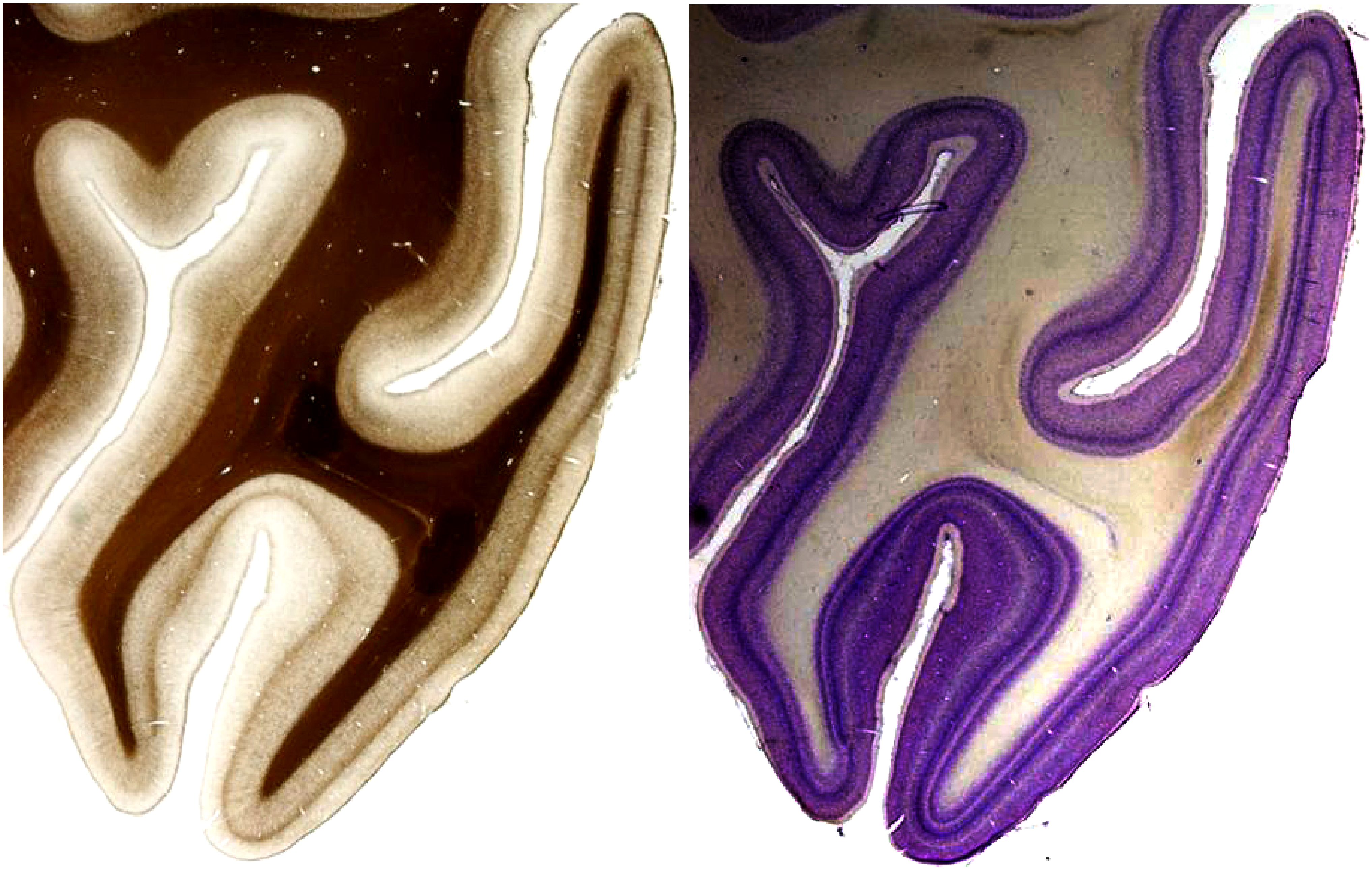
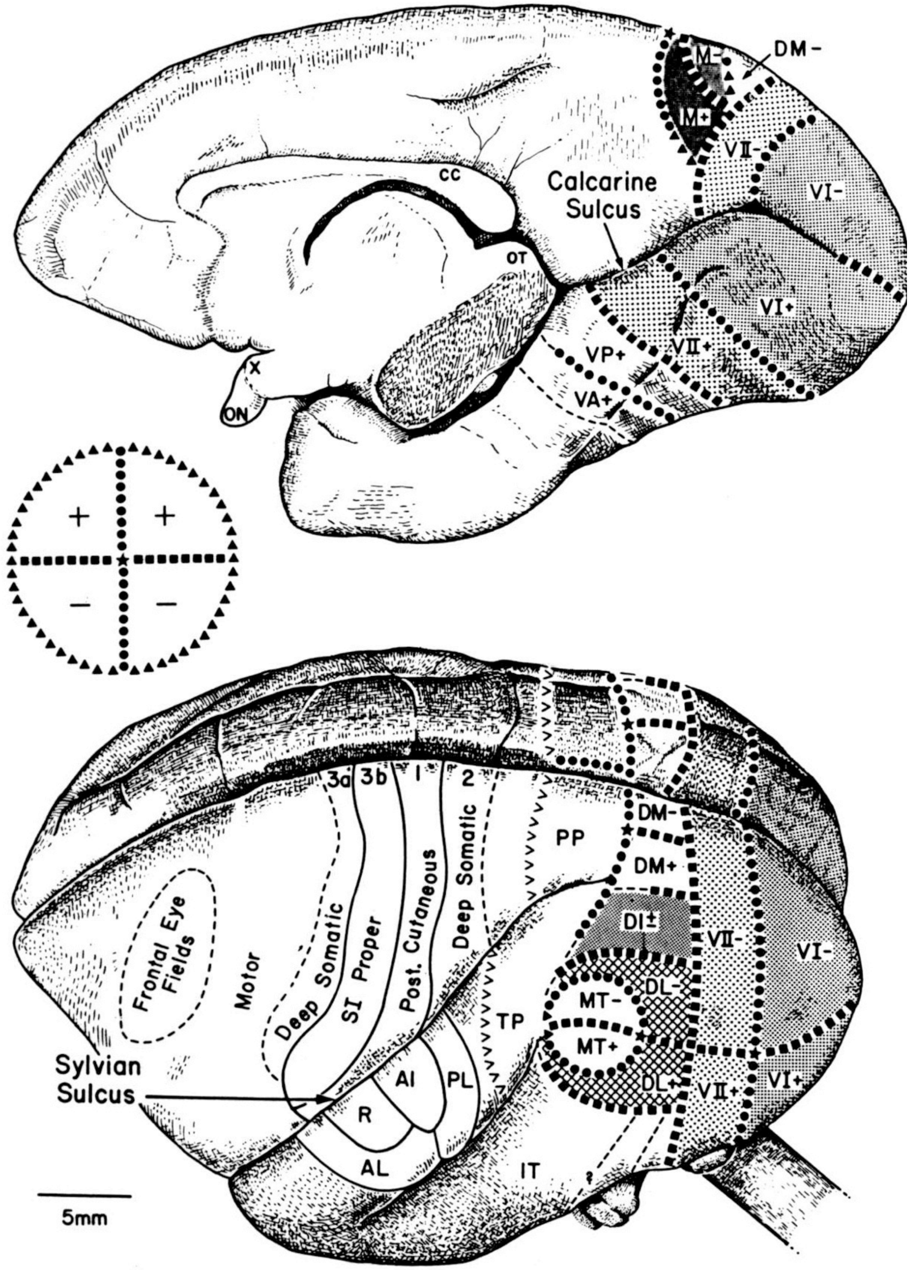
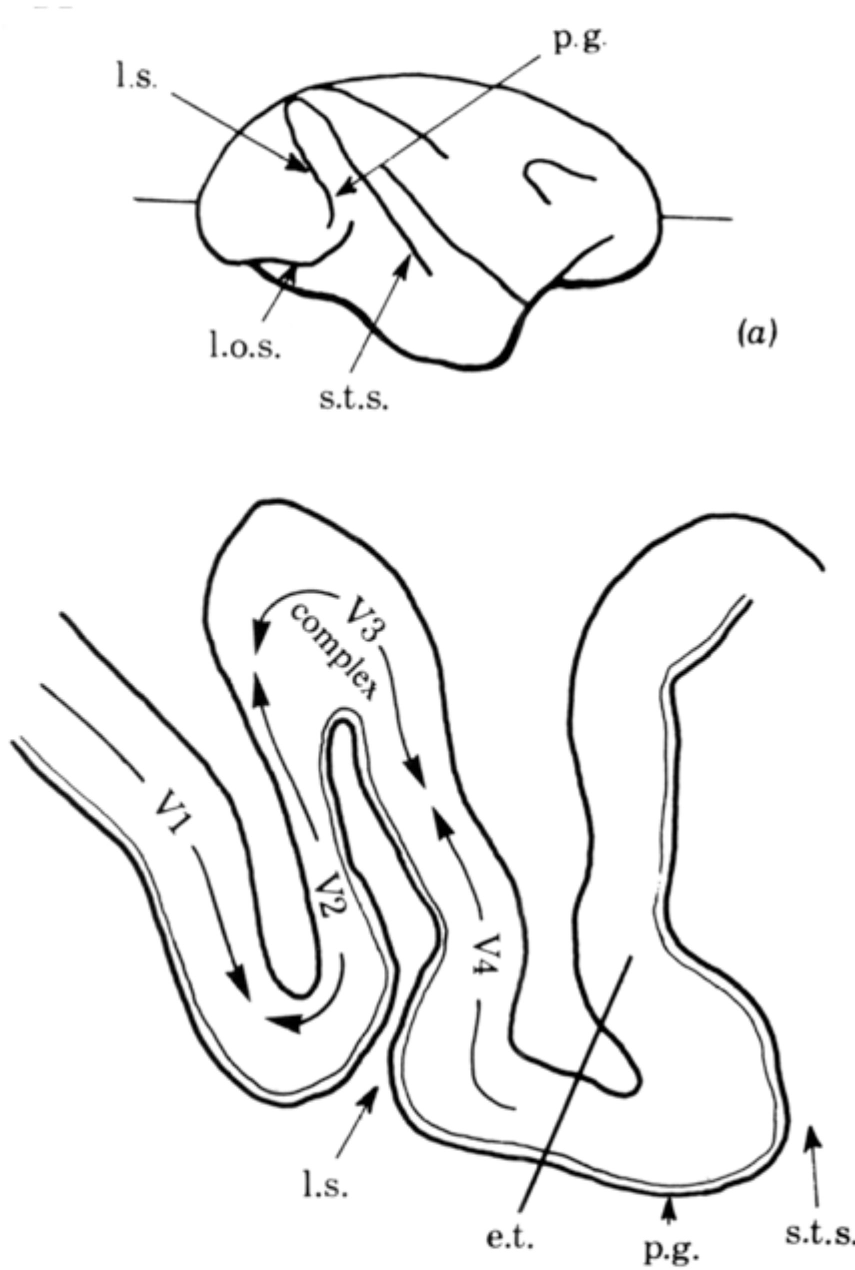
Macaque V1

