Chapter 3

Lightness, Brightness, Contrast, and Constancy

- Technically, we can divide color space into one luminance (gray scale) dimension and two chromatic dimensions. It is the luminance dimension that is most basic to perception. (p69)
- Luminance can be regarded as but one of three color dimensions, albeit the most important one. (p69)
- The lesson is that visualization is not good for representing precise absolute numerical values, but rather for displaying patterns of differences or changes over time, to which the eye and brain are extremely sensitive. (p70)

Neurons, Receptive Fields, And Brightness Illusions

- In the Hermann grid illusion, shown in Figure 3.4, black spots appear at the intersec- tions of the bright lines. The explanation is that there is more inhibition at the spaces between two squares, so they seem brighter than the regions at the intersections.

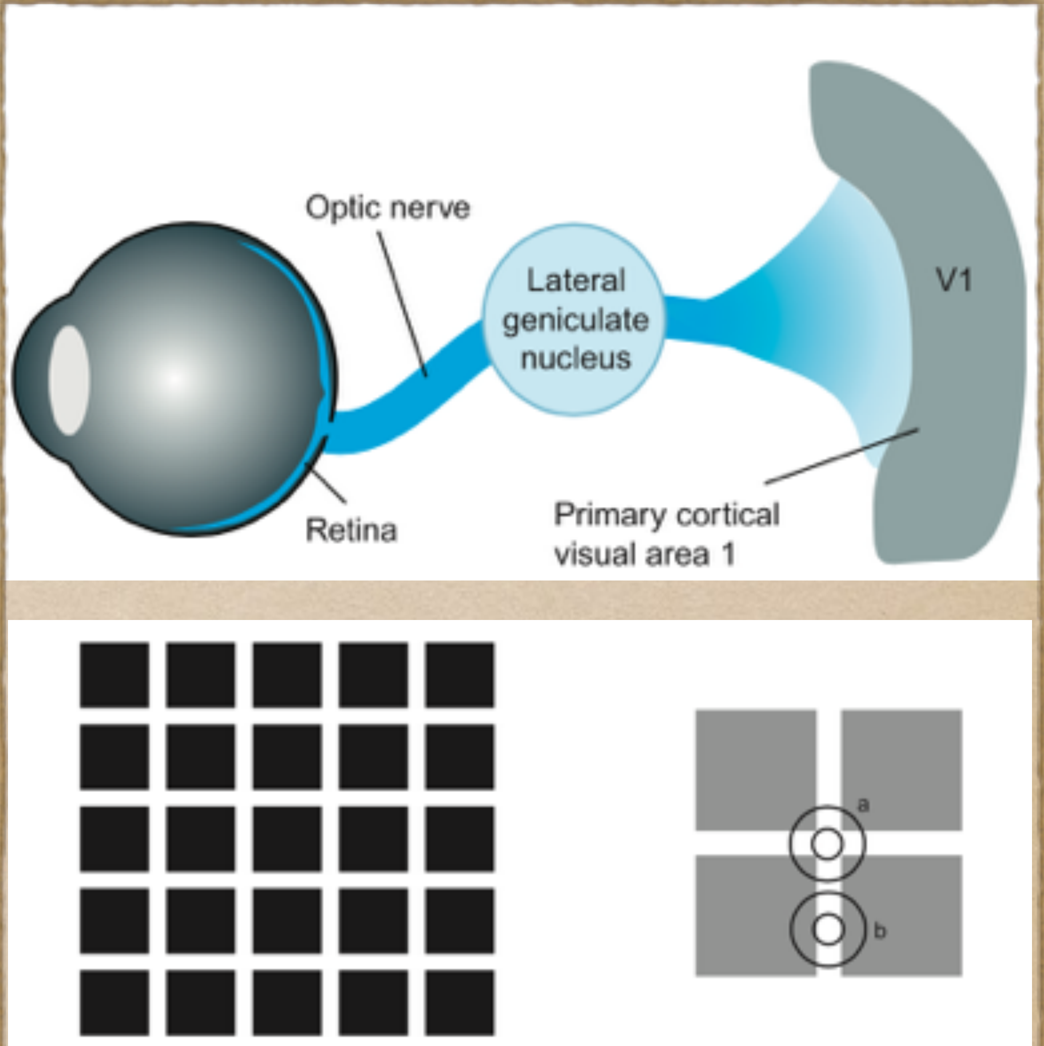

Figure 3.4 Hermann grid illusion. The black spots that are seen at the intersections of the lines are thought to result from the fact that there is less inhibition when a receptive field is at position (a) than at position (b).

In the Hermann grid illusion, shown in Figure 3.4, black spots appear at the intersec- tions of the bright lines. The explanation is that there is more inhibition at the spaces between two squares,

- The term simultaneous brightness contrast is used to explain the general effect whereby a gray patch placed on a dark background looks lighter than the same gray patch on a light background. Figure 3.5 illustrates this effect

- Figure 3.6 demonstrates a Mach band effect. At the point where a uniform area meets a luminance ramp, a bright band is seen. In general, Mach bands appear where there is an abrupt change in the first derivative of a brightness profile.

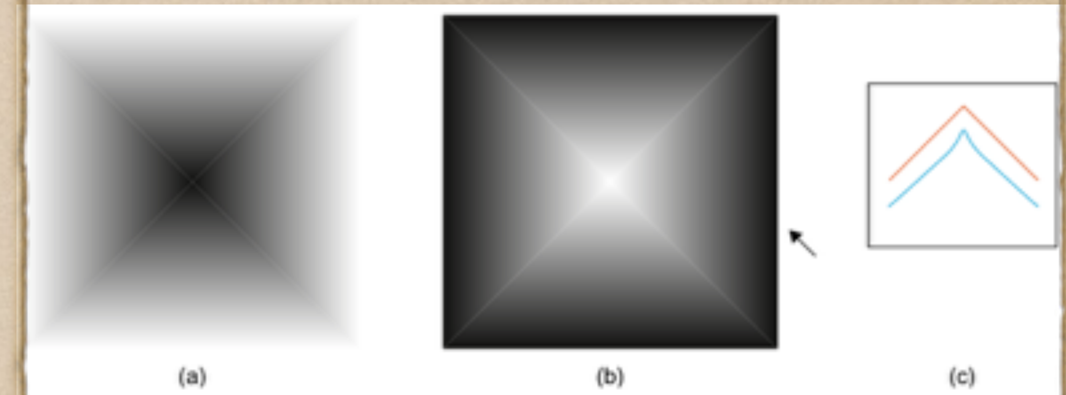

Figure 3.6 Illustration of Mach banding. (a, b) Dark and bright Mach bands are evident at the boundaries between the internal triangles. (c) The red curve shows the actual brightness profile between the two arrows. The blue curve shows how the application of a DoG filter models the bright bands that are seen.

- Avoid using gray scale as a method for representing more than a few (two to four) numerical values.

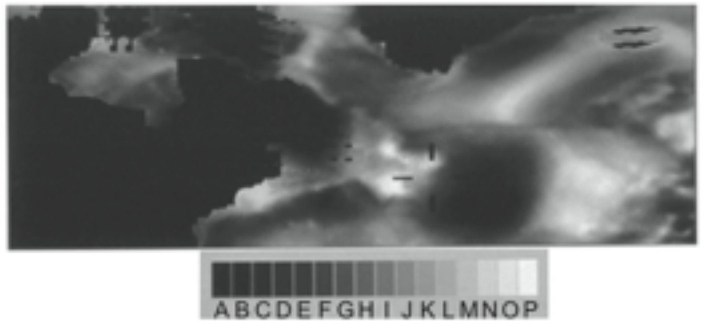

Figure 3.8 A gravity map of the North Atlantic Ocean. Large errors occur when gray-scale maps are read using a key. *(From Ware (1988). Reproduced with permission.)*

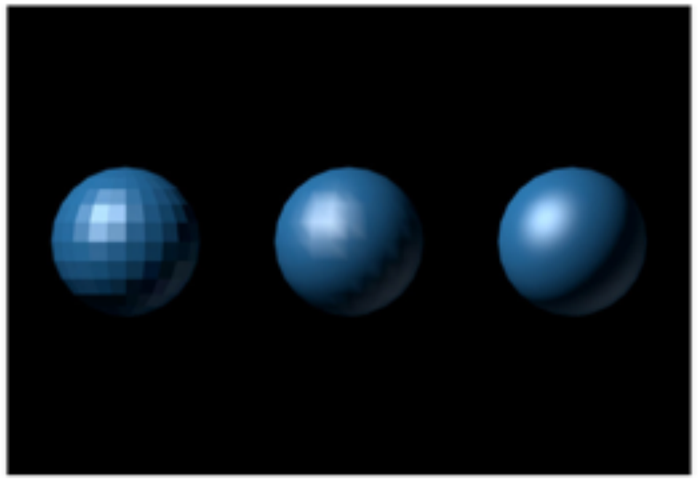

Figure 3.9 Three different shading methods used in computer graphics. Flat shading on the left is subject to the Chevreul illusion. Gouraud shading in the center results in Mach banding. Phong shading, on the right, produces something that looks smooth even though it is based on the same number of facets.

- Consider using Cornsweet contours instead of simple lines to define con-voluted bounded regions

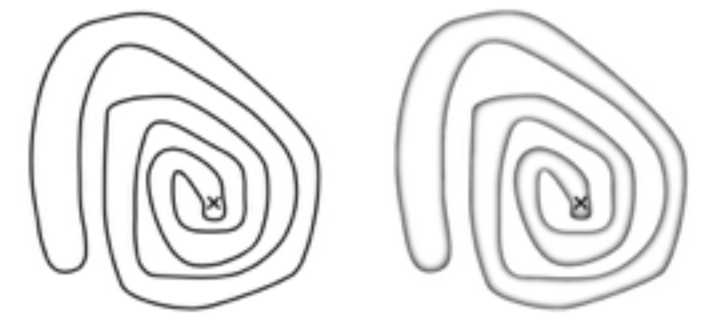

Figure 3.11 It is difficult to see if the X is inside or outside of the bounded region. Using a Cornsweet contour makes it possible to see the solution much more rapidly.

- Consider using adjustments in luminance contrast as a highlighting method. It can be applied by reducing the contrast of unimportant items or by locally adjust- ing the background to increase the luminance contrast of critical areas.
- It is worth emphasizing that it is not the amount of light that leads to visual distinct- ness, but the amount of luminance contrast that occurs with the background. Black on white is as distinctive as white on black.

Figure 3.12 Seurat deliberately enhanced edge contrast to make his figures stand out.

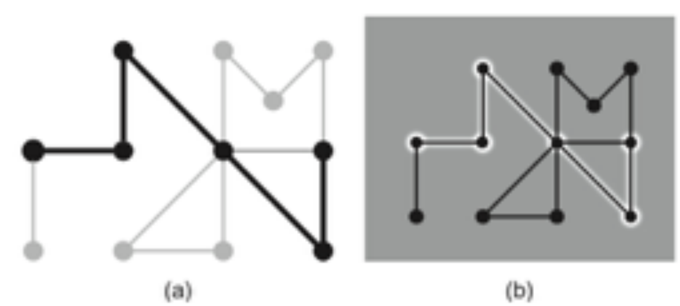

Figure 3.13 Two methods for highlighting a node–link diagram. (a) The contrast is reduced for the less important parts of the network. (b) The background contrast is increased using

Luminance (p80)

- Luminance is the easiest to define; it refers to the measured amount of light coming from some region of space. It is measured in units such as candelas per square meter. Of the three terms, only luminance refers to something that can be physically measured. The other two terms refer to psychological variables.
- We are about 100 times less sensitive to light at 450 nanometers than we are to light at 510 nanometers
- Use a minimum 3:1 luminance contrast ratio between a pattern and its background whenever information is represented using fine detail, such as texture variation, small-scale patterns, or text.
- the ISO goes on to recommend that a 10:1 ratio is optimal for text, and the same can be said of any display of detail.

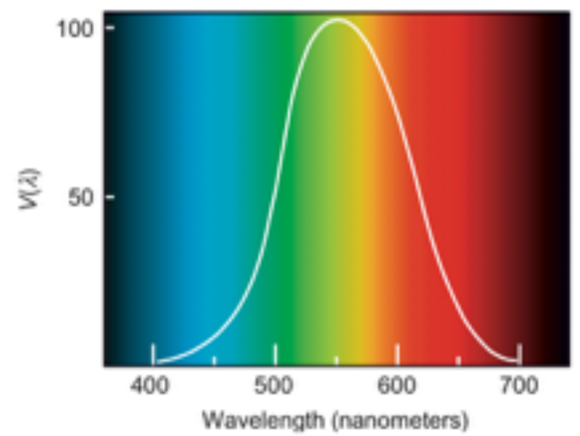

Figure 3.14 The CIE $V(\lambda)$ function representing the relative sensitivity of the human eye to light of different wavelengths.

Brightness and Lightness (p82)

- Brightness generally refers to the perceived amount of light coming from a source. In the following discussion, it is used to refer only to things that are perceived as self-luminous. Sometimes people talk about bright colors, but vivid or saturated are better terms.
- Lightness generally refers to the perceived reflectance of a surface. A white surface is light. A black surface is dark. The shade of paint is another concept of lightness.
- It cannot be emphasized enough that luminance is completely unrelated to perceived lightness or brightness.

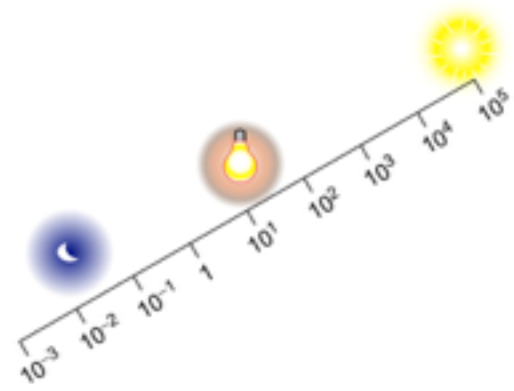

Figure 3.16 The eye/brain system is capable of functioning over a huge range of light levels. The amount of light available on a bright day at the beach is 10,000 times greater than the light available in a dimly lit room.

Perception of Surface Lightness (p87)

- In this case, the most important factor differentiating black from white is the ratio between the specular and the nonspecular reflected light. In the all-black world, the ratio between specular and nonspecular is much larger than in the all-white world.

(a) (b)

Figure 3.19 These two photographs show a scene in which everything is black and another where everything is white.

Contrast Crispening (89)

- If subtle gray-level gradations within the bounds of a small object are important, create low-luminance contrast between the object and its background.

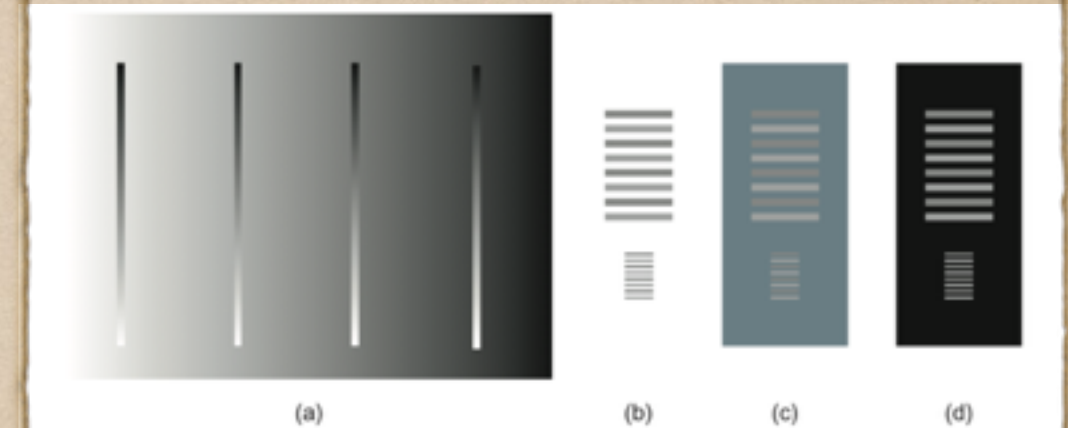

Figure 3.20 (a) All the gray strips are the same. Perceived differences between gray-scale values are enhanced where the values are close to the background gray value, an effect known as crispening. (b, c, d) The differences in the grays of the gray lattice are more evident (c) than with either the white (b) or the black (d) backgrounds, another example of crispening.

