Chapter 64

High-Level Organization of Motion

Ambiguous, Primed, Sliding, and Flashed

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Ambiguous Apparent Motion

In stroboscopic or apparent motion, a spot that jumps back and forth between two positions appears to be moving continuously back and forth, probably because it is adequate, although not optimal, to stimulate neural motion detectors.

[insert Video IV.64-1 here]

Ambiguous apparent motion stimuli can be constructed, as in the two-frame Video IV.64-1. Frame 1 flashes up two red spots at opposite corners of an imaginary square. Frame 2 flashes up spots at the other two corners (Gengerelli, 1948). What do you see? You may see horizontal apparent motion, back and forth along the top and bottom of the square, or you may see vertical apparent motion, back and forth up and down the left and right sides of the square. The stimulus is ambiguous and supports both of these interpretations equally, and your percept is likely to change back and forth pseudo-randomly between horizontal and vertical motion, even while the stimulus stays the same. If you attempt to influence which you see by means of "willpower," at first it seems possible, but then the percept seems to escape and show, as if it had a will of its own. Hiding two spots removes the ambiguity. Fixate the central cross and cover the two bottom spots with your hand. You will now see unambiguous horizontal motion along the top of the square. Remove your hand and the horizontal motion continues to dominate—

for a while. Similarly, covering up the two right-hand spots forces vertical motion up and down the left side of the square, which continues when all four spots are uncovered—for a while. This display is bistable, just as a Necker cube is, and the changing percepts from an unchanging stimulus are a way to see your brain's computations at work.

[insert Video IV.64-2 here]

Proximity can reduce ambiguity. In Video IV.64-2 one usually sees motion along the short edges of the rectangles: horizontal motion along the short top and bottom edges of the tall rectangles and vertical motion along the short vertical sides of the wide rectangles. Thus the visual system prefers to minimize path lengths.

There is a permanent perceptual bias in favor of seeing up-and-down motion between vertically aligned spots, which are both contained in one cortical hemisphere, as opposed to side-to-side motion of horizontally aligned spots on either side of the midline, which requires collaboration between the two hemispheres. For this reason it is better to put the spots at the corners of an imaginary diamond instead of a square.

Long-range spatial interactions affect the perceived apparent motion (Ramachandran & Anstis, 1983). If several such bistable figures are randomly scattered on a screen and presented simultaneously, then observers always see the same motion axis in all of them (all move vertically or all move horizontally), suggesting the presence of global field-like effects for resolving the motion ambiguity.

[insert Video IV.64-3 here with a b c under each image]

Temporal interactions can prime the perceived direction of apparent motion if a prior frame is added containing two more spots in line with two parallel sides of the diamond, as in Video IV.64-3a (Anstis & Ramachandran, 1987). The upper spot now always moves along those sides, down to the right, not the left, because the visual system prefers to see motion in a straight line rather than along an L-shaped trajectory. Visual inertia is still seen when the priming dots are presented to one eye and the test dots to the other, so the effect must be partly central. This “visual inertia” is also shown in Video IV.64-3b (Anstis & Ramachandran, 1987). In (b), an upright cross that suddenly jumps through 45° is ambiguous, since the apparent motion is equally likely to be clockwise (CW) or counterclockwise (CCW). But adding an initial cross that jumps unambiguously CW first biases the motion to be always CW.

In the same way, Pinkus and Pantle (1997) noted that the perceived motion of a vertical sine-wave luminance grating that undergoes an abrupt 180° phase shift (motion step) is ambiguous. The grating sometimes appears to move rightward, sometimes leftward. However, when the 180° step follows closely upon an unambiguous grating step of 90° to the right, as in Video IV.64-3c, the 180° step also appears to be to the right.

Local/Global Motion

Ambiguous static pictures such as the Necker cube or Rubin’s face/vase are very well known, but I shall now describe some ambiguously moving patterns, which the visual system can organize perceptually in different ways corresponding to different aspects of the movement (Anstis & Kim, 2011). The Gestalt notion of “common fate” needs to be refined to account for these ambiguities.

[insert Video IV.64-4 here]

Video IV.64-4 shows four pairs of red spots, each pair rotating about their common center. But if one inspects this pattern for 10 to 20 s, the pattern can suddenly reorganize and be seen as two large squares drifting over each other. I call this “local motion” when each spot groups with its single nearest neighbor, forming four pairs, and "global motion" when the spots reorganize into two quartets. During prolonged inspection the local and global motion tend to alternate, with the global motion gradually becoming more frequent. Proximity or similarity to local or distant partners can bias the percept toward local or global motion.

