MODELS OF MOTION PERCEPTION

1) Group and element motion

2) Motion pooling and aperture problem

3) Motion detection, segmentation and grouping

LOCAL DIRECTIONAL SELECTIVITY IS NOT ENOUGH!

Aperture problem
http://en.wikipedia.org/wiki/Motion_perception

Barberpole illusion
http://en.wikipedia.org/wiki/Barberpole_illusion

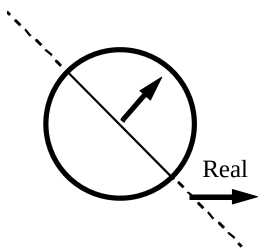
Plaids
http://www.brl.ntt.co.jp/people/nishida/demo/motionindex.html

Ternus effect (group and element apparent motion)
http://www.ruf.rice.edu/~pomeran/AlumniCollege2004Imagelist.htm

THE APERTURE PROBLEM

First described by Wallach,1935:
When *viewed* through a circular aperture, a straight line appears to move in the *direction* ***perpendicular*** *to its orientation*, regardless of its true direction of motion.

This occurs because *any component of motion parallel to the line causes no change* in the stimulus.



NOTE: This formulation is sometimes referred to as **"the *perceptual* aperture problem,"** to distinguish it from a similar issue that confronts individual neurons with finite-sized receptive fields.

Salvation through Structure?

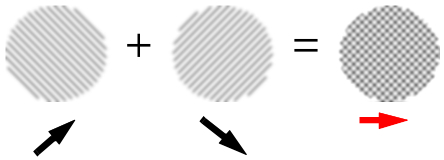
Large **"striped" periodic stimuli** (e.g. sinusoidal gratings) or long **straight lines** or **edges** are *degenerate* cases:
a single orientation

In real life we generally have available:
multiple orientations
features such as *corners, spots, or line ends*

Let's explore . . .

MOTION COHERENCE: PLAIDS

The superposition of two drifting sinusoidal gratings can result in the percept of *coherent (rigid) plaid* motion.



Coherent plaid motion is seen if *contrasts, velocities*, and *spatial frequencies* are similar.

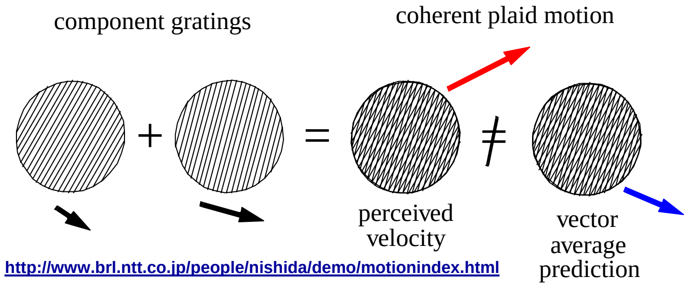
Otherwise, *transparent overlapping* motions can be seen, i.e., the component gratings are seen to *glide past* each other, often with a *segregation in depth.*

Question: In cases when gratings do cohere into a rigid plaid, how do we compute the ***velocity*** of the resultant plaid?

VECTOR AVERAGING

The resultant velocity *could* be the **average** (mean) of the ***normal velocity components*** of the individual gratings.

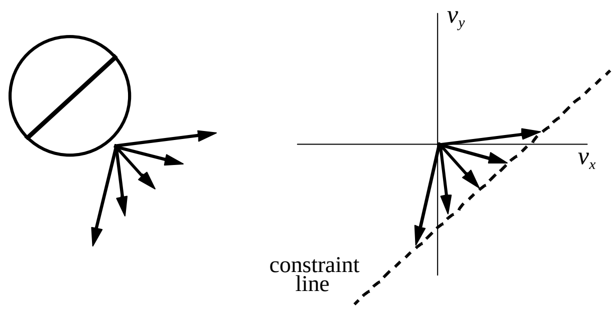
Usually, though, vector averaging does ***not*** account for data when the two component gratings **cohere** into a plaid.