Color

Chapter 4

- It is not much of an overstate- ment to say that color vision is largely superfluous in modern life; nevertheless, color is extremely useful in data visualization.
- 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.

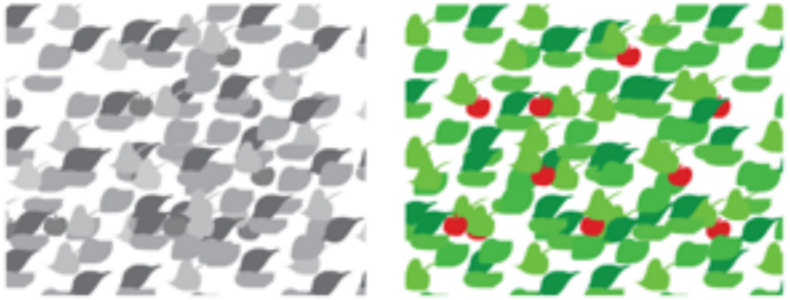

Figure 4.1 Finding the cherries is much easier with color vision.

Color Blindness (p

- About 10% of the male population and about 1% of the female population have some form of color vision deficiency.
- The most common deficiencies are explained by lack of either the long-wavelength-sensitive cones (protanopia) or the medium-wavelength-sensitive cones (deuteranopia).
- Both protanopia and deuteranopia result in an inability to dis- tinguish red and green, meaning that the cherries in Figure 4.1 are difficult for people with these deficiencies to see.

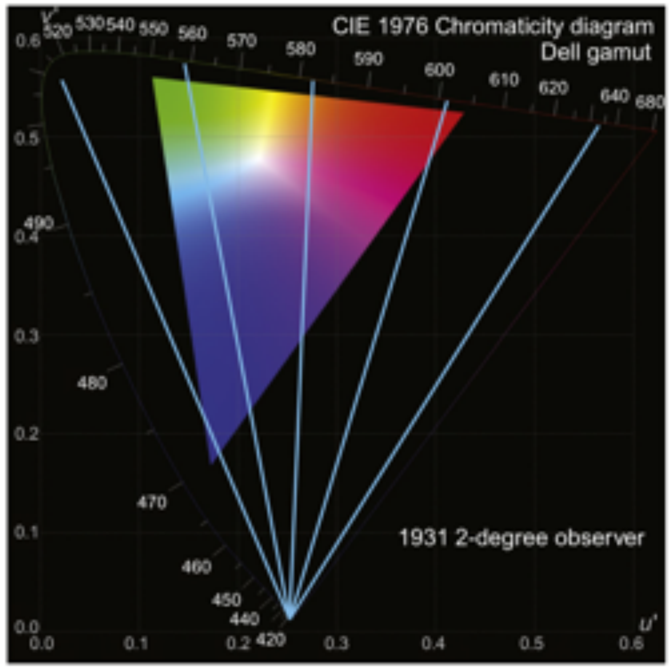

Figure 4.8 CIE *Lu′v′* UCS diagram. The lines radiating from the lower part of the diagram are called *tritanopic confusion lines*. Colors that differ along these lines can still be distinguished by the great majority of color-blind individuals.

- The darker the colors, the fewer we can see.
- Small patches of light give different results than large patches. In general, we are much more sensitive to differences between large patches of color. When the patches are small, the perceived differences are smaller, and this is especially true in the yellow–blue direction. Ultimately, with very small samples, small-field tritanopia occurs; this is the inability to distinguish colors that are different in the yellow–blue direction

- In the larger patches, the low- saturation colors are easy to distinguish. They are not so easy to distinguish in the small patches.
- Use more saturated colors when color coding small symbols, thin lines, or other small areas. Use less saturated colors for coding large areas.

Figure 4.9 (a) Large samples of saturated colors. (b) Large samples of the same colors less saturated. (c) Small samples of the same saturated colors. (d) Small samples of the less saturated colors.

Cross-cultural naming of colors (p. 109)

- In languages with only two basic color words, these are always black and white; if a third color is present, it is always red; the fourth and fifth are either yellow and then green, or green and then yellow; the sixth is always blue; the seventh is brown, followed by pink, purple, orange, and gray in no particular order.
- The cross-cultural evidence strongly supports the idea that certain colors—specifically, red, green, yellow, and blue—are far more valuable in coding data than others

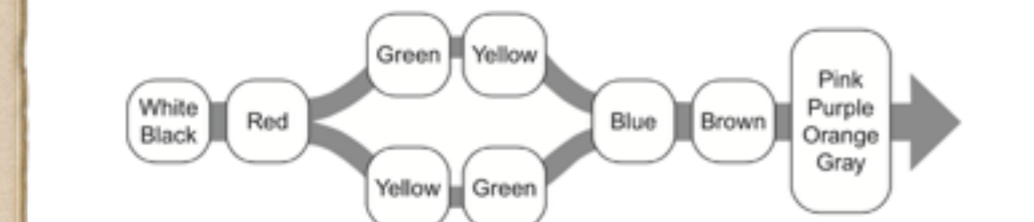

Figure 4.11 This is the order of appearance of color names in languages around the world, according to the research of Berlin and Kay (1969). The order is fixed, with the exception that sometimes yellow is present before green and sometimes the reverse is the case.

Unique hues (p109)

- If subjects are given control over a device that changes the spectral hue of a patch of light and are told to adjust it until the result is a pure yellow, neither reddish nor greenish, they do so with remarkable accuracy. In fact, they are typically accurate within 2 nm (Hurvich, 1981)
- Interestingly, there is good evidence for two unique greens. Most people set a pure green at about 514 nm, but about a third of the population sees pure green at about 525 nm (Richards, 1967)
- It is also significant that unique hues do not change a great deal when the overall luminance level is changed (Hurvich, 1981). This supports the idea that chromatic per- ception and luminance perception really are independent.

Categorical colors

- If a color is close to an ideal red or an ideal green, it is easier to remember. Colors that are not basic, such as orange or lime green, are not as easy to remember.
- The fact that only eight colors plus white were consistently named, even under these highly standardized conditions, strongly suggests that only a very small number of colors can be used effectively as category labels.
- The pure monitor red was actually named orange most of the time. A true color red required the addition of a small amount from the blue monitor primary.
- The specific regions of color space occupied by particular colors should not be given much weight. The data was obtained with a black background. Because of contrast effects, different results are to be expected with white and colored backgrounds.

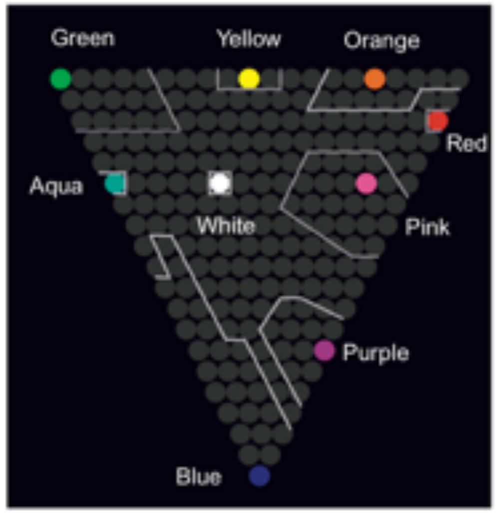

Figure 4.12 The results of an experiment in which subjects were asked to name 210 colors produced on a computer monitor. Outlined regions show the colors that were given the same name with better than 75% probability.

Properties of color Channels

- The most significant differences are between the two chromatic channels and the luminance channel, although the two color channels also differ from each other.
- To display data on the luminance channel alone is easy; it is stimulated by patterns that vary only from black to white through shades of gray.
- Patterns can be constructed that vary only for the red–green or the yellow–blue channel. A key quality of such a pattern is that its component colors must not differ in luminance. This is called an isolu- minant or equiluminous pattern
- According to a study by Mullen (1985), the red–green and yellow–blue chromatic channels are each capable of carrying only about one-third the amount of detail car- ried by the black–white channel. Because of this, purely chromatic differences are not suitable for displaying any kind of fine detail. Figure 4.13
- When small symbols, text, or other detailed graphical representations of information are displayed using color on a differently colored background, always ensure luminance contrast with the background. This guideline is a variation of G3.4.

Figure 4.13 Brown text on a blue gradient. Notice how difficult it is to read the text where the luminance is equal, despite a large chromatic difference. Brown is a dark yellow so these colors differ on the blue–yellow channel.

Spatial sensitivity, stereoscopic depth, motion sensitivity, form

- [G4.2] When small symbols, text, or other detailed graphical representations of information are displayed using color on a differently colored background, always ensure luminance contrast with the background. This guideline is a variation of G3.4.
- [G4.3] Ensure adequate luminance contrast in order to define features important for perceiving stereoscopic depth.
- Motion perception appears to be primarily based on information from the luminance channel.
- [G4.4] Ensure adequate luminance contrast in order to define features important for perceiving moving targets.
- Perception of shape and form appears to be processed mainly through the luminance channel (Gregory, 1977).
- [G4.5] When applying shading to define the shape of a curved surface, use adequate luminance (as opposed to chromatic) variation. This is a supplement to G2.1.

- [G4.6] If large areas are defined using nearly equiluminous colors, consider using thin border lines with large luminance differences (from the colors of the areas) to help define the shapes.
- To summarize this set of properties, the red–green and yellow–blue channels are infe- rior to the luminance channel in almost every respect.
- The implications for data display are clear. Purely chromatic differences should never be used for displaying object shape, object motion, or detailed information such as text.
- From this perspec- tive, color would seem almost irrelevant and certainly a secondary method for infor- mation display; nevertheless, when it comes to coding information, using color to display data categories is usually the best choice

Figure 4.14 Even large shapes are seen more clearly if a luminance contrast boundary is provided.

Color appearance

- Color (as opposed to luminance) processing, it would appear, does not help us to understand the shape and layout of objects in the environment. Color does not help the hunter aim an arrow accurately. Color does not help us see shape from shading and thereby shape a lump of clay or bread dough. Color does not help us use stereo- scopic depth to guide our hands when we reach out to grasp something.
- Color creates a kind of visual attribute of objects
- This suggests a most important role for color in visualization—namely, the coding of information. Visual objects can represent complex data entities, and colors can naturally code attributes of those objects

Color Contrast

- Chromatic contrast occurs in a way that is similar to the lightness contrast effects discussed and illustrated in Chapter 3. Figure 4.15 shows a color contrast illusion.
- Try comparing an image on a computer screen with that same image printed. Individual colors will undoubt- edly be very different, but the overall impression and the information conveyed will be mostly preserved.
- This is because relative color is much more important than absolute color.

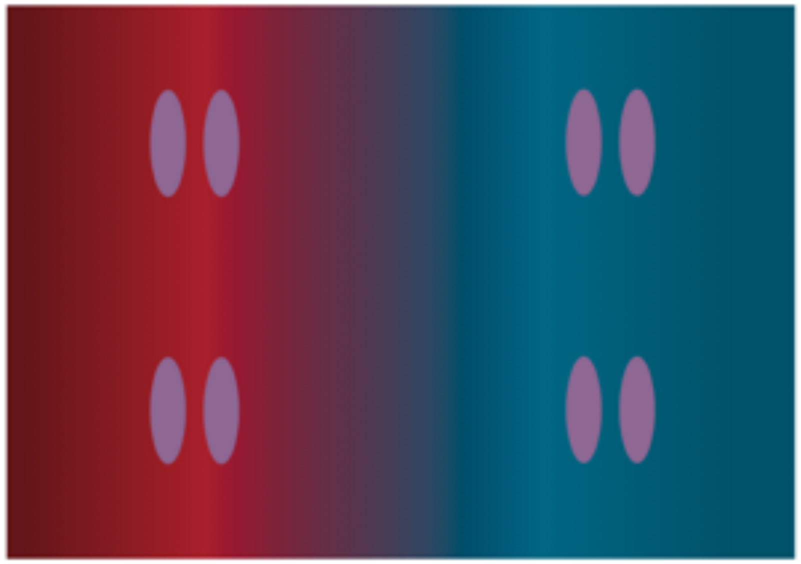

Figure 4.15 A color contrast illusion. The ellipses are all the same color but seem pinker on the right and bluer on the left.

Saturation

- A high-saturation color is vivid, and a low-saturation color is close to black, white, or gray.
- In terms of the color opponent channels, high-saturation colors are those that give a strong signal on one or both of the red–green and yellow–blue channels.
- These contours (figure 4.16a), derived from studies of human perception, show that it is possible to obtain much more highly saturated red, green, and blue colors on a monitor than yellow, cyan, or purple values.
- Figure 4.16(b) shows equal- saturations contours (not derived from perception) in the popular hue, saturation, and value (HSV) transformation commonly used in computer graphics (Smith, 1978).
- In particular, pure red, green, and blue on a monitor will be more perceptually saturated than pure cyan, magenta, or yellow
- [G4.7] If using color saturation to encode numerical quantity, use greater saturation to represent greater numerical quantities. Avoid using a saturation sequence to encode more than three values.

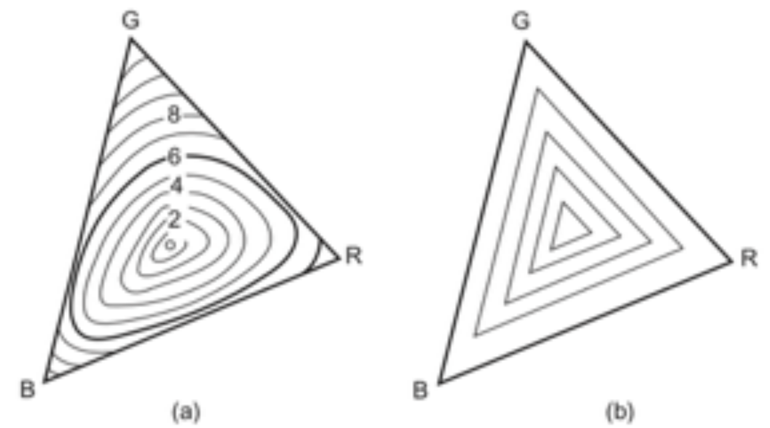

Figure 4.16 (a) The triangle represents the gamut of colors obtained using a computer monitor plotted in CIE chromaticity coordinates. The contours show perceptually determined equal-saturation contours. (b) Equal-saturation contours created using the HSV color space, also plotted in chromaticity coordinates.

Brown

- Brown is one of the most mysterious colors. Brown is dark yellow
- Unlike red, blue, and green, brown requires that there be a reference white somewhere in the vicinity for it to be perceived. Brown appears qualitatively different from orange yellow
- If color sets are being devised for the purposes of color coding—for example, a set of blues, a set of reds, a set of greens, and a set of yellows— in the case of yellows, brown may not be recognized as a set member.

Application 1: Color Specification Interfaces and Color Spaces

Color spaces

Figure 4.17 shows how hue and saturation can be laid out in two dimensions, with hue on one axis and saturation on the other, based on the HSV transformation of monitor primaries.

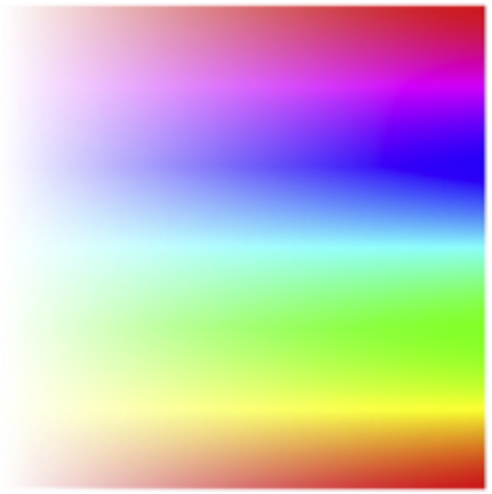

Figure 4.17 This plot shows hue and saturation, based on Smith's (1978) transformation of the monitor primaries.