[insert Video IV.64-5 here]

Thus Video IV.64-5 tends to be seen locally as four pairs of inward-looking faces. Setting members of each pair closer together or farther apart promotes local or global motion, respectively, and increasing the number of spots within a group from two to three or four makes the motion look more local (not shown).

In Video IV.64-6 one generally sees eight local pairs of spots moving around circular orbits, especially if one looks straight at a pair. When the circles are removed, as in Video IV.64-7, one generally sees two global, interdigitated octagons, especially if one looks at the middle of the figure.

[insert Video IV.64-6 here]
[insert Video IV.64-7 here]

Local and global motion are two different and incompatible solutions to the problem of binding dots into groups. They are incompatible because it is impossible to see the same dots as partaking in local and global groups simultaneously. I suspect that local motion is preattentive, whereas global motion is attentive. Local and global perceptual organizations are like scientific hypotheses that attempt to group the most data under the fewest and most general laws. Thus global motion would be a more generalized perceptual achievement because it organizes more spots into fewer groups.

Flying Bugs

The flying bugs illusion is an example of induced movement or relative movement (Duncker, 1929/1955). A familiar example is the moon, which appears to be sailing to the right when clouds drift across it moving to the left. The flying bugs illusion convincingly demonstrates that a moving background can strongly influence the perceived paths of small moving objects.

[insert Video IV.64-8 here]

In Video IV.64-8, two bugs fly around CW circular orbits, in counterphase so that when one bug is at 12 o'clock the other is at 6 o'clock. When a large background is added, also moving along a CW path without rotating and in step with the left-hand bug, there is a strong size illusion that the left-hand bug is flying around in much smaller circles than the right-hand bug, as shown in Video IV.64-9.

[insert Video IV.64-9 Size Illusion here]

This is because the left-hand bug moves exactly with the background, and therefore has zero movement *relative* to the background. The right-hand bug is out of phase with the background so it describes circles about twice as large as before *relative* to the background, although the orbits of both bugs have the same physical size.

[insert Video IV.64-10 here]

If the background reverses direction and moves CCW, a shape illusion is observed (Video IV.64-10). The left-hand bug seems to move mostly from side to side, while the right hand bug appears to move mostly up and down. This is because the circular motion of the bugs has a vertical (sin) component and a horizontal (cos) component. For the left-hand bug, the vertical component is in phase with the background so is mostly ignored, while its horizontal component moves in opposition to the background so is perceptually enhanced. The opposite is true for the right-hand bug.

[insert Video IV.64-11 here]

The background motion need not be continuous. In Video IV.64-11 it consists of a series of short-lived unrelated textures, with the first texture moving briefly toward 1 o'clock that is then abruptly replaced by a different texture moving toward 2 o'clock, then a third texture moving toward 3 o'clock, and so on. The moving textures look, and are, jerky and disconnected, but in combination they impart a smooth induced movement into the bugs' orbit, so this induced movement is local with respect to space.

Zivotofsky (2004) moved a single red test dot horizontally left or right while a dense background set of black dots on a white background moved vertically up or down. When the background-inducing dots moved up (down), the truly horizontally translating test dot appeared to drift at an angle down (up) from the horizontal. Farrell-Whelan, Wenderoth, and Wiese (2012) measured the angular function of Duncker's effect by moving the red spot in one direction and the random-dot background in a series of other directions. They found that induced movement was strongest when the two directions of motion differed by 30°, similar to the inducing angle that has been found to maximize other direction illusions.

Rhesus monkeys behave as if they perceive induced movement (Zivotofsky, Goldberg, & Powell, 2005). All of these results can be modeled by a simple algorithm in which the average motion of all the points in the whole field put together is subtracted from each individual point (Burt & Sperling, 1981).

Chopsticks Illusion

The closing blades of a pair of scissors form an intersection that can cut one's fingernails, and whose position can be perceived accurately, although it is not really an object. But moving intersections are sometimes grossly misperceived. In the chopstick illusion a vertical and a horizontal line overlap to form a cross. Each line follows a CW circular path without rotating, like the sponge in the hand of a window cleaner. The vertical and horizontal lines move in counterphase, with one line being at 6 o'clock when the other line is at 12 o'clock (Video IV.64-12a).

