Visual Displays

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Visual displays are depictions that convey information by means of elements beyond pure text. Examples include diagrams, maps, and computer interfaces. The common factor in all of these is their reliance on the "visual intelligence" of humans to organize graphically-presented information in a way that makes it easier to understand. The design of an effective visual display is based on general principles involving both the nature of human vision and the nature of the task. The particular medium used—paper, canvas, computer monitor, etc.—is irrelevant.

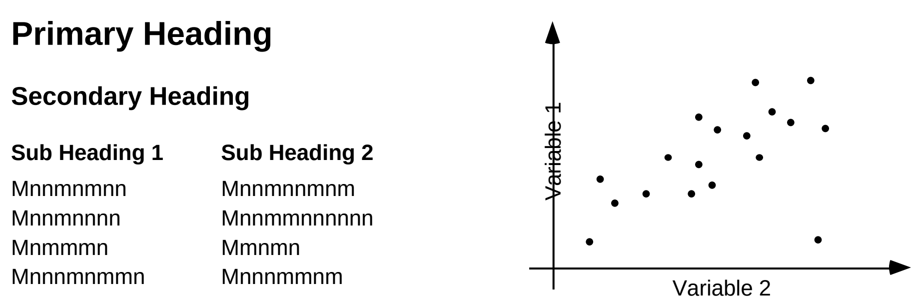
The use of visual displays has a long history. Drawings were used tens of thousand of years ago, likely for teaching. With the advent of writing, text became the dominant means of transmitting information, and reduced the involvement of visual perception to that of recognizing characters or words. But the use of drawings never completely disappeared. And displays such as maps were discovered to be a highly effective way of describing the two-dimensional surface of the Earth. More generally, it has been found that when a visual display draws on the appropriate mechanisms of visual perception, it can present information in a way that allows a viewer to understand it far more quickly, accurately, and memorably than if presented by text alone. It has also been found that successful design techniques sometimes point to previously unknown mechanisms.

When used to convey more abstract information by more metaphoric means, visual displays cross over into the domain of fine art. The two domains have a great deal of overlap, drawing on many of the same perceptual mechanisms. They are also very compatible—an effective visual display can have great esthetic appeal. However, the focus of visual display design is on the communication of relatively concrete information, with emphasis on speed and accuracy. As such, different principles are often involved, principles that depend on the nature of the task and on the tradition in which they were developed.

Graphic Design

Graphic design concerns displays centered around text, such as a page or poster. These generally contain graphic elements such as groups, lines, and figures; lines of text may sometimes be quite sparse (Figure 1a). The goal here is to present information to the viewer such that they can quickly and easily make sense of the display, with the most important text being perceived first.

Organization can be created by the use of lines or other graphic elements. However, such elements are usually kept to a minimum since they can distract attention. Instead, organization largely involves grouping of the text lines themselves (Figure 1b). Important design principles here include the use of Gestalt laws: alignment of edges (grouping via continuity of the text border), keeping related lines of text close to each other (grouping via proximity), and using the same size and color of font (grouping via similarity). Other principles concern the use of contrast to attract attention, and the use of multiple levels of visual structure; these are often used concurrently. For example, if a title line is at a higher structural level than the supporting text and has a higher contrast, attention will go to it first, allowing the viewer to obtain a summary before exploring further.



(a) Graphic Design (b) Data Visualization

Figure 1. *Examples of simple visual displays*. Here, the dataset is information about the weather at some location. (a) Unorganized text elements. The display is readable, but is relatively difficult to use. (b) Organized text elements. Organization uses the Gestalt principles of continuity (alignment of text), similarity (common font size and contrast), and proximity. Contrast is used to draw attention first to the primary heading. The result is much easier to read. (c) Bar chart. Data is represented via the height (and area) of the columns. Trends in the data can be easily perceived. (d) Interactive display. Here, the viewer can easily examine different aspects of the information in a dataset, allowing them to more easily get a sense of the entire situation.

An effective graphic design attempts to do this in two ways: (i) send visual attention to the most important points, ideally in appropriate order, and (ii) minimize the number of possible candidates by collecting the graphic elements into meaningful groups. Both can be done simultaneously if the display has the appropriate perceptual organization.

Drawings

Drawings convey information about the structure of an object via graphic elements similar to the object they depict. For example, a drawing of a house can have the graphic elements depicting the walls connected to the elements depicting the roof, just as the actual walls are connected to the actual roof. While text is generally unsuitable for this, it is often used to provide additional information about individual parts. Drawings are believed to engage a form of visual cognition based on mental imagery; a distinction is sometimes made between an “external” drawing in a display and the corresponding “internal” drawing in the viewer’s mind.

Several variants of drawings exist. Requiring the graphic elements to be as simple as possible results in *icons*, commonly used in signage and computer interfaces. Removing the need for the graphic elements to resemble real-world objects results in *diagrams*, which allow display of more abstract kinds of information, such as sequences of actions. Another variant is *comics*, in which sequences of drawings are used to convey information about events over time.

For all of these, the goal is to present as much understanding of the depicted object as needed. To do this, a drawing must focus visual attention on the important aspects of an item’s structure. This is achieved by selection: removing much of the irrelevant detail and highlighting parts of the remainder, e.g., by giving particular lines higher contrast. This contrasts with photographs, where such detail is retained and no highlighting is done. A drawing must ensure that the information is enough to allow the visual system to adequately understand the depicted item.