http://www.brl.ntt.co.jp/people/nishida/demo/motionindex.html

VELOCITY SPACE CONSTRAINT LINES

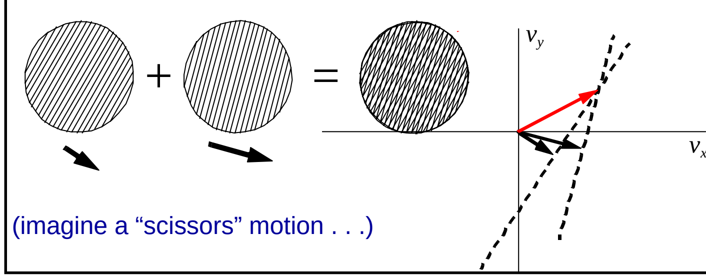
The possible positions of the leading edge of the bar (or line) after some time interval (Δt) define a **constraint line in velocity space.**



INTERSECTION OF CONSTRAINTS

The resultant velocity of the coherent plaid *could* be determined by the **intersection of constraint lines** of the component gratings. This is called the IOC solution Adelson and Movshon, 1982

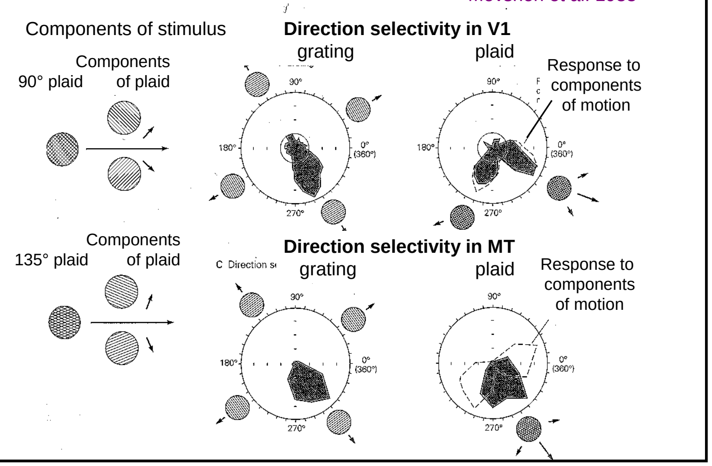
For the gratings below, the IOC solution would be:



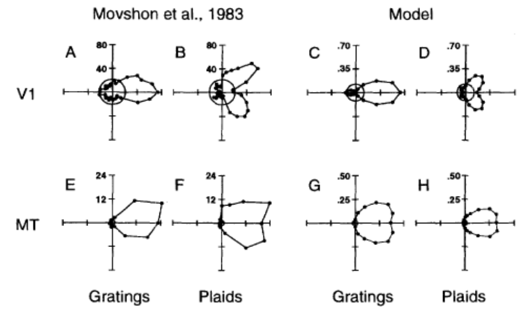
(imagine a “scissors” motion . . .)

PLAIDS:PATTERN AND COMPONENT CELLS MT AND V1

Movshon et al. 1983



PLAIDS: SIMONCELLI HEEGER MODEL



NOTE: MT simulations for pattern cells only
Pattern and component cells in MT are assumed to belong to separate populations

So far we have considered two proposals for taking advantage of the structure of motion stimuli in order overcome the **local aperture problem** for individual cells:

Vector averaging

Intersection of constraints (IOC) in *velocity space*

FEATURE TRACKING

The third possible way to combine motion of component gratings is by tracking the **unambiguous velocity of features** -- i.e., the “blobs” formed at *grating intersections* -- in the display.

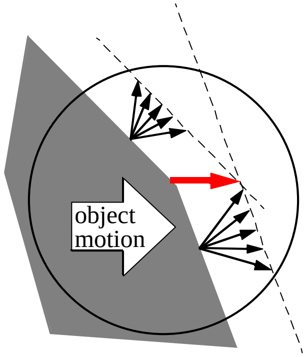
These *unambiguous signals* could then overwhelm the (“aperture”) *ambiguous signals* from the interiors of objects.

NOTE: The strength of **ambiguous signals** can be “down-regulated” by normalization/cross-direction inhibition.

Some unambiguous features are:
- **Line endings,** as in the barber-pole illusion
- **Line intersections,** as in plaid motion
- **Object corners**

IOC VS. FEATURE TRACKING

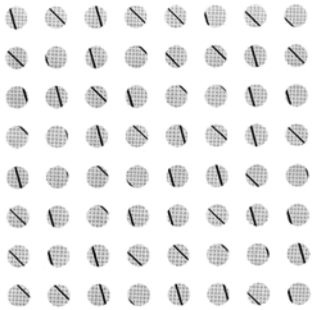
For a real corner
the **velocity resulting from the *IOC* computation**
and the **velocity of the *corner feature*** are identical!



