POINTS OF VIEW

Design of data figures

Data figures or graphs are essential to life-science communication. Using these tools authors encode information that readers later decode. It is imperative that graphs are interpreted correctly. Despite the importance and widespread use of graphs, we primarily rely on our intuition, common sense and precedent in published material when creating them—a largely unscientific approach.

Because accurately interpreting visual variables is such a vital step in understanding graphs, a rational framework for creating effective graphs would accommodate the needs of the reader and focus on the strengths of human perception. Conversely, we want to avoid displays of data that are misleading or difficult to discern. For example, it can be tough to accurately judge the differences between two curves (**Fig. 1a**). The disparity is actually constant but our perceptual system is attuned to detecting minimal distances so the divergence appears to decrease. Another shortcoming limits our ability to accurately judge relative area. This diminishes the usefulness of bubble charts. For example, the larger circle in **Figure 1a** is 14 times larger than the smaller circle.

In 1967, the French cartographer Jacques Bertin provided a wide theoretical framework for information visualization[1]. His analysis focused on the visual properties of graphical elements such as shape, orientation, color, texture, volume and size for displaying quantitative variation. He defined several visual operations needed to extract information stored in graphs. Cleveland and McGill were one of the first to measure people's ability to efficiently and accurately carry out these elementary perceptual tasks[2] (**Table 1**).

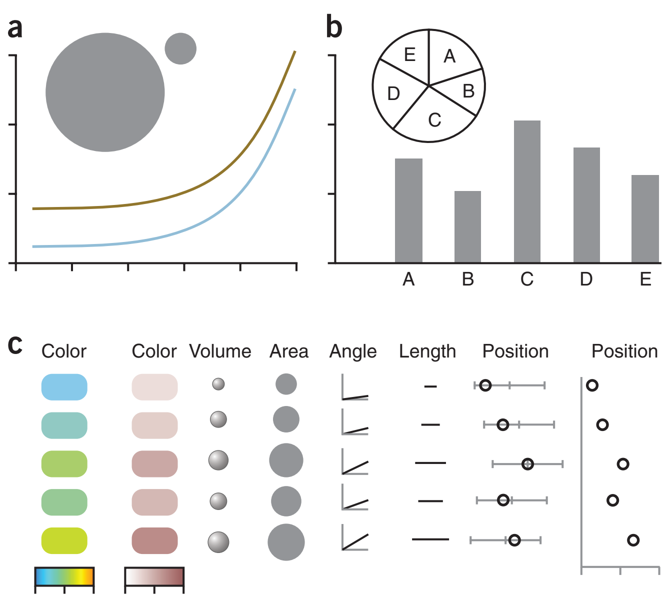

Figure 1 | Some visual estimations are more easily carried out than others. (**a**) Examples illustrating the difficulty in interpreting graphs and charts accurately. (**b**) Same data presented in a bar chart and in a pie chart. (**c**) Different visual variables encoding the same five values.

Table 1 | Elementary perceptual tasks

Rank	Aspect to compare
1	Positions on a common scale
2	Positions on the same but nonaligned scales
3	Lengths
4	Angles, slopes
5	Area
6	Volume, color saturation
7	Color hue

Tasks are ordered from most to least accurate. Information adapted from ref. 2.

When communicating with graphs, we want readers to perceive patterns and trends. This is distinct from conveying information through tables in which we report precise names and numbers. Cleveland and McGill's study assessed people's ability to judge the relative magnitude between two values encoded with a particular visual variable (for example, length, angle and others). In other words, they asked people to estimate how many times bigger *A* is when compared to *B*. Accuracy in their study does not imply reading out precise values from data points in graphs.

Different graph types depend on different visual assessments to uncover underlying trends. Pie charts are a common way to show parts of a whole. Most readers will likely judge angle when extracting information from pie charts, but they could also compare areas and arc length of the slices (**Fig. 1b**). Each of these perceptual tasks ranks low in efficiency and accuracy (**Table 1**). Plotting the same data as a bar chart effectively shows relative values (**Fig. 1b**).

When we occasionally need to invent new ways to graph data, we ideally want to use perceptual tasks that rank high in efficiency and accuracy (**Table 1**). In **Figure 1c**, I plotted the same five values using different encoding. In some cases, identifying magnitude and direction of change is laborious. In other cases, the trends are readily apparent. Encodings on the right more efficiently and accurately display the magnitude and direction of change. Though we can detect slight shifts in color hue, the relationship between hue and quantitative value is not obvious (see also ref. 3), making color hue one of the weaker methods to illustrate relative values.