Myelin *Nissl*





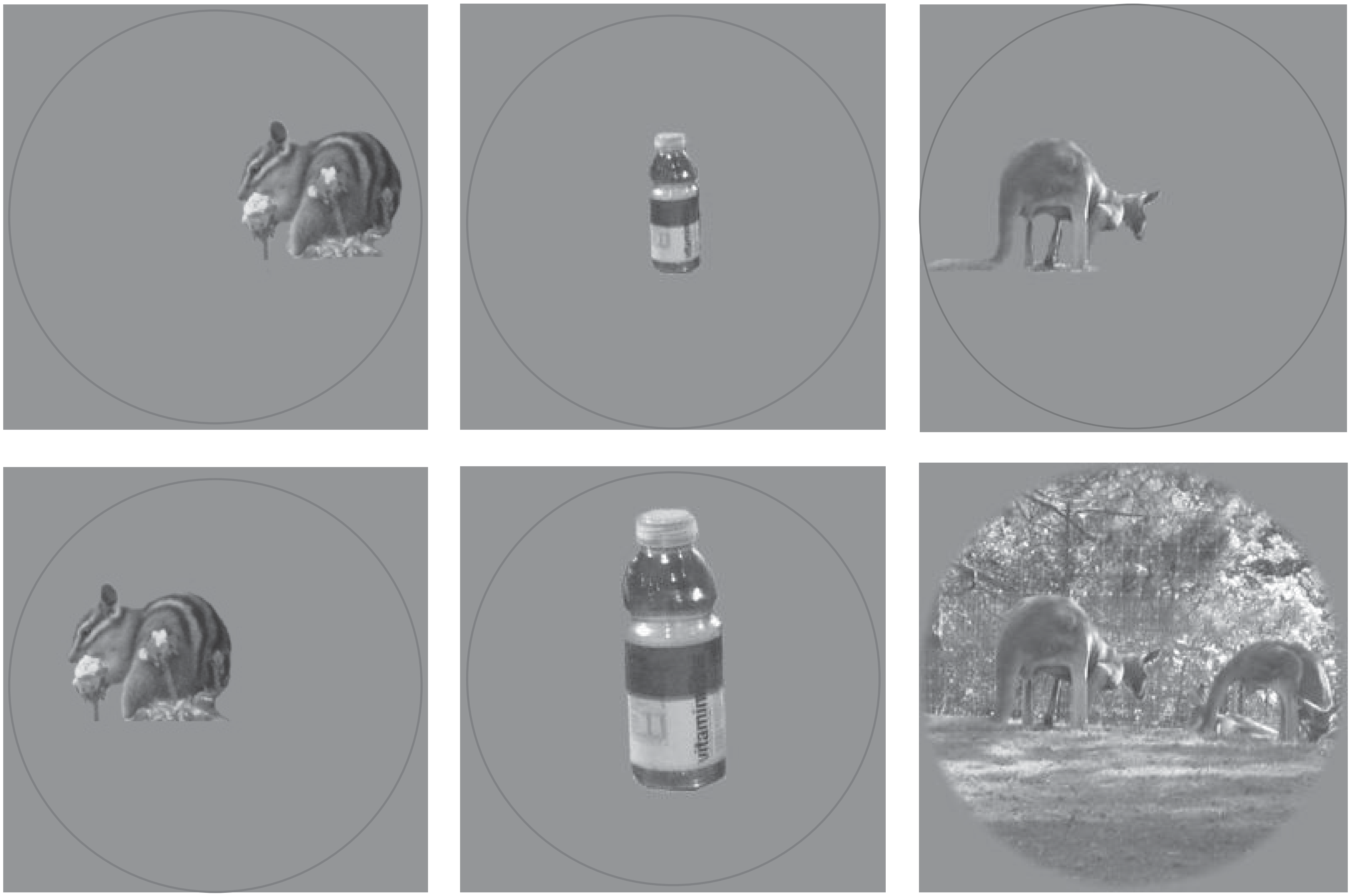
Allman & Kaas, 1981



Zeki, 1978

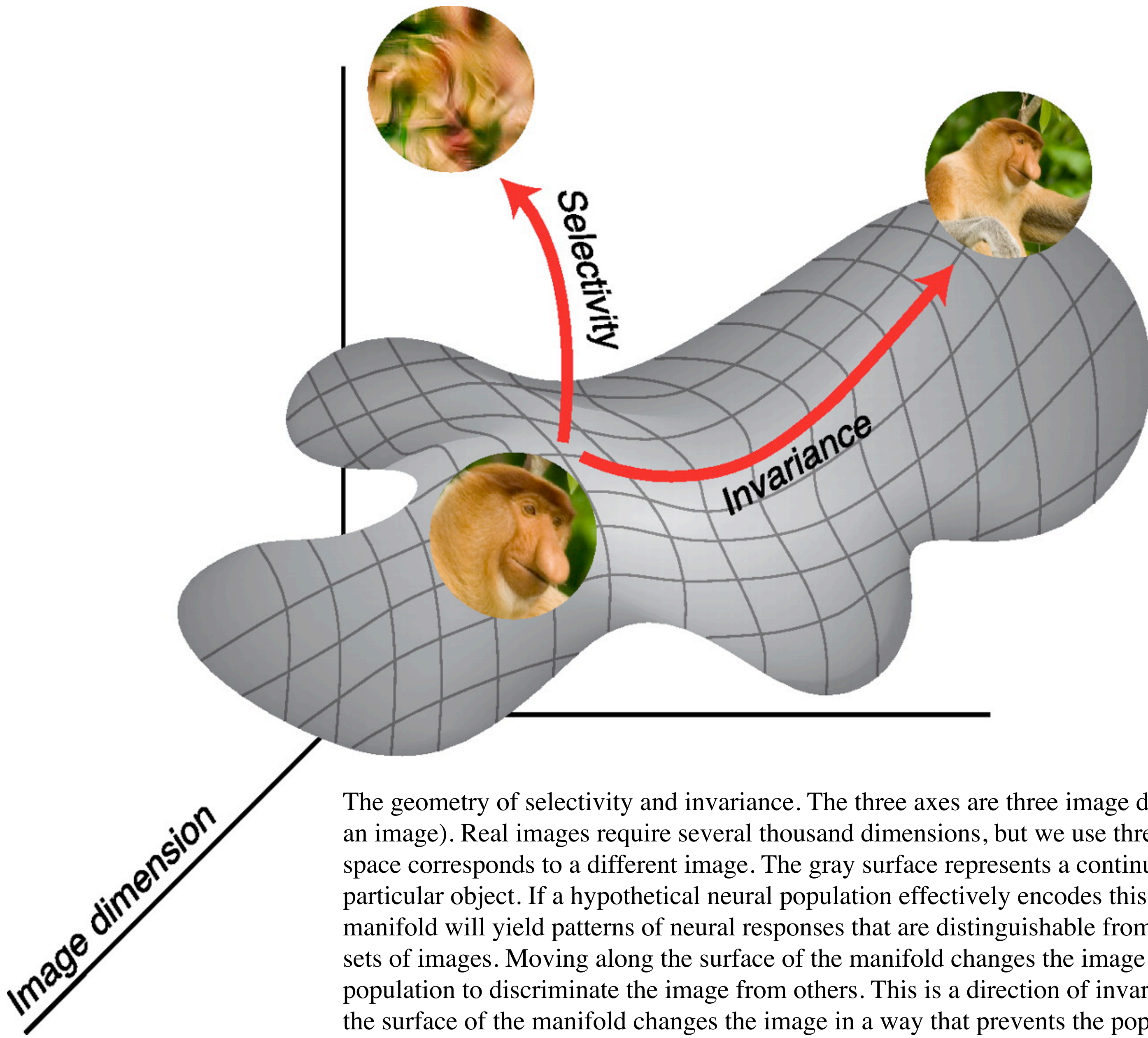
IT neurons are tolerant to identity-preserving transformations

Position | *Scale* | *Context*



Rust & DiCarlo, 2012

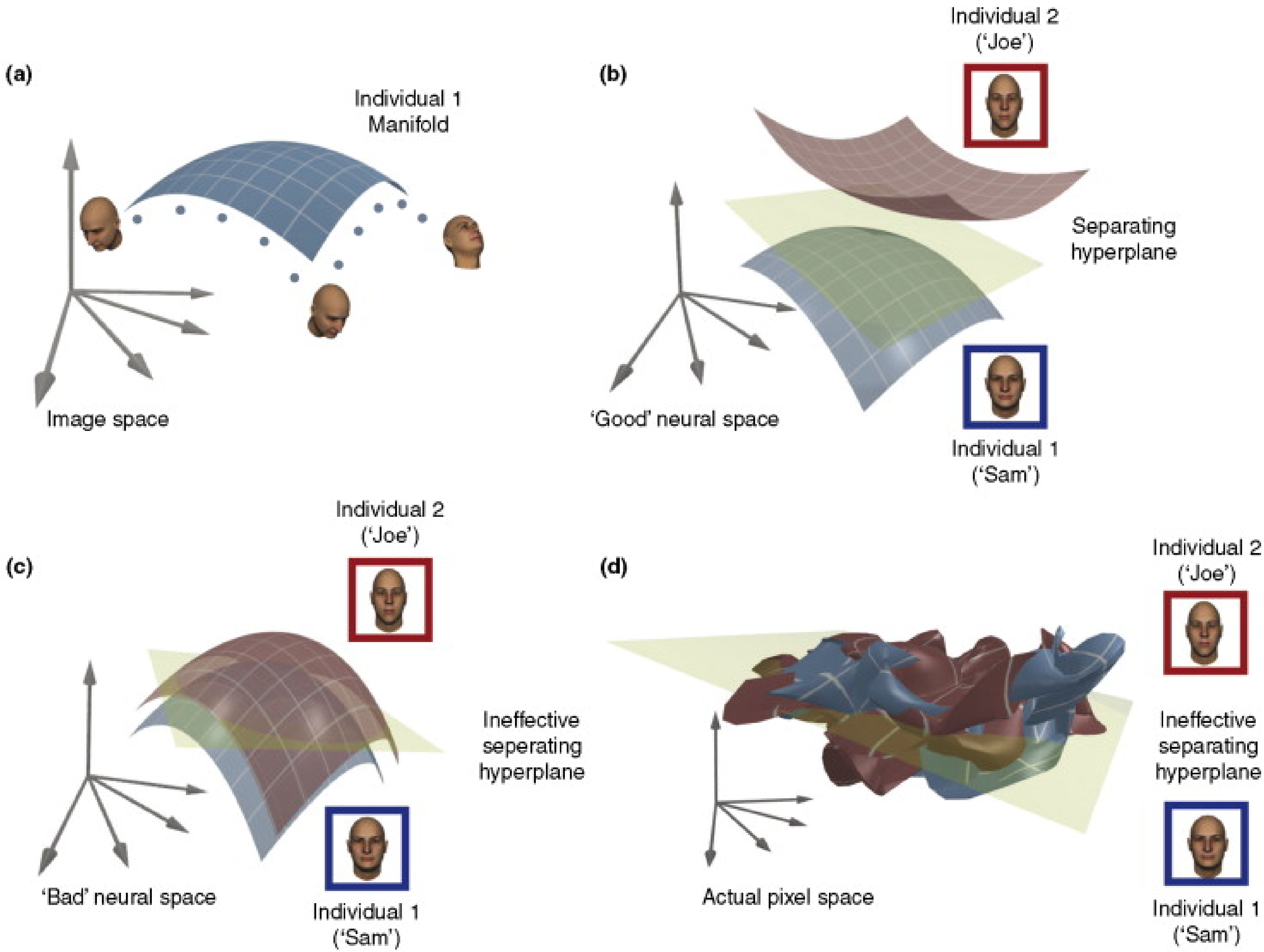
Selectivity and invariance



The geometry of selectivity and invariance. The three axes are three image dimensions (e.g., the values of three pixels in an image). Real images require several thousand dimensions, but we use three for simple visualization. Any point in the space corresponds to a different image. The gray surface represents a continuous subset, or manifold, of images of a particular object. If a hypothetical neural population effectively encodes this object's identity, all object images from this manifold will yield patterns of neural responses that are distinguishable from the patterns of responses induced by other sets of images. Moving along the surface of the manifold changes the image itself but maintains the ability of the neural population to discriminate the image from others. This is a direction of invariance. Moving away from, or orthogonal to, the surface of the manifold changes the image in a way that prevents the population from effectively discriminating. This is a direction of selectivity. The manifold shown here corresponds to a set of population responses that are selective for proboscis monkeys, not just for image patches with similar color and texture, but are also invariant to changes in size (near vs far) and context (face only vs face and body).

