Chapter 72. Attention-generated apparent motion

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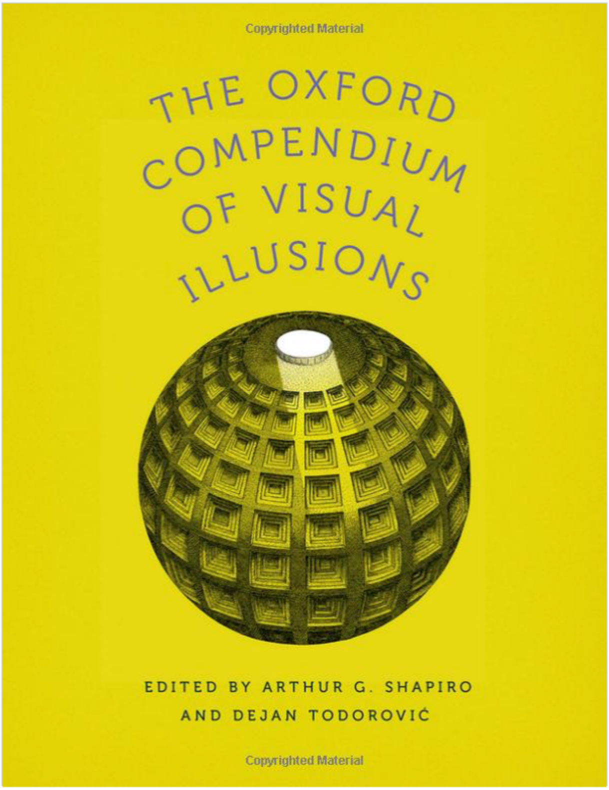

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Chapter 72
Attention-Generated Apparent Motion

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In attention-generated apparent motion (AGM), a display that appears to flicker but does not appear to have any obvious direction of motion will suddenly appear to move in a consistent direction when a particular feature in the display is attended. In the AGM displays illustrated in this chapter (Figs. IV.72-1, IV.72-2, and IV.72-3), attention causes apparent motion in either one of two opposite directions depending on the feature attended, such as left versus right slanting lines, black versus white dots, or red versus green stripes (Blaser, Sperling, & Lu, 1999; Lu & Sperling, 1995a). A variant of the procedure involves attending to a feature in a different task for an extended time period before the motion task. For example, looking for a red target in a visual search task for about an hour of total viewing time caused the direction of perceived motion in subsequently viewed ambiguous motion displays to remain biased in the "red" direction for a month (Tseng, Gobell, & Sperling, 2004).

The AGM illusion was created to demonstrate the existence of and reveal the mechanisms of feature-salience motion (third-order motion) perception. This required stimuli that were invisible to first- and second-order motion processes. The critical aspect was that only a feature's salience was marked from frame to frame, not the feature itself. A motion system transmits information only about the location, direction, and speed of movement. Information about what is moving—the features themselves—is carried by a pattern processing system. The key to demonstrating feature-salience motion is to use voluntary attention to influence which features are marked as salient in alternating-feature displays, in which frames made of one type of stimulus material are interleaved with frames made of another, entirely different type of material (Cavanagh, Arguin, & von Grunau, 1989). It does not matter if the actual features being marked change from frame to frame, as long as the marked locations follow a consistent motion trajectory.

The AGM illusion uses alternating feature displays with the following properties. First, motion is invisible to the first-order (Adelson & Bergen, 1985; Reichardt, 1957; Van Santen & Sperling, 1984) and second-order (Cavanagh & Mather, 1989; Chubb & Sperling, 1989) motion perception systems and would be visible only to a feature-salience motion system (Lu & Sperling, 1995a, 1995b, 2001b). Perceiving motion requires combining salience information from the two different materials. Second, one stimulus feature is inherently more salient in one type of frames. Third, the to-be-attended features are entirely ambiguous (have equal salience) in the other type of frames. Fourth, verbal instructions direct the subject to attend only to one of the two kinds of features in the feature-ambiguous frames, and fifth, opposite motion directions are perceived depending on which feature is attended in the equal-salience frames.

