Chapter 53. Second-order Mach Bands Chevreul, and Craik-O'Brien-Cornsweet Illusions

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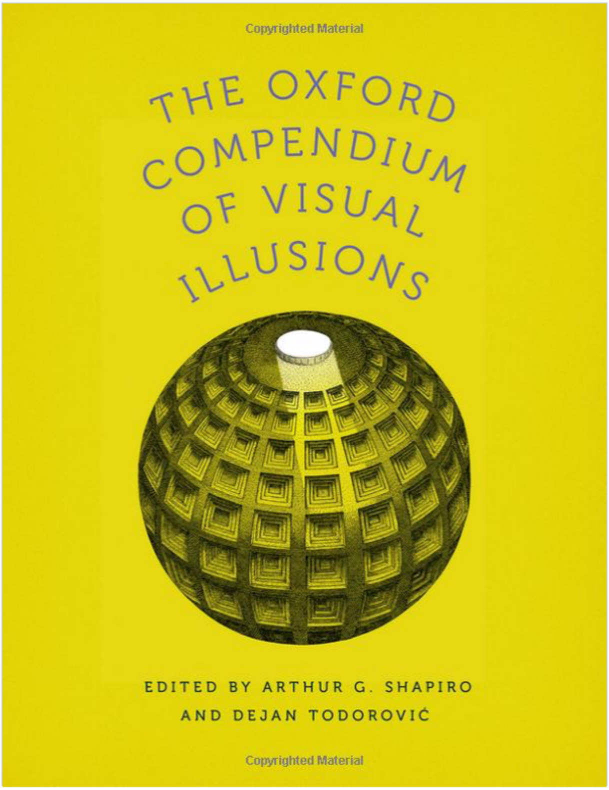

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Chapter 53
Second-Order Mach Bands, Chevreul, and Craik-O'Brien-Cornsweet Illusions

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INTRODUCTION

When two plateaus of constant luminance are joined by a linear luminance ramp (Fig. III.53-1a), illusory bands are perceived at the junctions—an induced dark band is perceived at the bottom of the ramp and a bright band near the top of the ramp (Fig. III.53-1b). This illusion was reported by Ernst Mach in the 19th century (Mach, 1865; Ratliff, 1965; Ross, Holt, & Johnstone, 1981) and now bears his name. Chevreul illusions (Cheveul, 1890; Ross et al., 1981; von Békésy, 1968) can be demonstrated with a luminance staircase that increases from step to step (Fig. III.53-2a–b). In the Craik-O'Brien-Cornsweet illusion (C-O-C; Cornsweet, 1970; Craik, 1940; O'Brien, 1958), concentric black and white rings imposed on a uniform surface change the (apparent) brightness of the entire circumscribed area (Fig. III.53-3a–b). In all of these illusions, the spatial distribution of perceived brightness diverges strikingly from the physical distribution of luminance. Lu and Sperling (1996) replaced the spatial variations of luminance in the stimuli that generate the three classic brightness illusions with spatial variations in texture contrast (Figures III.53-1c, III.53-2c, III.53-3c). The results are called second-order illusions because the theory for second-order processing involves two successive stages (Chubb & Sperling, 1989): first, a stage of rectification (a grossly nonlinear transformation) of luminance represented as positive and negative deviations of the luminance at a point from the overall mean luminance, and second, an analysis of the rectified deviations similar to the analysis of the original luminance stimuli.

The root of our second-order illusions is a random dynamic texture, the carrier, in which the luminance of each pixel is chosen randomly and independently and in which the expected luminance value of every pixel is the same. Imposed on this carrier texture there is a spatial modulation of contrast. The modulator of contrast in second-order textures serves the same role as a modulator of luminance in classical (first-order) patterns. However, in the second-order stimuli, only contrast modulation varies across space; the expected luminance is the same everywhere. To recover the modulator function from a first-order stimulus, we simply measure the luminance at each point and subtract the mean luminance. To recover the modulator function from a second-order texture stimulus, it is necessary to rectify the contrast values of each pixel of the stimulus. The (Weber) contrast of a pixel in an image is the luminance of that pixel minus the mean luminance of the image; that difference is then divided by the mean luminance of the image. A positive contrast indicates that a pixel is brighter than the mean brightness of the image, a negative contrast means that it is darker than the mean. Full-wave rectification is a monotonically increasing function of the absolute value of contrast (e.g., the absolute value itself, as in all the examples here) or the squared contrast. Except for random fluctuations, a random texture becomes equivalent to an ordinary luminance pattern upon absolute value rectification (Chubb & Sperling, 1989) and becomes accessible to standard linear analyses (matched linear filter followed by energy detection; e.g., Sperling, 1964).