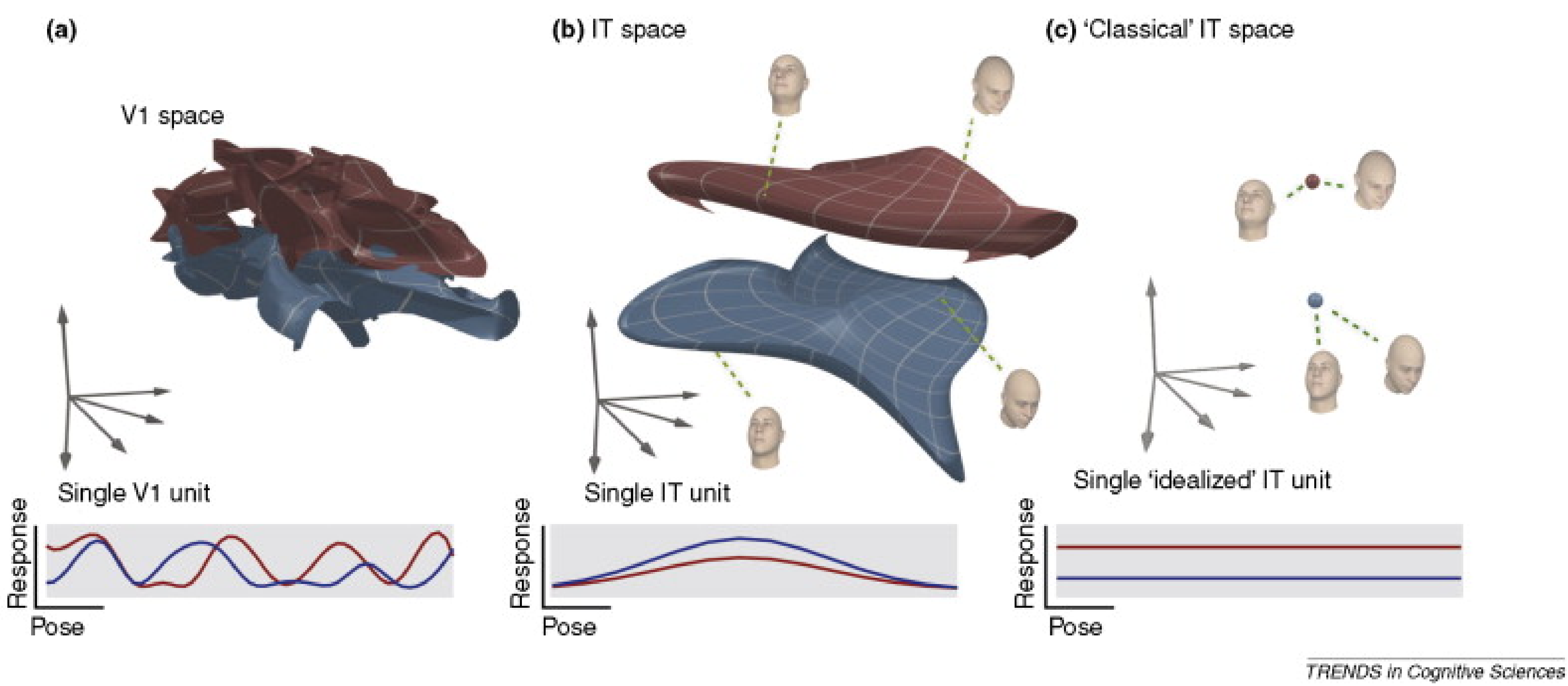
Freeman & Ziemba, 2011

Object tangling



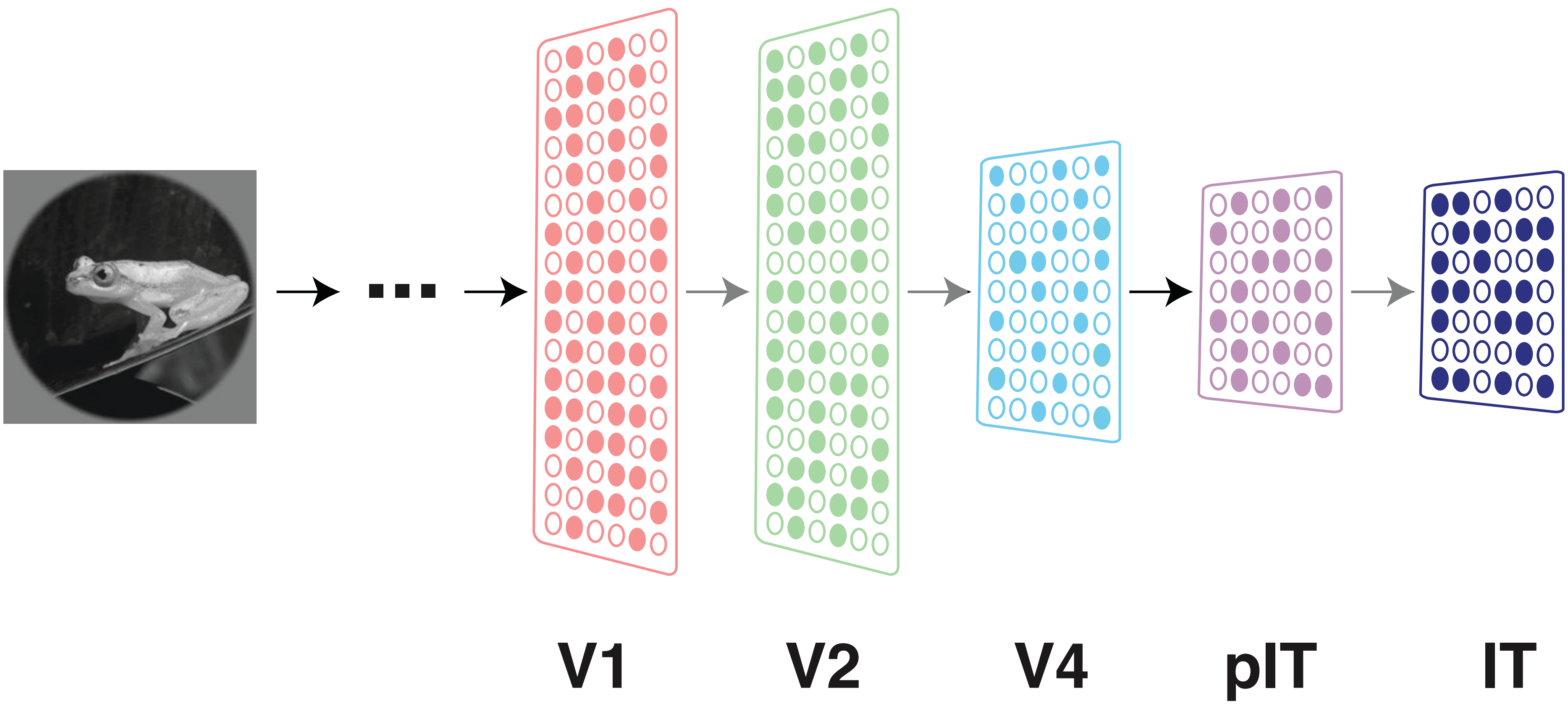
DiCarlo & Cox, 2007

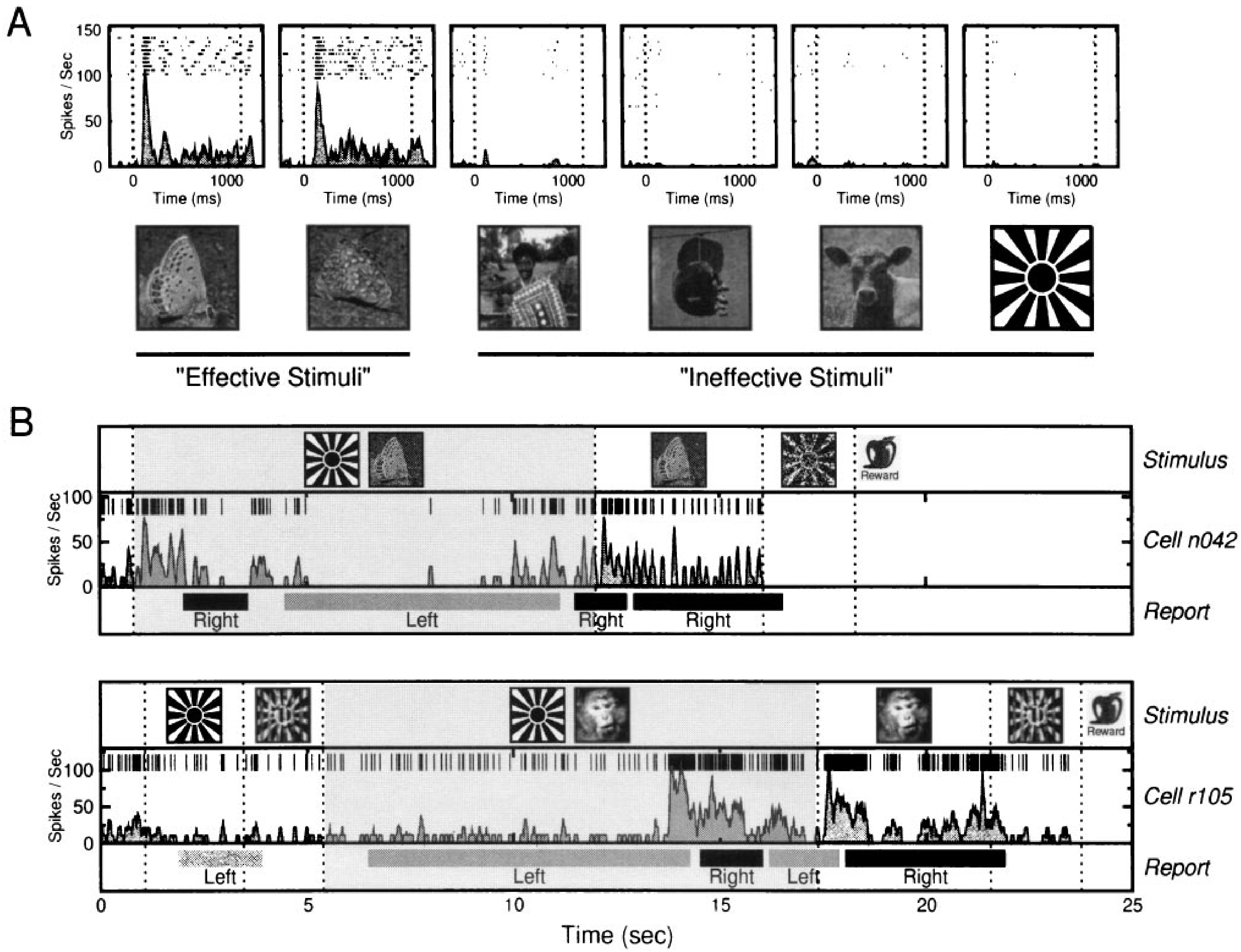
Untangling object manifolds along the ventral visual stream



DiCarlo & Cox, 2007

The form processing pathway maintains an "equally distributed" representation of images