Three different kinds of alternating-feature display stimuli are illustrated: depth/texture gratings (Fig. IV.72-1), full-wave/half-wave gratings (Fig. IV.72-2), and full-wave/color gratings (Fig. IV.72-3). In the depth gratings (Figs. IV.72-1b, IV.72-1d), for most observers, the near-appearing peaks are naturally more salient than the background valleys; however, the two textures in Figures IV.72-1a, IV.72-1c, and IV.72-1e have equal salience. In the full-wave gratings (Fig. IV.72-2), the high-contrast areas are naturally more salient than the low-contrast areas. Half-wave gratings (Solomon & Sperling, 1994) are made of alternating areas of white dots on a dark grey background and black dots on a light grey background. After calibration for each subject (Lu & Sperling, 2001a), the areas of white and of black spots have equal salience. In the isoluminant chromatic gratings (Fig. IV.72-3), after isoluminant calibration for each subject (Lu & Sperling, 2001a), the relative salience of the red and green areas depends on the ratio of their chromaticity; the red and green areas can be made to have equal salience by adjusting the ratio (Blaser et al., 1999; Claeys, Lindsey, De Schutter, & Orban, 2003; Lu, Lesmes, & Sperling, 1999).

In all three alternating-feature displays, the phase shift between successive frames is 90°, thereby successive even-numbered frames in the sequence are separated by 180°, as are successive odd-numbered frames. Motion between frames separated by 180° is totally ambiguous. The perception of coherent motion would require combining information from even and odd frames, which are separated by 90°, the ideal separation for motion detection (Van Santen & Sperling, 1984). For each given alternating-feature motion display, the

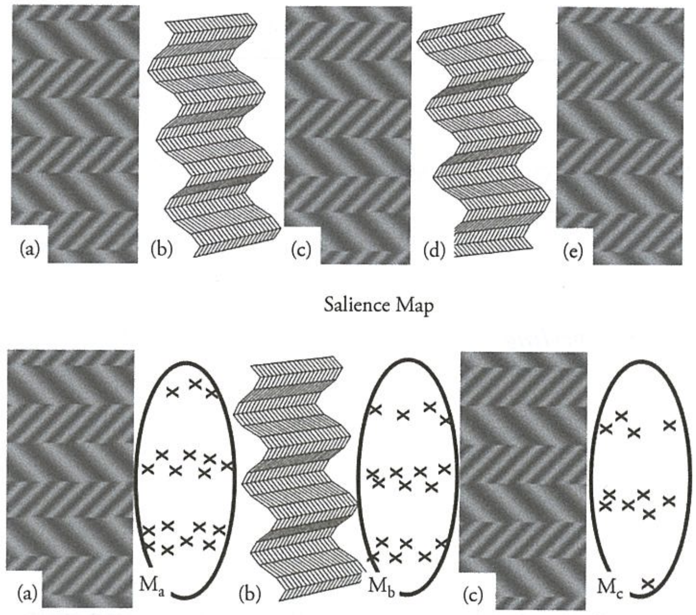

Figure IV.72-1. The depth/texture alternating feature display. First row: A sequence of five superimposed consecutive frames (a–e); the grating pattern in each frame is displaced by 90° from the previous one. The texture frames (a, c, e) are shown as they appeared to the observer; the depth stereograms, (b, d; uniformly textured surfaces that vary in perceived depth) are indicated schematically. Second row: First three frames (a, b, c) and a feature-salience map associated with each frame. The most salient features of the depth frames are the near peaks (upper peaks in the panels) marked by Xs in the salience map (M_b). When a subject attends to the coarse grating, the coarse stripes are marked in the salience map (Xs in M_a and M_c). The direction of perceived motion (downward) follows the space-time trajectory of the Xs as indicated by the dashed line from upper left to lower right. The opposite direction of motion has no support in M_a and M_c; perceiving this bottom-to-top motion would require attending to the fine stripes. (After Lu, Z. L., & Sperling, G. (1995a). Attention-generated apparent motion. *Nature, 377*(6546), 237–239, with permission.)