[insert Video IV.64-12 here]

The illusion arises in the central intersection where the lines cross. This intersection actually moves CCW around a circle, but it is incorrectly perceived as moving CW. The argument goes in two stages. First, the middle of each line gives no unambiguous information about its motion—that information comes from the tips or terminators of the lines. Second, the CW motion is in fact the relative movement of each of the two lines with respect to the other (Bruno & Bertamini, 2013). A tiny observer standing on either of the lines would see the other line as rotating CW around him or her.

If a floating outline square is added that just touches all four tips of the two rotating lines, the illusion is abolished and the intersection is correctly seen as a rigid X-intersection moving CCW, even though the terminators are fully visible (Video IV.64-12b). The reason is that the terminators are now seen not as informative true ends of lines but as the "extrinsic" visible parts of extended lines that continue behind the square frame and give no clue as to the real motion of the lines. Intrinsic terminators signal the physical end of an edge of an object, whereas extrinsic terminators are caused by occlusion. Intrinsic terminators provide an unambiguous motion signal regarding the true direction of object motion, while extrinsic terminators provide a locally ambiguous signal that must be suppressed for accurate motion computation (Liden & Pack, 1999; Shimojo, Nakayama, & Silverman, 1989).

Thus when the terminators are perceived as intrinsic, they drive the chopstick illusion, but when they are perceived to be extrinsic—a consequence of occlusion by the aperture—they are ignored. Stoner and Albright (1994) comment,

> [Results like these] are particularly important because they emphasize the ability of cues for feature classification to "act at a distance," governing the integration of motion signals at locations in the image where segmentation cues are either absent or ambiguous. Models of motion signal integration must thus provide for the influence of such non-local information.

Regarding Numbers of Intersections Versus Tips

In Video IV.64-12 there are four line terminators but only one intersection. We tested whether the tips won out by sheer force of numbers by increasing the number of lines. In Video IV.64-13 there are 10 vertical and 10 horizontal lines, which gives 40 terminators and 100 (= 10^2) intersections. Now the intersections outnumber the terminators by 2.5:1, yet a chopstick illusion is still seen. We conclude that the chopstick illusion is not caused by mere force of numbers.

[insert Video IV.64-13 here]

Instead of a horizontal and a vertical line, one can use two overlapping transparent squares, with each square moving CW. The places where the sides of the two squares intersect in Video IV.64-14 actually move CCW but appear to move CW. It is not necessary for the squares to obey the rules of transparency (Metelli, 1974): the illusion still holds whatever the brightness of the region of overlap (not shown).

[insert Video IV.64-14 here]

The shape of the aperture makes a difference. In Video IV.64-15 a the moving lines are viewed through an oblique slot in a *visible* black mask. This gives no illusion, and the central intersection looks like a rigid cross circling CCW. But Video IV.64-15b shows an oblique slot in an *invisible* white mask.

[insert Video IV.64-15 here]

In (a), the mask is visible and the intersection is correctly seen as rotating CCW, since the terminators are treated as extrinsic and ignored. In (b), the oblique mask is invisible and the illusion returns; the central intersection appears to move obliquely, parallel to the oblique paths of the terminators, because these terminators are treated as intrinsic and are taken into account.

[insert Video IV.64-16 here]

Eye Movements

Observers have great difficulty in tracking the movements of a sliding intersection. It moves CCW but appears to move CW, and eye movements show 10 times the errors of a control condition (not shown), in which observers simply track a cross that circles CW (Anstis & Ito, 2010). Video IV.64-16 shows the same stimuli as Video IV.64-12, with the real-time attempted eye-tracking movements of an observer superimposed in red. The blue disk that marks the intersection in the movie was not shown to the observer. Notice that the observer tracks very well when the vertical and horizontal lines are framed by a floating outline square, but his performance goes to pieces when the frame is removed so that the chopstick illusion reappears. The problem is that the sliding intersection is not parsed as an object. This suggests that pursuit eye movements are not driven by "dumb clockwork" but are instead dependent upon top-down signals based on object parsing. This almost 10-fold ratio in tracking errors suggests that smooth pursuit movements are not merely a bottom-up retinal feedback system (Krauzlis & Lisberger, 1994; Lisberger, Morris, & Tychsen, 1987) but may be strongly influenced by top-down cognitive processes such as object interpretation (Kowler, 1990).