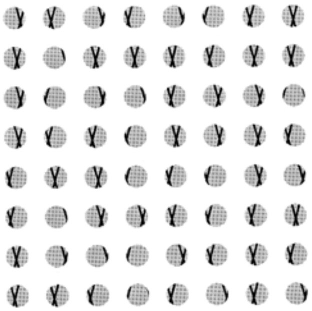
MOTION INTEGRATION ACROSS APERTURES

Consider the following displays*

Mingolla, Todd and Norman, 1992



Line intersections absent



Line intersections present

MULTI-APERTURE DISPLAYS

Ennio's hunch:
Overall the visual system probably uses a *combination* of **vector-average** of the component motions and **feature-tracking.**
Cf: Lorenceau et al. 1993

MOTION GROUPING

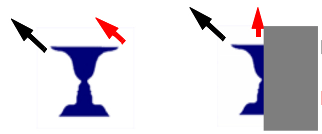
Barberpole illusion

http://en.wikipedia.org/wiki/Barberpole_illusion

LINE TERMINATORS

Intrinsic terminators: belong to the line (or object)
Extrinsic terminators: do not belong to the line (or object).

The object is seen to extend behind some occluder.



Black arrow:
actual motion of object
Red arrow:
perceived motion of terminator

Extrinsic terminators are useful cues for **occlusion** in a scene.

Motion of such terminators tells us little about the direction of motion of the occluded object.

MOTION SEGMENTATION AND GROUPING

Locally ambiguous, contradictory, disconnected signals must be transformed into a ***coherent motion percept***

1st pass: Need overall *agreement among motion directions*

Aperture ambiguity -- Find object *directions* and object *speeds* consistent with *local motion data*

2nd pass: Use figure/ground information to *weight* motion signals appropriately -- ***extrinsic/intrinsic***

Big picture: Use motion signals for **figure/ground segmentation**

Get: correct objects on correct trajectories

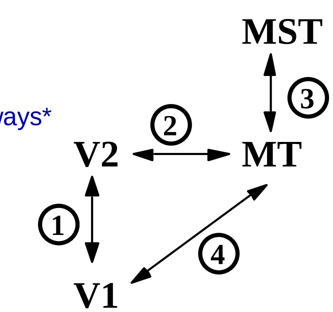
MODEL

Grossberg, Mingolla, Viswanathan, 2001

Model stages implemented as nonlinear ordinary differential equations.

Form-Motion interactions

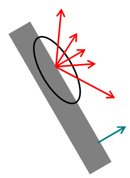
"What" and "Where" pathways*



*Multiple aspects of a percept

THE APERTURE PROBLEM REVISITED

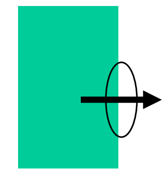
All single neurons are subject to the **aperture problem** for edges that are *longer* than *their receptive fields*.



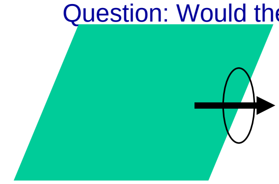
The detector can pick up, at best, only the **normal component of velocity.**

ORIENTATION AND DIRECTION

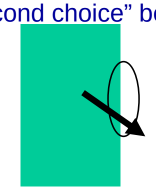
Consider: MT cell whose optimal stimulus is a vertical edge moving to the right.



Question: Would the cell's "second choice" be . . .



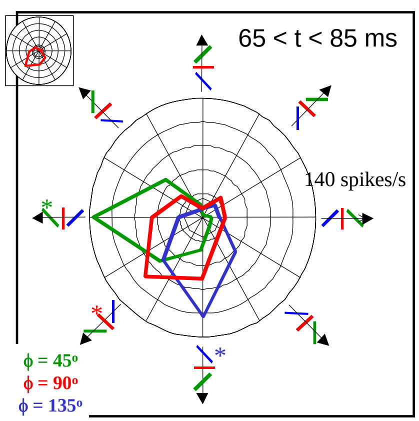
or



?

Answer: It depends on ***when*** you ask!