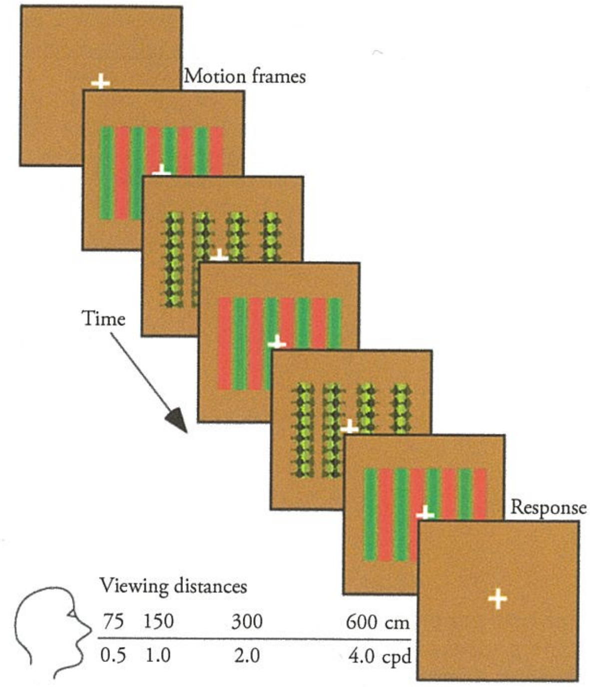

Figure IV.72-3. Five frames of the fullwave/chromatic gratings stimuli. The term "full-wave" merely indicates alternating areas of high- and low-contrast random binary noise; chromatic gratings are isoluminant color gratings. (Sperling, G., Reeves, A., Blaser, E., Lu, Z.-L., & Weichselgartner, E. (2001). Two computational models of attention. In J. Braun, C. Koch, & J. L. Davis (Eds.), Visual attention and cortical circuits. Cambridge, MA: MIT Press. Pp. 177–214, with permission.)

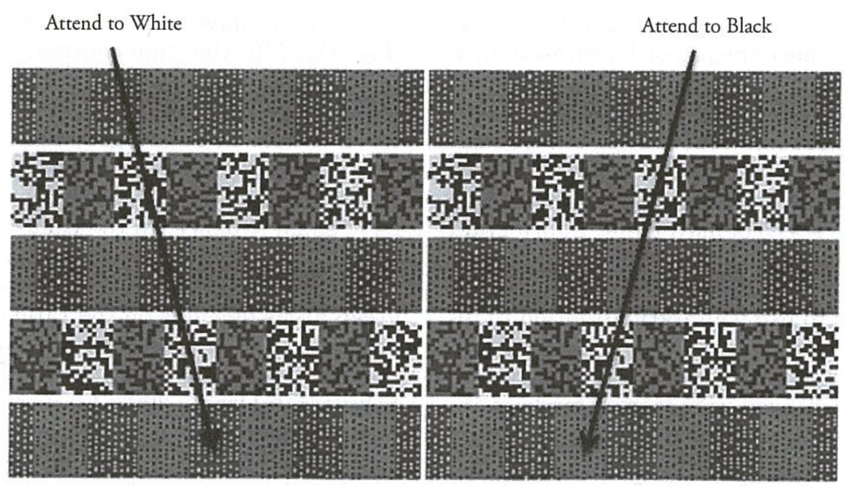

Figure IV.72-2. Left column: Five frames of the full-wave/half-wave stimuli. The term "full-wave" indicates alternating areas of high- and low-contrast random binary noise; "half-wave" indicates alternating areas of white dots on a dark grey background and black dots on a light grey background. Both frames have the same expected luminance everywhere and therefore do not stimulate the first-order (luminance) motion system. Prior to any attention instructions, the half-wave frames are calibrated individually for each subject to find a contrast ratio of white to black for which the direction of perceived motion of the displays was completely random. Right column: The trajectory from high-contrast areas of full-wave frames (which are automatically salient) to white spots of half-wave frames (made salient by attention) produces perceived motion to the right. Within an experimental session, only one type of attention instruction is given. (After Lu, Z. L., & Sperling, G. (2001). Sensitive calibration and measurement procedures based on the amplification principle in motion perception. *Vision Research, 41*(18), 2355–2374, with permission.)