Communicating with graphs depends on authors encoding information for readers to decode. Graphs' effectiveness can benefit from attention to their visual design. Composing figures with strong visual cues and relying on accurate perceptual tasks supports the visual assessment critical for interpreting information from graphs. Next month we will explore salience, the use of visual properties as differentiators.

Bang Wong

1. Bertin, J. *Semiology of Graphics*, English translation by W.J. Berg (University of Wisconsin Press, Madison, Wisconsin, USA, 1983).
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POINTS OF VIEW

Gestalt principles (Part 1)

Gestalt principles of perception are theories proposed by German psychologists in the 1920s to explain how people organize visual information[1]. Gestalt is a German word meaning shape or form. The principles describe the various ways we tend to visually assemble individual objects into groups or 'unified wholes'. They are highly relevant to the design of charts and graphs as well as the reports that contain them.

Gestalt is the interplay between the parts and the whole. Kurt Koffka, one of the founding fathers of Gestalt psychology, made a statement about this. He said, "The whole is 'other' than the sum of its parts." This phrase has been translated to the familiar saying, 'the whole is greater than the sum of its parts'. A classic example of subjective contour is illustrated in **Figure 1a**. We clearly see edges of a white triangle that does not exist. Koffka insisted that the emergent entity is 'other' (not greater or lesser) than the sum of the parts. By composing elements on the page according to specific principles, we can add additional layers of meaning.

In the following discussion, to be continued in next month's column, we will explore several Gestalt principles. Here we will examine the principles of similarity, proximity, connection and enclosure. The fundamental concept behind these principles is grouping; we tend to perceive objects that look alike, are placed close together, connected by lines or enclosed in a common space as belonging together. These are simple but powerful ways to build context for information.

The principle of similarity is likely familiar to many. We often use color, size and shape to organize data objects into categories. As readers, we tend to see things that are similar to be more related than things that are dissimilar (**Fig. 1b**). We can apply this observation to all elements on the page; by repeating graphical treatments including font, type size, orientation and white space, we can design elements so they appear more related.

Another quality that inclines us to make associations between

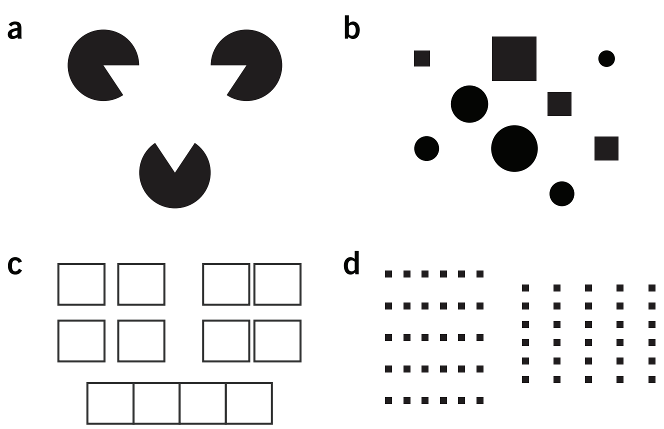

Figure 1 | Gestalt principles. (**a**) An illustration of subjective contour. (**b**) Similar objects are visually grouped. (**c**) Objects placed close to one another are seen as going together. (**d**) Relative proximity elicits vertical or horizontal correlations between objects.

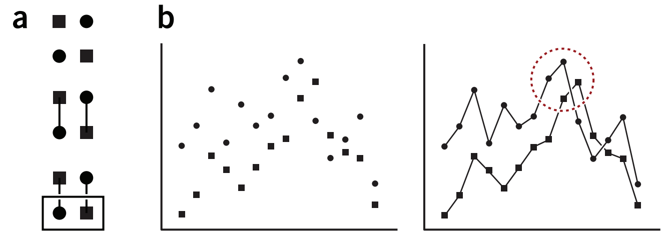

Figure 2 | Principles of grouping. (**a**) Relative strength of grouping by similarity, proximity, connection and enclosure. (**b**) Lines in graphs create clear connection. Enclosure is an effective way to draw attention to a group of objects.

objects is proximity. We tend to group objects placed close together. We can apply this principle when organizing figure panels. In a grid of evenly spaced panels, it can be unclear at first glance how one should dissect the information contained within (**Fig. 1c**). Are we to compare the panels or read them in succession? If the reader is to make two pairwise comparisons, then grouping the four panels as two pairs reinforces our natural tendency to relate proximal objects (**Fig. 1c**). If, however, we want readers to review the panels one after another, then arranging the panels in a row provides a natural order that supports reading them sequentially (**Fig. 1c**).

