, and color for multidimensional discrete data. Each has its own special set of requirements. Some readers may wish to skip directly to the applications, sampling the more technical introduction only as needed.

Trichromacy Theory

The most important fact about color vision is that we have three distinct color receptors, called *cones*, in our retinas that are active at normal light levels—hence *trichromacy*. We also have rods, sensitive at low light levels, but they are so overstimulated in all but the dimmest light that their influence on color perception can be ignored. Thus, in order to understand color vision, we need only consider the cones. The fact that there are only three receptors is the reason for the basic three-dimensionality of human color vision. The term *color space* means an arrangement of colors in a three-dimensional

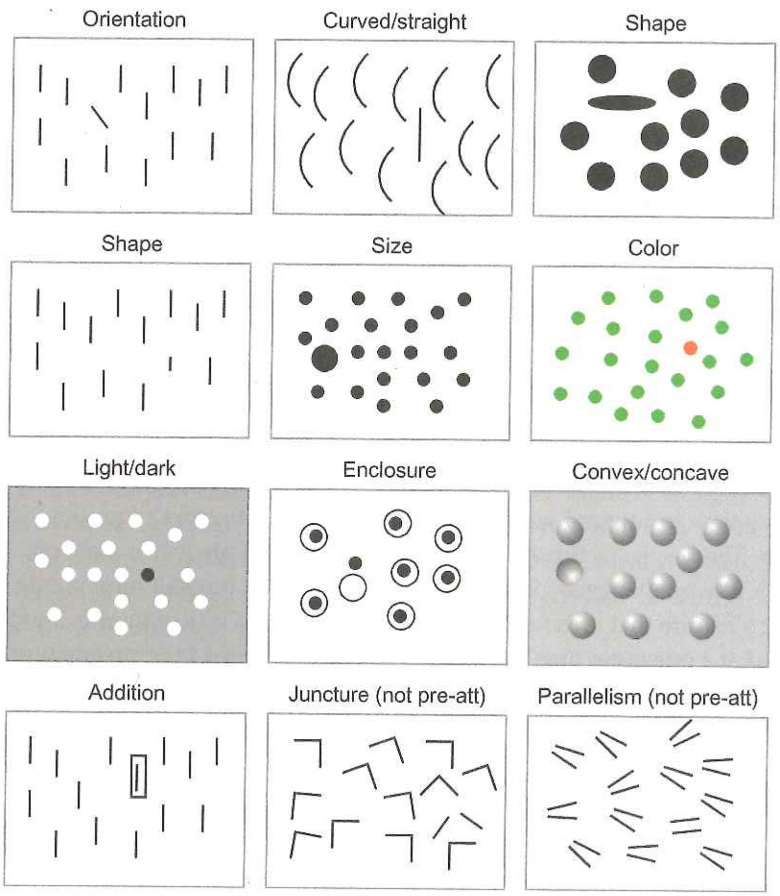


Figure 5.11 Most of the preattentive examples given here can be accounted for by the processing characteristics of neurons in the primary visual cortex.

mark on a map as being of type A, it should be differentiated from all other marks in a preattentive way. There have been literally hundreds of experiments to test whether various kinds of features are processed preattentively. Figure 5.11 illustrates a few of the results. Orientation, size, basic shape, convexity, concavity, and an added box around an object are all preattentively processed. However, the junction of two lines is not preattentively processed; neither is the parallelism of pairs of lines, so it is more difficult to find the targets in the last two boxes in Figure 5.11.

The features that are preattentively processed can be organized into a number of categories based on form, color, motion, and spatial position.

- Line orientation
- Line length
- Line width

here. The point of showing it is to illustrate how the color-mapped variables tend to be seen integrally and independently (separably) from the shape variables, which also tend to be viewed holistically, making up the lozenge shapes.

Integral–Separable Dimension Pairs

The preceding analysis presented integral and separable dimensions as if they were qualitatively distinct. This overstates the case; a continuum of integrality–separability more accurately represents the facts. Even between the most separable dimension pairs, there is always some interference between different data values presented using the different channels. Likewise, the most integral dimension pairs can be regarded analytically to some extent. We can, for example, perceive the degree of redness and the degree of yellowness of a color—for example, orange or pink. Indeed, the original experimental evidence for opponent color channels was based on analytic judgments of exactly this type (Hurvich, 1981).

