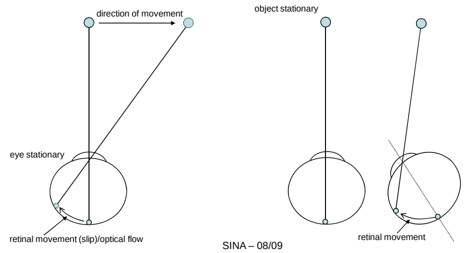
Detecting Movement

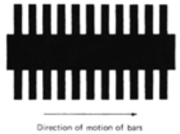
- How do we perceive movement?
- This is not a simple question because we are never stationary observers (eyes and head move)
- An important issue is how we discriminate the motion of the external world from the motion caused by our own movement



- Motion is so important to adaptive behavior in animals that simple animals (like frogs and rabbits) cannot even see objects unless they are moving
- Retinal ganglion cells in frog and rabbit have been found to be sensitive to movement in particular directions
- In cats and monkeys ganglion cells are not sensitive to movement, however cells in the visual cortex are
- Directionally selective cells in the human visual system could form the basis of the image-retina movement system

- Motion aftereffect (waterfall illusion)
- These are probably caused by adaptation of the motion-specific detectors that are tuned to the direction of movement of the stimuli in the scene
- These effects suggest that motion detectors are not retinal in origin
- Example: interocular transfer and binocular rivalry
  - suggest that motion detectors are located in an area of the brain where inputs from the two eyes are combined

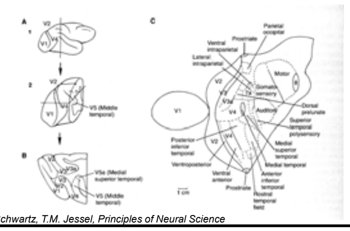
Another example (Tynan and Sekuler 1975)



- "phantom" grating in the blank area moving in the same direction of the bars
- phantom disappears if half of the stimulus is occluded (top/bottom portion)
- again interocular transfer…

Visual Motion in the Cortex

- Proportion of cells which respond to visual motion with selectivity for the direction of movement is large in layer 4B of V1, Middle Temporal Area (MT, V5) and Medial Superior Temporal Area (MST, V5a)
- Magnocellular LGN projects to layer 4C of V1 and from here to MT through layer 4B of V1
- It is expected that processing of visual motion information progresses along this pathway



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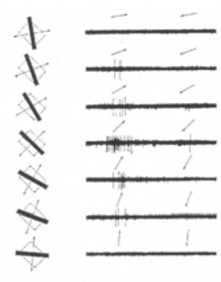
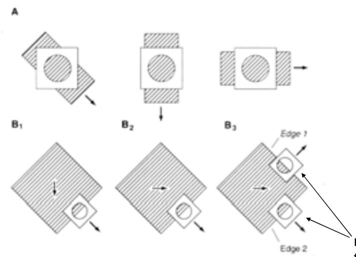
- Directionally sensitive receptors in V1



direction-selective neurons fire maximally when a bar of light moves through their receptive field → preferred direction

Aperture problem



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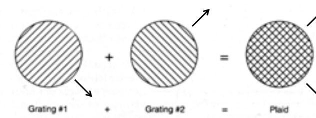
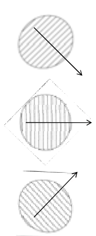
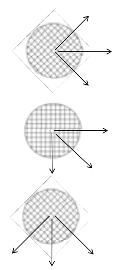


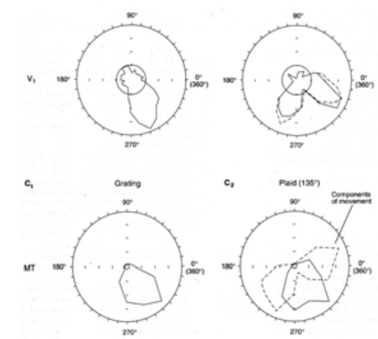
- Neurons in V1 and majority of MT are *component direction selective*, they respond to motion of the single component of the plaid
- …but some neurons in MT are *pattern direction selective*, they respond to motion of the plaid



Neuron in V1	Neuron in MT
activation	activation
x	x
x	x



Component Selective Neuron (MT or V1)	Pattern Selective Neuron (MT)
activation	x
x	activation
activation	x



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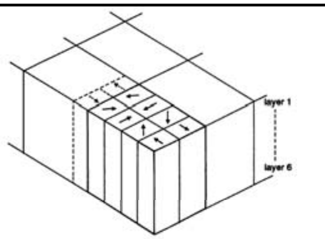


Figure 10.3 Columnar organization of MT.

