Motion Perception

Uses of motion information:
Detection
Grouping
Distance
Shape
Heading

Measuring motion information:
Motion measurement mechanisms
Correspondence problem
Aperture problem
Brain areas
Detection

The image of an object must move on the retina or it will disappear. Examples: stabilized images, retinal vasculature.

Grouping

Image features that move together tend to be grouped together (Gestalt principle of common fate).
Motion cues to distance. When fixating the horizon while translating in a car or train, the nearer an object the faster it moves across the retina. When fixating a closer object while translating, the further an object from the fixated object the faster it moves across the retina.
Demonstration of shape from motion. If small lights are attached at each joint in the human body, the static pattern of lights is nearly incomprehensible. However, as soon as the person moves the scene becomes easy interpret. For example, here are the static patterns for two people dancing. A second demonstration in class showed random dot movies of a rotating objects.
Optic flow is a key source of information for heading (which is the direction of one's own motion). This figure illustrates the local motion vectors produced during translation toward a point on the horizon indicated by the vertical line. The length of the line segment attached to each dot shows the speed of the motion, the direction of the line shows the direction of the motion. Each dot represents an arbitrary point on the ground plane.
The upper figure shows optic flow similar to the example in the previous slide. The lower figure shows the optic flow vectors when the person is fixating at a nearby point while continuing to translate toward the point on the horizon. Notice that the flow pattern changes a great deal. Humans still correctly interpret this flow pattern. The optic flow pattern when approaching a nearby surface (e.g., a wall) can be used to judge the time until contact with the surface, even if the observer does not know how fast he/she is moving.
Motion Perception

Uses of motion information:
Detection
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Measuring motion information:
Visual latency
Motion measurement mechanisms
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Aperture problem
Brain areas
Visual Latency

Contrast

Luminance (e.g., Pulfrich effect)

Spatial frequency

Three factors that affect visual response latency.
Changes in response latency for 12 different neurons in primary visual cortex (V1) as a function of stimulus contrast. Response latency decreases an average of 20-30 ms as the contrast is increased. (Time shift = change in response latency).
Luminance (light intensity) also affects latency. One demonstration of this is the Pulfrich effect. A filter (which reduces luminance) causes a longer latency of neural response in the left eye. Thus, the moving green bar can appear at location P in the left eye but at another location in the right eye. The result is an effective disparity which causes the bar to appear to be at location Q (a different depth). The bar appears to be at a greater distance than P when motion is left to right.
Reaction time as a function of target spatial frequency (Breitmeyer 1975). The higher the spatial frequency the longer it takes to see the target and hence the longer to push a button.
Motion is extremely important to measure accurately. The brain probably uses several different kinds of mechanism to measure motion.

**Mechanisms for Motion Measurement**

- Delayed summation
- Feature tracking
- Motion blur
- Combining motion components
Schematic of simple delayed summation circuit for creating a direction selective simple cell. A stimulus moving right to left will result in signals arriving at the summation site at different times and so no spikes will be generated at the output.
On the other hand, a stimulus moving left to right will result in signals arriving at the summation site simultaneously and so spikes will be generated at the output.
Space-time plot of a moving vertical bar.
Top-down view (x-t) of the space time plots of a moving bar.
A separable linear receptive field (weighting function) or impulse response function. Linear filters that are separable in space-time are not direction selective.
Separable linear filters can be combined to obtain direction selective filters.
Linear Direction Selective Filter

\[ H(u, v, w) = H_s(u)H_z(v)H_t(w)\left[1 - \frac{d_s}{2}(1 \pm \text{sign}(u)\text{sign}(w))\right] \]

\[ d_s = \text{direction selectivity in } x \text{ direction} \]

\[ \text{sign}(u) = +1 \text{ for } u \geq 0 \text{ and } -1 \text{ for } u < 0 \]

Fourier representation of a linear-quadrature spatio-temporal filter.
Cortical spatio-temporal RF measured with reverse correlation.
Optimal Linear RFs for Speed Estimation

Time (ms)

Position (arcmin)

-30 0 30

f_1 f_2 f_3 f_4

f_5 f_6 f_7 f_8

[Legend: -0.2 -0.1 0.0 0.1 0.2]
Direction selective filters that behave like complex cells can be obtained by squaring and summing (non-linearly combining) linear direction selective filters.
Schematic of non-linear direction selective filter (Reichardt detector).
Sperling and Sondi showed that Reichardt and Energy filters are nearly equivalent.
Robert Adams described the waterfall illusion after visiting this waterfall in 1834 (Aristotle, 384-322 BCE, noted this effect). This effect is predicted by adaptation of direction selective neurons in the visual cortex.

To explain other motion mechanisms we need to talk about a couple of computational problems that arise in motion perception.
The correspondence problem in motion perception becomes most obvious in the case of “apparent motion”, a phenomena exploited to create movies.
When a moving object is viewed through a small aperture (such as the small region that a V1 receptive field covers) there can be considerable confusion about the actual direction of motion. This is the “aperture” problem.
The Aperture Problem and
The Intersection of Constraints Construction
Estimating Motion Direction

- Measure velocity components at different spatial orientations and then combine the velocity components in some fashion (e.g., “intersection of constraints”).

- Match feature or object locations over time.

- Measure the spatial orientation of motion streaks created by low-level temporal integration.
The middle temporal area (MT) is an area that appears to be specialized for motion processing and is a cortical area where there is evidence for a neural solution to the aperture problem.
A

\[ 90^\circ \]

\[ + \]

\[ 90^\circ \]

\[ = \]

\[ \]

B

\[ 143^\circ \]

\[ + \]

\[ 37^\circ \]

\[ = \]

\[ \]
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Simoncelli and Heeger Model

Sine wave components of A

Intersection of constraints

Complex cells tuned to set of orientations, spatial frequencies, and temporal frequencies
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Motion Streak Hypothesis

- Moving features produce spatial streaks due to temporal integration.

- These spatial streaks are encoded by spatial orientation selective mechanisms in the visual cortex.

- The visual system determines motion direction from these spatial orientation responses (and via other mechanisms as well).
A. Slower feature motion

B. Faster feature motion
Stimuli for neurophysiological test of the motion streak hypothesis.