meanings, we use context to select the meaning intended by the speaker. But context is involved at an even earlier level in speech perception because it allows us to recognize sounds as words. We perceive spoken words as a sequence of vowel and consonant sounds, that is, as a sequence of phonemes. Perceptually, each phoneme seems fixed, but acoustically, a phoneme can vary considerably depending on context. We hear the same /d/ sound in *die* and *due,* but the initial auditory signal of these words is different. This difference arises because of the flowing nature of speech production. As we articulate one phoneme, we are preparing to articulate the next, and the resulting co-articulation is reflected in the acoustical signal. The processes that underlie speech perception use contextual information to automatically and effortlessly compensate for the effect of co-articulation, resulting in a phonemic constancy similar to the lightness constancy described earlier.

In some situations, such as a noisy party or a crowded restaurant, the acoustical signal may be insufficient for reliable speech recognition. In these situations, we may rely heavily on lipreading to understand what is being said. But even when the speech signal is clear and we are not consciously paying attention to the speaker's mouth, visual context can influence phoneme perception. This automatic processing of facial movements explains why a dubbed movie can be particularly difficult to understand: We cannot ignore the visual context even when it is misleading.

Like the other aspects of perception described here, phoneme recognition is a topic of intensive research. Although this process is not completely understood, a full description will involve the integration of contextual information across time and across senses. Although it may seem paradoxical, we perceive phonemes as having stable properties that are independent of context precisely because we are so adept at interpreting them in context.

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See also Constancy; Lightness Constancy; Motion Perception; Nonveridical Perception; Speech Perception; Vision; Visual Scene Perception

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CONTRAST ENHANCEMENT AT BORDERS

Nineteenth-century visual scientists such as Michel-Eugène Chevreul, Ernst Mach, Hermann von Helmholtz, Ewald Hering, and Johannes Peter Müller discovered that simultaneously presented stimuli could affect each other's perceived contrast. For example, notice how each of the solid stripes in Figure 1 appears lighter on the left than on the right, even though each stripe has the same physical intensity across its width. This illusion is called "Mach bands," and it illustrates how the contrast of a stimulus is enhanced at its borders. This entry describes spatial and temporal contrast enhancement at borders.

Spatial Contrast Enhancement at Borders

Visual spatial contrast is the perceived difference in brightness or color between two or more locations in the visual scene. Perceived contrast is determined by the physical difference in intensity and color between two adjoining areas. Thus, contrast is not

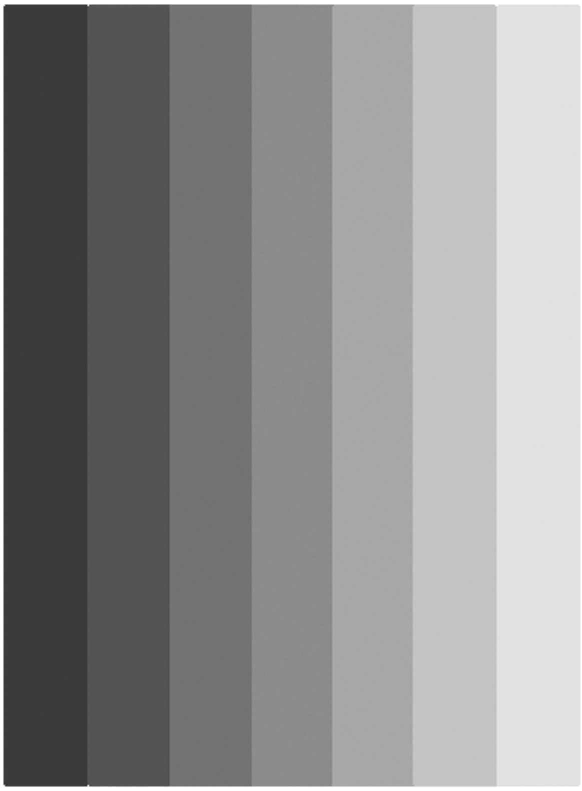

Figure 1 Mach Bands

Source: Chevreul, M. E. (1987).

Notes: This Mach band demonstration was originally designed by Chevreul in 1839. Notice how each vertical stripe appears to be lighter on the left than on the right. This illusory effect is caused by contrast enhancement at the borders.

a physical quantity but a perceptual comparison between two areas. The neural computation underlying the perception of contrast is partly carried out by lateral inhibition circuits in the visual system. Lateral inhibition is the process by which an excited neuron suppresses the activity of its neighbors across visual space. Lateral inhibition circuits are found in all levels of the visual system (such as in the bipolar and ganglion cells of the retina) as well as in other sensory systems. One perceptual consequence of lateral inhibition is that stimuli to both sides of a luminance border are differentially enhanced in an illusory fashion (as in Figure 1).

