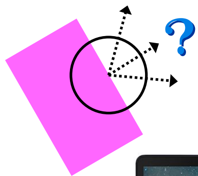
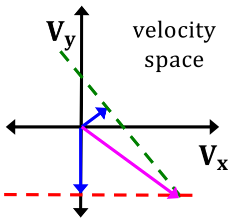
Aperture Problem

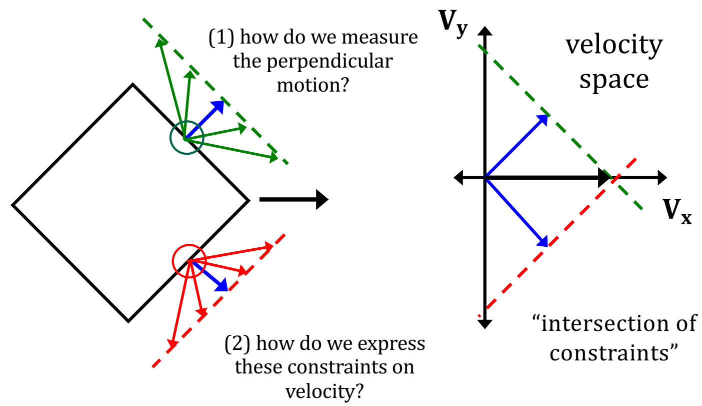
velocity field



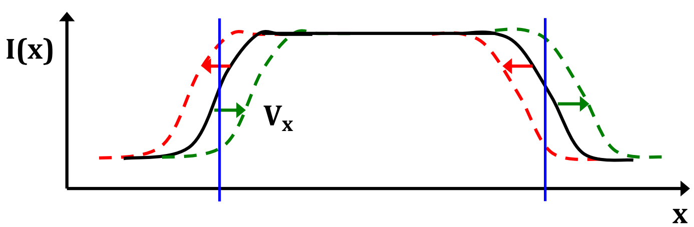
"local" motion detectors only measure *component of motion* perpendicular to moving edge



Computing 2D velocity from motion components



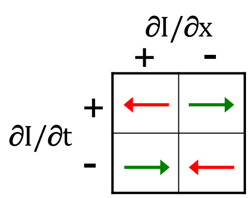
Measuring motion in one dimension



V_x = velocity in x direction

- rightward movement: $V_x > 0$
- leftward movement: $V_x < 0$
- speed: $|V_x|$
- pixels/time step

$$V_x = -\frac{\partial I/\partial t}{\partial I/\partial x}$$



Measuring motion components in 2-D

(1) *gradient* of image intensity

$\nabla I = (\partial I/\partial x, \partial I/\partial y)$

(2) time derivative

$\partial I/\partial t$

(3) velocity along gradient:

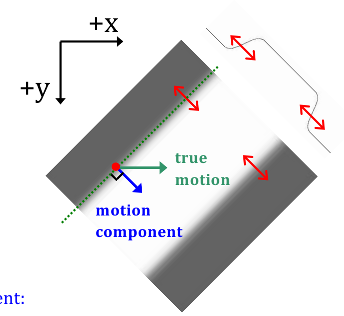
$v^{\perp}$

- movement in direction of gradient:

$v^{\perp} > 0$

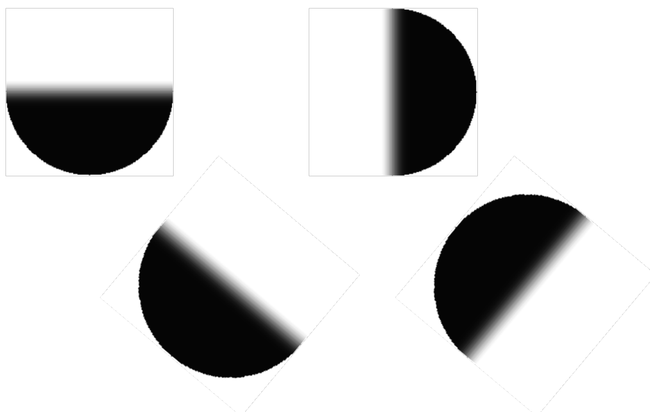
- movement opposite direction of gradient:

$v^{\perp} < 0$



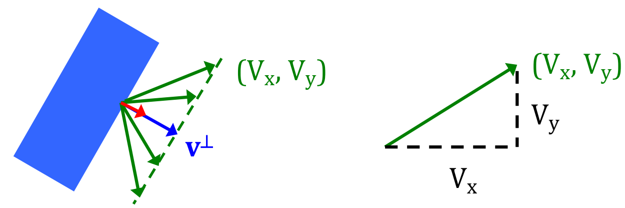
$$v^{\perp} = -\frac{\partial I/\partial t}{|\nabla I|} = -\frac{\partial I/\partial t}{[(\partial I/\partial x)^2 + (\partial I/\partial y)^2]^{1/2}}$$

Direction of the gradient
$\nabla I = (\partial I/\partial x, \partial I/\partial y)$



5

2-D velocities (V_x,V_y) consistent with $v^\perp$



All (V_x, V_y) such that the component of (V_x, V_y) in the direction of the gradient is $\mathbf{v}^\perp$

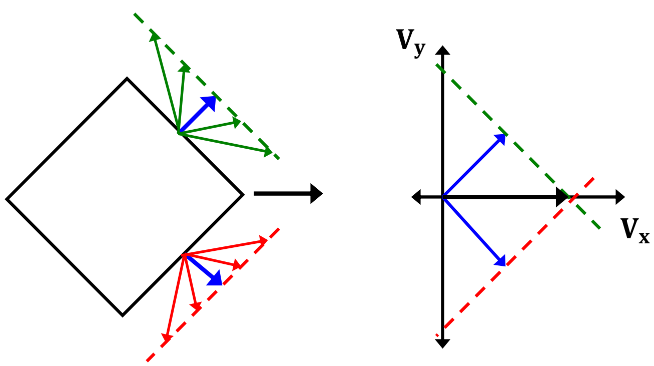
(u_x, u_y): unit vector in direction of gradient

Use the *dot product:* $(V_x, V_y) \bullet (u_x, u_y) = \mathbf{v}^\perp$

$$V_x u_x + V_y u_y = \mathbf{v}^\perp$$

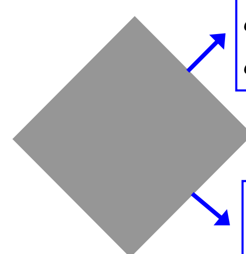
6

Time-out exercise



7

Details...



$\partial I/\partial x = 10$
$\partial I/\partial y = -10$
$\partial I/\partial t = -30$

→ (V_x, V_y) ??

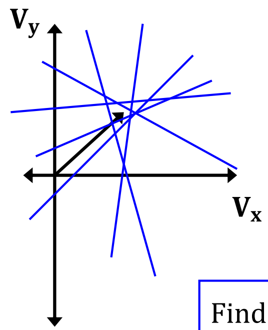
$\partial I/\partial x = 10$
$\partial I/\partial y = 10$
$\partial I/\partial t = -30$

For each component:
(1) u_x
(2) u_y
(3) $v^\perp$
(4) $V_x u_x + V_y u_y = v^\perp$

solve for V_x, V_y

8

In practice…



Previously…

$V_x u_x + V_y u_y = v^{\perp}$

New strategy:

Find (V_x, V_y) that ***best fits*** all motion components together

Find (V_x, V_y) that minimizes:

$$\Sigma(V_x u_x + V_y u_y - v^{\perp})^2$$

"least squares fit"

9

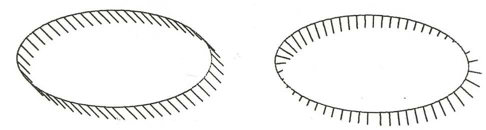
Option 2: *Smoothness* assumption:

Compute a velocity field that:

(1) is consistent with local measurements of image motion (perpendicular components)