- [G4.8] In an interface for specifying colors, consider laying out the red–green and yellow–blue channel information on a plane. Use a separate control for specifying the dark–light dimension.
- Figure 4.18(a) shows a color circle with red, green, yellow, and blue defining opposing axes. Many such color circles have been devised over the past century. They differ mainly in the spacing of colors around the periphery.
- Figure 4.18(b) shows a color triangle with the monitor primaries, red, green, and blue, at the corners. This color layout is convenient because it has the property that mixtures of two colors will lie on a line between them (assuming proper calibration); however, because of linear interpolation, only a very weak yellow occurs between the red and green corners (50% red, 50% green). The strongest yellow on a monitor comes from having both red and yellow at full strength.
- Figure 4.18(c) shows a color square with the opponent color primaries, red–green and yellow–blue, at opposite corners (Ware & Cowan, 1990).
- Figure 4.18(d) shows a color hexagon with the colors red, yellow, green, cyan, blue, and magenta at the corners. This represents a plane through the single-hexcone color model (Smith, 1978). The hexagon representation has the advantage that it gives both the monitor primaries (red, green, and blue) and the print primaries (cyan, magenta, and yellow) prominent positions around the circumference.
- [G4.9] In an interface for designing visualization color schemes, consider providing a method for showing colors against different backgrounds.

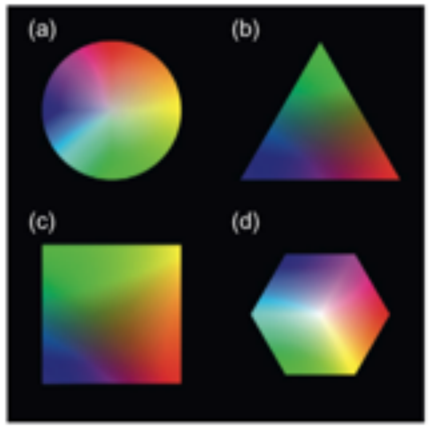

Figure 4.18 A sampling of four different geometric color layouts, each of them embodying the idea of a chromatic plane. (a) Circle. (b) Triangle. (c) Square. (d) Hexagon.

Color Naming Systems

- The Natural Color System (NCS), a standardized color naming system, has been developed based on Hering's opponent color theory (1920). NCS was developed in Sweden and is widely used in England and other European countries.
- As shown in Figure 4.19, red, green, yellow, and blue lie at the ends of two orthogonal axes.
- Colors are also given independent values on a black–white axis by allocating a blackness value between 0 and 100.
- A third color attribute, intensity (roughly corresponding to saturation), describes the distance from the grayscale axis. In NCS, for example, the color spring nymph becomes 0030-G80Y20, which expands to blackness 00, intensity 30, green 80, and yellow 20 (Jackson et al., 1994)
- In North America, other systems are more popular than NCS. The Pantone® system is widely used in the printing industry, and the Munsell system is an important reference for surface colors.

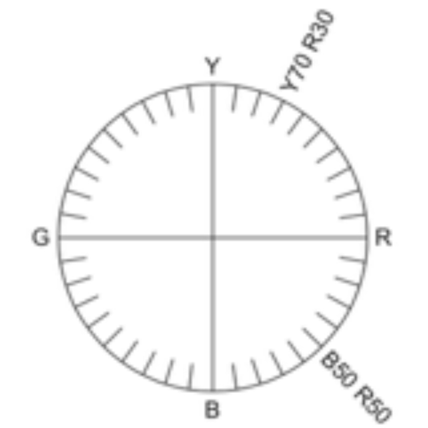

Figure 4.19 The Natural Color System (NCS) circle, defined midway between black and white. Two example color names are shown in addition to the "pure" opponent color primaries. One is an orange yellow and the other is purple.

Application 2: Color for Labeling (Nominal Codes) (p. 122)

- Color can be extremely effective when we wish to make it easy for someone to classify visual symbols into separate categories; giving the objects distinctive colors is often the best solution.

- Chromatic coding can often be employed in a way that only minimally interferes with data presented on the luminance channel.

Distinctness, Unique hues

- [G4.11] Consider using red, green, yellow, and blue to color code small symbols.
- A method for reducing contrast effects is to place a thin white or black border around the color-coded object.
- In addition, we should never display codes using purely chromatic differ- ences with the background. There should be a significant luminance difference in addition to the color difference.
- [G4.12] For small color-coded symbols, ensure luminance contrast with the back- ground as well as large chromatic difference

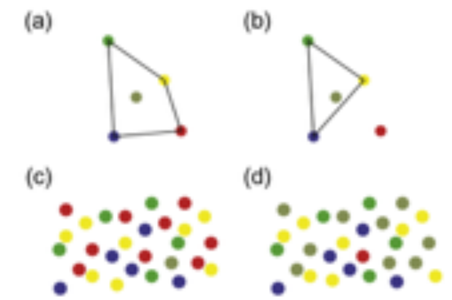

Figure 4.20 The convex hull of a set of colors is defined as the area within a rubber band that is stretched around the colors when they are defined in CIE tristimulus space. Although illustrated in two dimensions here, the concept can easily be extended to three dimensions. (a) Gray is within the convex hull of red, green, yellow, and blue. (b) Red lies outside the convex hull of green, blue, yellow, and gray. (c) The gray dot is difficult to find in a set of red, green, yellow, and blue dots. (d) The red dot is easy to find in a set of green, blue, yellow, and gray dots.

Contrast with background, Color blindness, Number

- [G4.13] If colored symbols may be nearly isoluminant against parts of the background, add a border having a highly contrasting luminance value to the color, for example, black around a yellow symbol or white around a dark blue symbol.
- Color-blind people cannot distinguish colors that differ in a red–green direction.
- Almost everyone can distinguish colors that vary in a yellow–blue direction, as shown in Figure 4.8. Unfortunately, this drastically reduces the design choices that are available.
- [G4.14] To create a set of symbol colors that can be distinguished by most color- blind individuals, ensure variation in the yellow–blue direction.
- [G4.15] Do not use more than ten colors for coding symbols if reliable identification is required, especially if the symbols are to be used against a variety of backgrounds.

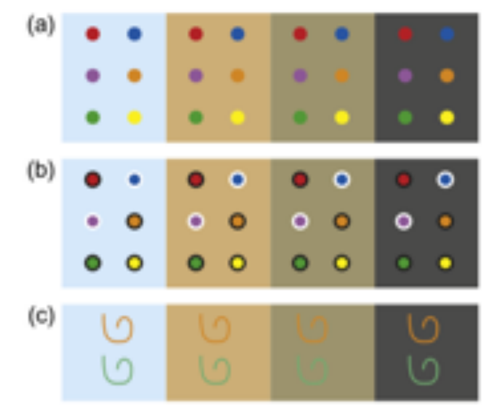

Figure 4.21 (a) Note that at least one member of the set of six symbols lacks distinctness against each background. (b) Adding a luminance contrast border ensures distinctness against all backgrounds. (c) Showing color-coded lines can be especially problematic.

Field size

- [G4.16] Use low-saturation colors to color code large areas. Generally, light colors will be best because there is more room in color space in the high-lightness region than in the low-lightness region.
- [G4.17] When color coding large background areas overlaid with small colored symbols, consider using all low-saturation, high-value (pastel) colors for the background, together with high-saturation symbols on the foreground.
- [G4.18] When highlighting text by changing the color of the font, it is important to maintain luminance contrast with the background. With a white background, high-saturation dark colors must be used to change the font color. Alternatively, when changing the background color, low-saturation light colors should be used if the text is black on white.

Figure 4.22 On the left is a map using low-saturation light colors for the area coding and high-saturation dark colors for the town and city symbols and linear features. On the right, a much worse solution shows high-saturation coding for areas and low-saturation symbols and linear features. Maps were generated using ColorBrewer2 (http://colorbrewer2.org).

Conventions

- Color-coding conventions must sometimes be taken into account. Some common conventions are red = hot, red = danger, blue = cold, green = life, and green = go
- In China, for example, red means life and good fortune, and green sometimes means death.
- The following is a list of 12 colors recommended for use in coding: red, green, yellow, blue, black, white, pink, cyan, gray, orange, brown, purple. They are illustrated in Figure 4.24.
- The first four colors, together with black and white, are chosen because they are the unique colors that mark the ends of the opponent color axes.
- The entire set corresponds to the 11 color names found to be the most common in the cross-cultural study carried out by Berlin and Kay (1969), with the addition of cyan.
- The colors in the first set of six would normally be used before choosing any from the second set of six.

Figure 4.24 A set of 12 colors for use in labeling. The same colors are shown on a white and a black background.

- Sometimes it is useful to group color codes into families. This can be done by using hue as a primary attribute denoting family membership, with secondary values mapped to a combination of saturation and lightness. Figure 4.25 illustrates some examples.
- Generally, we cannot expect to get away with more than two different color steps in each family. The canonical red, green, and blue hues make good categories for defining families.
- Yellow is not so good because dark yellow is perceived as belonging to a different family and yellow has few discriminable saturation steps
- Interior designers often consider a family of warm colors (nearer to red in color space) to be distinct from a family of cool colors (nearer to blue and green in color space), although the psychological validity of this is questionable
- Interior designers often consider a family of warm colors (nearer to red in color space) to be distinct from a family of cool colors (nearer to blue and green in color space), although the psychological validity of this is questionable

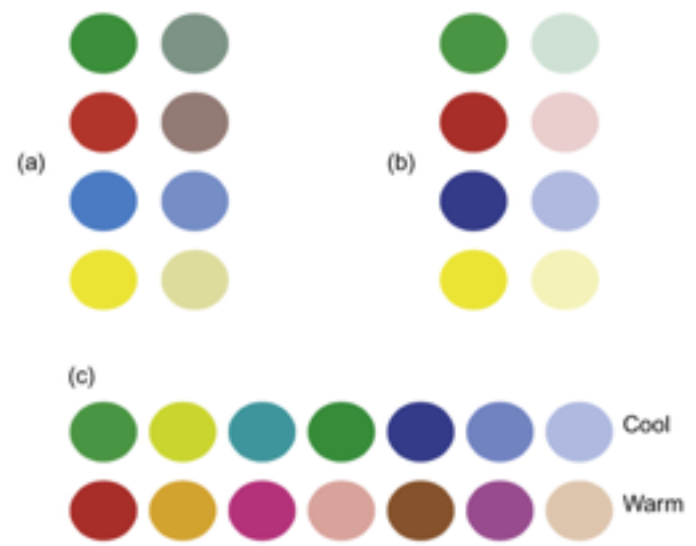

Figure 4.25 Families of colors. (a) Pairs related by hue; family members differ in saturation. (b) Pairs related by hue; family members differ in saturation and lightness. (c) A family of cool hues and a family of warm hues.

Application 3: Color Sequences for Data Maps

The most common coding scheme used in data visualization is a color sequence that approximates the physical spectrum, like that shown in Figure 4.26(b). Although this sequence is frequently used in physics and other disciplines and has some useful prop- erties, it is not a perceptual sequence.

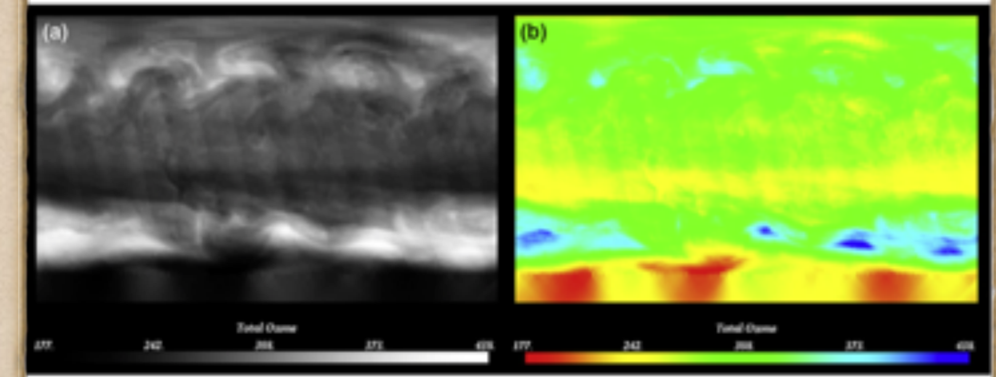

Figure 4.26 The same data showing ozone concentrations in the southern hemisphere is represented using (a) grayscale and (b) spectrum approximation pseudocolor sequences. (Images courtesy of Penny Rheingans (Rheingans, 1999).)

- Figure 4.27 shows seven different color sequences, but which is best and why?
- The whole spectrum is not perceptually ordered, although short sections of it are. For example, sections from red to yellow, yellow to green, and green to blue all vary monotonically (they continuously increase or decrease) on both the red– green and yellow–blue channels.

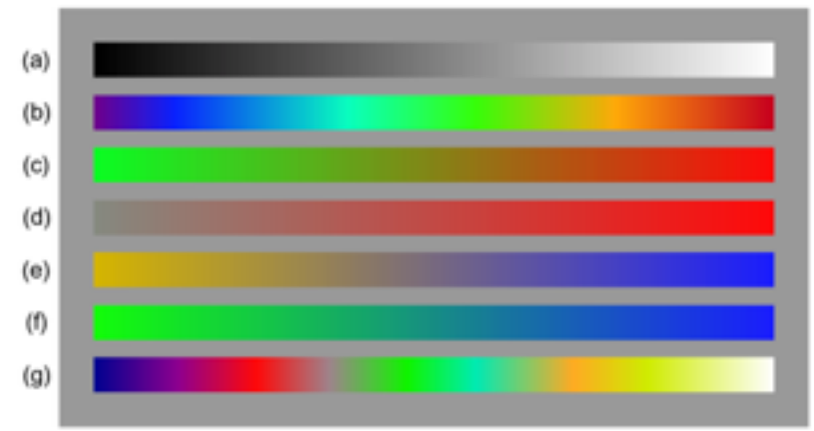

Figure 4.27 Seven different color sequences: (a) Grayscale. (b) Spectrum approximation. (c) Red–green. (d) Saturation. (e, f) Two sequences that will be perceived by people suffering from the most common forms of color blindness. (g) Sequence of colors in which each color is lighter than the previous one.

Form and Quantity

- Because the luminance channel helps us see forms, a grayscale sequence should allow us to see forms much better than pure color sequences (no luminance variation). See Figure 4.26(a). The highs are white, the lows are black, and complex swirling patterns can be seen in the ozone concentrations. Look at Figure 4.26(b). Here red, green, and blue areas clearly stand out, but this visual segmentation is mean- ingless; it is not clear which areas are high and low, and much less detail is seen overall.
- [G4.19] Use a spectrum approximation pseudocolor sequence for applications where its use is deeply embedded in the culture of users. This kind of color sequence can also be used where the most important requirement is reading map values using a key. If this sequence is used, the spacing of the colors should be carefully chosen to provide discriminable steps.

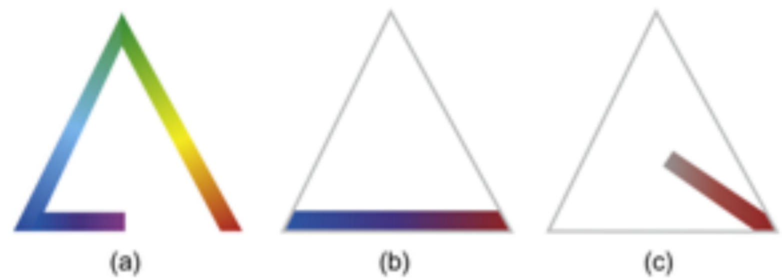

Figure 4.28 Sequences on a chromaticity diagram. (a) Spectrum approximation. (b) Blue–red sequence. (c) Saturation sequence.