Proximity could be considered a special case of grouping by similarity because of the underlying spacing between objects. Relative spacing between columns and rows can dramatically affect whether we group the components vertically or horizontally (**Fig. 1d**).

Whereas objects grouped by similarity and proximity are seen as loose confederations, grouping by connection and enclosure leads us to associate them as a unified whole. The relative strength each principle exerts on perceptual grouping is illustrated in **Figure 2a**. Lines create clear connection and bring out the overall shape of the data (**Fig. 2b**). They provide a useful method for encoding information in graphs and network diagrams. Finally, grouping by enclosure resulting in elements bounded in a common region is powerful enough to overcome similarity, proximity and connection (**Fig. 2**).

The Gestaltists described phenomena about how we organize bits and pieces of visual information into larger units. This perceptual organization is deeply ingrained in the visual experience. When we present visual information, including blocks of text projected on screen, it is helpful to arrange the elements into a meaningful structure. One framework is simply to group related information. The principles of similarity, proximity, connection and enclosure provide simple rules to draw correlations between visual elements.

Next month, we will examine the principles of visual completion and continuity, which describe our tendency to fill in missing information to perceive shapes as being complete to the greatest degree possible.

Bang Wong

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POINTS OF VIEW

Gestalt principles (Part 2)

Our visual system attempts to structure what we see into patterns to make sense of information. The Gestalt principles describe different ways we organize visual data. Last month, we looked at four principles that incline us to group objects when they are made to look alike, are placed near one another, are connected by lines or are enclosed in a common space[1]. This month, we will examine the principles of visual completion and continuity. These principles are useful in page layout work and when we compose figures and slides.

Visual interpolation creates interesting illusions in which we see contours that do not actually exist. The Kanizsa triangle[2] we looked at last month is a famous example of illusory or subjective contours (**Fig. 1a**). The 'Pac-Man' shapes align to form what appears to be well-defined edges of a triangle.

Another example of visual completion is shown in **Figure 1b**. We automatically and spontaneously perceive a full circle behind the square. In reality, several shapes are possible in the occluded area. This disparity between the actual visual stimulus and what we think (or know) we should be seeing points to the psychology involved in seeing. It is likely that we complete the object behind the square as a circle because it produces a simple and familiar shape.

Because we have a strong tendency to see shapes as continuous to the greatest degree possible, we fill in voids with visual cues found elsewhere on the page. This means every element on a page affects how we perceive every other element. Visual completion enables us to forgo the extraneous lines, boxes, bullets and other graphical elements that tend to clutter our presentations.

Graphics and text can be considered shapes with vertices and edges. To construct unified compositions, align these constituent parts to form meaningful blocks of information (**Fig. 2a**). Simple geometric shapes provide a base structure on which to organize and build content (**Fig. 2b**). It is helpful to actually draw these background shapes and use them as alignment guides. I have shown examples of guides as dotted lines in **Figure 2**, which would not exist in the final figure. Placing components on the guide's path anchors the information and helps the audience identify patterns. Curvilinear guides are useful in sequencing information because they create a clear path through the material. Such alignment produces invisible lines that connect content.

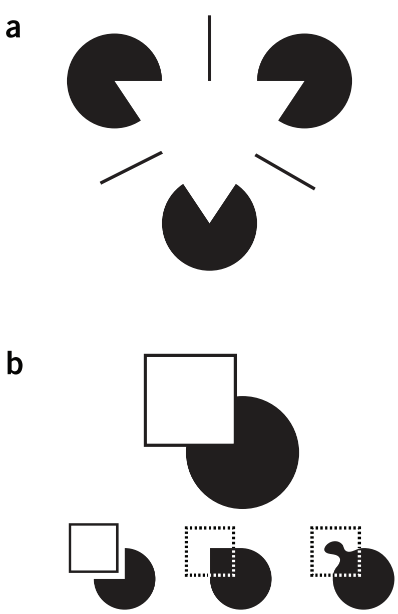

Figure 1 | Visual completion. (**a**) The Kanizsa triangle and illusory contour. (**b**) Spontaneous and automatic completion of occluded surfaces as a simple and familiar circle.