A
Spikes / Sec
150
100
50
0
0
1000
Time (ms)
"Effective Stimuli"
"Ineffective Stimuli"
B
Stimulus
Reward
Cell n042
Report
Right
Left
Right
Right
Cell r105
Left
Left
Right
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Right
0
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10
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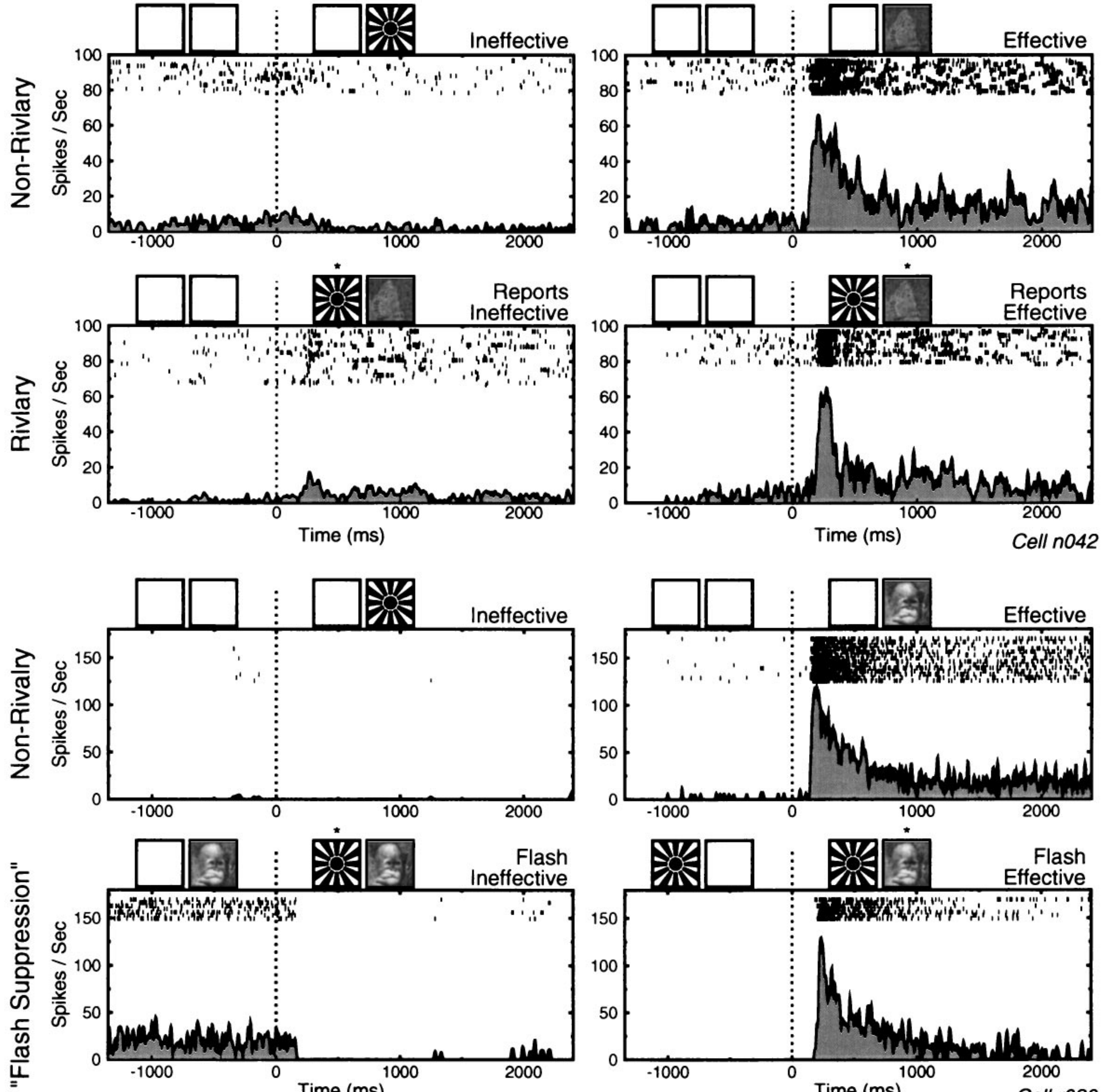
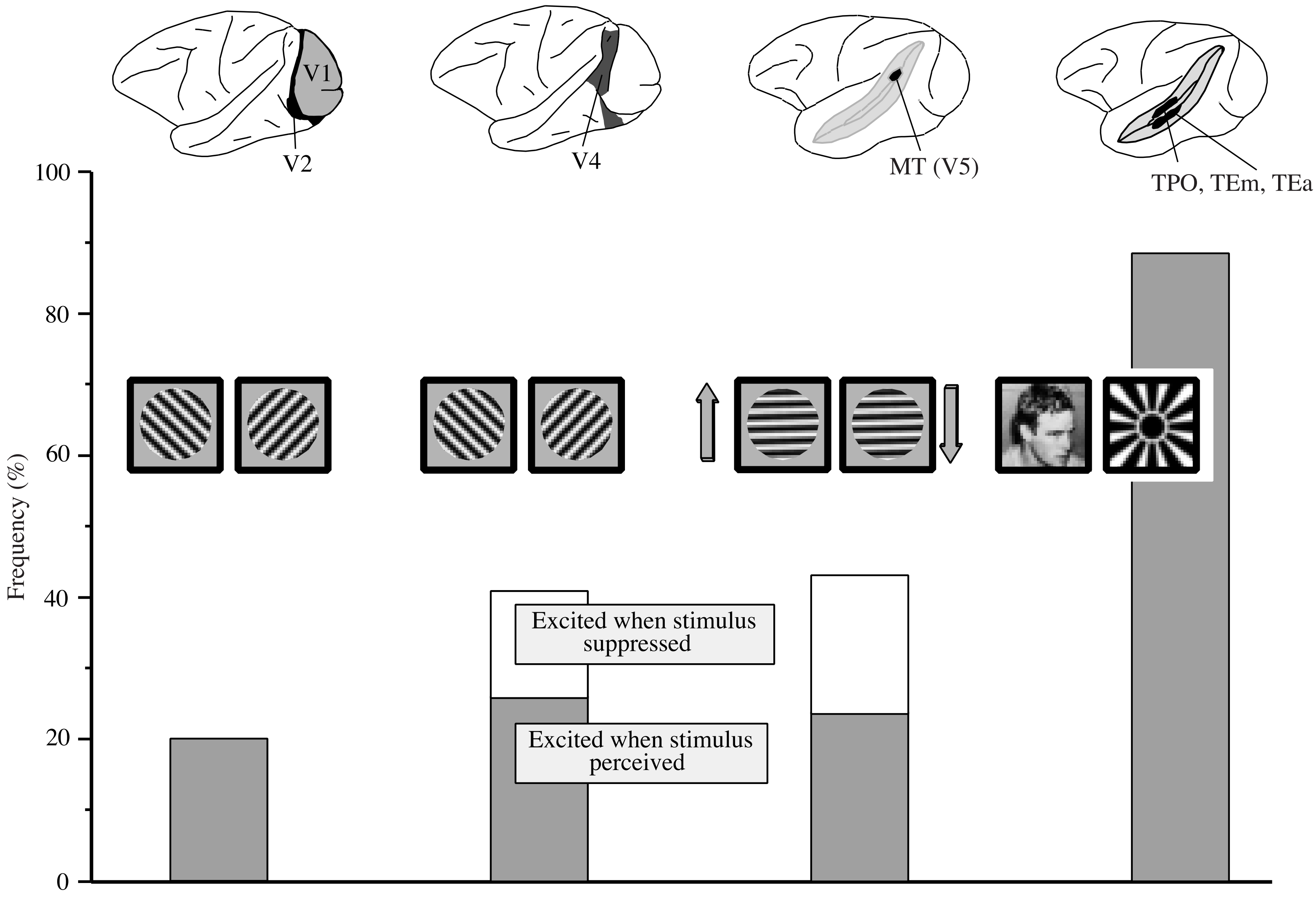
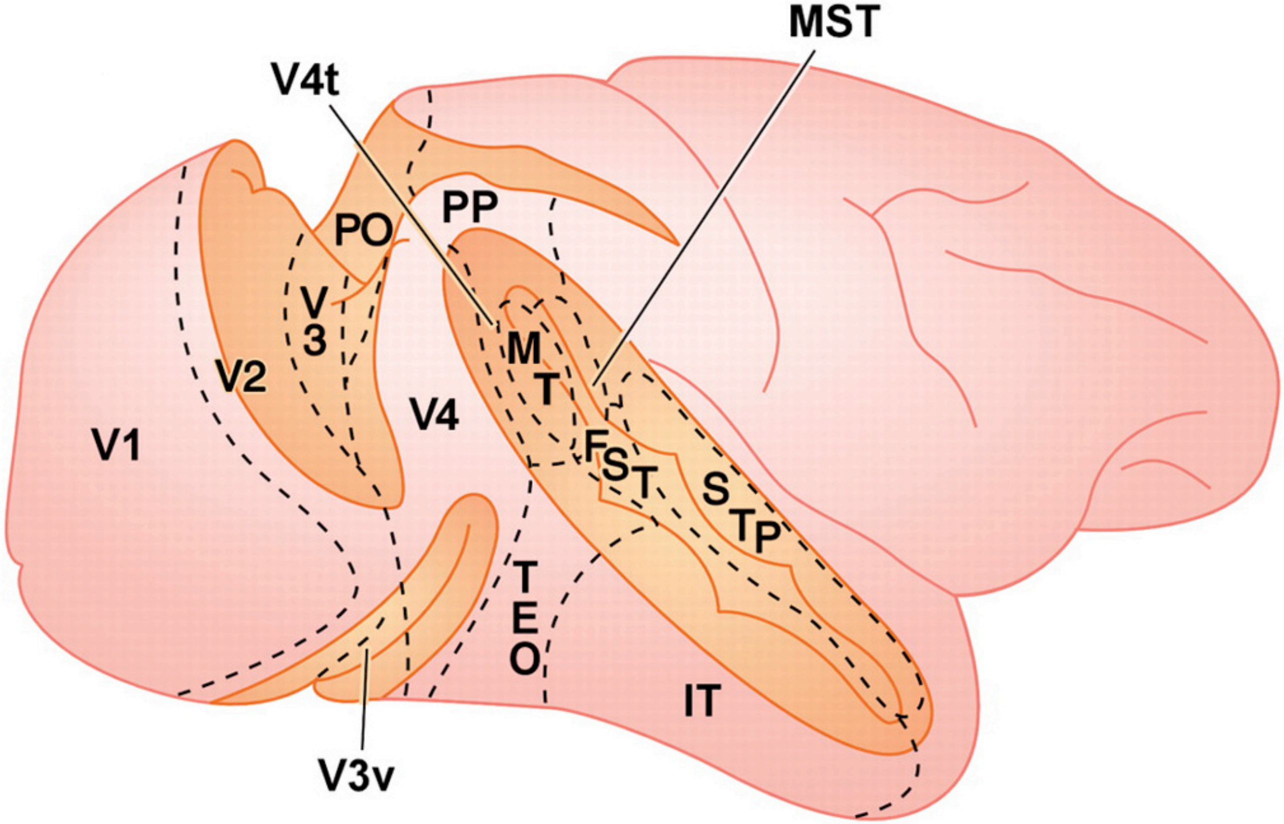
20
25
Time (sec)

Correlation of IT activity and perceptual state during binocular rivalry (Sheinberg and Logothetis, 1997)



Correlation of IT activity and perceptual state during binocular rivalry (Logothetis, 1998)



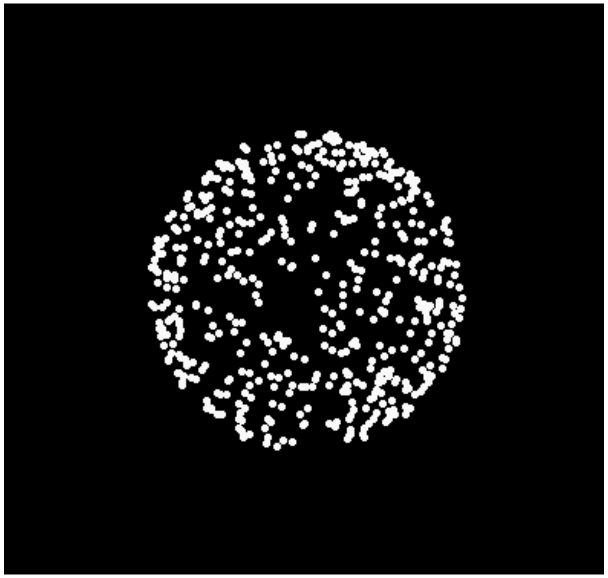


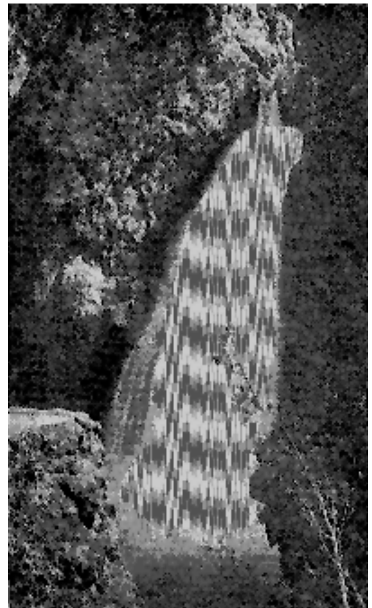
Dorsal pathway
Space, motion, action

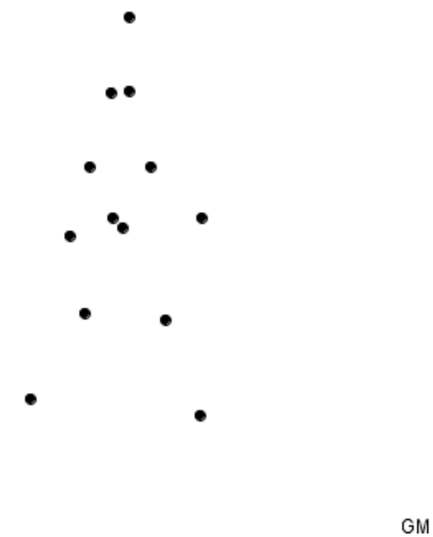
Ventral pathway
Form, recognition, memory

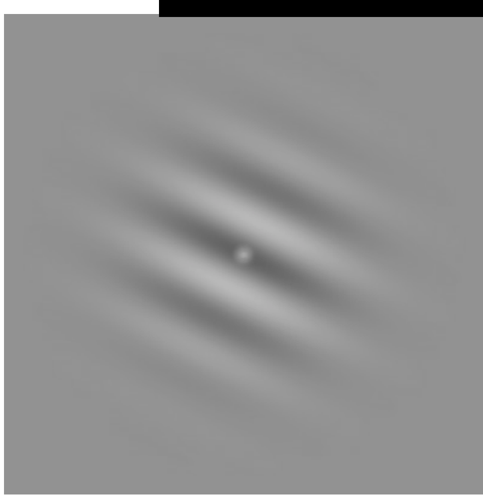
Ungerleider & Mishkin, 1982

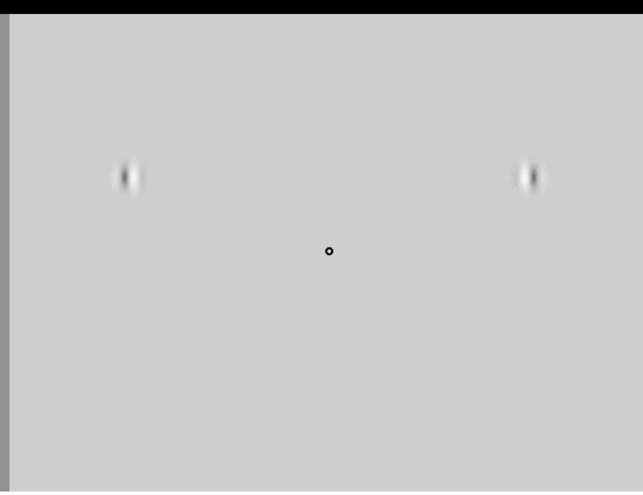
Why motion?