Another corollary of contrast enhancement at borders is that non-borders (such as the interiors of objects) are perceptually suppressed by the same lateral inhibition circuits that enhance the borders. Indeed, neurons in early visual areas are activated only by the borders (edges or corners) of stimuli, not by their interiors. The process is metabolically efficient in that it reduces the metabolic demand required to respond to the presentation of a stimulus. Only the neurons at the edges of surfaces require energy to respond, whereas the neurons in the interiors do not require as much energy (because they are quiescent). Thus, our visual system sees the edges of surfaces, and then uses this information to create the middles, through a process called filling-in. The neural circuits underlying filling-in have been localized to cortical visual areas beyond area V1 (such as areas V2 and V3).

Temporal Contrast Enhancement at Borders

Contrast is increased at their temporal borders (that is, their onsets and terminations) as well as at the spatial borders of stimuli, also because of lateral inhibition. And just as the interiors of spatial stimuli are suppressed when compared with their borders, so too are the temporal mid-lives of stimuli suppressed when compared with their onset and termination. The result is that the perceived contrast of a stimulus is highest just after it turns on and then again after it turns off. Visual masking (the effect in which the visibility of a target stimulus is reduced by a masking stimulus that does not overlap the target in space or time) occurs perceptually when the neural responses to the target onset or termination are inhibited.

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See also Contrast Perception; Lateral Inhibition; Light Measurement; Receptive Fields; Vision: Temporal Factors; Visual Illusions

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CONTRAST PERCEPTION

Sensitivity to light is common in the animal word. Even the one-celled euglena have eyespots that enable them to sense light. Only animals with eyes can sense differences in the light coming from different objects in their environment (*contrast*). Humans sense the intensity of light, but they are much more sensitive to contrast. What this means is that when intensities change slowly, as at sunset, we can tell that the intensity of light is changing, but we have a much better sense of differences in brightness between one object and another (*contrast perception*). Sensitivity to contrast makes it possible for us to see in detail what is around us and to do so over a huge range of intensities. This ability depends critically on the fact that different objects reflect light differently. Both the intensity and the spectrum (wavelengths) of light vary from one region of a scene to another. For example, in a scene with grass and a dark gray road, the grass will reflect more light and the light will be concentrated in the middle wavelengths; the road will reflect less light and it will have a broad spectrum of wavelengths. In this example, as in most real-world situations, both brightness contrast and color contrast are present. This entry focuses on brightness contrast perception.

There are several different measures of contrast, but they all indicate the *ratio* of light intensity in one location to the intensity in another. For scenes that are seen by reflected light, as most scenes are, the contrast remains constant as the light falling on the scene (illumination) changes. For example, going from bright daylight to dusk, the contrast (ratio) between the intensities of the grass and the road remains the same. Many visual systems, including ours, are designed to be sensitive to contrast.

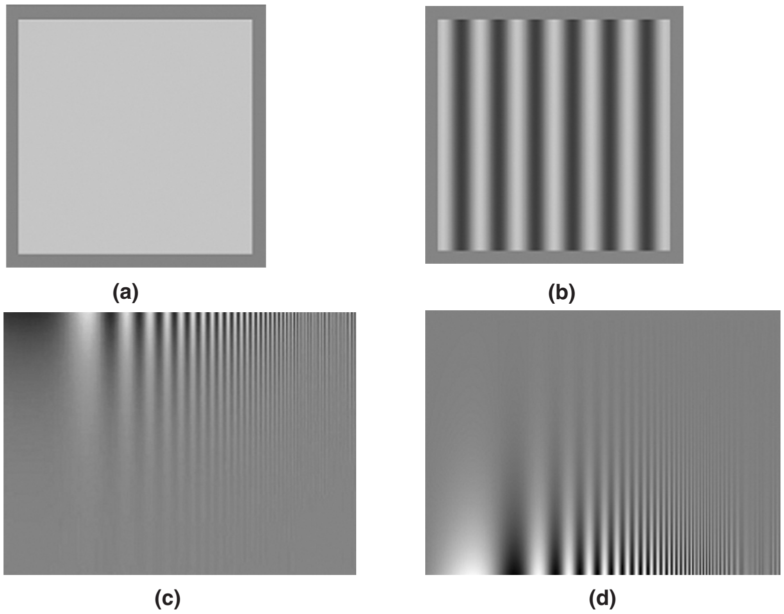

Figure 1 Spatial Patterns and Contrast Perception

Notes: (a) A uniform gray rectangle on a darker background. (b) A sine wave grating with the same contrast as the rectangle and background in 1(a). (c) A grating that decreases in stripe width from left to right and decreases in contrast from bottom to top. At normal reading distance, stripes of middle widths are visible higher in the image and thus at lower contrasts than are wide or narrow stripes. We see intermediate stripe widths better than we see wide or narrow stripe widths. The stripes that are seen best will vary with distance because the width in the retinal image determines visibility. An image like this was first created by Fergus Campbell and John Robson in 1964.