Figure 5.23 provides a list of display dimension pairs arranged on an integral–separable continuum. At the top are the most integral dimensions. At the bottom are

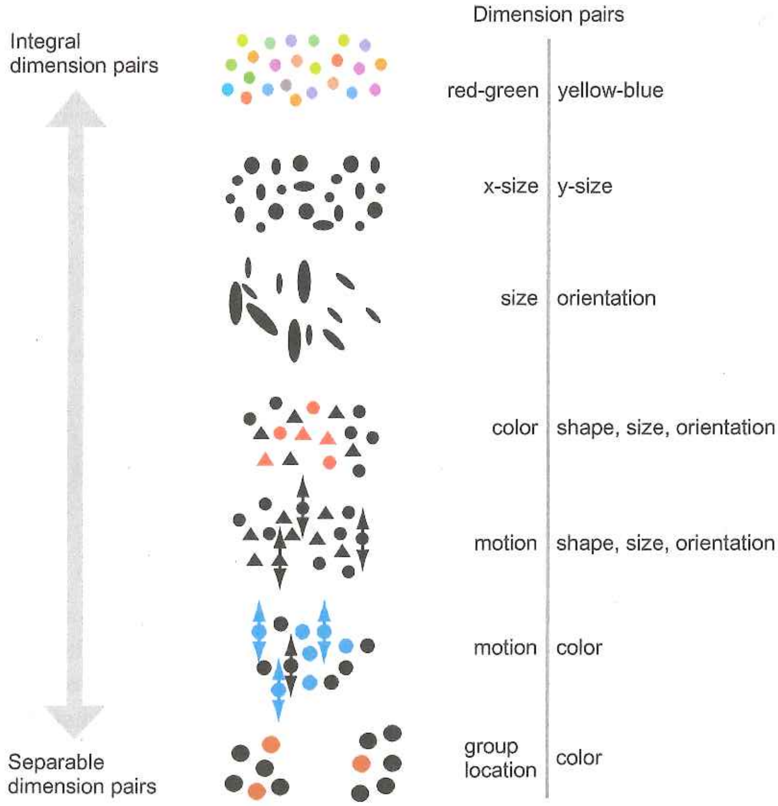
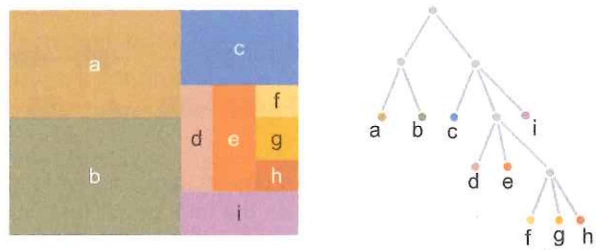


Figure 5.23 Examples of glyphs coded according to two display attributes. At the top are more integral coding pairs. At the bottom are more separable coding pairs.



(a) (b)

Figure 6.59 (a) A treemap representation of hierarchical data. Areas represent the amount of data stored in the tree data structure. (b) The same tree structure, represented using a conventional node–link diagram.

The original treemap was based on the following algorithm. First, the rectangle is divided with a vertical partition according to the number of branches from the base of the tree. Next, each subrectangle is similarly divided, but with horizontal partitions. This process is repeated to the leaves of the tree. The area of each leaf on the tree corresponds to the amount of information that is stored there.

The great advantage of the treemap over conventional tree views is that the amount of information on each branch of the tree can be easily visualized. Because the method is space-filling, it can show quite large trees containing thousands of branches. The disadvantage is that the non-leaf nodes are not shown and the hierarchical structure is not as clear as it is in a more conventional tree drawing. Of course, there are many hybrid designs where, for example, a node–link representation is used and the size of the node points represents some quantity.

[G6.28] Consider using a treemap to display tree structured data where it is only necessary to display the leaf nodes and where it is important to display a quantity associated with each leaf node.

[G6.29] Consider using a node–link representation of a tree where the hierarchical structure is important, where internal (non-leaf) nodes are important, and where quantitative attributes of nodes are less important.

Patterns in Motion

To this point, we have mainly discussed the use of static patterns to represent data, even though the data is sometimes dynamic—as in the case of a vector field representing a pattern of moving liquid or gas. We can also use motion as a display technique to represent data that is either static or dynamic. The perception of dynamic patterns is not understood as well as the perception of static patterns, but we are very sensitive to