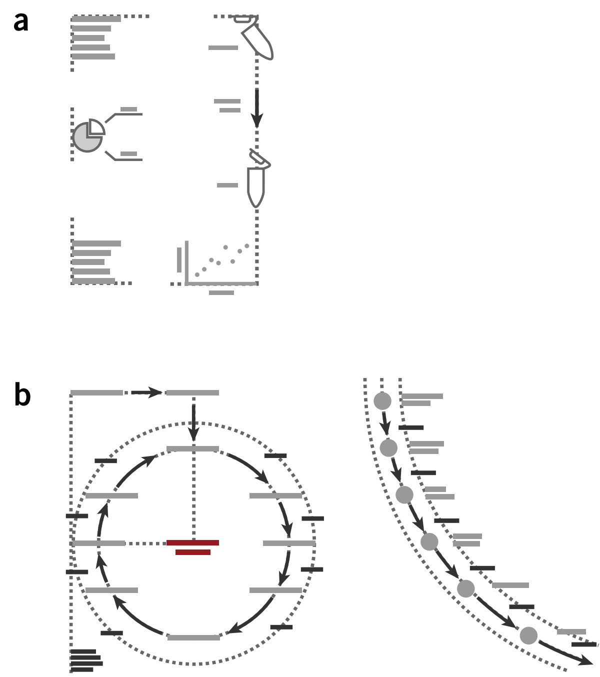

Figure 2 | Alignment. (**a**) Graphics and text used as vertices and edges of geometric shapes. (**b**) Geometric and curvilinear shapes used as flexible guides to align content.

Our eyes are acutely aware of small misalignments; compositions that use guides tend to look clean and professional. We can create different alignment guides for different information. For example, labels that describe an action can be distinguished from those for names. Moreover, we can combine alignment with the Gestalt principles of similarity, proximity, connection and enclosure to group information and structure the content. The action labels can be distinguished from the name labels with color or typographical treatment.

Our goal is to lay out information in a way that enhances its message. In structuring the components of a slide or figure, we inevitably affect the surrounding white space. White space is a vital part of design; it frames the content and gives our eyes a place to rest. Next month, we will look at 'negative space' to complete our exploration of composition.

Bang Wong

1. Wong, B. *Nat. Methods* **7**, 863 (2010).
2. Kanizsa, G. *Organization in Vision: Essays on Gestalt Perception* (Praeger Publishers, New York, 1979).

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POINTS OF VIEW

Salience

In last month's column we explored ways to encode data that enhance 'accuracy' when readers decode information from graphs. This month, we will focus on salience as a way to differentiate graphical symbols and improve 'speed' when reading graphs.

Salience is a visual quality that sets an object apart from its surroundings. The intent is to create contrast. Incidentally, much of design is about balancing contrasting elements, a topic we will explore in another column. Certain graphical treatments make objects seemingly pop from the page, whereas others require focused attention to see the object. In **Figure 1a**, we can spot the 'A's immediately, but 'P's are more difficult to find. There is insufficient contrast in shape alone for us to quickly identify the individual letters without additional visual cues. Similarly, the pair of lines at a right angle to one another is easy to see, but the single oblique line takes longer to locate in a field of like objects (**Fig. 1a**).

The Nobel Prize–winning work of the neurophysiologists David Hubel and Torsten Wiesel helps us understand how the brain processes visual information. They discovered that individual neurons in the primary visual cortex are highly excitable by features of color, orientation, size and motion, but the neurons' response differs depending on the type of visual stimuli. Some neurons are rapidly excited when individuals are presented with lines at one angle, but other cells respond best to lines at another angle. Complex patterns are processed by later stages of the visual system.

There are several reasons why we might want to present information so that it can be immediately recognized. First, by decreasing the amount of time it takes our audience to see relevant patterns and trends, we lower their cognitive load. This is especially useful for slide- and poster-based presentations in which visual and aural information typically compete for attention. Second, helping our audience see certain features of the data rapidly allows the visual cortex to simultaneously make sense of additional visual features[1].

The design lesson is fairly straightforward. To make something easy to find, make it stand out by varying the object's primary visual feature. For example, give the object a color, size or orientation that is substantially different from that of the other objects on the page. Motion is a particularly potent differentiator; consider an animated GIF or bouncing icon's ability to command our attention. For this reason, we should temper our use of motion with the importance of the object being animated. Some basic visual features to create salience are shown in **Figure 1b**.

