

## Motion vision: Are ‘speed lines’ used in human visual motion?

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**Motion analysis poses problems for any visual system, not least because of the ambiguities inherent in motion signals. Recent studies suggest that the human motion system may exploit ‘motion streaks’ – analogous to the cartoonist’s speed lines – to help resolve the direction of ambiguous motion.**

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It is commonly assumed that the form and motion components of vision are processed through separate cortical pathways, form being processed through an occipital-temporal or ventral stream, also referred to as the ‘what’ system, whereas motion is processed through an occipital-parietal or dorsal stream, the so-called ‘where’ system [1,2]. This dichotomy is in keeping with the principle of modular design of the brain, popular with many visual scientists [3,4]; but forceful arguments have been put forward for an alternative point of view ([5], which I discussed recently in these pages [6]).

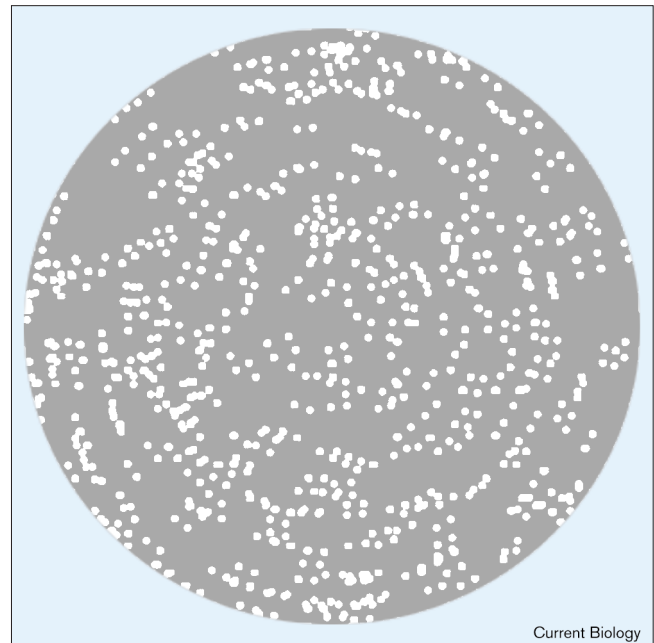
Despite the strong appeal of the idea of specialisation in visual processing, there is good evidence that form and motion are not entirely independent in the human visual system. The most dramatic example of interdependence is Gunner Johansson’s classic demonstration of ‘biological motion’ [7], produced by affixing dim lights to the joints of an actor in an otherwise darkened room. When stationary, the lights form a meaningless jumble; but as soon as the actor moves, the human form is unmistakable. Indeed, with only the joints illuminated, human observers can discern the sex, age and many other attributes of the walker, even in the face of high levels of visual noise.

Another example of form depending on motion is ‘spatio-temporal interpolation’, simply illustrated by observing an object move behind a slatted fence [8]. Although the image is visible only through the thin slits in the fence, one sees moving images as complete two-dimensional forms; the visual system uses motion information to interpolate the hidden spatial information from the temporal sequences at the slits. When the images are stationary, they collapse to unrecognisable one-dimensional lines. The interpolated stimuli behave in all senses like real physical stimuli, showing similar spatial acuity [9] and providing input for systems of perceptual organisation [10].

Both of the demonstrations described above show that motion can influence form perception. Now, in a recent issue of *Current Biology* [11], John Ross and collaborators at the University of Western Australia report evidence that the inverse can occur, where static form dictates the structure of global motion. Their demonstration depended on the use of so-called ‘Glass patterns’ [12] — moiré patterns generated from a random dot pattern by duplication, rotation and superposition (Figure 1). The local organisation of the resulting randomly positioned dot pairs is apparent only on close inspection, but the pattern has a strong and immediate global circular appearance. Other rules of pair assignment can create different perceptual organisations, including radial, hyperbolic or striped patterns.

Ross *et al.* [11] displayed dynamic sequences of these glass patterns, where each frame contained a new and independent random draw of dot pairs (see the demonstration on

**Figure 1**



Example of a circular Glass pattern used in the experiments of Ross *et al.* [11]. It comprises 100 randomly positioned pairs of dots, with one dot in the pair thrown down at random and the other rotated by a fixed distance. The pairs can be discerned only on close inspection, but global circular structure is strong and immediate. When sequences of these patterns are displaced, each with a totally independent draw of random dot pairs, there is a strong sensation of rotation, even though there is no motion energy in the circular direction.