(2) has the *least amount of variation* possible

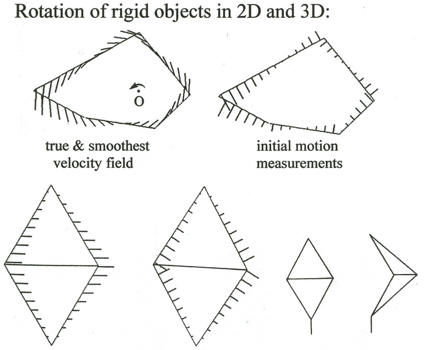
Pure Translation:



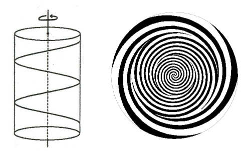
10

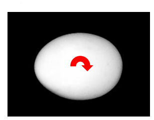
When is the *smoothest* velocity field *correct?*

Rotation of rigid objects in 2D and 3D:



When is it *wrong?*

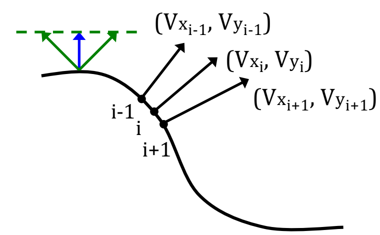




motion *illusions*

11

Computing the smoothest velocity field



motion components:

$V_{x_i} u_{x_i} + V_{y_i} u_{y_i} = v^{\perp}_i$

change in velocity:

$(V_{x_{i+1}} - V_{x_i}, V_{y_{i+1}} - V_{y_i})$

Find (V_{x_i}, V_{y_i}) that minimize:

$$\Sigma(V_{x_i} u_{x_i} + V_{y_i} u_{y_i} - v^{\perp}_i)^2 + \lambda[(V_{x_{i+1}} - V_{x_i})^2 + (V_{y_{i+1}} - V_{y_i})^2]$$

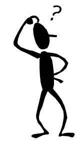
deviation from image motion measurements **+** variation in velocity field

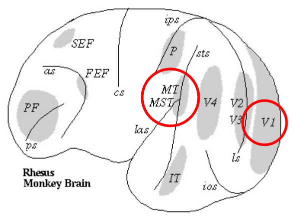
12

Two-stage motion measurement

motion components → 2D image motion

Movshon, Adelson, Gizzi & Newsome





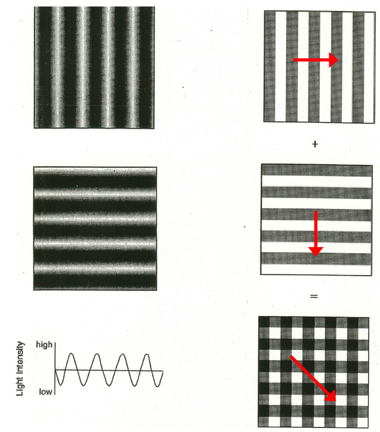
V1: high % of cells selective for direction of motion (especially in layer that projects to MT)

MT: high % of cells selective for direction and speed of motion

lesions in MT → behavioral deficits in motion tasks

13

Testing with sine-wave "plaids"



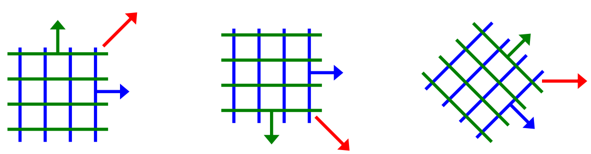
Moving plaid demo:

http://www.georgemather.com/MotionDemos/PlaidMP4.html

Movshon et al. recorded responses of neurons in area MT to moving plaids with different component gratings

14

Logic behind the experiments



(1) **(2)** **(3)**

Component cells measure perpendicular components of motion

e.g. selective for vertical features moving right

predicted responses: **(1)** yes **(2)** yes **(3)** no

Pattern cells integrate motion components

e.g. selective for rightward motion of pattern

predicted responses: **(1)** no **(2)** no **(3)** yes

15

Movshon et al. observations

- Cortical area V1:

  all neurons behaved like component cells

- Cortical area MT:

  layers 4 & 6: component cells

  layers 2, 3, 5: pattern cells

  Evidence for two-stage motion measurement!

- Perceptually, two components are not integrated if:

  large difference in spatial frequency

  large difference in speed

  components have different stereo disparity

16