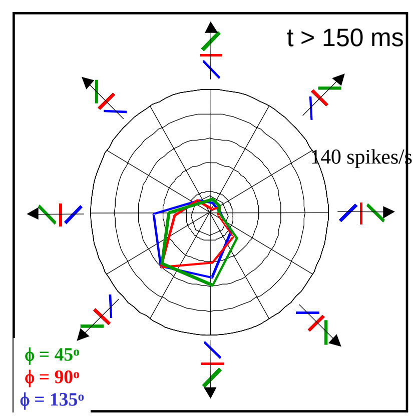
EARLY DIRECTIONAL MT CELL RESPONSE



Pack CC, Born RT
Temporal dynamics of a neural solution to the aperture problem in visual area MT of macaque brain. *Nature*. 2001 Feb 22; **409**(6823):1040-2.

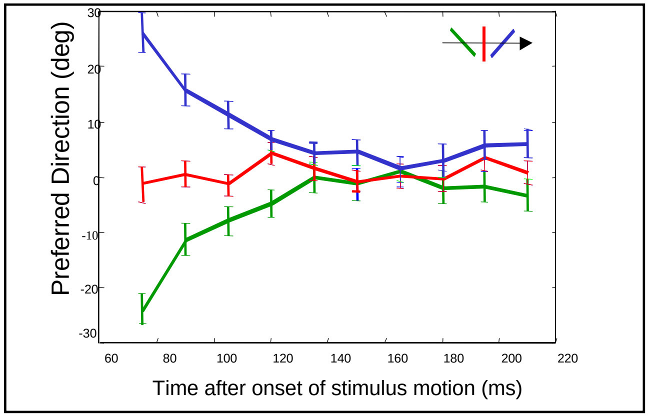
MT initially encodes component of motion perpendicular to bar orientation.

LATER *MT* CELL RESPONSE



Later responses are not dependent on bar orientation.

MT POPULATION RESPONSE



MT solves the aperture problem “gradually”.

QuickTime™ and a
Cinepak decompressor
are needed to see this picture.

easy

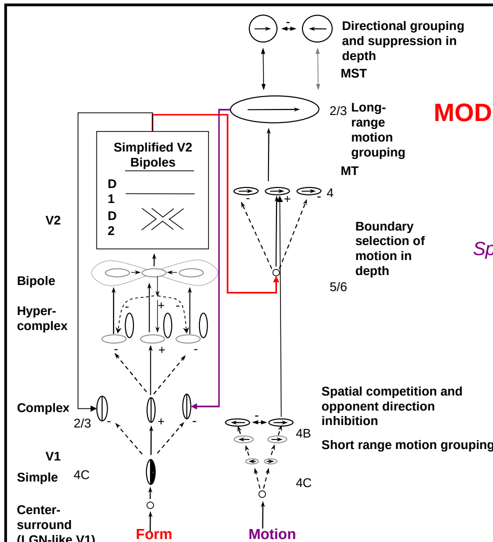
MOTION GROUPING ACROSS OCCLUDERS

Lorenceau and Alais (2001) claim: “Contours implying convex, closed forms (good Gestalts) are given the “green light” for motion integration, whereas contours implying open, concave forms trigger a veto that prevents motion binding.”

Berzhanskaya, Grossberg, and Mingolla, in Spatial Vision, explain this data using:

- V1 → V2 Figure-Ground Separation
- V2 → MT Form-Motion Interaction
- MT ↔ MST Motion Grouping

3D FORMOTION MODEL MACROCIRCUIT

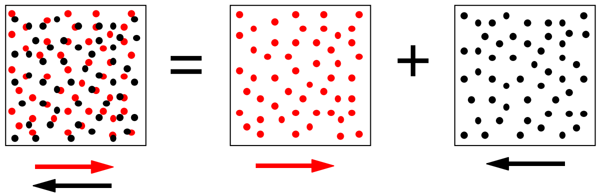


Berzhanskaya
Grossberg
Mingolla
Spatial Vision, 20(4), 337-395.

a “quasi-laminar” model of form and motion interactions

MOTION TRANSPARENCY

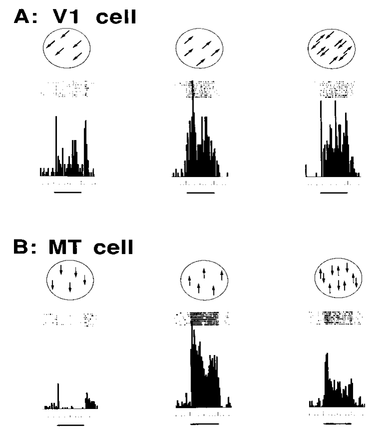
Stimulus: A field of random dots with two subsets moving in different directions.