[http://www.psy.uwa.edu.au/dbadcock/dynamic\\_glass\\_movies.htm](http://www.psy.uwa.edu.au/dbadcock/dynamic_glass_movies.htm)). As the positions of dots on successive frames are completely uncorrelated with those in the previous frames, there is no information in the motion vectors of the sequence that could create a sense of coherent motion. Motion signals are present, but they are totally random, resulting from the chance positioning of new dot pairs near the previous ones (like a detuned television set). Human observers of such frame sequences do not see random motion, however, but rather strong coherent rotation, sometimes clockwise, sometimes anticlockwise, but always following the circular organisation of the stationary pattern. Under suitable conditions, subjects were literally unable to distinguish between this illusion of circular motion and real circular motion generated by a frame-wise displacement of dots along the circular trajectory. Radial and striped Glass patterns also give rise to motion in the direction of the static form, but the effects in this case are slightly weaker, as they are with stationary Glass patterns [13].

This demonstration casts further doubts on the idea that form and motion are processed separately, by showing that purely static form can give a coherent structure to random motion. Where may this interaction occur? One possibility that Ross *et al.* [11] consider is that the form and motion streams are not completely separate, but interact at various levels, so the coherent circular form imposes a coherent structure on the otherwise random motion. This is certainly possible, particularly in the light of the considerable cross-talk known to occur between the pathways. Indeed a recent functional magnetic resonance imaging (fMRI) study reported elsewhere in this issue of *Current Biology* [14] suggests that both form and motion can activate the dorsal stream.

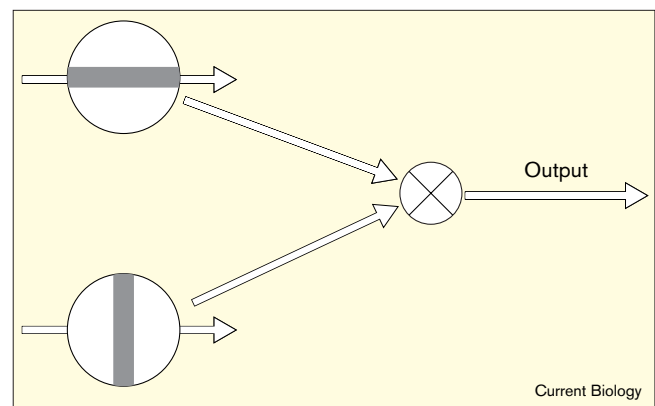
There is, however, another possibility for these findings, one that to my mind is far more interesting and plausible. Form may guide motion perception at an early level of motion analysis, acting through mechanisms that may serve to disambiguate motion signals under normal conditions. It has long been known that motion signals are inherently ambiguous, as well illustrated by the 'barber-pole illusion' which was described and studied by the Gestalt psychologist Hans Wallach [15]. When the old-fashioned red and white striped barber pole rotates, viewers do not perceive the horizontal motion physically produced by the rotation, but upward motion following the direction of the pole. The reason for the illusion is that a moving stimulus produces motion vectors of different speeds and directions, spanning 90° either side of the true direction of motion. If the aperture through which the stimulus is viewed is small compared with the stimulus size — as in a barber pole — there is little information to choose one motion vector over another, and the perceived direction of motion follows the borders of the aperture.

Because of their limited spatial extent, motion detectors of the mammalian visual system are also prone to this ambiguity, the origin of what has become known as the 'aperture problem'. While there exists a variety of two-dimensional velocity information that could be used to resolve this ambiguity [16,17], a novel possibility has recently been suggested by Wilson Geisler [18]. Geisler points out that, as the visual system integrates information over time (for about 100 milliseconds), localised features on moving objects should leave behind 'motion streaks' in the direction of motion, much as occurs in still photography with slow shutter speed. The orientation of these streaks could provide rich information about the direction of image motion, easily exploitable by orientation-selective neurons of the primary visual cortex.

Geisler has accumulated both psychophysical [18] and electrophysiological evidence [19] that the visual motion system can indeed be influenced by motion streaks, and has provided a detailed computational model of how this may occur. Basically it requires a multiplicative interaction between detectors oriented orthogonal to the direction of motion, and those oriented along the direction of motion (Figure 2). One detector responds to the general direction of motion with a very broad tuning for direction, the other to the stationary streak; together they create a unit selective for both speed and direction.