- [G4.20] If it is important to see highs, lows, and other patterns at a glance, use a pseudocolor sequence that monotonically increases or decreases in luminance. If reading values from a key is also important, cycle through a variety of hues while trending upward or downward in luminance.
- A better choice may be to design a sequence that cycles through a variety of colors, each one lighter than the previous. Sometimes this is called a spiral color sequence, because it can be thought of as spiraling upward in color space.
- The designer of such a sequence can take advantage of the fact that monitor blue has much lower luminance than monitor red, which in turn has lower luminance than moni- tor green. Yellow, being the sum of red and green, has a very high luminance, almost equal to white. This is the basis for the sequence design shown on the right in Figure 4.29.

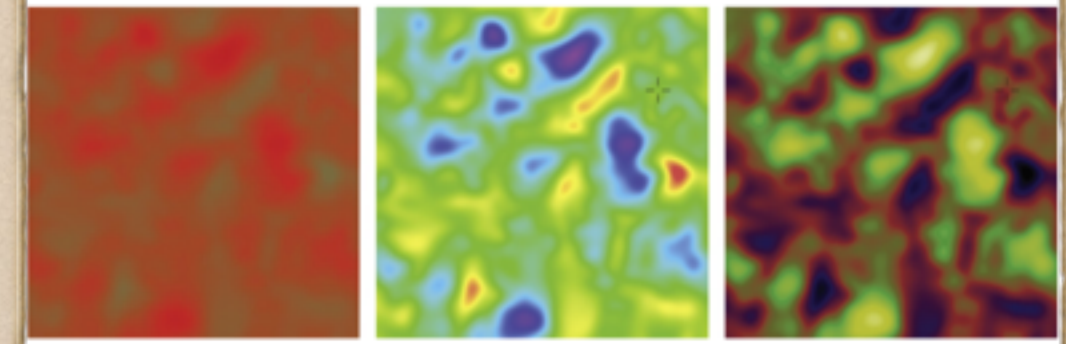

Figure 4.29 The same data represented with saturation, spectrum, and spiral color sequences. The spiral sequence makes it possible to easily see both the highs and lows, as well as read values accurately from a key.

Interval Pseudocolor Sequences, Ratio Pseudocolors

- To support unskilled map readers, contours can be usefully combined with pseudocoloring, as shown in Figure 4.30(a). Even better may be a stepped pseudocolor sequence as shown in Figure 4.30(b).
- No known visualization technique is capable of accurately conveying ratios with any precision; however, a sequence can be designed that effectively expresses a zero point and numbers above and below zero.

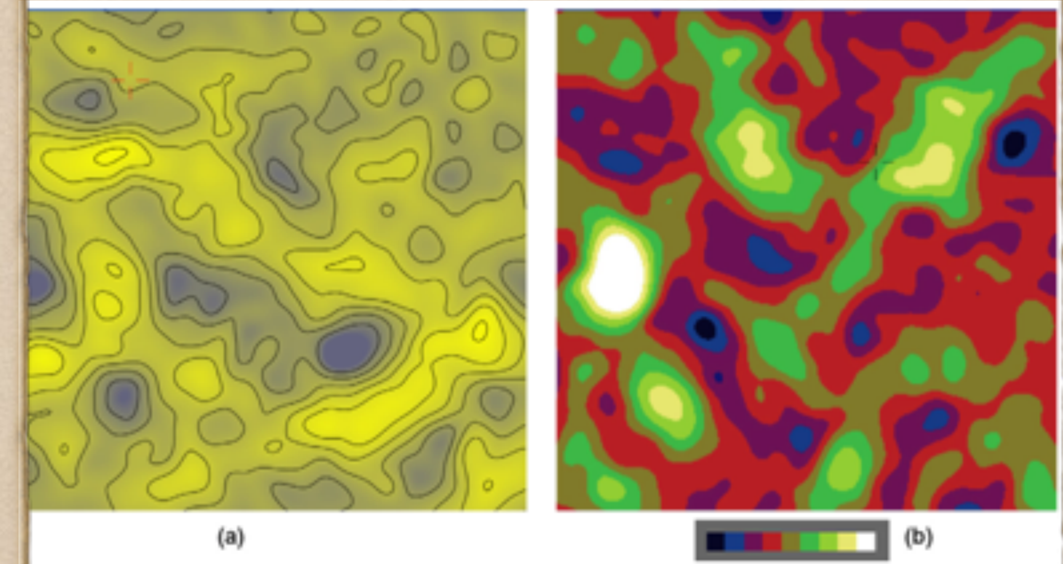

Figure 4.30 (a) Contours can show equal intervals in the data although numerical labels must be added for most applications. (b) A sequence of colors in discrete steps may be more reliably read using a key than a smoothly blended sequence.

- The example in Figure 4.31 shows a map of the stock market provided by SmartMoney .com. Market capitalization is represented by area, luminance encodes the magnitude of value change in the past year, and green–red encodes gains and losses.
- Spence and Efendov (2001) found that a red–green sequence was most effective, confirming the greater informa- tion-carrying capacity of this channel compared to the yellow–blue channel.

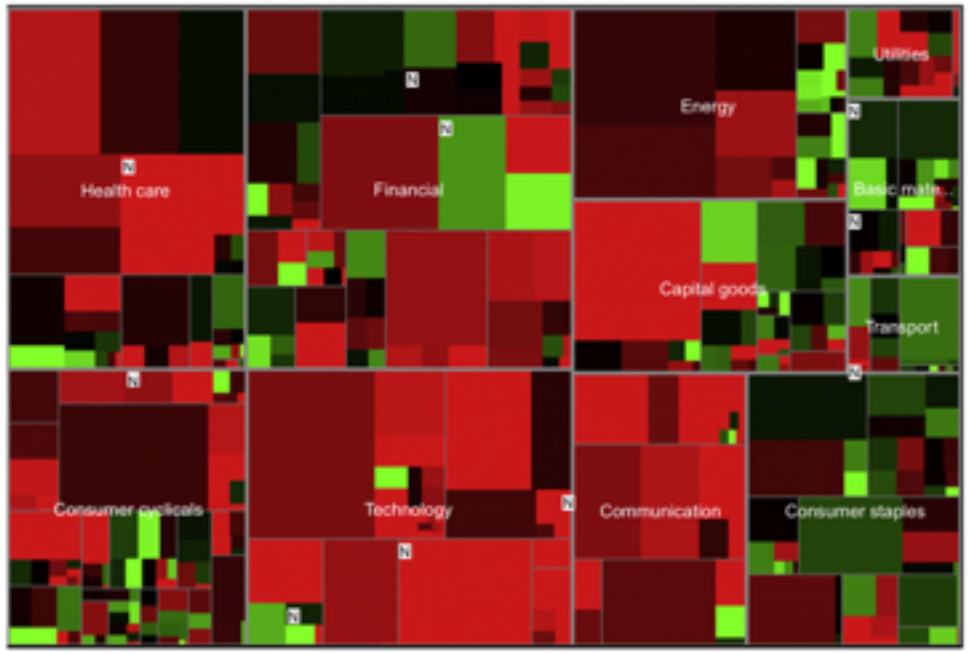

Figure 4.31 A color sequence with black representing zero. Increasing positive values are shown by increasing amounts of red. Increasing negative values are shown by increasing amounts of green. The map itself is a form of treemap (Johnson & Shneiderman, 1991). (*Courtesy of SmartMoney.com.*)

Bivariate Color Sequences (p.134)

- In general, it is better to map data dimensions to perceptual color dimensions. For example:
  - Variable one → hue
  - Variable two → saturation

  or

  - Variable one → hue
  - Variable two → lightness
- Figure 4.32 gives an example of a bivariate color sequence from Brewer (1996a) that maps one variable to yellow–blue variation and the other to a combination of light–dark variation and saturation. It suffers from the usual problem that the low-saturation colors are difficult to distinguish.
- As a word of caution, it should be noted that bivariate color maps are notoriously dif- ficult to read.
- We do not seem to be able to read different color dimensions in a way that is highly separable.
- Pseudocoloring is not the only way to display a two-dimensional scalar field. Generally, when the goal is to display two variables on the same map, it may be better to use visual texture, height difference, or another channel for one variable and color for the other, in this way mapping data dimensions to more perceptually separable dimensions

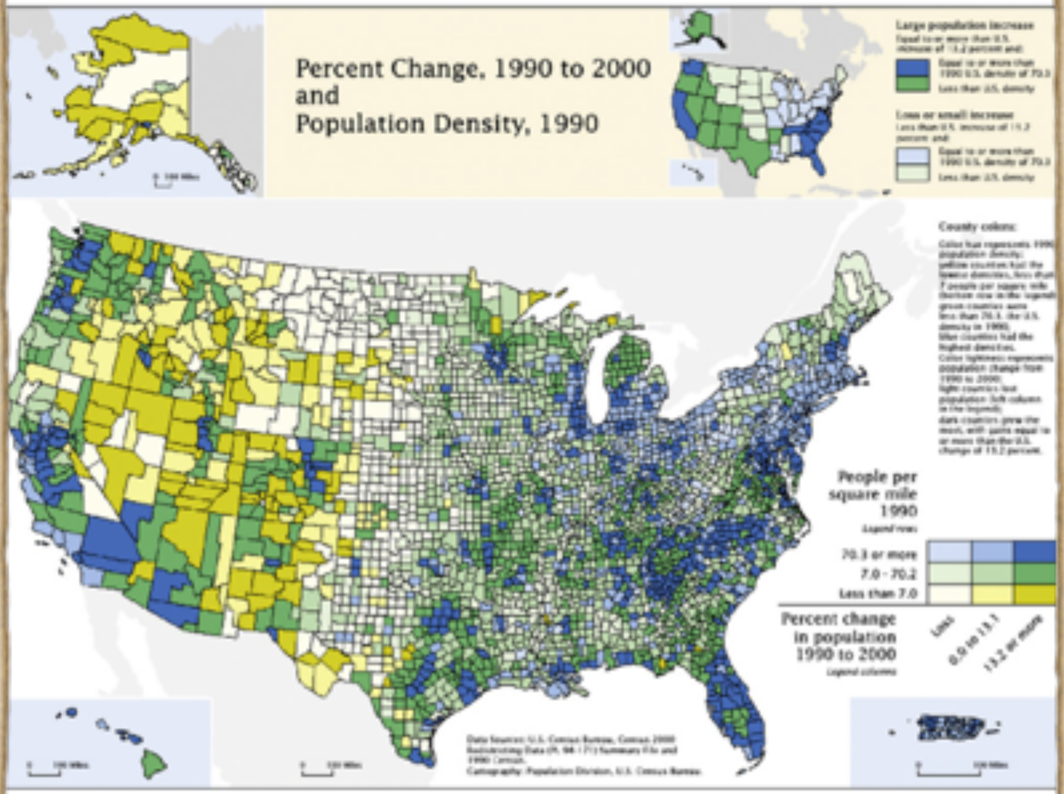

Figure 4.32 A bivariate coloring scheme using saturation and lightness for one variable and yellow–green–blue hue variation for the other. (*Courtesy of Cindy Brewer.*)

Application 4: Color Reproduction

The visual system is built to perceive relationships between colors rather than absolute values. For this reason, the solution to the color reproduction problem lies in preserving the color relationships as much as possible, not the absolute values. It is also important to preserve the white point in some way, because of the role of white as a reference in judging other colors.

- The set of all colors that can be produced by a device is called the gamut of that device. The gamut of a monitor is larger than that of a color printer (roughly the gamut of surface colors shown in Figure 4.7).
- Stone et al. described the following set of heuristic principles to create good mapping from one device to another:
  - The gray axis of the image should be preserved. What is perceived as white on a monitor should become whatever color is perceived as white on paper.
  - Maximum luminance contrast (black to white) is desirable.
  - Few colors should lie outside the destination gamut.
  - Hue and saturation shifts should be minimized.
  - An overall increase of color saturation is preferable to a decrease.

- Figure 4.33 illustrates, in two dimensions, what is in fact a three-dimensional set of geometric transformations designed to accomplish the principles of gamut mapping. In this example, the process is a transformation from a monitor image to a paper hard copy, but the same principles and methods apply to transformations between other devices.
  - Calibration.
  - Range scaling.
  - Rotation
  - Saturation scaling.

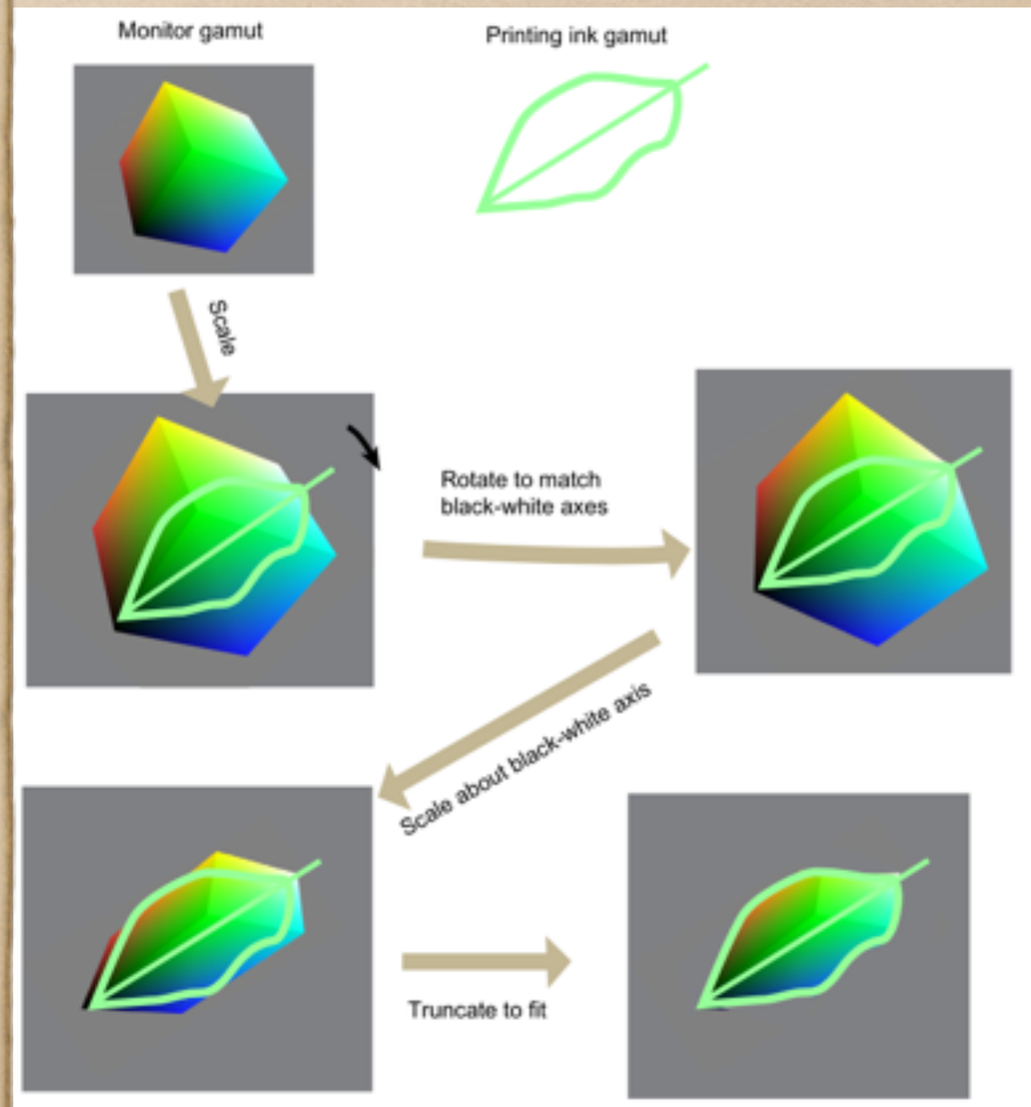

Figure 4.33 Illustration of the basic geometric operations in gamut mapping between two devices, as defined by Stone et al. (1988).