[insert Video IV.64-17 here]

Sliding Rings

In Video IV.64-17 the terminators were removed by bending the lines around into rings. Two dots or gaps painted on each ring played the role previously played by the line terminators. These local dots radically altered the global percept of the entire rings. When the dots rotated in step with the rings (Video IV.64-17a), observers reported a single rigid welded figure eight, rotating coherently. This satisfies the rigidity constraint (Ullman, 1979). When the dots floated at 12 o'clock on each ring (Video IV.64-17b), observers reported two separate rings sliding over each other. This minimizes the motion within each ring by sacrificing rigidity (Shiffrar & Pavel, 1991; Ullman, 1979). Thus each ring coheres with its dot rather than with its intersection.

[insert Video IV.64-18 here]

Video IV.64-18 shows that sliding rings caused the same collapse in eye movements that Video IV.64-16 produced with sliding lines. Observers had no trouble in tracing the apparently rigid rings from Video IV.64-17a, but they made gross tracking errors when viewing the apparently sliding rings in Video IV.64-17b. Once again, the blue disks marking the intersections were not shown to the observer. These results cannot be predicted from the vague idea that the visual system prefers "simplicity" or a "good Gestalt."

The Flash Grab Illusion

The flash grab illusion is a new(ish) illusion in which the positions of lines are misperceived when they are flashed up on rotating backgrounds (Cavanagh & Anstis, 2013). The lines get apparently dragged along in the direction of the underlying movement.

[insert Video IV.64-19 here]

Look at Video IV.64-19. At first you see red vertical lines, flashing in alternation with green vertical lines. Note that the red and green lines are truly vertical and congruent. But when rotating sectored disks fade up into view behind them, the red lines appear to be tilted inward like the side bars of a capital A, while the green lines appear to tilt outward like the letter V. The effect is greatest when, as here, the lines are flashed up just as the direction of the rotating disks reverses. On the left-hand disk, the red line is dragged CW by the CW motion that comes just after the red flash, and similarly the green flashed line is dragged CCW by the CCW motion that follows it. Observers can look straight at either disk, but the effect is best if one gazes at the spot halfway between the two disks.

[insert Video IV.64-20 here]

Video IV.64-20 (the "wonky cross") is similar, except that instead of just vertical lines an upright red cross now flashes up in alternation with a congruent upright green cross. Of course the two crosses are exactly superimposed. But when the rotating disk fades in, two things happen: First, the verticals are apparently tilted out of the vertical, as before. Second, the horizontals are tilted by different amounts, such that the arms of each cross appear to intersect at an acute angle instead of at a right angle. The reason is that the verticals of each cross lie on the edge of a rotating sector of the background disk, while the horizontal arms lie on the middle of rotating sectors. Clearly, the moving sector edges drag the arms of the cross much more effectively than the midsectors do.

[insert Video IV.64-21 here]

What causes the flash grab effect? Basically it is caused by a perceptual shortening of motion trajectories (Sinico, Parovel, Casco, & Anstis, 2009). Video IV.64-21 shows a vertical bar that rotates slowly CW through 180° and back again. The top end of the bar is correctly seen to rotate back and forth between 12 o'clock and 6 o'clock. But when the bar speeds up, its trajectory is grossly underperceived and it seems rotate back and forth between about 1 o'clock and 5 o'clock. Suppose that the bar were to flash red each time it reached the vertical (not shown); the bar would appear to be tilted first toward 1 o'clock and then toward 5 o'clock. This is the flash grab effect. The flashes play no causal role in the illusion; they simply mark out the perceived endpoints of the rotating bar. To explain the apparent shortening of the motion trajectory, we conjecture that the visual system keeps a running average, with a time window of about 100 ms, of the position of the rotating bar. This averaging will round off the ends of the trajectory and make it appear shorter than it really is. Clearly the position of a moving object is not coded in some pure form but is influenced or contaminated by the context of its own motion. Although the flash grab effect most resembles the flash drag effect, it differs from this in the following ways: (a) it has a different temporal profile, (b) it requires attention, and (c) it is about 10 times larger.

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Video IV.64-1.

Ambiguous apparent motion. One can see two spots jumping back and forth, either horizontally or vertically but not both at once. The ambiguous motion flips back and forth randomly between the two directions over time. Hiding the top two spots with one's hand primes horizontal motion of the two bottom spots, which generally persists for a while after the hand is removed. This stimulus is like a "dynamic Necker cube."

Video IV.64-2.