George Mather, Patrick Cavanagh, and others

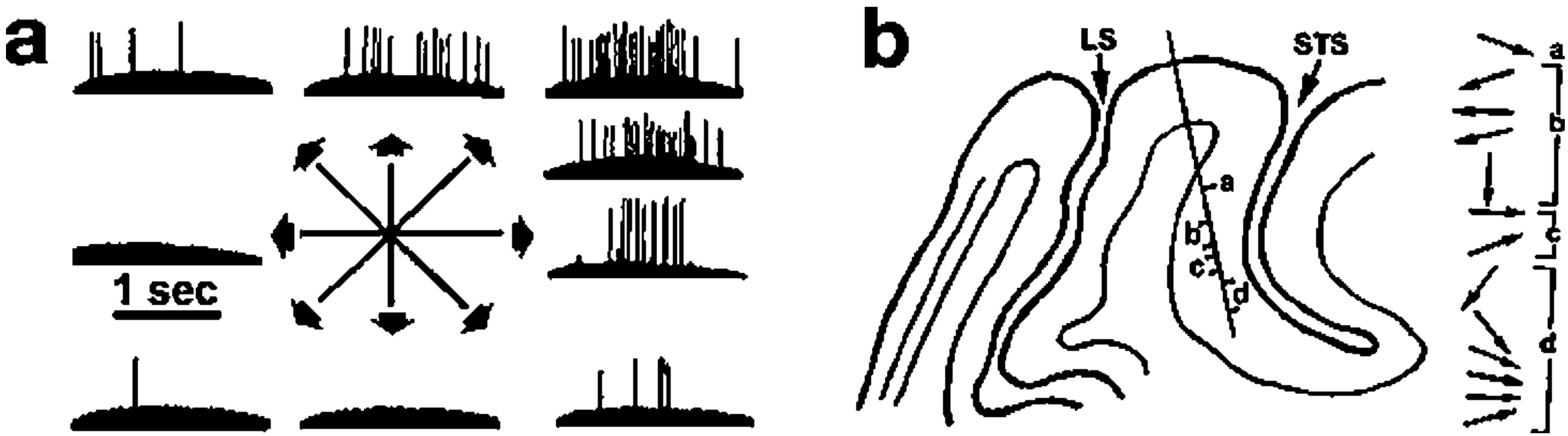
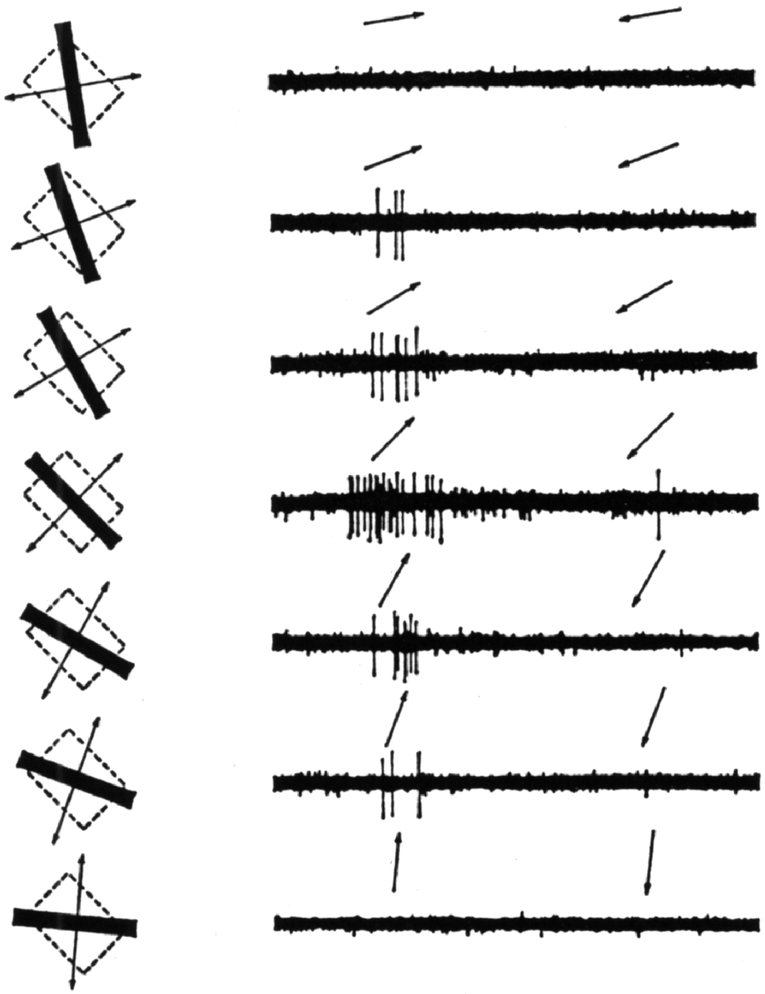


Figure 1

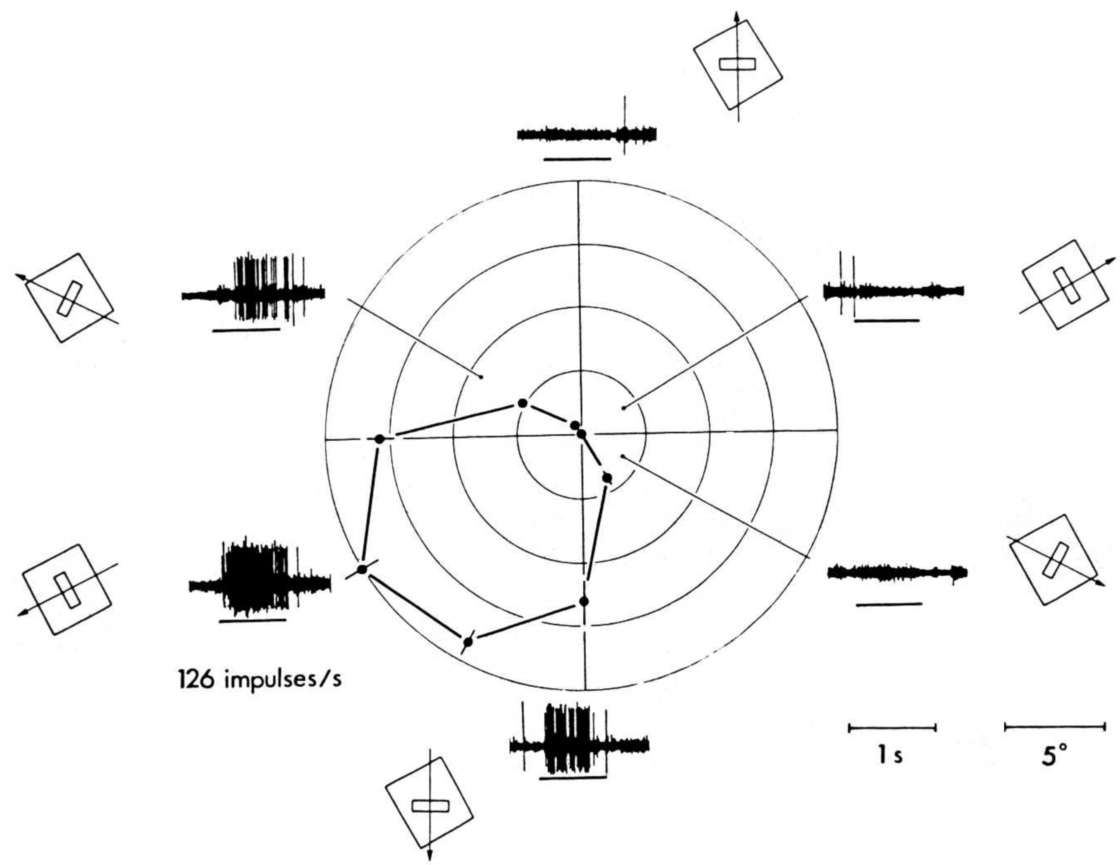
First demonstration of direction selectivity in macaque MT/V5 by Dubner & Zeki (1971). (*a*) Neuronal responses to a bar of light swept across the receptive field in different directions (modified from figure 1 of Dubner & Zeki 1971). Each trace shows the spiking activity of the neuron as the bar was swept in the direction indicated by the arrow. The neuron's preferred direction was up and to the right. (*b*) Oblique penetration through MT (modified from figure 3 of Dubner & Zeki 1971) showing the shifts in preferred direction indicative of the direction columns subsequently demonstrated by Albright et al. (1984). See also **Figure 4**.