Chapter 5

Visual Salience and Finding Information

- Step 1. A visual query is formulated in the mind of the person, relating to the problem to be solved.
- Step 2. A visual search of the display is carried out to find patterns that resolve the query.
- The most common kinds of things used in data visualization— namely, are graphical symbols and glyphs.
    - A graphical symbol is a graphical object that represents an entity.
    - A glyph is a graphical object designed to represent some entity and convey one or numerical attributes of that entity.
        - A well- designed glyph is one that, in addition to being easily found, supports rapid and accurate resolution of visual queries regarding the ordinal, interval, or ratio quantities that are expressed.

Eye Movements

- There are three important types of eye movements:
  - 1. Saccadic movements.
    - As a general principle, visual search will be considerably more efficient for more compact displays because eye movements will be shorter and faster.
    - [G5.1] To minimize the cost of visual searches, make visualization displays as compact as possible, compatible with visual clarity. For efficiency, information nodes should be arranged so that the average saccade is 5 degrees or less
  - 2. Smooth-pursuit movements.
    - When an object is moving smoothly in the visual field, the eye has the ability to lock onto it and track it.
  - 3. Convergent movements (also called vergence movements).
    - When an object moves toward us, our eyes converge. When it moves away, they diverge. Convergent movements can be either saccadic or smooth.
- Saccadic suppression:
  - During a saccadic eye movement, we are less sensitive to visual input.
- Accommodation
  - When the eye moves to a new target at a different distance from the observer, it must refocus, or accommodate, so that the target is clearly imaged on the retina. An accommodation response typically takes about 200 msec.
  - As we age, however, the ability to accommodate declines and refocusing the eyes must be accomplished by changing eyeglasses, by moving the head or use laser surgery to make one eye have a near focus and the other a far focus

- Three things determine what is easily findable:
    - 1. A priori salience. Some patterns excite more neural activity in the feature maps than others.
    - 2. Top-down salience modification.
    - 3. Scene gist.

- There are three basic high-level channels that match the areas shown in Figure 5.2—namely, color, form, and motion.
- [G5.2] Use different visual channels to display aspects of data so that they are visually distinct.

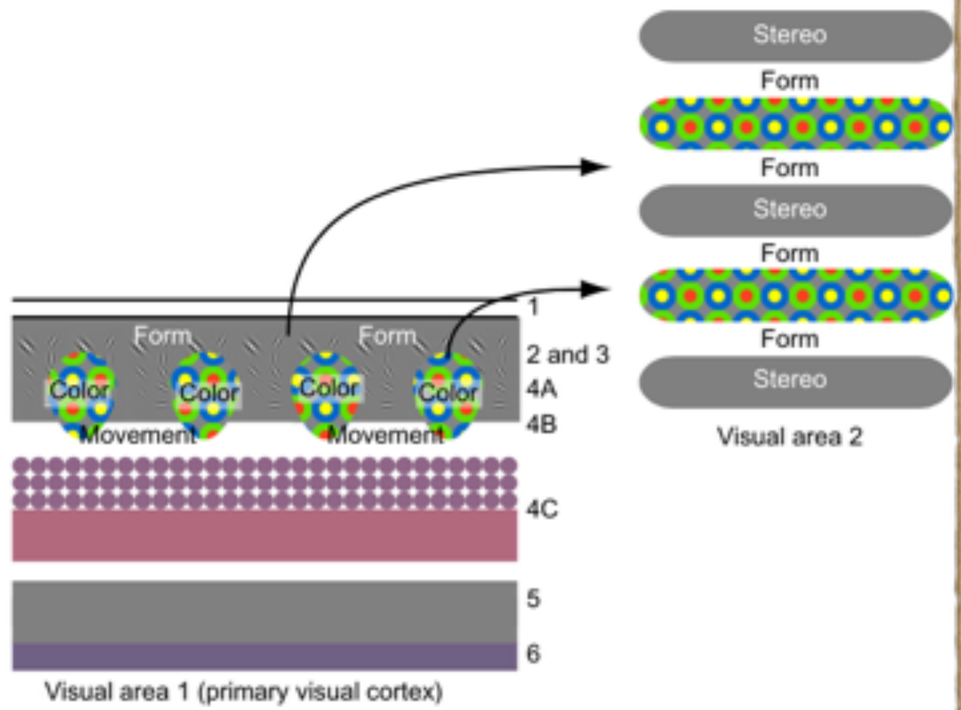

Figure 5.2 Architecture of the primary visual cortex. (*Redrawn from Livingston & Hubel (1988).*)

Visual Distinctness

- Figure 5.5 shows the letters of the alphabet on top of a random visual noise pattern that has a range of spatial frequencies from low to high (Solomon & Pelli, 1994). As can be seen, the letters are difficult to perceive where the background has spatial fre- quency components similar to the letters. This is an example of visual interference between spatial frequency subchannels.
- [G5.3] To make symbols easy to find, make them distinct from their background and from other symbols; for example, the primary spatial frequency of a symbol should be different from the spatial frequency of the background texture and from other symbols.

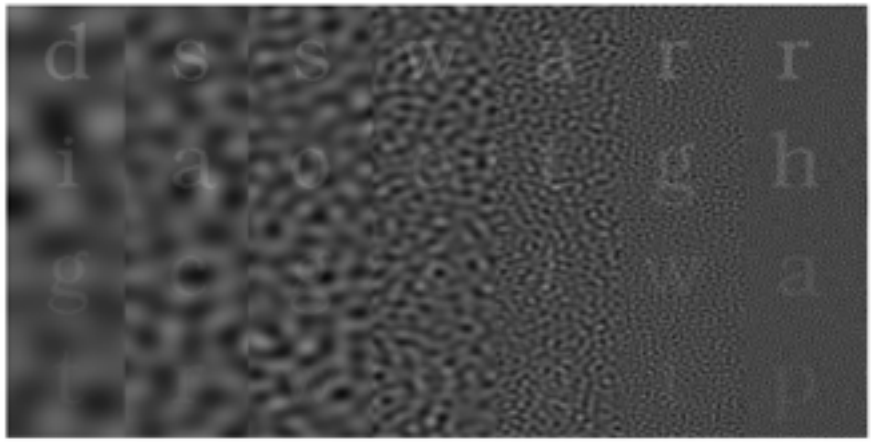

Figure 5.5 The letters are harder to see where they lie on top of visual noise that has spatial frequency components similar to the letters. *(From Solomon & Pelli (1994). Reproduced with permission.)*

Feature Maps, Channels, and Lessons for Visual Search

- Eye movements are directed to feature map regions that best match the target properties. Figure 5.7 illustrates the idea. On the left is a set of symbols. On the right is how this image appears in a few of the feature maps.
- A search for red objects yields three candidate targets, and a search for black objects yields three different targets.
- A search for a left-slanted shape yields two strong and two weak targets. The oblique edges of the triangular symbols produce the weak signals, and these will somewhat distract in a search for the left-oriented bars.

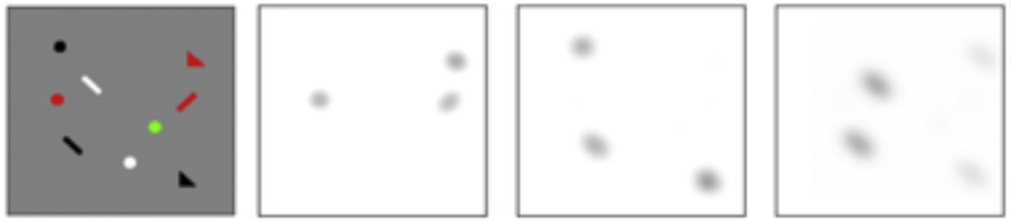

Figure 5.7 The symbols shown on the left are processed via a set of feature maps and the result directs eye movements.

- The squares and circles are not very distinct because the differences are encoded in high spatial frequencies (see Figure 2.25 in Chapter 2, which shows how spatial sensitivity declines with high spatial frequencies). If the symbols were made larger they would be more distinct.
- The other examples in the center and the right have much more distinctive spatial subchannel components. Some use both color and form to increase separation in feature space.

Figure 5.8 Feature channels can be used to make symbols more distinct from one another. The graphs on the right use redundant color coding in addition to more distinctive shapes.

Preattentive Processing

- Still, although the term is misleading, we shall continue to use it because of its widespread adoption.
- Early researchers thought that it must occur prior to conscious attention, although a more modern view is that attention is integral
- In essence, preattentive processing determines what visual objects are offered up to our attention and easy to find in the next fixation (Findlay & Gilchrist, 2005), so prior attention is part of the phenomenon.
- As a rule of thumb, anything that is processed at a rate faster than 10 msec per item is considered to be preattentive. Typical processing rates for nonpreattentive targets are 40 msec per item and more (Treisman & Gormican, 1988).

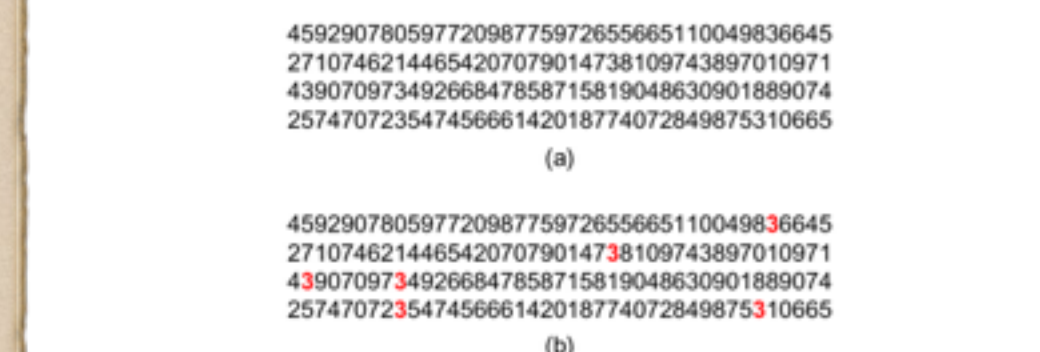

Figure 5.9 Preattentive processing. (a) To count the 3s in this table of digits, it is necessary to scan the numbers sequentially. (b) To count the 3s in this table, it is only necessary to scan the red 3s because they pop out from their surroundings.

- Figure 5.11 illustrates a few of literally hundreds of experiments to test whether various kinds of features are processed preattentively.
- 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

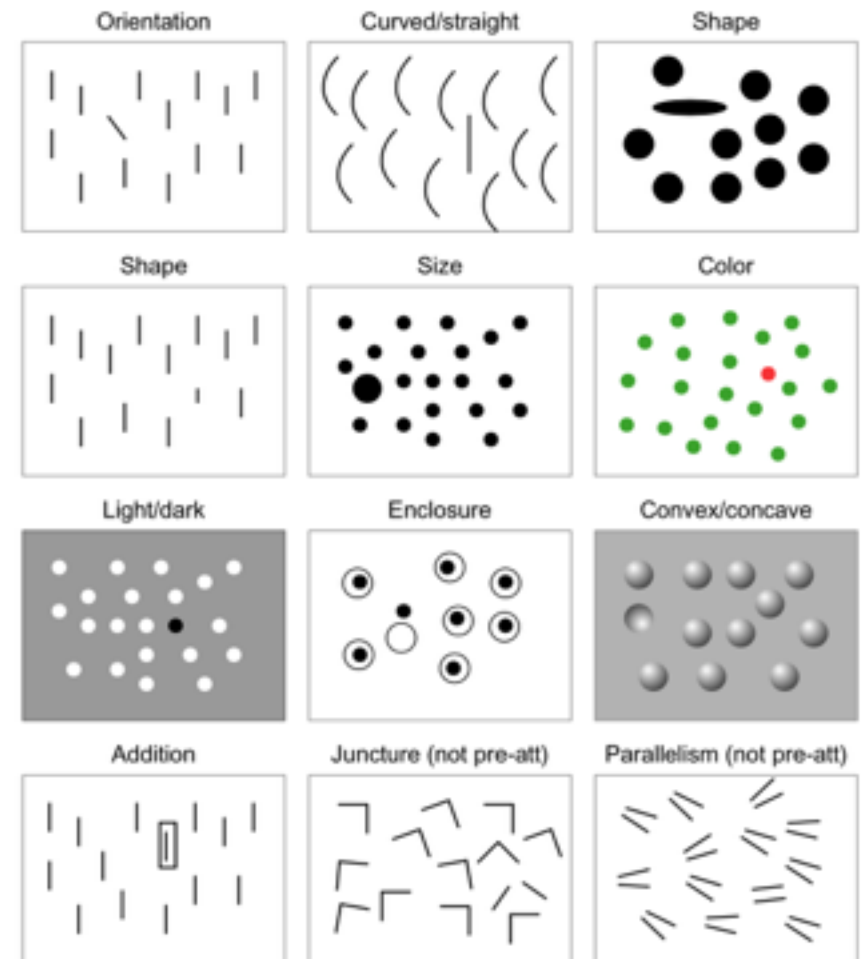

Figure 5.11 Most of the preattentive examples given here can be accounted for by the processing characteristics of neurons in the primary visual cortex.

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
- Size
- Curvature
- Spatial grouping
- Blur
- Added marks
- Numerosity (one, two, or three objects)

- Color
- Hue
    - Intensity
- Motion
    - Flicker
    - Direction of motion
- Spatial position
    - Two-dimensional position
    - Stereoscopic depth
- Convex/concave shape from shading

- There is a risk of misinterpreting the findings of psychophysical studies and proposing a new kind of detector for every distinct shape.
- It is also important to note that not all preattentive effects are equally strong. There are degrees of popout.
- In general the strongest effects are based on color, orientation, size, contrast, and motion or blinking, corresponding to the findings of neuropsychology.
- Also, there are degrees of difference. Large color differences have more popout than small ones. Some popout effects occur with no instruction and are difficult to miss, such as the red 3s in Figure 5.9 and blinking points
- So the term preattentive should not be taken too literally because prior attention must be given to prime the relevant properties using the tuning mechanisms we have already discussed.
- [G5.6] Use strong preattentive cues before weak ones where ease of search is critical

Attention and Expectations

- A problem with most research into attention, according to a book by Arien Mack and Irvin Rock (1998), is that almost all perception experiments (except their own) demand attention in the very design.
- Usually we pay very little attention to what goes on around us.
- Humans do not perceive much unless we have a need to find something and a vague idea of what that something looks like. In most systems, brief, unexpected events will be missed.
- Studies have shown that two factors are important in determining whether something stands out preattentively: the degree of difference of the target from the nontargets and the degree of difference of the nontargets from each other
- [G5.7] For maximum popout, a symbol should be the only object in a display that is distinctive on a particular feature channel; for example, it might be the only item that is colored in a display where everything else is black and white.

Figure 5.12 On the left, the right-slanted bar pops out; on the right, it does not. Yet, most of the distractors on the right have an orientation that is more different from the target orientation than the distracters on the left.

Highlighting and Asymmetries

- Adding marks to high- light a symbol is generally better than taking them away (Treisman & Gormican, 1988).
- If all of the symbols in a set except for a target object have an added mark, the target will be less distinctive.
- Another assymetry is the finding that a big target is easier to see surrounded by small targets than a small target surrounded by big targets. Several examples are given in Figure 5.13.
- Kosara et al. (2002) suggested blurring everything else in the display to make certain information stand out. They call the technique semantic depth of field
- [G5.10] When color and shape channels are already fully utilized, consider using motion or blink highlighting. Make the motion or blinking as subtle as possible, consistent with rapid visual search.
- As Figure 5.13 illustrates, blur works well, although again there is an obvious potential drawback to the technique. By blurring, the designer runs the risk of making impor- tant information illegible, as it is usually not possible to reliably predict the interests of the viewer.

Figure 5.13 A number of highlighting methods that use positive asymmetric preattentive cues: sharpness, added surrounding feature, added shape.

Coding with Redundant Properties

- [G5.11] To make symbols in a set maximally distinctive, use redundant coding wherever possible; for example, make symbols differ in both shape and color.
- We can choose to make something distinct on a single feature dimension, such as color, or we can choose to make it distinct on several dimensions, such as color, size, and orientation. This is called redundant coding.