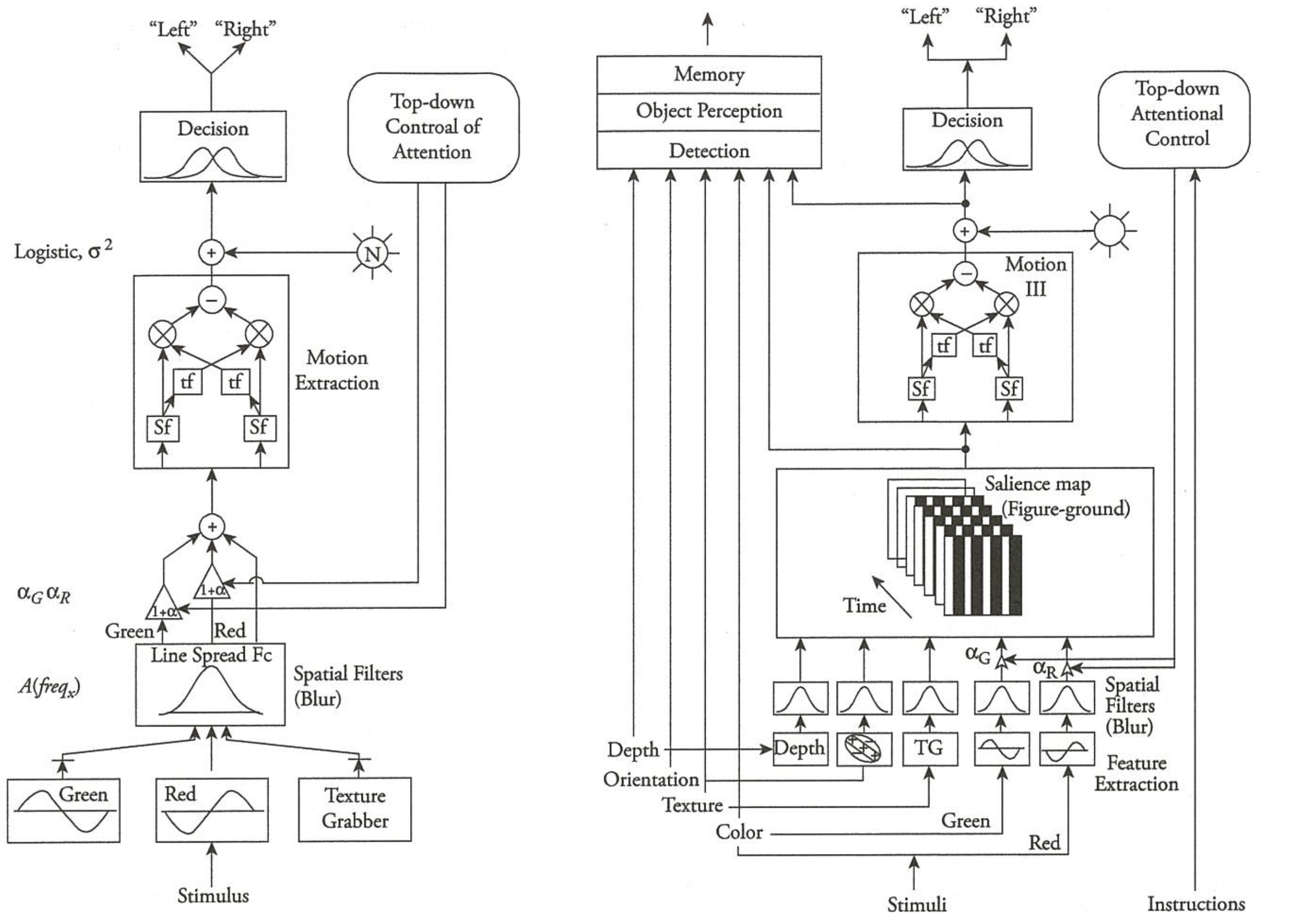

Figure IV.72-4. Models for attention processes in third-order motion. (a) A computational model of attention processes in third-order motion that in (b) is embedded in a more comprehensive model of visual processing. The inputs to the model are stimuli and attention instructions; the computational output is a direction-of-motion judgment. There are two types inputs: visual stimuli and attention instructions. Stimulus inputs are analyzed along various dimensions: depth, orientation, texture, and color channels are indicated. For the present experiments, it is only necessary to consider color (red and green) and texture processing. Instructions to attend to a color are assumed in only the salience pathway to increase the gain of the attended color signal to a value greater than 1.0 so that the attended color input is amplified by $1 + \alpha_G$ or $1 + \alpha_R$. The salience map is the sum of all the stimulus inputs in the salience pathway; its output goes to the Motion III (third-order) computation and (in b) also joins the stimulus inputs in the object-processing pathway. The third-order motion computations is represented as a Reichardt model. It produces a real-valued output that indicates a direction of motion and is perturbed by additive noise N. A decision process outputs a response "right" if its input is greater than a criterion and "left" otherwise. (b) A more general model that shows sensory inputs bypassing the salience computation en route to subsequent processing. Although high salience does not seem to perturb the appearance of objects, it does eventually determine what signals are analyzed and remembered. The third-order motion signal is also available to subsequent perceptual processes, as indicated. (After Blaser, E., Sperling, G., & Lu, Z. L. (1999). Measuring the amplification of attention. *Proceedings of the National Academy of Sciences USA, 96*(20), 11681, and Sperling, G., Reeves, A., Blaser, E., Lu, Z.-L., & Weichselgartner, E. (2001). Two computational models of attention. In J. Braun, C. Koch, & J. L. Davis (Eds.), Visual attention and cortical circuits. Cambridge, MA: MIT Press. Pp. 177–214, with permission.)

perceived motion direction depends on which stimulus feature is being attended in the equal-salient frames.