V1

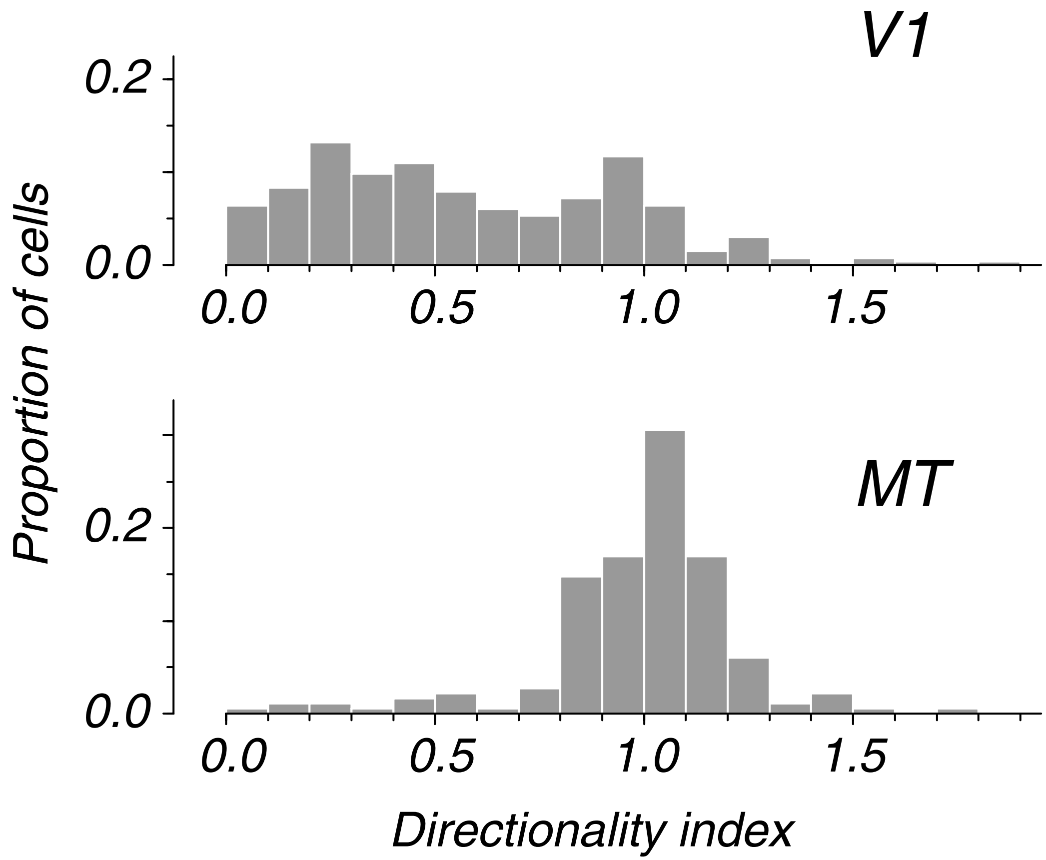


Hubel & Wiesel, 1968

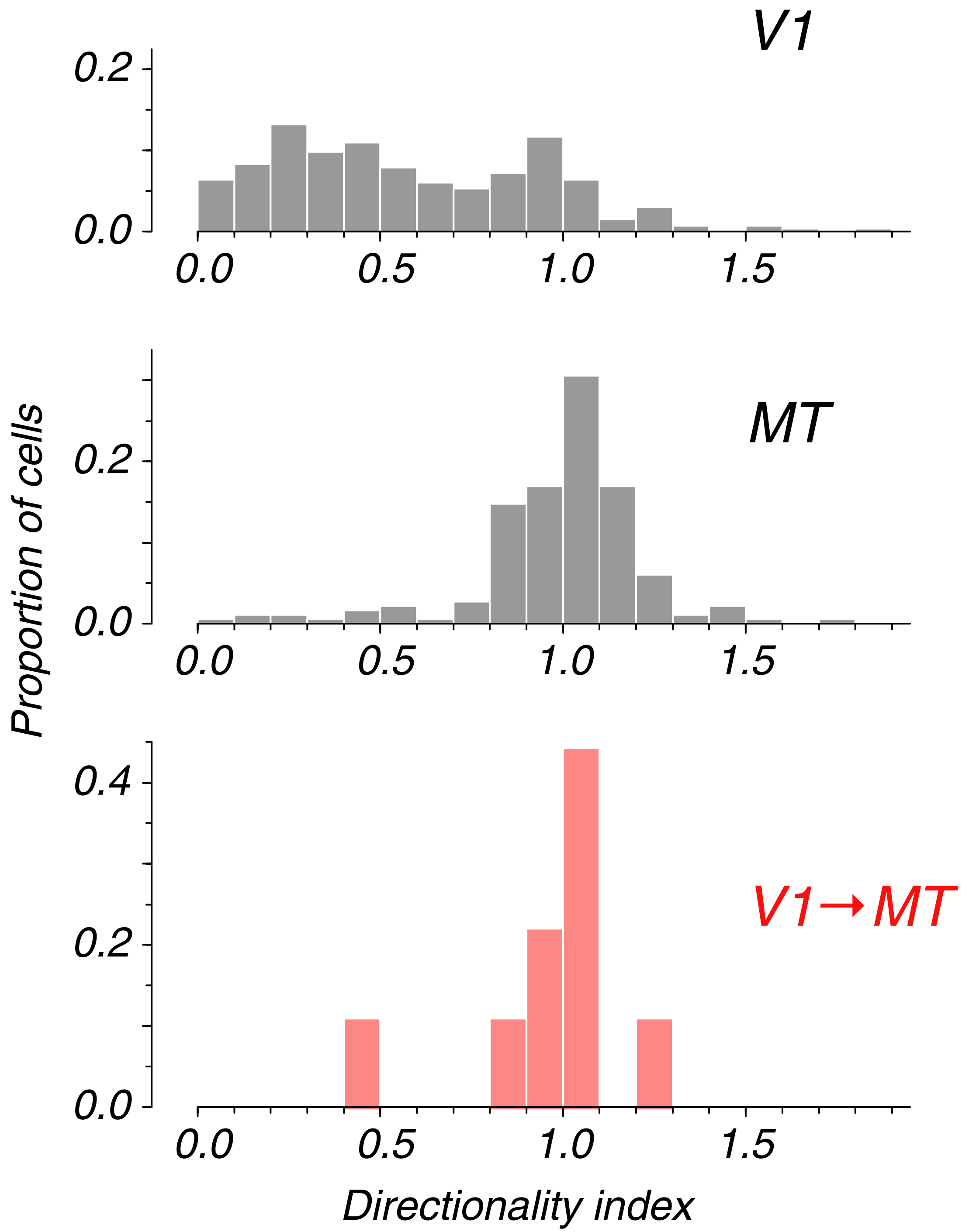
MT



Maunsell & Van Essen, 1983



Movshon & Newsome, 1996



Movshon & Newsome, 1996

Center-surround interactions in MT

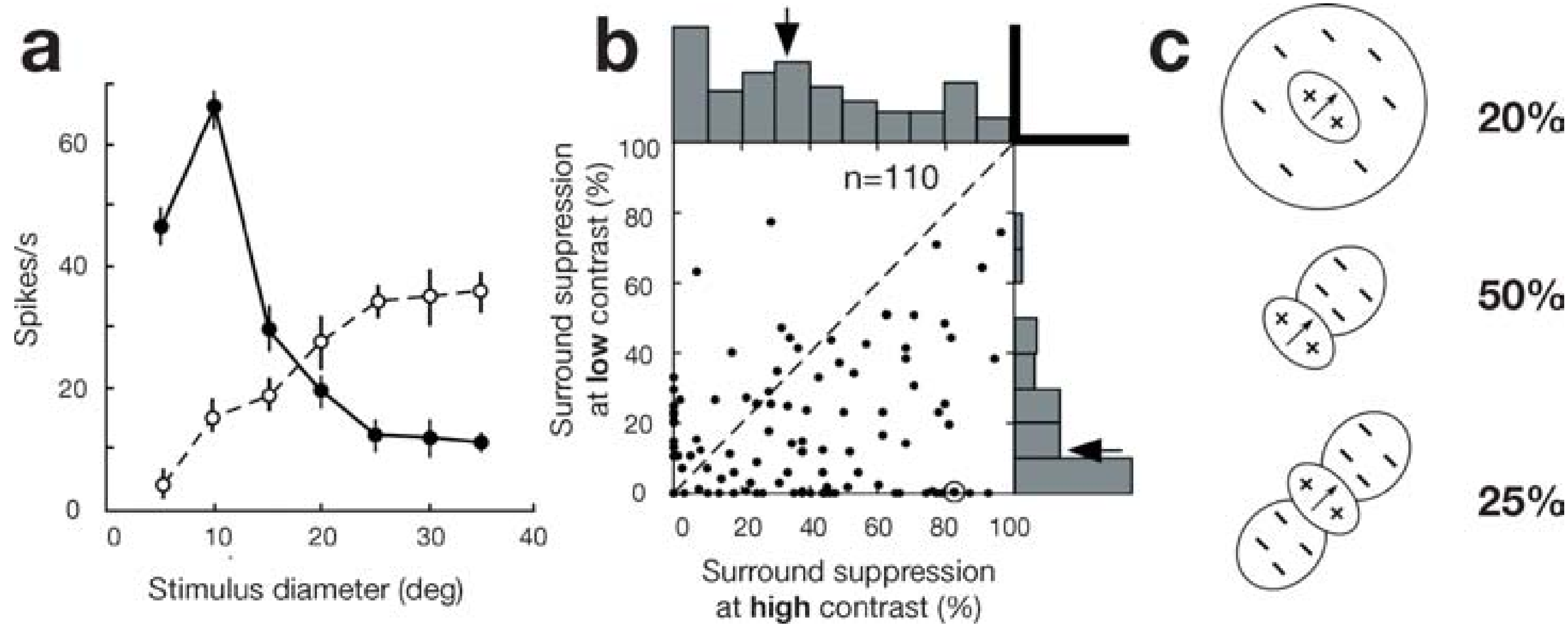


Figure 6

Center-surround interactions in MT. (*A*) Effect of contrast on center-surround interactions for one MT neuron. When tested with high-contrast random dots (RMS contrast 9.8 cd/m^2) the neuron responded optimally to a circular dot patch 10° in diameter and was strongly suppressed by larger patterns. The same test using a low-contrast dot pattern (0.7 cd/m^2) revealed strong area summation with increasing size. (*B*) Population of 110 MT neurons showing the strength of surround suppression measured at both high and low contrast. Surround suppression was quantified as the percent reduction in response between the largest dot patch (35° diameter) and the stimulus eliciting the maximal response. Each dot represents data from one neuron; the dashed diagonal is the locus of points for which the surround suppression was unchanged by contrast. The circled dot is the cell from panel *A*. (*C*) Asymmetries in the spatial organization of the suppressive surround (after Xiao et al. 1997). Different kinds of surround geometry are potentially useful for calculating spatial changes in flow fields that may be involved in the computation of structure from motion. Neurons whose receptive fields have circularly symmetric surrounds (*top*) are postulated to underlie figure-ground segregation. The first- (*middle*) and second-order (*bottom*) directional derivatives can be used to determine surface tilt (or slant) and surface curvature, respectively (Buracas & Albright 1996). Panels *A* and *B* are from Pack et al. 2005.