Second-order Mach bands, Chevreul, and C-O-C illusions are shown in Figures III.53-1c, III.53-2c, and III.53-3c. In

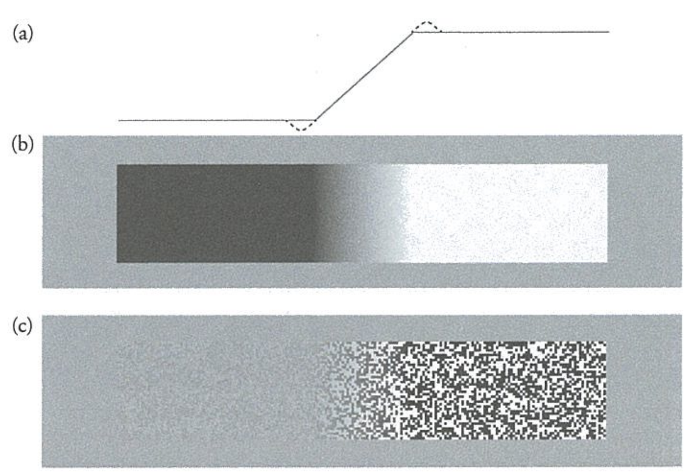

Figure III.53-1. (a) Luminance modulation function (luminance as a function of space) for a classical Mach band stimulus. The dotted curves illustrate the percept. (b) A first-order Mach band pattern. (c) A second-order Mach band pattern. Decreased brightness/contrast is perceived near the foot of the ramp, and increased brightness/contrast is perceived near the top of the ramp in (b) and (c). (Reproduced with permission of Z.-L. Lu and G. Sperling.)

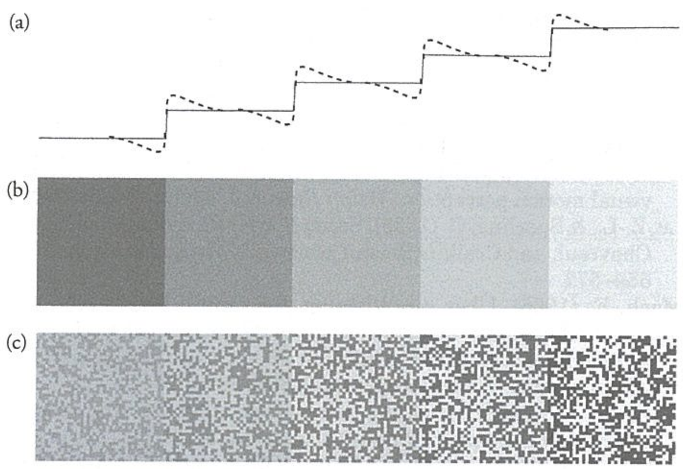

Figure III.53-2. (a) Luminance modulation function (luminance as a function of space) for a classical Chevreul stimulus. The dotted curves illustrate the percept. (b) A first-order Chevreul stimulus pattern. (c) A second-order Chevreul stimulus pattern. An illusory brightness/contrast valley is perceived at the foot of each step and an illusory peak brightness/contrast at the lip of the step in (b) and (c). (Reproduced with permission of Z.-L. Lu and G. Sperling.)

formal experiments, these stimuli are calibrated photometrically and psychophysically so that the modulator is invisible to first-order processes. Luminance calibration is not possible in a printed version. Also, the formal experiments involve dynamic stimuli, only a single frame of which is shown in the printed version. The magnitude of the second illusions depends on viewing distance—a close viewing distance works better.

When viewing the second-order Mach band patterns (Fig. III.53-1c), our observers reported that they perceived a low-contrast band near the low-contrast end of the ramp and a high-contrast band near the high-contrast end of the ramp. These subjective impressions were quite strong. A contrast-matching experiment using reference bars placed at six spatial locations, corresponding to the top and bottom of the ramp and the two plateaus, confirmed and quantified the general subjective impressions. We found Mach bands with generally similar magnitudes in luminance and in these second-order texture-contrast stimuli.