- Figure 5.14 illustrates a conjunction search task in which the targets are three red squares. It turns out that this kind of search is slow if the surrounding objects are squares (but not red ones) and other red shapes. We are forced to do a serial search of either the red shapes or the square objects. This is called a conjunction search, because it involves searching for the specific conjunction of redness and shape attributes (Treisman & Gelade, 1980).

Figure 5.14 Searching for the red squares is slow because they are identified by a conjunction of shape and color.

Representing Quantity

- [G5.16] When designing a set of glyphs to represent quantity, mapping to any of the following glyph attributes will be effective: size, lightness (on a dark background), darkness (on a light background), vividness (higher saturation) of color, or vertical position in the display.
- [G5.17] Ideally, use glyph length or height, or vertical position, to represent quantity. If the range of values is large, consider using glyph area as an alternative. Never use the volume of a three-dimensional glyph to represent quantity.

Figure 5.24 The same information is shown using length, area, and volume. Research shows that the quantities shown in the volume display on the right will be mostly judged according to the relative area of the images, not according to volume, resulting in large errors.

Representing Absolute Quantities

- Visualization is mostly about seeing patterns in data, and this means that seeing if a particular variable is relatively larger or smaller than another is what is critical, rather than reading an absolute quantity.
- Generally, only three to five distinct values can be reliably read using simple graphical variables such as color, size, or lightness.
- There are a number of solutions to the problem of representing quantities. One is simply to add numbers to a glyph, or a numerical scale; see Figure 5.25(a, b).
- A second solution is to create a glyph that by its shape conveys numerical values. The best known example of this is the wind barb, which is shown in Figure 5.25(c).

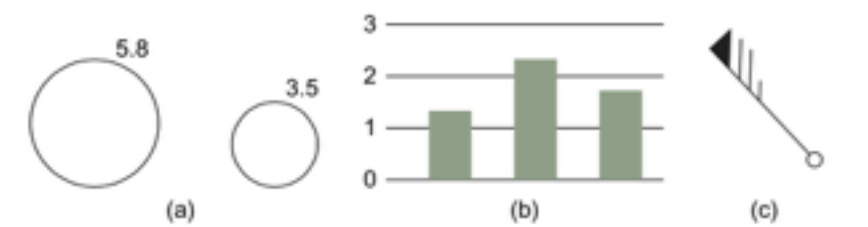

Figure 5.25 Three different ways that more exact numerical values can be read from a diagram.

Multidimensional Discrete Data: Uniform Representation versus Multiple Channels

- Table 5.1 lists the most useful low-level graphical attri- butes that can be applied to glyph design, with a few summary comments about the number of dimensions available.
- Many of these display dimensions are not independent of one another. To display texture, we must use at least one color dimension (luminance) to make the texture visible.
- Overall, we will probably be fortunate to display eight types of dimensional data clearly, using color, shape, spatial position, and motion to create the most differentiated set possible.
- There is also the issue of how many resolvable steps are available in each dimension.
- When we require rapid preattentive processing, only a handful of colors are available.
- The number of orientation steps that we can easily dis- tinguish is probably about four.

Table 5.1 *Graphical attributes that may be useful in glyph design.*

Visual Variable	Dimensionality	Comment
Spatial position	Three dimensions: X, Y, Z	
Color	Three dimensions: defined by color opponent theory	Luminance contrast is needed to specify all other graphical attributes.
Shape	Size and orientation are basic but there may be more usable dimensions	The dimensions of shape that can be rapidly processed are unknown; however, the number is certainly small.
Surface texture	Three dimensions: orientation, size, and contrast	Surface texture is not independent of shape or orientation; uses one color dimension.
Motion coding	Approximately two to three dimensions; more research is needed, but phase is critical	
Blink coding	One dimension	Motion and blink coding are highly interdependent.

Stars and Whiskers

- In the whisker plot, each data value is represented by a line segment radiating out from a central point, as shown in Figure 5.26(a). The length of the line segment denotes the value of the corresponding data attribute.
- A variant of the whisker plot is the star plot (Chambers et al., 1983). This is the same as the whisker plot but with the ends of the lines connected, as in Figure 5.26(b).
- It is possible to show a large number of variables with whisker or star plots, but this does not mean that the results will be intelligible.
- In order to minimize interference between similarly oriented con- tours, a much smaller number of whiskers is recommended—four is probably the max- imum.
- It may also be useful to change the amount of "energy" in glyph segments by altering the line width as well as the length of the line; see Figure 5.26(c).

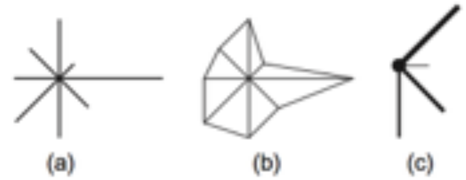

Figure 5.26 (a) Whisker plot. (b) Star plot. (c) Whisker plot with only four variables and varying width.

Tunnel Vision, Stress, and Cognitive Load

- They found a dramatic drop in detection rate for objects in the periphery of the visual field (down from 75% correct to 36% correct) as the task load increased.
- [G5.19] When designing user interrupts, peripheral alerting cues must be made stronger if the cognitive load is expected to be high.

The Role of Motion in Attracting Attention

- We have a low ability to detect small targets in the periphery of the visual field.
- Peripheral vision is color blind, which rules out color signals
- The set of requirements suggests two possible solutions. One is to use auditory cues. In certain cases, these are a good solution, but they are outside the scope of this book. Another solution is to use blinking or moving icons.
- Anecdotal evidence, however, indicates that a possible disadvantage of flashing lights or blinking cursors is that users find them irritating.
- Thus, the most effective reminder might be an object that moves into view, disappears, and then reappears every so often.

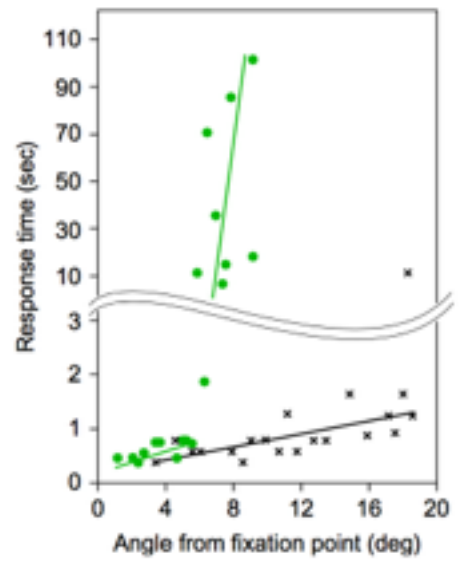

Figure 5.27 Results of a study by Peterson and Dugas (1972). The task was to detect small symbols representing aircraft in a simulation display. The circles show the response times from the appearances of static targets. The crosses show response times from the appearances of moving targets. Note the two different scales.

Conclusion

- To a great extent what we need to see as well as what we expect to see will have a large influence on what we actually see.
- For glyphs to be seen rapidly, they must stand out clearly from all other objects in their near vicinity on at least one coding dimension.
- The lessons from this chapter have to do with fundamental tradeoffs in design choices about whether to use color, shape, texture, or motion to display a particular set of variables.
- The basic rule is that, in terms of low-level properties, "like" interferes with "like." If we have a set of small symbols on a textured background, a texture with a grain size similar to that of the symbols will make them difficult to see.
- There is more separability between channels. If we wish to be able to read data values from different data dimensions, each of these values should be mapped to a different display channel.

Chapter 6
Static and moving patterns

(p. 179-237)

- At the early stages of feature abstraction, the visual image is analyzed in terms of primitive elements of form, motion, color, and stereoscopic depth.
- At the middle 2D pattern- perception stage, active processes driven by top-down visual queries cause contours to be formed, distinct regions to be segmented, and connections to be made.
- At the top level, objects and scenes are discovered, using information about the connections between component parts, shape-from-shading information, and so on.
- Finally, objects and significant patterns are pulled out by attentional processes to meet the needs of the task at hand.

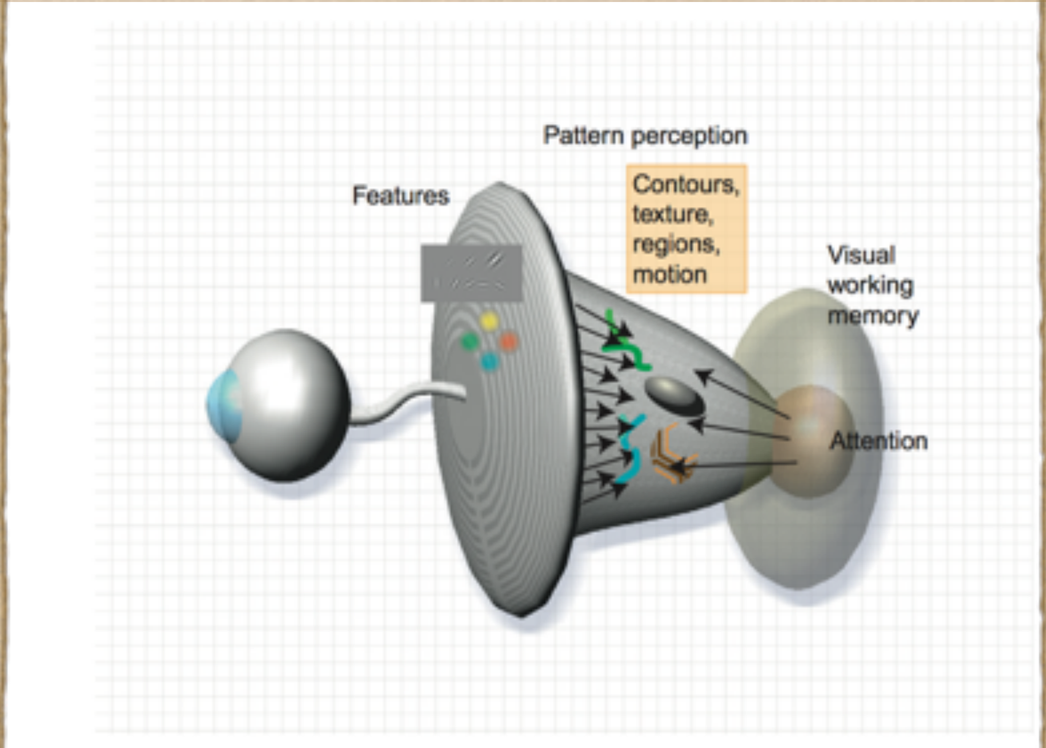

Figure 6.1 Pattern perception occurs in a middle ground where bottom-up feature processing meets the requirements of top-down active attention.

Gestalt Laws

- The word Gestalt simply means "pattern" in German.
- The Gestalt laws easily translate into a set of design principles for information displays.
- Eight Gestalt laws are discussed here: proximity, similarity, connectedness, continuity, symmetry, closure, relative size, and common fate (the last concerns motion perception and appears later in the chapter).

Proximity

- [G6.1] Place symbols and glyphs representing related information close together.
- Figure 6.2 shows two arrays of dots that illustrate the proximity principle. Only a small change in spacing causes us to change what is perceived from a set of rows, in Figure 6.2(a), to a set of columns, in Figure 6.2(b). In Figure 6.2(c), the existence of two groups is perceptually inescapable.

Figure 6.2 Spatial proximity is a powerful cue for perceptual organization. A matrix of dots is perceived as rows on the left (a) and columns on the right (b). In (c) we perceive two groups of dots because of proximity relationships.

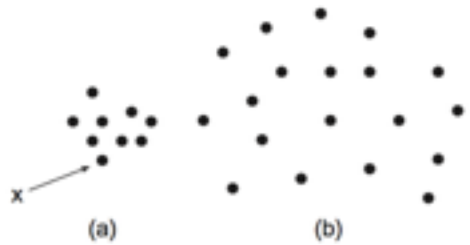

Figure 6.3 The principle of spatial concentration. The dot labeled x is perceived as part of cluster a rather than cluster b.

Similarity

- In Figure 6.4(a, b) the similarity of the elements causes us to see rows more clearly.
- In Figure 6.4(a, b) the similarity of the elements causes us to see rows more clearly. In terms of perception theory, the concept of similarity has been largely superseded. The channel theory and the concepts of integral and separable dimensions provide much more detailed analysis and better support for design decisions.
- In Figure 6.4(a, b) the similarity of the elements causes us to see rows more clearly. In terms of perception theory, the concept of similarity has been largely superseded. The channel theory and the concepts of integral and separable dimensions provide much more detailed analysis and better support for design decisions.
- [G6.2] When designing a grid layout of a data set, consider coding rows and/or columns using low-level visual channel properties, such

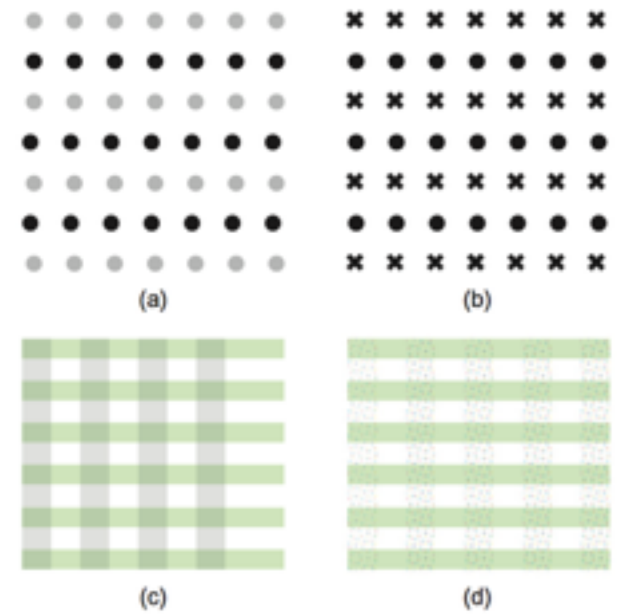

Figure 6.4 (a, b) According to the Gestalt psychologists, similarity between the elements in alternate rows causes the row percept to dominate. (c) Integral dimensions are used to delineate rows and columns. (d) When separable dimensions (color and texture) are used, it is easier to attend separately to either the rows or the columns.

Connectedness

- The demonstrations in Figure 6.5 show that connectedness can be a more powerful grouping principle than proximity, color, size, or shape.
- [G6.3] To show relationships between entities, consider linking graphical repre- sentations of data objects using lines or ribbons of color.

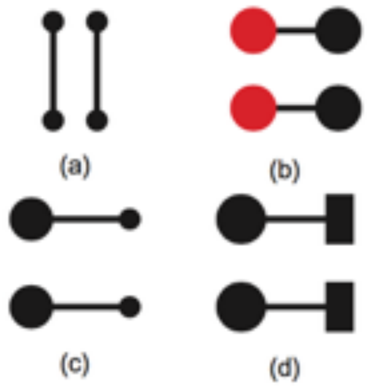

Figure 6.5 Connectedness is a powerful grouping principle that is stronger than (a) proximity, (b) color, (c) size, or (d) shape.

Continuity

- The Gestalt principle of continuity states that we are more likely to construct visual enti- ties out of visual elements that are smooth and continuous, rather than ones that contain abrupt changes in direction. (See Figure 6.6.)
- It should be easier to identify the sources and destinations of con- necting lines if they are smooth and continuous. This point is illustrated in Figure 6.7.

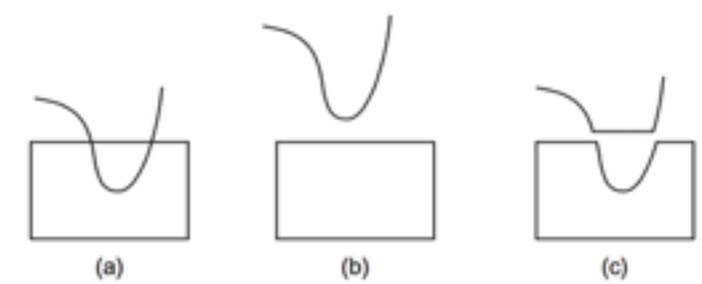

Figure 6.6 The pattern on the left (a) is perceived as a smoothly curved line overlapping a rectangle (b) rather than as the more angular components shown in (c).