Speed tuning

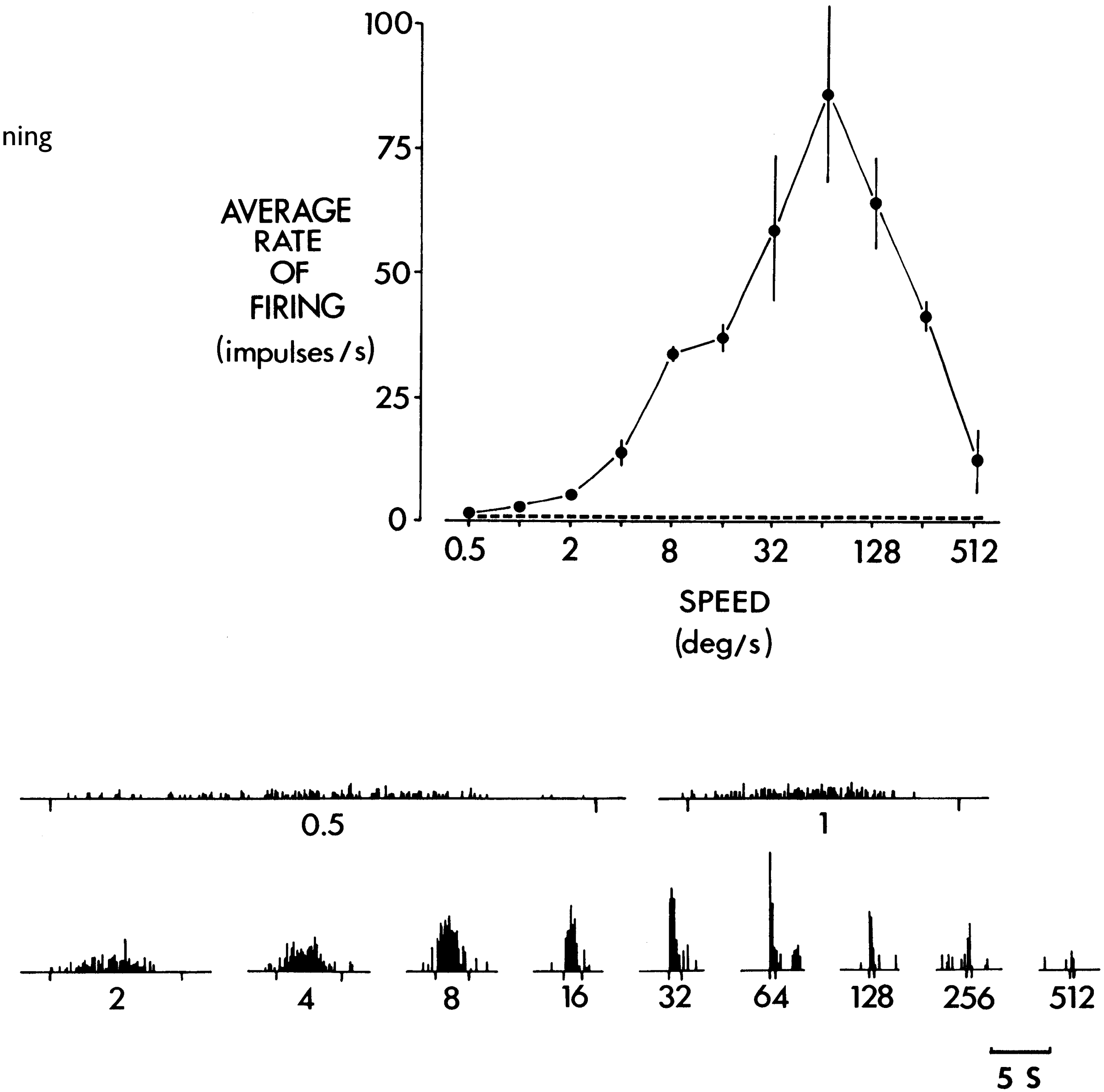
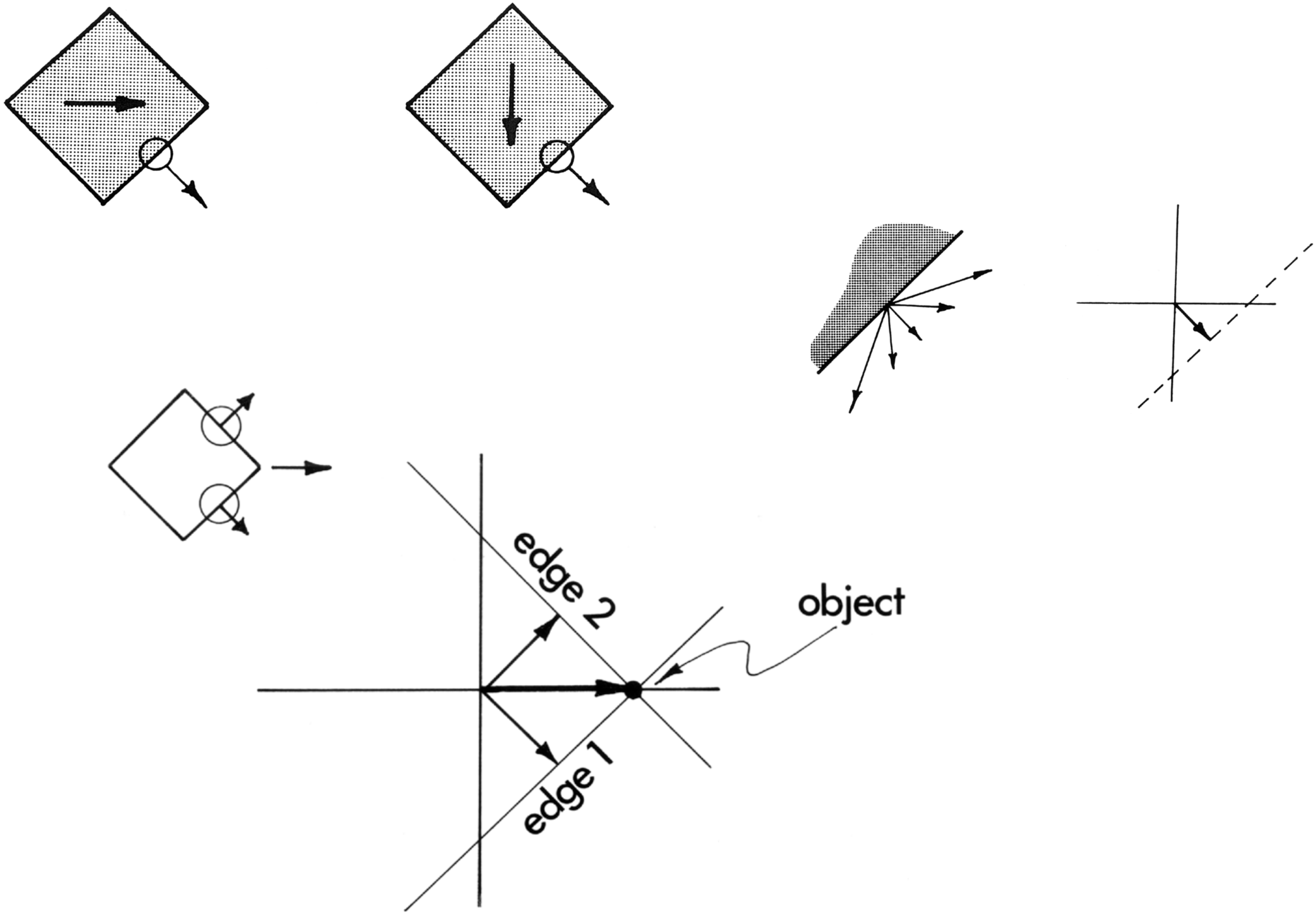
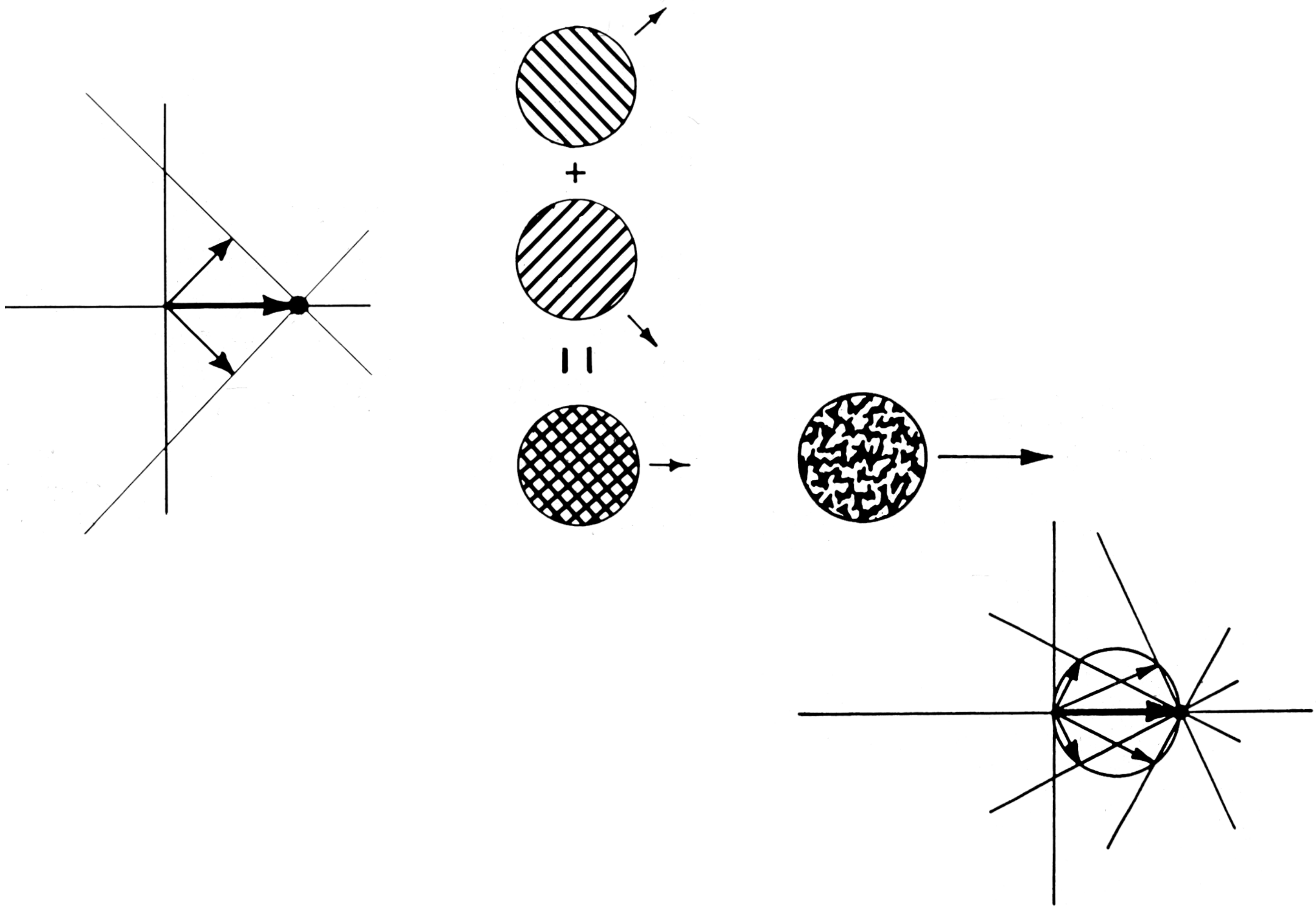


FIG. 5. Responses of a representative unit in MT to stimuli moving in its preferred direction at different speeds. In this and all subsequent plots the speed axis is logarithmic. Bars indicate the standard errors of the mean for five repetitions of each speed. A dashed line marks the background rate of firing. This unit, like most in MT, had a sharp peak in its response curve. Summed response histograms in the lower half of the figure show that the peak rate of firing closely follows the average rate of firing. Tic marks under each histogram denote times of stimulus onset and offset. The receptive field was 15° across and each stimulus traversed 20°.