- Unique property of MT is that the preferred direction of individual cells is regularly arranged in localized regions
- Cells preferring the same direction are clustered in a region elongated vertical to the cortical surface, the preferred direction gradually changes in a clockwise or counterclockwise direction along the cortical surface

from: Keiji Tanaka, Representation of Visual Motion in the Extrastriate Visual Cortex

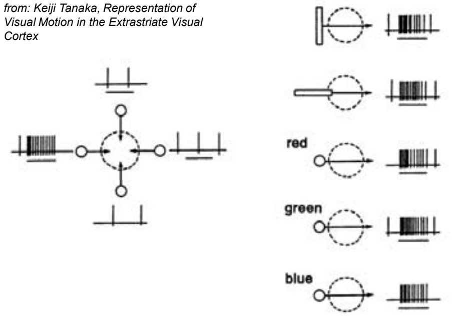


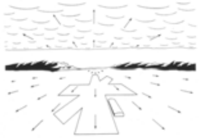
Figure 10.1 Responses of a typical MT cell. They are selective for the direction of motion but not the orientation of the slit or the color of the stimulus.

Perception of self-motion

- Movement can be caused by:
  - movement of external objects
  - movement of the observer's body (self motion)
- Self motion affect a larger part of the visual field
- Object movement and observer's movement often occur at the same time, the movement of the object with respect to the background should be extracted

Optical Flow

- Motion over a wide field of view (OF) is related to self-motion. Examples:
  - parallel translation: image components move in the same directions, with the same speed
  - forward/backward motion: image components move in radial directions (expansion/contraction)
  - head rotation (around the optical axis): rotation of the image components
- Perception of self-motion is critical for:
  - controlling action (locomotion, balance or eye-movements)
  - obstacle avoidance (time to contact)



The (dorsal) MST contains neurons which respond selectively to expansion/contraction and cw/ccw rotation

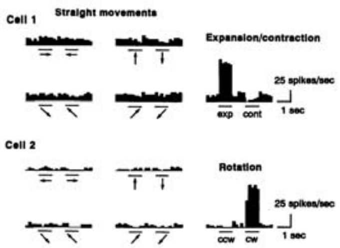


Figure 10.5 Responses of two dorsal MST cells, one specific to expansion (Cell 1) and the other specific to clockwise rotation (Cell 2). Exp, cont, ccw, and cw represent expansion, contraction, clockwise rotation, and counterclockwise rotation, respectively. (Reprinted with permission from Tanaka and Saito, 1989.)

Extraction of object versus background motion

- Critical when the observer moves the eyes/head or body in general
- Neurons in MT have center/surround inhibition selective for direction and speed of movement

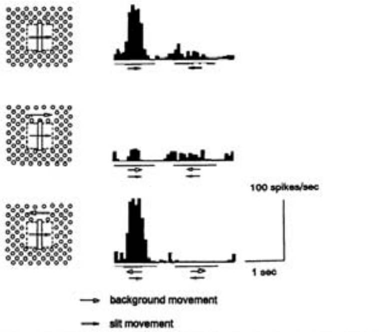
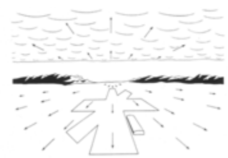


Figure 10.10 Surround inhibition selective for the direction of motion, found in half of MT cells. (Reprinted with permission from Tanaka et al., 1986.)