Understanding a drawing relies heavily on shape perception. Gestalt principles are also useful, both for grouping, and for figure recognition. The accurate recovery of three-dimensional structure can also be important. This is not always possible from a single view, but a set of drawings (each of a different view) may allow this.

Maps

Maps convey information about the distribution of items or properties—for example, cities or precipitation—over the surface of a world, typically the Earth. As with drawings, graphic elements such as lines and regions are dominant, with text only providing information about individual items or parts. Maps also have a strong emphasis on selection: a map generally provides information only about particular aspects of a particular part of a world.

However, maps differ from drawings in several ways. First, except for the occasional need to represent altitude, there is little intent to convey three-dimensional structure. Also, accuracy is often more of a challenge. At large scales, severe distortions arise from projecting the surface of a sphere onto a flat sheet; indeed, it is impossible to accurately portray both direction and area simultaneously. Finally, maps often need to convey information about several dimensions at each location, e.g., population density and average income across a city.

Effective maps rely on the use of several perceptual abilities. Shape perception and spatial perception support the understanding of two-dimensional structures such as rivers and boundaries. Another perceptual aspect is attentional crowding: the extent to which a high density of symbols can be easily understood. Perceptual considerations also influence the choice of graphic variables—e.g., which properties should represent cities of different sizes. Effective maps use properties that correspond to basic visual features, such as size, shape, orientation, and hue. These allow for immediate grouping of regions with similar properties, and also allow visual attention to easily select particular subsets of properties.

Visual Interfaces

Visual interfaces are displays used for the control of a process. A common example is *human-computer interaction*, where the interface is used to control the actions of a computer. Here, the display not only provides the operator with information (e.g., files on the desktop), but also supports interactions with it (e.g., opening folders), as well as control of operations beyond the computer itself (e.g., sending email). More generally, visual interfaces can support effective *human-machine interaction*, in which a human operator controls a machine—perhaps a computer, but perhaps a car or aircraft.

To be effective, interfaces must make good use of a wide range of perceptual abilities. In addition to the visual intelligence used for other kinds of display, perceptual processes must also support effective action. An example of this is situation awareness, the ability to combine pieces of information into an understanding sufficient to determine the appropriate action. For example, combining information from different views (via mirrors or cameras) makes it possible to determine whether it is possible to turn into an adjacent lane.

Other relevant abilities are the initiation and control of motor movement. To support initiation, the display of the command must be such that engaging it appears to be a natural way to act. The display should also support the use of automatic actions that do not interfere with other operations. If designed well, the resulting interface will be *transparent*, allowing the operator to focus on the task itself rather than the tools. An interesting possibility here is to design interfaces for the "how" stream in vision, a nonconscious system concerned with the real-time control of actions, which may be largely separate from the system underlying our conscious experience of the world.

Data Visualization

Data Visualization displays present datasets in a form intended to allow the viewer to rapidly perceive any patterns they may contain, such as trends and outliers. Examples are graphs and scatterplots. The goal here is to "use vision to think"—to use the visual intelligence of the viewer to analyze the contents of the display, reducing the need to carry out this out at higher cognitive levels.

Several forms of data visualization have been developed. Graphs and bar charts are perhaps the simplest of these, being based on static graphic elements, and typically displaying a medium-sized dataset of tens or hundreds of items. In a graph, each item in the set is represented by an element with a location corresponding to the information it contains—e.g., the number of sales for a particular month. A bar chart is similar, except that the height of the bar replaces vertical position (Figure 1c). Multiple properties per item can be represented by multiple graphic properties, such as the size and color of the elements. Relevant perceptual abilities include attentional selection of particular categories, grouping of similar items into clusters, and the perception of the overall shape and orientation of these clusters, which reflect things such as trends and correlations. Interactive displays have also been developed, allowing different aspects of a dataset to be easily examined (Figure 1d). Perceptual abilities having to do with motor control and navigation in virtual spaces are relevant here.

Specialized displays have recently been developed for large datasets. In *scientific visualization*, data is displayed as a dense image, with each point containing information about physical properties that are not necessarily visible in their own right—e.g., the density, pressure, and temperature of a fluid within an engine. Successful interpretation uses several kinds of visual intelligence, including edge detection, color perception, and shape perception. Meanwhile, *information visualization* is concerned with the display of more abstract data, such as communication networks or financial predictions. Many of the same principles and perceptual mechanisms are also relevant here. Because consideration is no longer restricted to the physical world, nonintuitive patterns are more often encountered, requiring the mapping to perceptual abilities to be pushed to its limits.

Another recent development is the emergence of *visual analytics.* Displays here not only allow the visual system to use its own intelligence, but also support higher-level thinking when the lower-level mechanisms are insufficient. For example, allowing an analyst to explore the incidence of a disease as a function of various factors (e.g., geographical location, social network) might help determine important transmission factors, even if the relevant patterns are not immediately evident from the visual display alone. More generally, visual analytics systems are intended to provide a seamless coupling of the various kinds of human intelligence with various kinds of machine intelligence, enabling a single user to make sense of immense amounts of imperfect, complex data.

See also **Attention; Computer Graphics and Perception; Graphs (Data Visualization); Perceptual Organization: Vision; Pictorial Depiction and Perception; Visual Cognition; Visual Search**

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