Ross *et al.*'s [11] demonstration may be a limiting case of resolving motion ambiguity with motion streaks. The random sequences of dots provide a motion signal that is truly ambiguous, with no bias in any direction (as is perceived with unstructured random displays). But when

**Figure 2**



Schematic representation of Geisler's model [18] of a neural sensor that can determine motion direction from motion streaks. The output of a neuron, or population of neurons, with oriented receptive fields but no directional selectivity (responding to the motion streak) is combined with that of direction selective cells of orthogonal orientation preference. The combination of the two types of cells greatly enhances the selectivity of the motion detection unit.

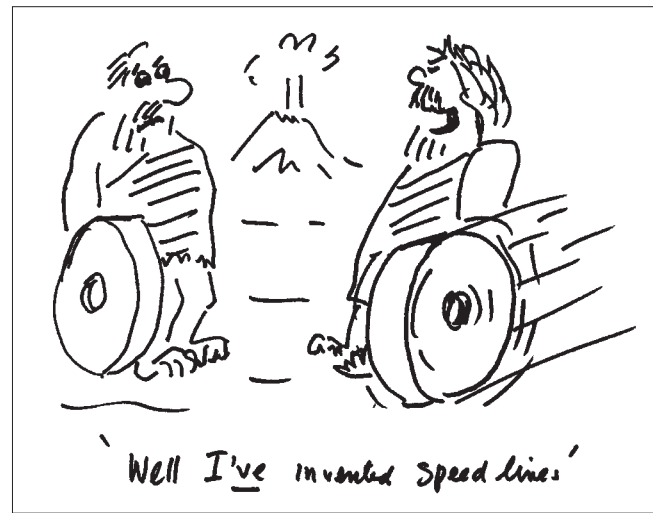
Glass patterns are used, the dot pairs — which approximate small line segments — will stimulate local orientation-selective detectors oriented in the circular direction. If Geisler's [18] theory is correct, then these detectors should interact with those selective to the direction of motion, privileging motion in the circular motion. Note that, although the sensation of motion is global, the interactions could occur at an early stage in processing, prior to the mechanisms that integrate local motion signals to produce optic flow. As the static streak has no preferred direction, the direction of the circular motion should be ambiguous, as observers report.

I find myself particularly drawn to this idea, having had a long-standing interest — stretching back to my post-graduate days — in the problem of 'motion smear': the fact that objects moving at moderate speeds do not appear smeared, even though their images are integrated by the visual system for an eighth of a second [20]. I suggested [8] that the key may lie not in specialised deblurring mechanisms, but in the motion detectors themselves, which are tuned along the spatio-temporal trajectory of the moving object so as to annul its motion. But is this not contrary to what Geisler [18] and Ross *et al.* [11] now suggest: that smear is not a problem for the visual system to eliminate but a valuable source of information? Possibly, but I suspect there is no real conflict. Information could be exploited by the visual system to aid in velocity perception without it actually encroaching into our perceptual representation. Indeed, more recent measurements [21] show that blur discrimination in human vision is uncorrelated with the phenomenological blur seen in stimuli moving for various durations.

Having said that, it is interesting to note that cartoonists routinely use motion streaks or 'speed lines' to indicate animation, a technique introduced by Rudolph Dirks in his famous strip "*the Katzenjammer Kids*". The lines provide an immediate and powerful indication of motion to both young and old readers, leaving little ambiguity of their rôle (Figure 3). Even animated cartoons often use this device to enhance the impression of speed. Is it possible that the lines are somehow tapping into the mechanisms of visual motion analysis?

Apart from helping to understand visual motion processing, the ideas and experiments of Geisler [18] and Ross *et al.* [11] should also encourage caution when considering modular analysis in vision (and perhaps other sensory and cognitive areas). There may well exist examples where motion can be considered separately from form, and vice versa. For example, the optic flow generated when we move through our environment (invaluable information for navigation) can probably be analysed independently of its spatial content, and indeed seems to activate separate brain regions [22,23]. However, it is hard to imagine that the

Figure 3



Speed lines are a common device used by cartoonists to indicate motion, particularly fast motion. They were first employed by Rudolph Dirks, in his famous strip "*the Katzenjammer Kids*" (Dirks was also the first to use speech balloons).

colour of Schumacher's Ferrari is analysed by an area that 'ignores' its shape and motion, responding to a disembodied 'redness', or that its shape is analysed by an area that 'pretends' the car is stationary. These attributes are closely bound in the physical stimulus, and cannot be arbitrarily separated. To analyse the shape of objects in motion requires form analysers specialised for moving objects, tuned to their speed and direction, as demonstrated by the examples of biological motion and spatio-temporal interpolation. And just as motion can provide invaluable information for form analysis, so can static form information feed into the motion system, helping to solve the inherent ambiguities of detecting motion with localised mechanisms.

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