In the Chevreul illusion, a contrast modulator is made of monotonically increasing (or decreasing) steps. We generated both first-order (luminance) and second-order Chevreul stimuli (Fig. III.53-2). Each stimulus has five steps and all stimuli have the same overall spatial dimensions. When viewing the second-order texture-contrast and luminance Chevreul patterns, all six observers reported that they perceived low-contrast bands on the foot side of edges and high-contrast bands on the lip side of edges. These subjective impressions were quite strong. A nulling procedure confirmed and quantified the general subjective impressions: the magnitudes of the illusory Chevreul bands were estimated by the magnitudes of the incremental hills and valleys needed to cancel the illusion. The measured amplitudes were quite similar for the first-order luminance stimulus and for the second-order noise texture.

The stimuli that exhibit the C-O-C illusion are composed of textures whose modulator is a function only of radius in a polar coordinate system (Fig. III.53-3). In the experiment, modulator consists of four segments: (a) a constant

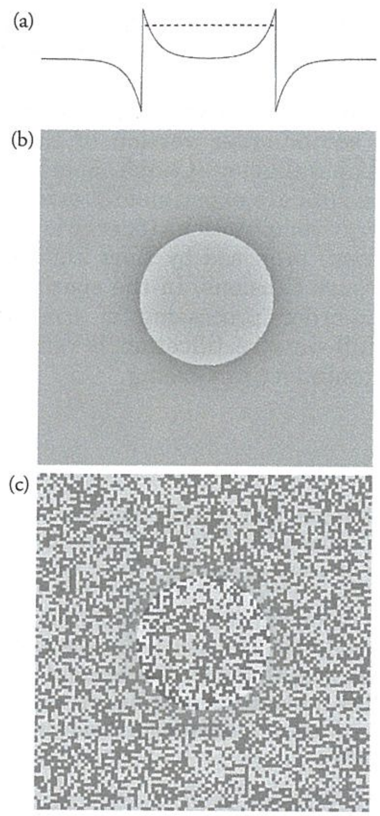

Figure III.53-3. (a) A luminance modulation function (luminance as a function of space) for a classical C-O-C stimulus. The dotted line illustrates the illusory percept. (b) A first-order C-O-C stimulus pattern. (c) A second-order C-O-C stimulus pattern. The illusion is an increase in apparent brightness/contrast of the entire central area in (b) and (c). (Reproduced with permission of Z.-L. Lu and G. Sperling.)

inner disk; (b) an inner ring with smaller than average values of the modulator; (c) an adjacent, concentric outer ring with larger values; and (d) the background with the same value as the inner disk. Seven comparison patterns, differing only in inner disk contrast values, were displayed simultaneously with the C-O-C patterns. Subjects were instructed first to look at the C-O-C pattern for 5 s and then to find and select the comparison stimulus whose inner disk contrast best matched the center contrast of the C-O-C pattern. All subjects—indeed everyone who has seen the full-wave C-O-C pattern—has invariably matched it to a comparison pattern with lower center contrast. The second-order C-O-C stimulus reliably produces an illusory reduction of contrast of magnitude comparable to the illusory contrast reduction in the first-order version.

Classical Mach bands, Chevreul, and C-O-C illusions are demonstrated in dynamic full-wave stimuli (i.e., stimuli made up of random carrier textures and modulators that, when subjected to absolute value rectification, become equivalent to the stimuli used in the original first-order illusions). None of these illusions is perceptible in half-wave stimuli (Lu & Sperling, 1996), that is, stimuli that are neutral to first-order (Fourier) and to second-order (full-wave) analyses but become equivalent to luminance stimuli after positive or negative half-wave rectification. Together these results indicate that the perceptual processes governing second-order spatial interactions, like those governing second-order motion perception (Chubb & Sperling, 1989; Lu & Sperling, 1995; Solomon, Sperling, & Chubb, 1993), reflect full-wave (versus half-wave) rectification. Full-wave interaction was experimentally demonstrated as the modus of the second-order version of the simultaneous brightness contrast illusion (Chubb, Sperling, & Solomon, 1989). These results are experimental evidence in favor of the type of energy computations (energy is square-law full-wave rectification) proposed by Burr and Morrone (1994) to account for such illusions. In the spatial domain, as in motion, second-order processing of contrast-modulated stimuli, after full-wave rectification, is remarkably similar to first-order luminance processing.

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