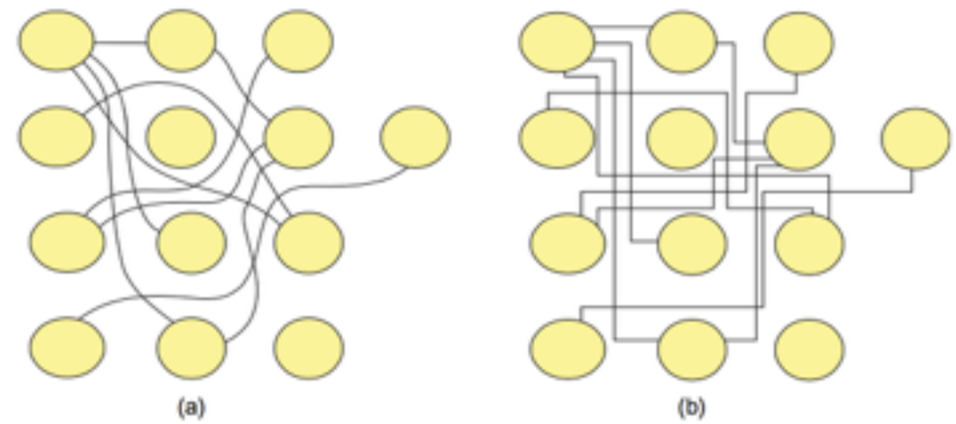

Figure 6.7 In (a), smooth continuous contours are used to connect nodes in the diagram; in (b), lines with abrupt changes in direction are used. It is much easier to perceive connections with the smooth contours.

Symmetry

- The symmetrically arranged pairs of lines in Figure 6.8 are perceived more strongly as forming a visual whole than the pair of parallel lines.
- A possible application of symmetry is in tasks in which data analysts are looking for similarities between two different sets of time-series data. It may be easier to perceive similarities if these time series are arranged using vertical sym- metry, as shown in Figure 6.9, rather than using the more conventional parallel plots.
- To take advantage of symmetry the important patterns must be small.
- We are most sensitive to symmetrical patterns that are small, less than 1 degree in width and 2 degrees in height, and centered around the fovea. Dakin and Herbert (1998)
- The display on the right in Figure 6.9 is far too large to be optimal from this point of view.

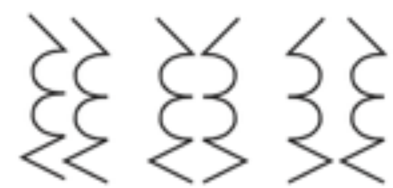

Figure 6.8 The pattern on the left consists of two identical parallel contours. In each of the other two patterns, one of the contours has been reflected about a vertical axis, producing bilateral symmetry. The result is a much stronger sense of a holistic figure.

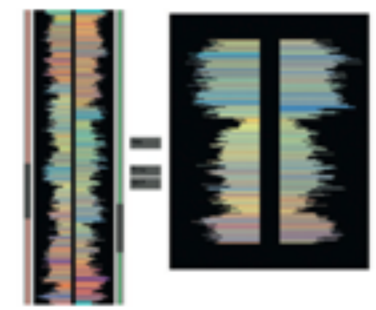

Figure 6.9 An application designed to allow users to recognize similar patterns in different time-series plots. The data represents a sequence of measurements made on deep ocean drilling cores. Two subsets of the extended sequences are shown on the right.

Symmetry

- We more readily perceive symmetries about vertical and horizontal axes, as shown in Figure 6.10(a, b); however, this bias can be altered with a frame of reference provided by a larger-scale pattern, as shown in Figure 6.10(c) and (d). See Beck et al. (2005).
- [G6.4] Consider using symmetry to make pattern comparisons easier, but be sure that the patterns to be compared are small in terms of visual angle (<1 degree horizontally and <2 degrees vertically). Symmetrical relations should be arranged on horizontal or vertical axes unless some framing pattern is used.

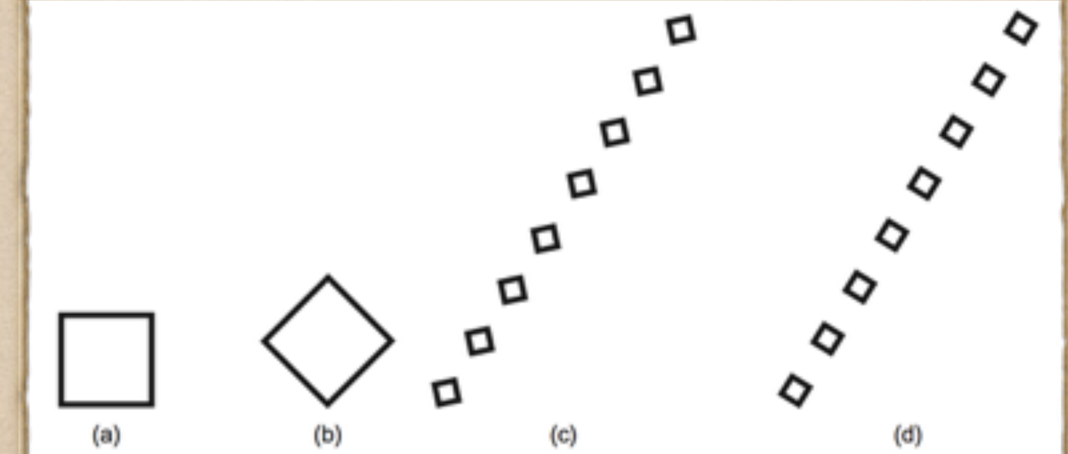

Figure 6.10 Because symmetries about vertical and horizontal axes are more readily perceived, (a) is seen as a square and (b) is seen as diamond. (c, d) A larger pattern can provide a frame of reference that defines the axes of symmetry; (c) is seen as a line of diamonds and (d) as a line of squares.

Closure and Common Region

- There is a perceptual tendency to close contours that have gaps in them. This can help explain why we see Figure 6.11(a) as a complete circle and a rectangle rather than as a circle with a gap in it as in Figure 6.11(b).
- Closed contours are widely used to visualize set concepts in Venn–Euler diagrams.
- A Venn diagram is a more restricted form of Euler diagram containing all possible regions of overlap.
- The two most important perceptual factors in this kind of diagram are closure and continuity. A fairly complex structure of overlapping sets is illustrated in Figure 6.12, using an Euler diagram.

Figure 6.11 The Gestalt principle of closure holds that neural mechanisms operate to find perceptual solutions involving closed contours. In (a), we see a circle behind a rectangle, not a broken ring as in (b).

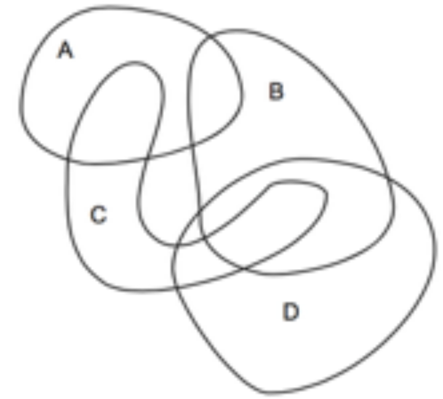

Figure 6.12 An Euler diagram. This diagram tells us (among other things) that entities can simultaneously be members of sets A and C but not of A, B, and C. Also, anything that is a member of both B and C is also a member of D. These rather difficult concepts are clearly expressed and understood by means of closed contours.

Closure and Common Region

- When the boundary of a contour-defined region becomes complex, what is inside or outside may become unclear. In such cases, using color, texture, or Cornsweet con- tours (discussed in Chapter 3) will be more effective (Figure 6.13).
- Although simple contours are generally used in Euler diagrams to show set membership, we can effec- tively define more complex sets of overlapping regions by using color and texture in addition to simple contours (Figure 6.14).

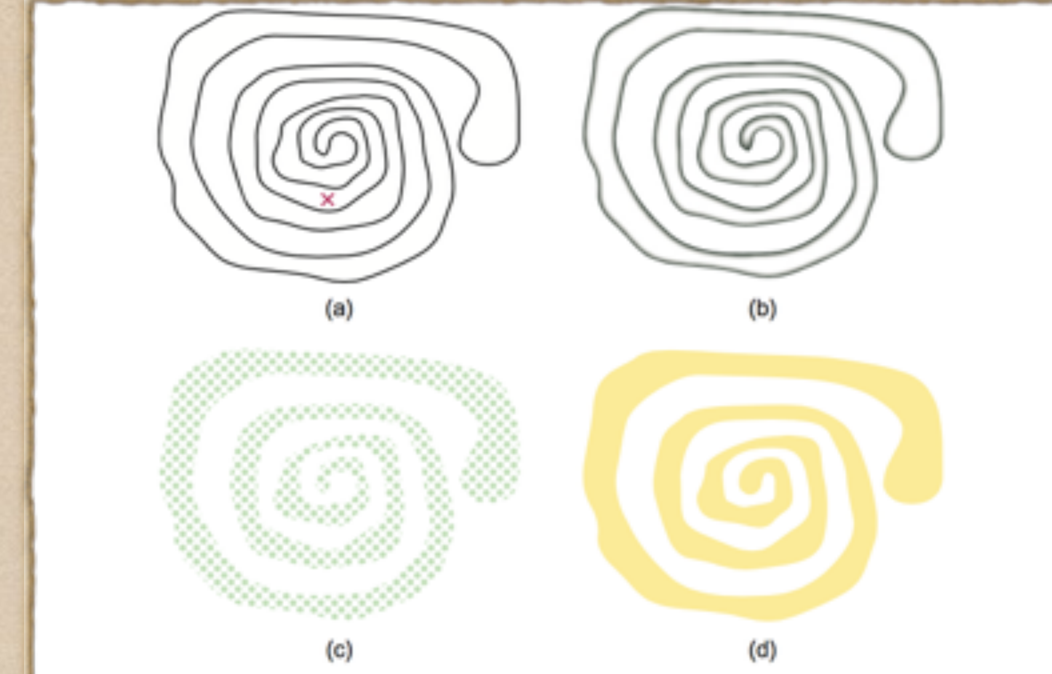

Figure 6.13 When the shape of the region is complex, a simple contour (shown in the upper left) is inadequate. (a) It is not easy to see if the x is inside or outside of the enclosed region. Common region can be defined less ambiguously by means of (b) a Cornsweet (1970) edge, (c) texture, or (d) color.

Figure 6.14 An Euler diagram enhanced using texture and color can convey a more complex set of relations than a conventional Euler diagram using only closed contours.

Closure and Common Region

- Figure 6.15 shows an example from Collins et al. (2009) where both transparent color and contour are used to define extremely convoluted boundaries for three overlapping sets.
- [G6.5] Consider putting related information inside a closed contour. A line is ade- quate for regions having a simple shape. Color or texture can be used to define regions that have more complex shapes.
- [G6.6] To define multiple overlapping regions, consider using a combination of line contour, color, texture, and Cornsweet contours.

Figure 6.15 Both contour- and color-defined regions have been added to make clear the distribution of hotels (orange), subway stations (brown), and medical clinics (purple). (*From Collins et al. (2009). Reproduced with permission.*)

Figure and Ground

- The position of every object within the frame tends to be judged relative to the enclosing frame (see Figure 6.16)
- A figure is something objectlike that is perceived as being in the foreground. The ground is whatever lies behind the figure.
- In general, smaller components of a pattern tend to be perceived as objects.
- In Figure 6.17(a), a black propeller is seen on a white background, as opposed to the white areas being perceived as objects.
- Closed contour, symmetry, and the surrounding white area all contribute to the perception of the two shapes in Figure 6.17(b) as figures, as opposed to cut-out holes.
- But, by changing the surroundings, as shown in Figure 6.17(c), the irregular shape that was perceived as a gap in Figure 6.17(b) can be made to become the figure.
- [G6.7] Use a combination of closure, common region, and layout to ensure that data entities are represented by graphical patterns that will be perceived as figures, not ground.

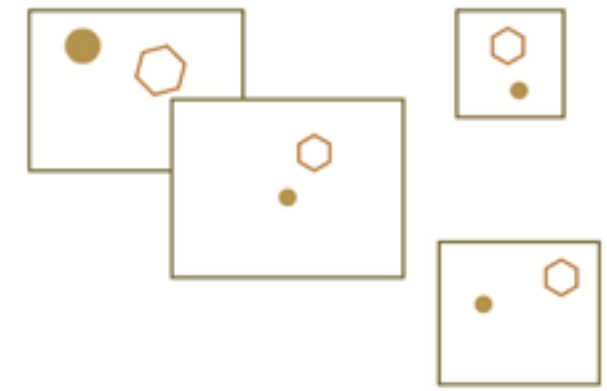

Figure 6.16 Closed rectangular contours strongly segment the visual field. They also provide reference frames. The positions and sizes of the enclosed shapes are, to some extent, interpreted with respect to the surrounding frame.

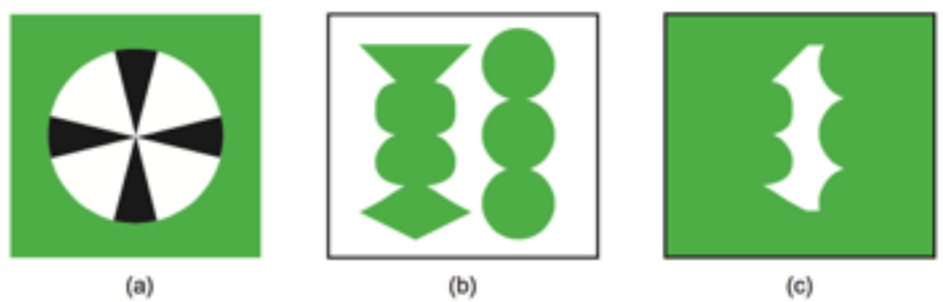

Figure 6.17 (a) The black areas are smaller and therefore more likely to be perceived as an object. It is also easier to perceive patterns that are oriented horizontally and vertically as objects. (b) The green areas are seen as figures because of several Gestalt factors, including size and closed form. The area between the green shapes in (c) is generally not seen as a figure.

Figure and Ground

- The vase percept is supported mostly by symmetry and being a closed region.
- Conversely, the faces percept is mostly driven by prior knowledge, not gestalt factors.
- It is only because of the great importance of faces that they are so readily seen. The result is a competition between high-level and mid- level processes.

Figure 6.18 Rubin's Vase. The cues for figure and ground are roughly equally balanced, resulting in a bistable percept of either two faces or a vase.

More on Contours

- Contours are continuous, elongated boundaries between regions of a visual image, and the brain is exquisitely sensitive to their presence.
- A contour can be defined by a line, by a boundary between regions of differ- ent color, by stereoscopic depth, by motion patterns, or by the edge of a region of a particular texture.
- Contours can even be perceived where there are none. Figure 6.19 illustrates an illusory contour; a ghostly boundary of a blobby shape is seen even where none is physically present

Figure 6.19 Most people see a faint illusory contour surrounding a blobby shape at the center of this figure.