Ambiguous apparent motion is often driven by proximity, so that motion is seen between nearest neighbors. Thus the perceived motion is usually horizontal in the top left panel and vertical in the bottom right panel.

Video IV.64-3.

Ambiguous apparent motion can be primed to go in the direction of a preliminary nonambiguous motion.

Video IV.64-4.

Local versus global motion. In this ambiguous stimulus, four pairs of spots rotate locally about their common centers. Following an inspection period, the percept can change suddenly into two large squares of spots, each following a global circular path. Global tends to predominate more over local motion as time passes.

Video IV.64-5.

Local versus global motion. The motion of this stimulus stably remains local as two lovers gaze into each other's eyes.

Video IV.64-6.

Local versus global motion. Gaze at any one of these rotating pairs and the motion tends to remain local, aided by the blue circles that show the local trajectories.

Video IV.64-7.

Local versus global motion. Fixate the center of this video, which resembles Video IV.64-6 without the circles. One then see two intertwined global octagonal arrays.

Video IV.64-8.

Flying bugs: Control condition. Two bugs fly around in circles. Note: They follow exactly these same orbits in Videos IV.64-2 and IV.64-3.

Video IV.64-9.

Flying bugs: Size illusion. The left-hand bug seems to fly in much smaller circles, because it moves in step with the background so it has no motion relative to the background. The right-hand bug has the same physical motion as the left-hand bug, but it moves strongly relative to the background, so its perceived motion is increased.

Video IV.64-10.

Flying bugs: Shape illusion. The left-hand bug seems to fly from side to side, because the vertical component of its circular motion matches the vertical motion of the background so is perceptually cancelled out. Conversely, the horizontal component of its circular motion is strongly against that of the background so is perceptually enhanced. The opposite is true for the right-hand bug, which seems to fly up and down.

Video IV.64-11.

Bursts of background motion still make the right-hand bug's orbit look much bigger than the left-hand bug's.

Video IV.64-12.

The yellow vertical and horizontal rods follow counterphase CW paths. The central intersection of the rods seems to move CW in the left-hand display and CCW in the right-hand display. Actually it moves CCW in both displays.

Video IV.64-13.

Even with many chopsticks the illusion is still seen, even though the 100 intersections far outnumber the 40 line tips (terminators).

Video IV.64-14.

The chopstick illusion is still seen with two moving transparent squares. The intersections of the squares move CCW but still seem to move CW.

Video IV.64-15.

A cross, seen through an obliquely oriented window, moves CCW around a circle. When the edges of the window are visible (left), the motion is seen correctly. But when the edges are invisible (right), the lines and the intersections all appear to slide obliquely, parallel to the long sides of the window.

Video IV.64-16.

Observers made pursuit eye movements to track first the rigid intersections in Video IV.64-12, right, and then the sliding intersections in Video IV.64-12, left. Tracking errors were 10 times greater in the latter case. (The blue spot was not present in the original tracked stimulus.) (Video by Hiro Ito.)

Video IV.64-17.

Both rotating figure eights are identical. But (left) when the white gaps are painted on to the rings and rotate with them, observers report a single rigid figure eight rotating. When (right) the gaps “float” at 6 and 12 o’clock, the figure separates perceptually into two separate rings sliding over each other.

Video IV.64-18.

Observers’ eye movements pursued first the rigid intersections in Video IV.64-17, left, and then the sliding intersections in Video IV.64-17, right. Tracking errors were 10 times greater in the latter case. (The blue spot was not present in the original tracked stimulus.) (Video by Hiro Ito.)

Video IV.64-19.

Flashed red and green bars are always vertical. But when superimposed on sectored disks that rotate back and forth, the bars are perceptually sucked along in the direction of the motion that follows the flashes. They then appear to tilt back and forth.

Video IV.64-20.

Flash grab illusion: “Wonky cross.” Same as Video IV.64-19 except with horizontal cross bars added. The crosses look tilted, and their intersections no longer look orthogonal. This is because the moving black/white edges of the rotating sectored disk grab the verticals and have more pulling power than the midpoint of sectors that grab the horizontals.

Video IV.64-21.

Flash grab illusion. Bar rotates back and forth through 180°. At slow speeds this is seen veridically, but at fast speeds the trajectory is underestimated and looks like ~120°, never quite reaching the vertical (“from 1 o’clock down to 5 o’clock”). This underestimation is thought to underlie the flash grab illusion.