In reality, design problems are complex. Typically we want several parameters to be easily searchable at the same time. The solution is to use noncompeting visual features. However, there is a limit to how many features we can overlay onto one another because visual conjunctive search (that is, looking for a target based on two or more visual features) takes concentration, and it can be difficult to retain those objects in memory for pattern assembly. **Figure 2a** shows a real-world example that relies on many simultaneous visual features.

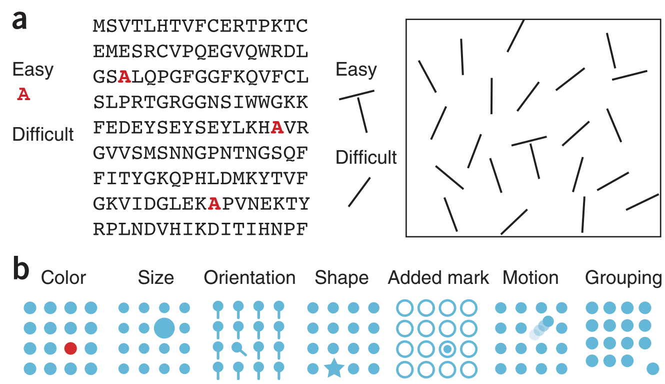

Figure 1 | Salience through visual features. (**a**) Certain elements can be seen in a single glance, whereas others are difficult to find. (**b**) Examples of visual features that make objects distinct.

The amount of information presented should ideally match the question the researcher looking at the data is trying to answer. On the computer, analytical tools could allow users to customize data encodings and turn off unwanted layers of information. In print, authors can present multiple views of the same data with only certain parameters plotted to best communicate the message (**Fig. 2b**).

Creating salience will facilitate the audience's ability to quickly process information. This is particularly useful in talks and when multiple channels of communication are used at once. Also, knowing the different ways in which contrast is created helps avoid its inadvertent use.

We explored the elements of graphing data in the first three columns. We looked at how color and shape confer accurate and efficient reading of individual parts of graphs. Next month, I will introduce the 'Gestalt principles' that describe how we tend to organize multiple objects into patterns to make sense of them.

Bang Wong

1. Ware, C. *Visual Thinking for Design* (Morgan Kaufmann Publishers, Burlington Massachusetts, USA, 2008).

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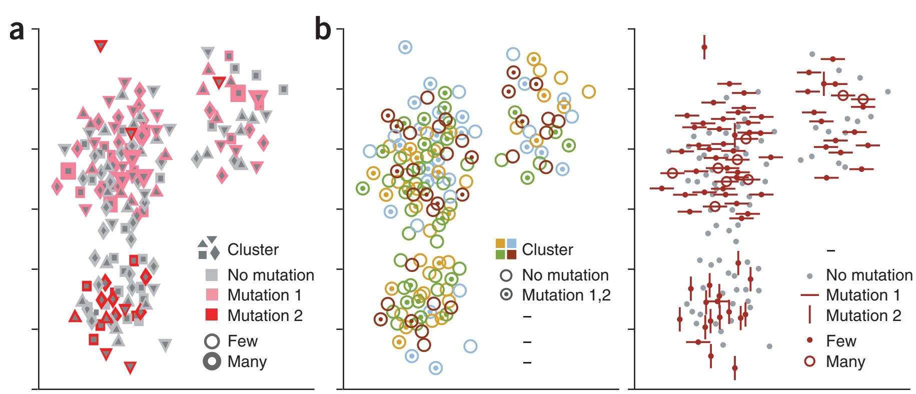

Figure 2 | Visual conjunctions. (**a**) Simultaneous use of many graphical features can impede visual assembly of the data. (**b**) Multiple views of the same data with limited parameters plotted can better communicate specific relationships.

POINTS OF VIEW

Salience to relevance

In science communication, it is critical that visual information be interpreted efficiently and correctly. The discordance between components of an image that are most noticeable and those that are most relevant or important can compromise the effectiveness of a presentation. This discrepancy can cause viewers to mistakenly pay attention to regions of the image that are not relevant. Ultimately, the misdirected attention can negatively impact comprehension.

Salience is the physical property that sets an object apart from its surroundings. It is particularly important to ensure that salience aligns with relevance in visuals used for slide presentations. In these situations, information transmission needs to be efficient because the audience member is expected to simultaneously listen and read. By highlighting relevant information on a slide, we can direct a viewer's attention to the right information. For example, coloring a row or column of a table will preferentially direct attention to the selected material (**Fig. 1a**). As information presented as tables typically appears homogenous, it is especially helpful to define what is most important. The same approach can be applied to plots and graphs to delineate segments of data (**Fig. 1b**). Whereas these techniques are not appropriate for all journal publications, annotating information presented in slides can be an effective mechanism to enable the audience to better grasp what is being said and shown.