More on Contours

- Subjects had to detect the presence of a continuous path in a field of 256 randomly oriented Gabor patches
- More interesting, even quite wiggly paths were readily seen if the Gabor elements were aligned as shown in

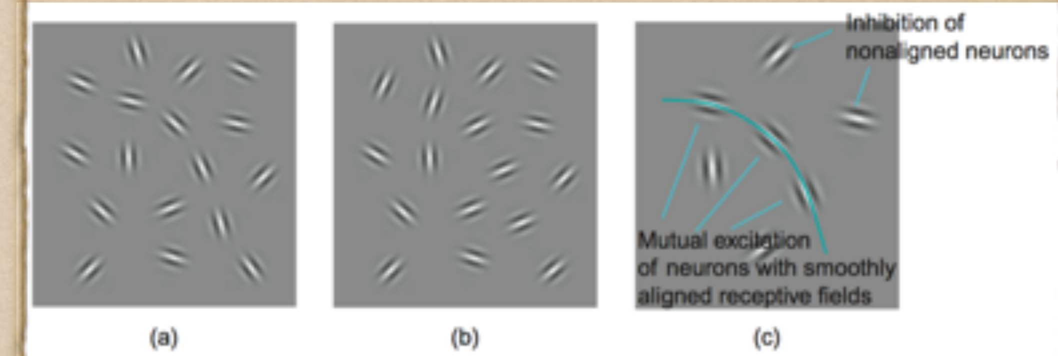

Figure 6.20 An illustration of the experiments conducted by Field et al. (1993). If the elements are aligned as shown in (a) so that a smooth curve can be drawn through some of them, a curve is seen. If the elements are at right angles, no curve is seen (b). This effect is explained by mutual excitation of neurons (c).

Representing Vector Fields: Perceiving Orientation and Direction

- The basic problem of representing a vector can be broken down into three components (Figur 6.21)
- There are direct applications of the Field et al. (1993) theory of contour perception in displaying vector field data.
- A common technique is to create a regular grid of oriented elements, such as the one shown in Figure 6.22(a).

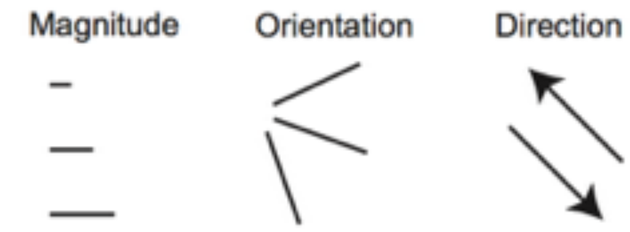

Figure 6.21 The components of a vector.

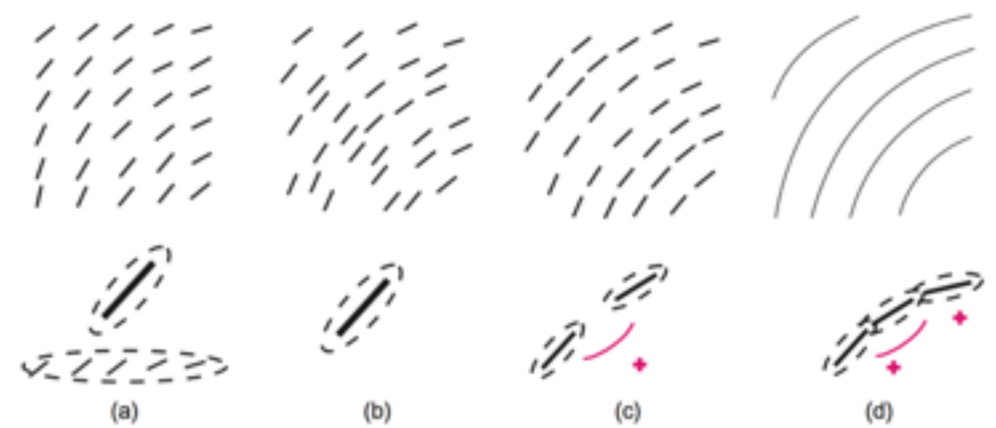

Figure 6.22 The results of Field et al. (1993) suggest that vector fields should be easier to perceive if smooth contours can be drawn through elements representing the flow. (a) A gridded pattern will weakly stimulate neurons with oriented receptive fields but also cause the perception of false contours from the rows and columns. (b) Line segments in a jittered grid will not create false contours. (c) If contour segments are aligned, mutual reinforcement will occur. (d) The strongest response will occur with continuous contours.

Representing Vector Fields: Perceiving Orientation and Direction

- Instead of the commonly used grid of small arrows, one obvious and effective way of representing vector fields is through the use of continuous contours; a number of effec- tive algorithms exist for this purpose. Figure 6.23 shows an example.
- This effectively illustrates the orientation of the vector field, although it is ambiguous in the sense that for a given contour there can be two directions of flow.
- In addition, Figure 6.23 does not show magnitude.

Figure 6.23 Streamlines can be an effective way to represent vector field or flow data. But here the direction is ambiguous and the magnitude is not shown. (*From Turk & Banks, 1996; with permission.*)

Comparing 2D Flow Visualization Techniques (p.193 -

- Laidlaw et al. (2001) carried out an experimental comparison of the six different flow visualization methods, illustrated in Figure 6.24
- (a) arrows on a regular grid
- (b) arrows on a jittered grid to reduce perceptual aliasing effects
- (c) triangle icons, with icon size proportional to field strength and density inversely related to icon size (Kirby et al., 1999)
- (d) line integral convolution (Cabral & Leedom, 1993)
- (e) large-head arrows along a streamline using a regular grid (Turk & Banks, 1996)
- (f) large-head arrows along streamlines using a constant spacing algorithm (Turk & Banks, 1996).
- The streamline methods of Turk and Banks, shown in Figure 6.24(f), proved best for showing advection.

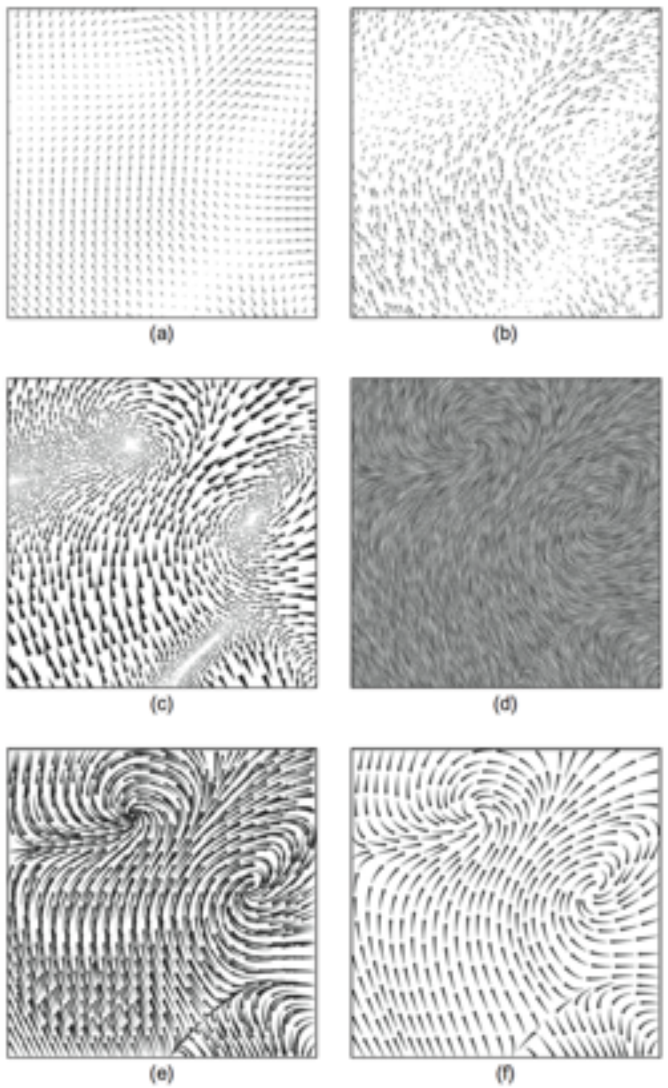

Figure 6.24 Six different flow visualization techniques evaluated by Laidlaw et al. (2001). (*From Laidlaw et al. (2001). Reproduced with permission.*)

Showing Direction

- [G6.8] For vector field visualizations, use contours tangential to streamlines to reveal the orientation component.
- [G6.9] To represent flow direction in a vector field visualization, use streamlets with heads that are more distinct than tails, based on luminance contrast. A streamlet is a glyph that is elongated along a streamline and which induces a strong response in neurons sensitive to orientations tangential to the flow.

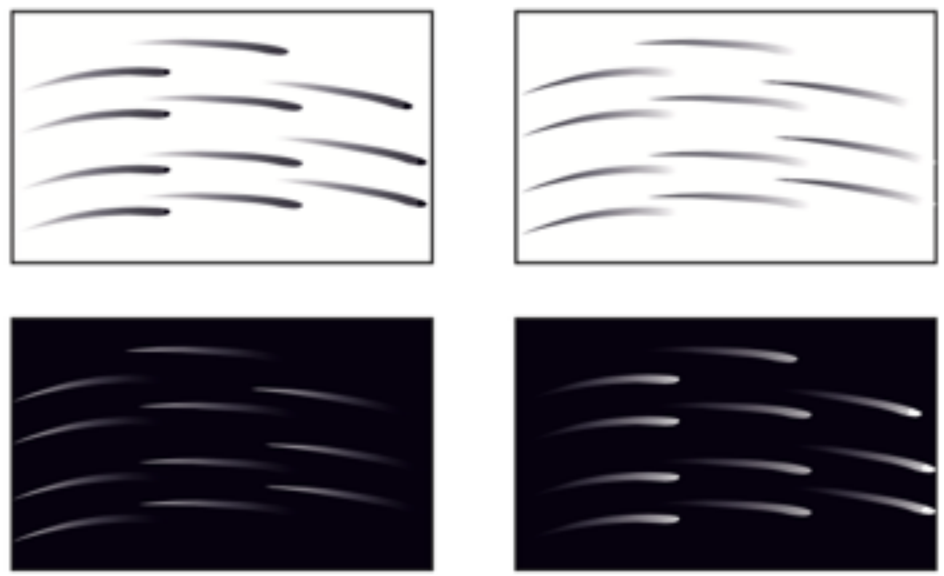

Figure 6.27 Vector direction can be unambiguously given by means of lightness change along the particle trace, relative to the background. This gives the greatest asymmetry between the different ends of each trace.

Showing Direction

- Figure 6.28 gives an example that follows both guidelines G6.8 and G6.9, and in addition uses longer and wider graphical elements to show regions of stronger flow (Mitchell et al., 2009).
- [G6.10] For vector field visualizations, use more distinct graphical elements to show greater field strength or speed. They can be wider, longer, more contrasting, or faster moving.

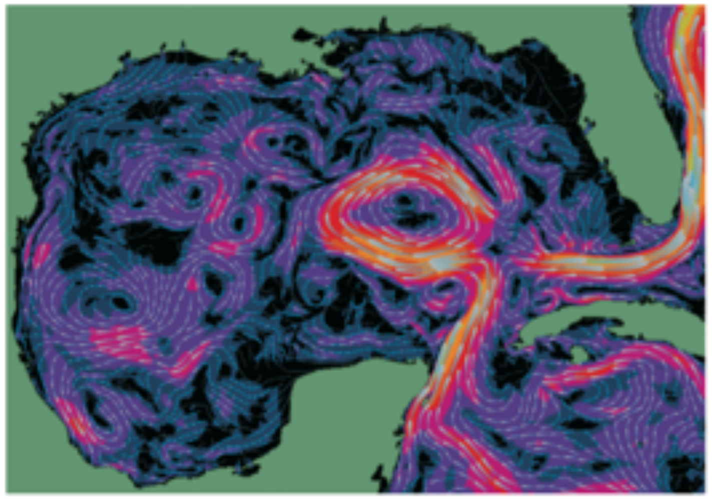

Figure 6.28 The surface currents in the Gulf of Mexico from the AMSEAS model. Head-to-tail elements are used, with each element having a more distinct head than tail. Speed is given by width, length, and background color.

Texture: Theory and Data Mapping

- Like color, we can use texture as a nominal code, displaying different categories of information, or as a method for representing quantity over a spatial map, using texture to provide ordinal or interval coding.
- Texture segmentation is the name given to the process whereby the brain divides the visual world into regions based on texture.
- The rules of texture segmentation are very similar to the rules for individual target salience. Indeed, the boundary between having many glyphs and having a texture is poorly defined, and texture can be thought of as a densely populated field of small glyphs.
- The Malik and Perona (1990) type of segmentation model is illustrated in Figure 6.29
- This model predicts that we will divide visual space into regions according to the predomi- nant spatial frequency and orientation information. A region with large orientation and size differences will be the most differentiated. Also, regions can be differentiated based on texture contrast. A low-contrast texture will be differentiated from a high- contrast texture with the same orientation and size components.
- Figure 6.30 illustrates the Gabor segmentation theory applied to the classic perceptual conundrum. Why are the Ts and Ls difficult to distinguish? And why are they easy to distinguish when the Ts are rotated? The Gabor model accurately predicts what we see.

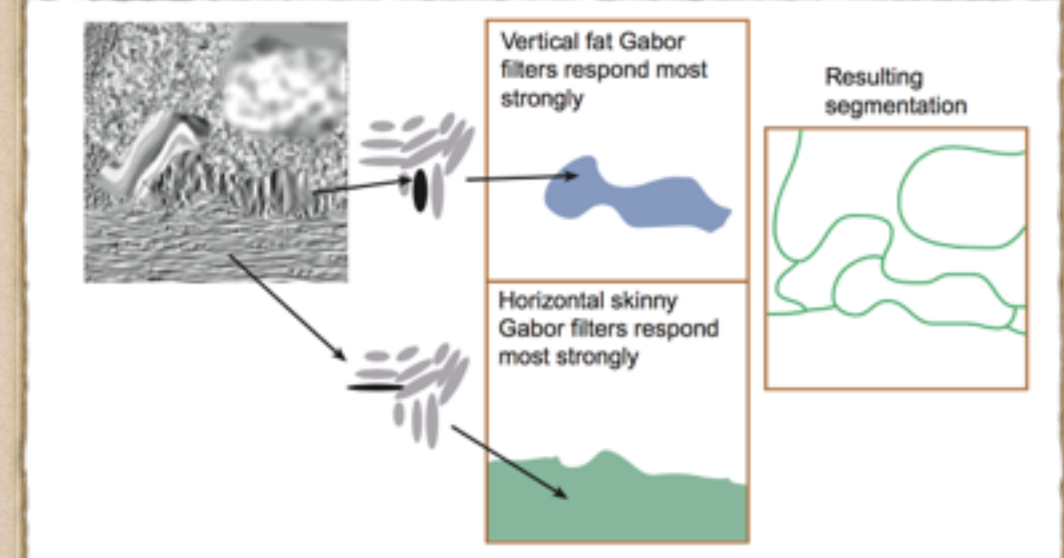

Figure 6.29 A texture segmentation model. Two-dimensional feature maps of Gabor detectors filter every part of the image for all possible orientations and sizes. Extended areas that excite similar classes of detectors form perceived regions of the image.

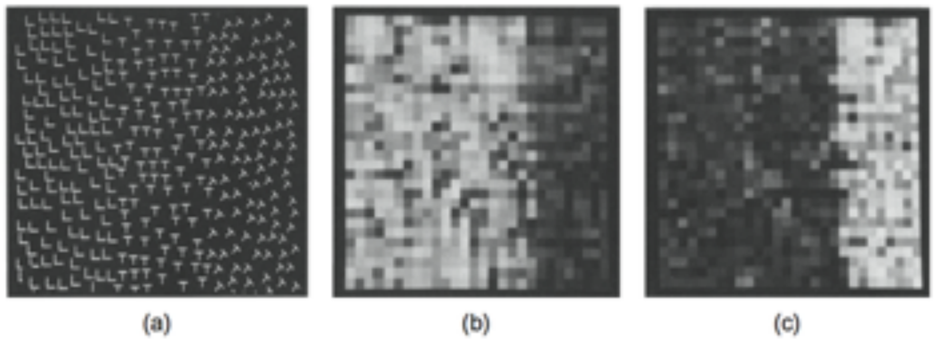

Figure 6.30 (a) The Ts and Ls in the left and middle are difficult to visually separate, but the region of rotated Ts on the right is easier to spot. (b) The output of a feature map consisting of vertical Gabors. (c) The output of a feature map consisting of oblique Gabors. (*From Turner (1986). Reproduced with permission.*)

Chapter 11

Visual Thinking Processes

- [G11.1] Design cognitive systems to maximize cognitive productivity.
- Cognitive productivity is the amount of valuable cognitive work done per unit of time.