Lu and Sperling (1995a) found that, at a rate of 67 ms/frame, some subjects immediately perceived motion in a direction consistent with the attention instruction. Others did not. However, after several hundred trials, every subject who participated in the experiment perceived motion in the direction consistent with the attention instruction. At this point, the instruction was reversed (i.e., attend to the previously unattended texture), and trials were continued until performance again stabilized. The task is easier at slower frame rates (e.g., 133 ms/frame). Blaser et al. (1999) showed that the perceived direction from the full-wave/chromatic gratings display depends on both the ratio of chromaticity of the red-green grating and attention instruction; attention amplifies the salience of the attended color. Tseng et al. (2004) showed that, after about one hour of searching for red targets in a search experiment, perceived motion direction from the full-wave/chromatic gratings display remained biased in the red direction for a month.

The latent motion in AGM displays is invisible to first- or second-order motion mechanisms, and the direction of apparent motion depends on the particular feature attended. The illusion suggests the mechanism of third-order motion: At each moment in time, the *x, y* locations of the most significant features are marked (the salience map; Itti, Koch, & Niebur, 1998; Koch & Ullman, 1985). For example, when figure–ground distinctions are meaningful, being marked leads to being labeled "figure." Motion is computed by standard algorithms (Adelson & Bergen, 1985; Reichardt, 1957; Van Santen & Sperling, 1984) from the spatiotemporal changes of the map (Fig. IV.72-4a).

AGM and other related phenomena are all encompassed within the salience map theory (Fig. IV.72-4b). A dynamic salience map of the locations of the most salient stimulus features is determined jointly by stimulus strength (bottom-up) and by selective attention (top-down). Motion is computed directly and automatically from the salience map, but the map also can be used to guide other processes such as object recognition in attention-guided search and memory storage in location-cued recall tasks (Shih & Sperling, 2002; Sperling, 1960).

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