Human vision is highly selective. When multiple stimuli are in a scene they compete for our visual attention. We make sense of the visual field by selecting, in turn, one or few objects for detailed analysis at the expense of all others. Cognitive scientists create 'salience maps' to describe the relative visibility of objects in an image that explain what we might look at first, second and so on[1].

Using the concept of a salience map, we can rely on relative visibility to order content on the page and help us design better graphics. There are several graphical variables—including color, shape, size and position—we can use to create salience (see October 2010 column)[2]. Salience is a relative property that depends on the relationship of one object to other objects on the page. Information that is presented physically larger is usually easier to see and is likely to be read first. In a composition where most of the parts are oriented vertically and horizontally, elements placed at a diagonal stand out. On a backdrop of predominantly black-and-white elements, colored information is highly conspicuous (**Fig. 1**).

a

Color name	RGB (1–255)
Black	0, 0, 0
Orange	230, 159, 0
Sky blue	86, 180, 233
Bluish green	0, 158, 115
Blue	0, 114, 178
Vermillion	213, 94, 0

b

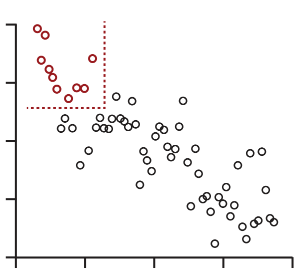

Figure 1 | Matching salience to relevance draws visual attention to important information. (**a**) Table with a row highlighted. (**b**) Segments of data in a plot emphasized with color.

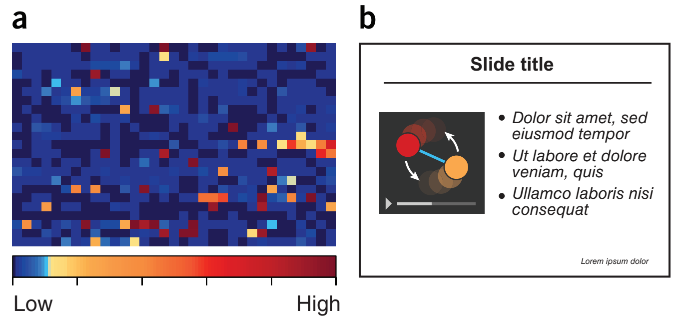

Figure 2 | Discordances between salience and relevance can be harmful. (**a**) The relative visibility of hues in the color scale is asymmetric, making higher values (represented by deep red) less apparent. (**b**) Continuously moving images can be distracting and can compromise the viewer's ability to concentrate on other content.

In contrast, unintentional and inadvertent assignment of salience can be harmful to the communicative potential of images. In the sample heatmap shown in **Figure 2**, the authors chose a color scale that makes common sense, using deep red to represent high values. But in this case lower values are actually more salient than higher ones because deep red is hard to see against the deep blue background of the lowest values.

What stands out is often taken as most important or relevant. In one study, researchers assessed the effects of salience on the ability of test subjects to accurately answer questions that required interpreting weather maps. By alternating the relative visibility of task-relevant and task-irrelevant information (in this case, information about pressure and temperature, respectively) they found that display factors such as salience had large effects on task performance[3]. For example, a question about wind direction was supposed to elicit an answer about air pressure, but when data on temperature were made most apparent, subjects incorrectly responded with a reference to temperature, having been influenced by the salience of the temperature data presented.

In presentations, a potential source of misalignment between salience and relevance is in the use of moving images. Presenters may include short movies (for example, a rotating three-dimensional structure). When these movies are allowed to loop continuously, this powerful competing stimulus makes it nearly impossible to concentrate on other content, as motion is one of the most potent mechanisms for attracting attention. For this reason, animation in PowerPoint slides should be used judiciously. The element being animated should direct our attention to the most relevant content that supports the primary message of the slide. An oscillating arrow will draw more of our attention than the objects it is intended to highlight.

It is well recognized that how the same information is presented can dramatically affect comprehension. Making relevant information visually obvious will ensure that viewers notice the right content. To get a sense of what is most salient on the screen, stand back and squint.

Next month, I will conclude this segment of 'design principles' by discussing the value of 'design' itself.

Bang Wong

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