Percept: The field is decomposed into two superimposed *transparent surfaces seen in depth* and sliding across each other.

Note: In the actual display, all dots have the same color and can be differentiated only on the basis of motion cues.
http://www.brl.ntt.co.jp/people/nishida/demo/motionindex.html

V1 / MT CELLS under transparency conditions

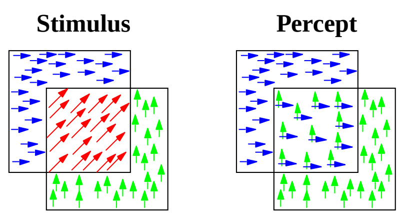


V1 cells react strongly to the preferred direction of motion even when opposite motion is present

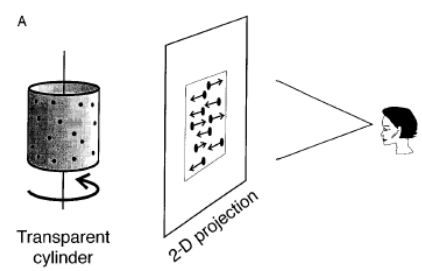
Not the case in MT (opponent inhibition)

Snowden et al., 1991

VELOCITY DECOMPOSITION



http://www.brl.ntt.co.jp/people/nishida/demo/motionindex.html



MOTION AFTEREFFECT (MAE)

Waterfall Illusion
+ motion capture

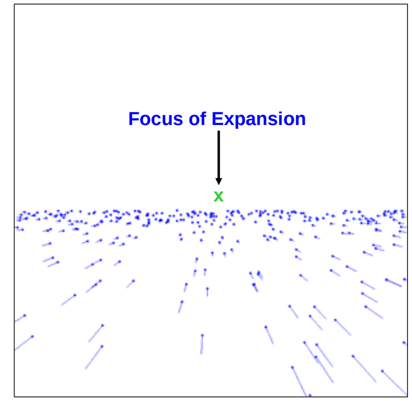
http://www.lifesci.sussex.ac.uk/home/George_Mather/Motion/index.html

VISUAL INFORMATION: OPTIC FLOW

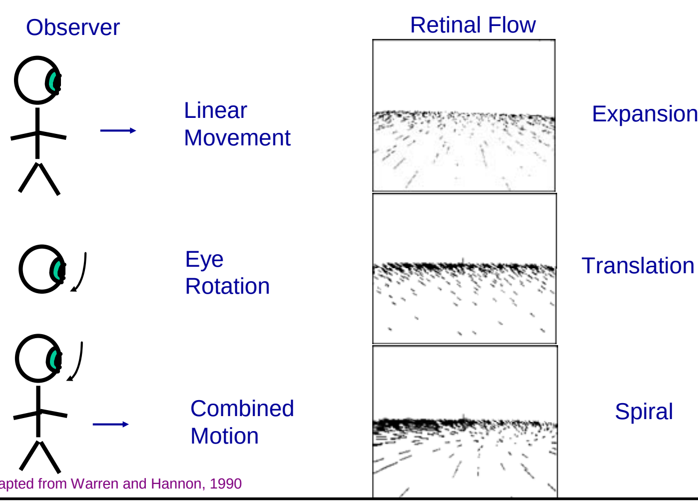
Optic flow is the displacement of visible points relative to a moving observer

The optic flow field is useful for navigation

Singularity in flow field specifies heading
. . . as long as your eye is not “tracking” an object In the scene!

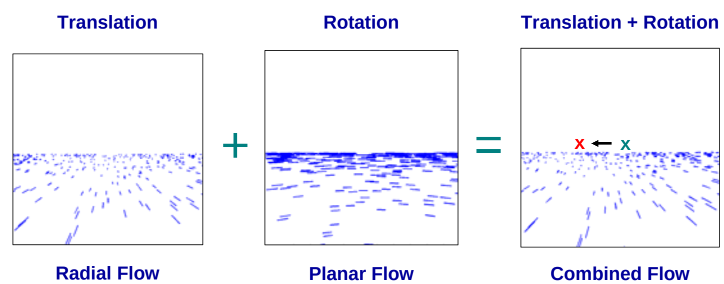


Optic Flow during Navigation



Adapted from Warren and Hannon, 1990

OPTIC FLOW DURING NAVIGATION



Focus of expansion shifts during eye rotation

Effects of eye rotation can be discounted using extraretinal information