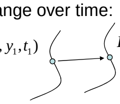
Optical Flow (Horn and Schunck 1981)

- Assume object is "flat", incident illumination is uniform
- Image intensity is differentiable → reflectance varies smoothly
- Derive equation that relates change in image brightness at a point to the motion of a certain pattern



- Assume brightness does not change over time:

$$\frac{dE}{dt} = 0$$



- Consider a patch that moves of *δx*, *δy* in *δt*

$$E(x, y, t) = E(x + \delta x, y + \delta y, t + \delta t)$$

- First order expansion of *E(x,y,t)*:

$$E(x + \delta x, y + \delta y, t + \delta t) = E(x, y, t) + \delta x \frac{\partial E}{\partial x} + \delta y \frac{\partial E}{\partial y} + \delta t \frac{\partial E}{\partial t}$$

when $\delta t \to 0$

$$\frac{dx}{dt}\frac{\partial E}{\partial x} + \frac{dy}{dt}\frac{\partial E}{\partial y} + \frac{\partial E}{\partial t} = 0$$

$\frac{dx}{dt} = u, \frac{dy}{dt} = v$ flow components

$\frac{\partial E}{\partial t} = E_t$ rate of change of illumination of a single point/patch

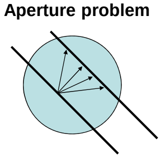
$\frac{\partial E}{\partial x} = E_x, \frac{\partial E}{\partial y} = E_y$ rate of change along x, y (image gradient)

→ $E_x u + E_y v + E_t = 0$ **Fundamental Flow Equation**

or

$(E_x, E_y) \cdot (u, v) = -E_t$

Aperture problem



we need additional constraints to solve the problem

- Assume points have same velocity, find a least squares solution of an over constrained system

$$\begin{bmatrix} -E_t^{(x_0, y_0)} \\ \vdots \\ -E_t^{(x_n, y_n)} \end{bmatrix} = \begin{bmatrix} E_x^{(x_0, y_0)} & E_y^{(x_0, y_0)} \\ \vdots & \vdots \\ E_x^{(x_n, y_n)} & E_y^{(x_n, y_n)} \end{bmatrix} \cdot \begin{bmatrix} u \\ v \end{bmatrix}$$

$$\mathbf{y} \cong \mathbf{A}\mathbf{x}$$

$$\begin{bmatrix} u \\ v \end{bmatrix}_{ls} = (\mathbf{A}^T\mathbf{A})^{-1}\mathbf{A}^T\mathbf{y}$$

- Horn and Schunck (81): add a *smoothness* constraint:

$$C = \left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2$$

this is equivalent to assuming that neighboring points have similar velocity

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- Minimize:

flow eq. — smoothness const.

$$J=\iint\left(E_x u+E_y v+E_t\right)^2+\alpha C\,dxdy$$

- Solve Euler-Lagrange equations:

$$E_x^2 u+E_x E_y v=\alpha\nabla^2 u-E_x E_t$$
$$E_y^2 v+E_x E_y u=\alpha\nabla^2 v-E_x E_t$$

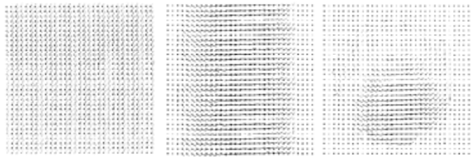
- Approximate:

$$\nabla^2 u\approx(u-u_{av})$$
$$\nabla^2 v\approx(v-v_{av})$$

1/12	1/6	1/12
1/6	-1	1/6
1/12	1/6	1/12

- Iterative solution:

$$u^{k+1}=u_{av}^k-E_x\left[E_x u_{av}^k+E_y v_{av}^k+E_t\right]/\left(\alpha+E_x^2+E_y^2\right)$$
$$v^{k+1}=v_{av}^k-E_y\left[E_x u_{av}^k+E_y v_{av}^k+E_t\right]/\left(\alpha+E_x^2+E_y^2\right)$$
$$u^0=0, v^0=0$$



flow for translation of a pattern (left), a rotating cylinder (center) and a sphere (right) (from: *Horn and Schunck, 1981*)