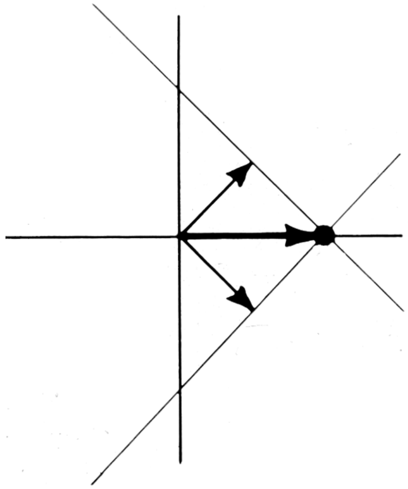


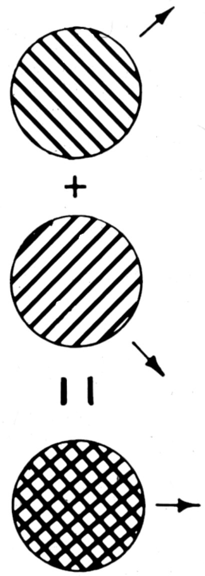
Movshon, Adelson, Gizzi & Newsome, 1985



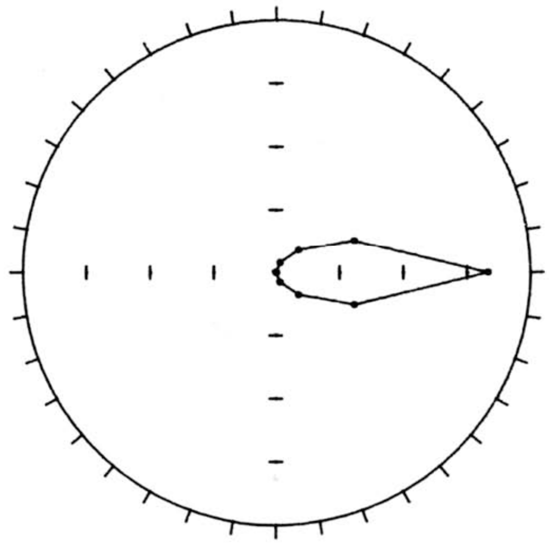
Movshon, Adelson, Gizzi & Newsome, 1985

Gratings, plaids, and coherent motion

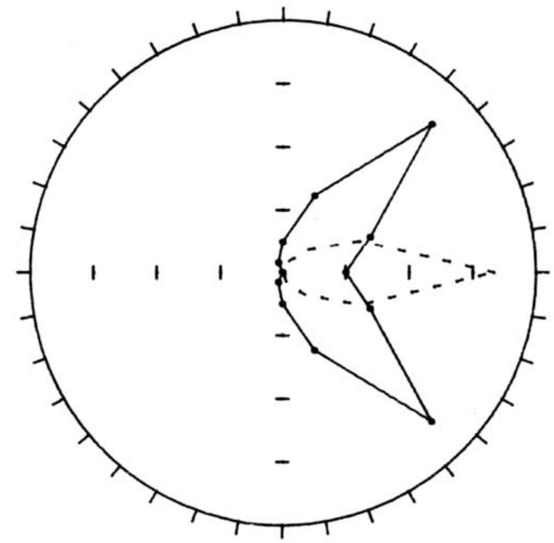




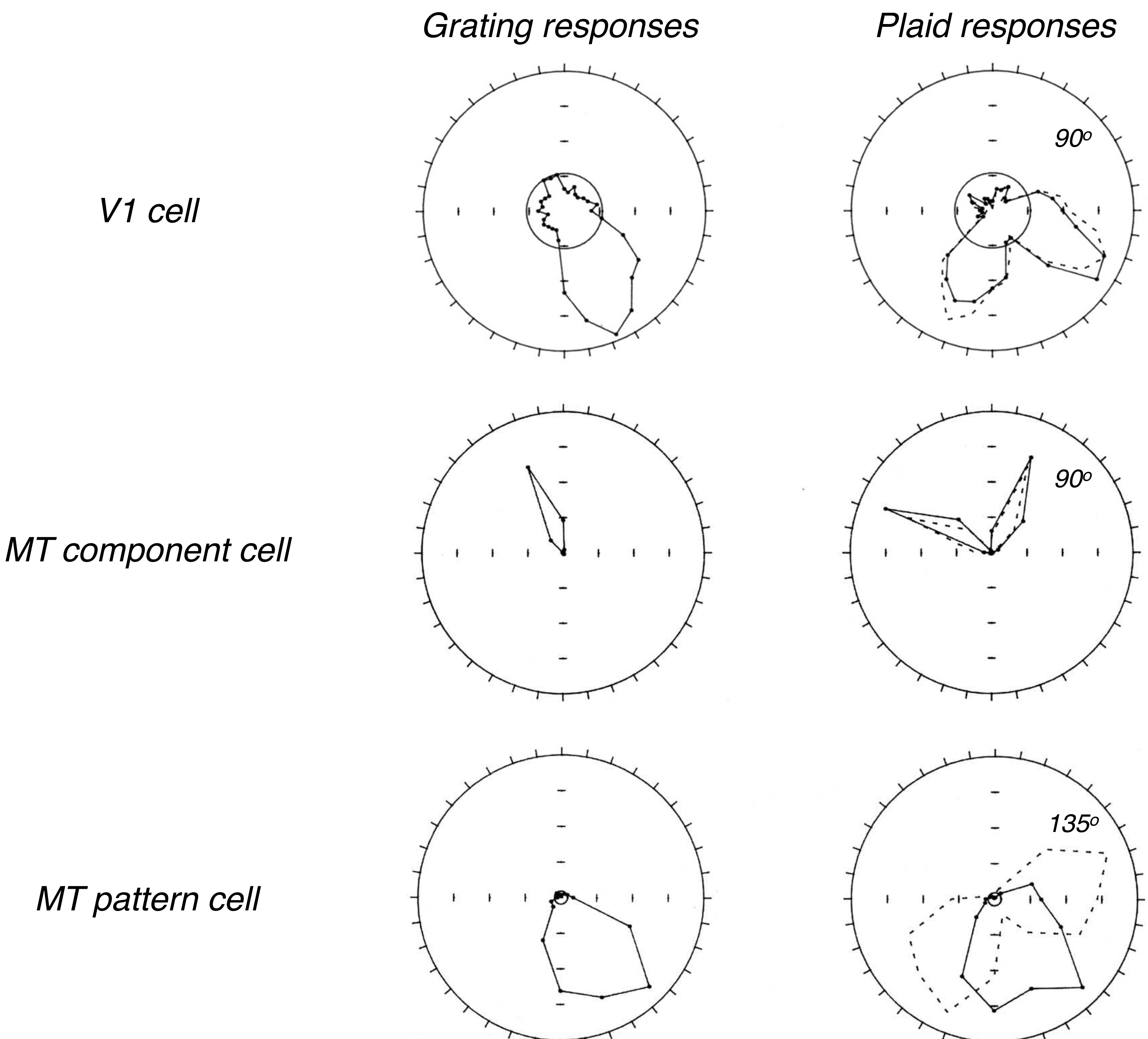
Grating response



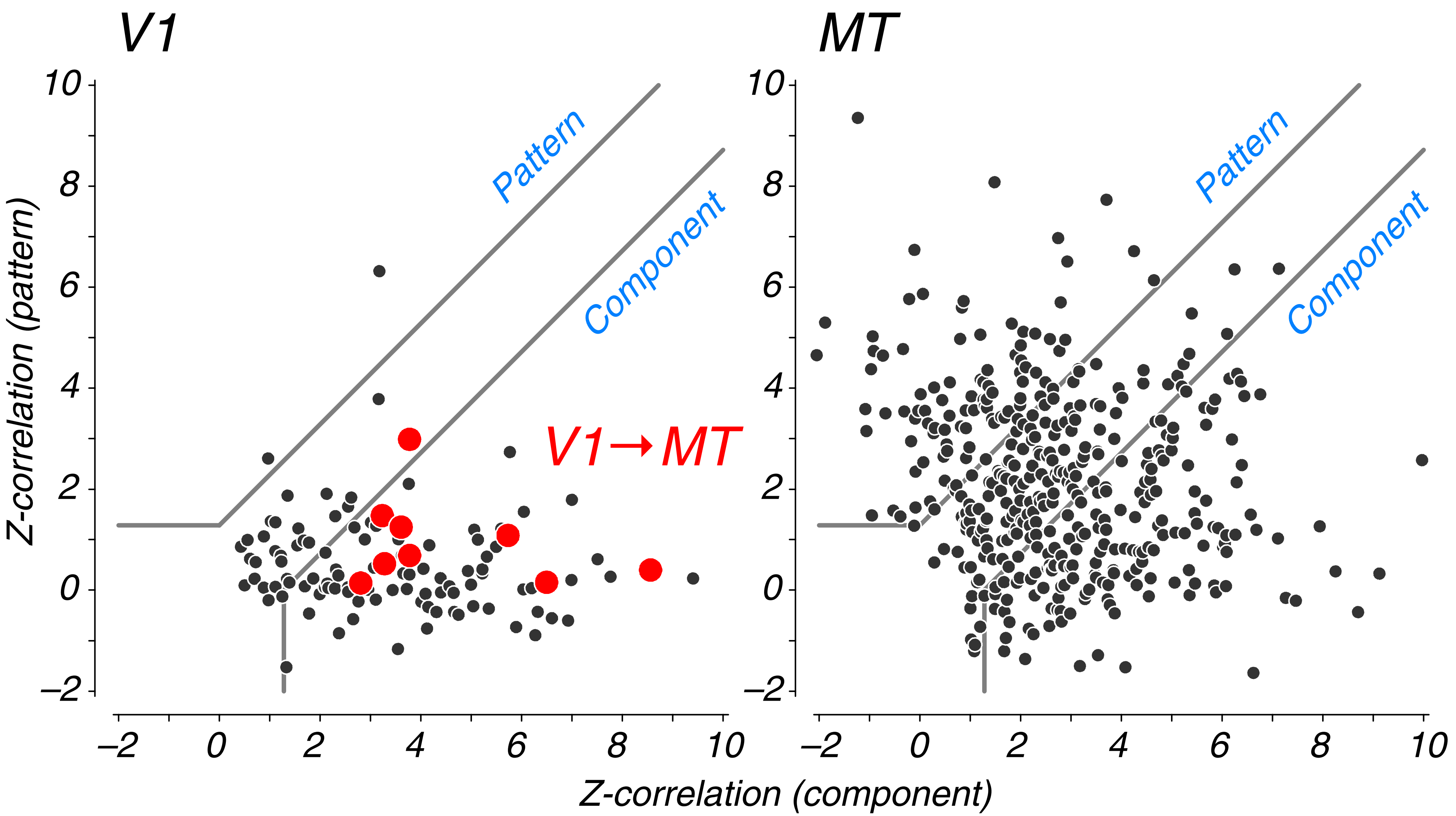
Predicted plaid response



Movshon, Adelson, Gizzi & Newsome, 1985

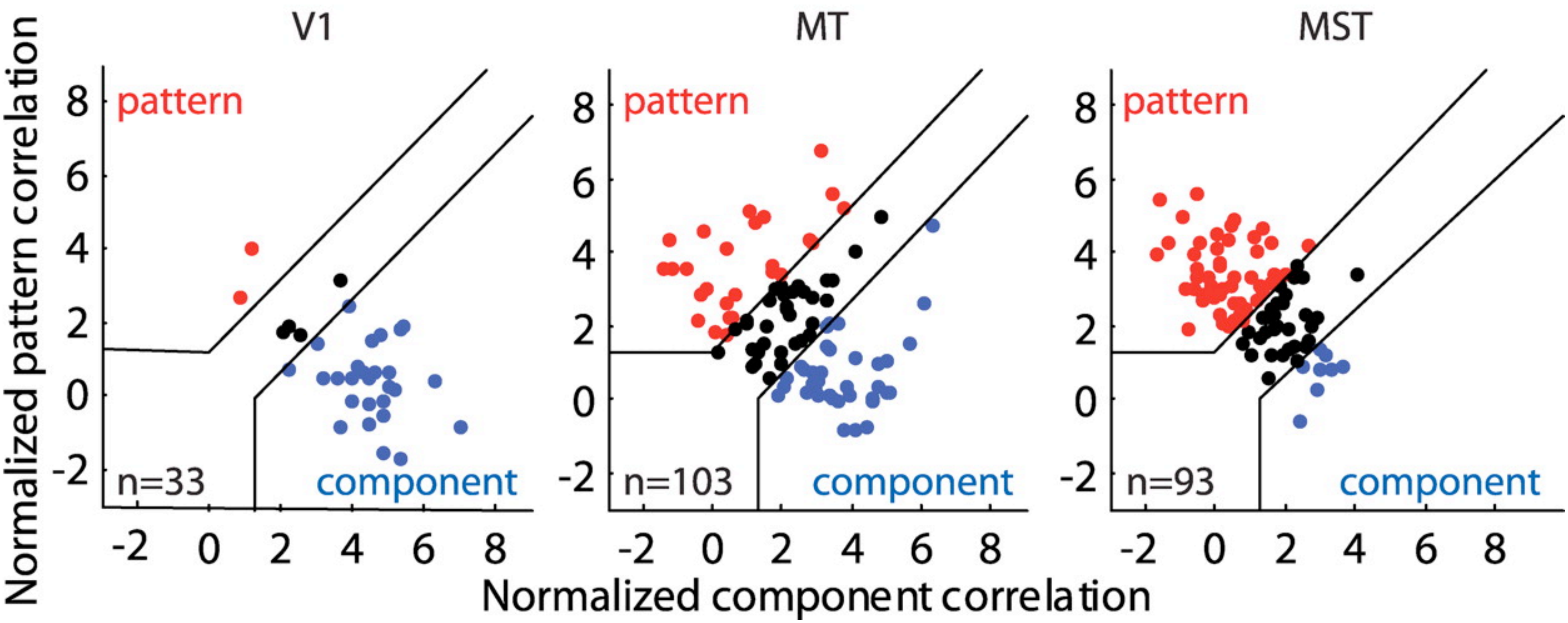


Movshon, Adelson, Gizzi & Newsome, 1985



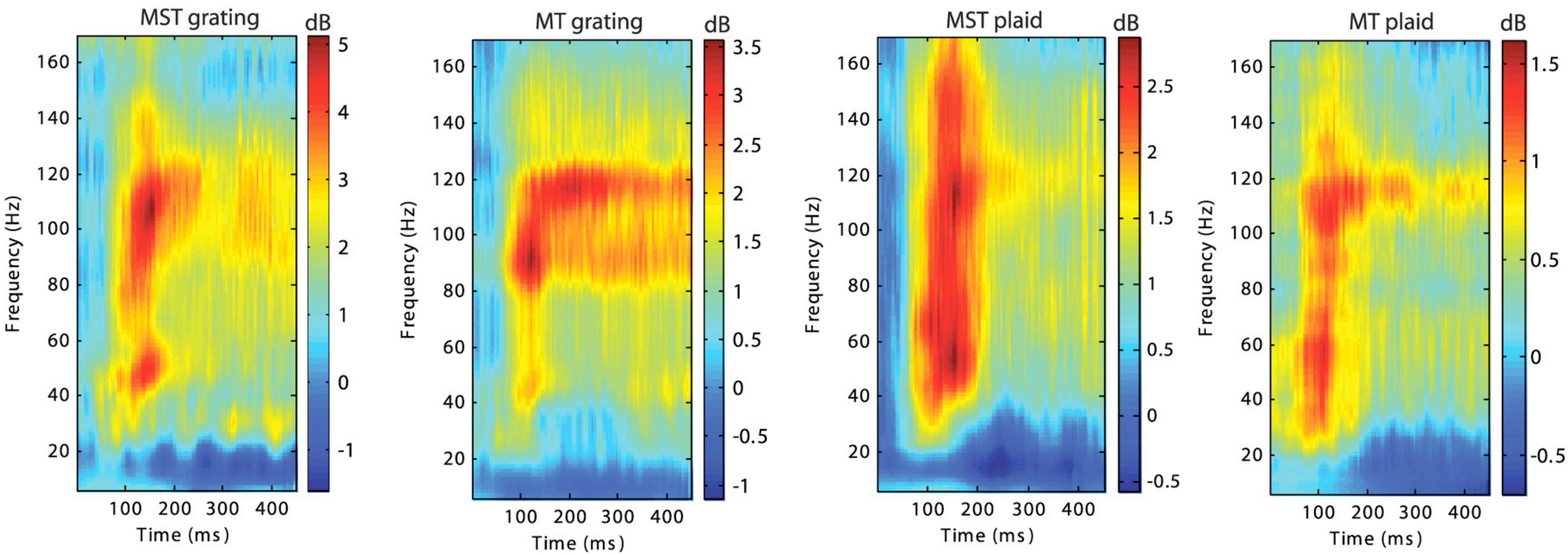
Movshon & Newsome, 1996

MST also contains a high proportion of pattern cells



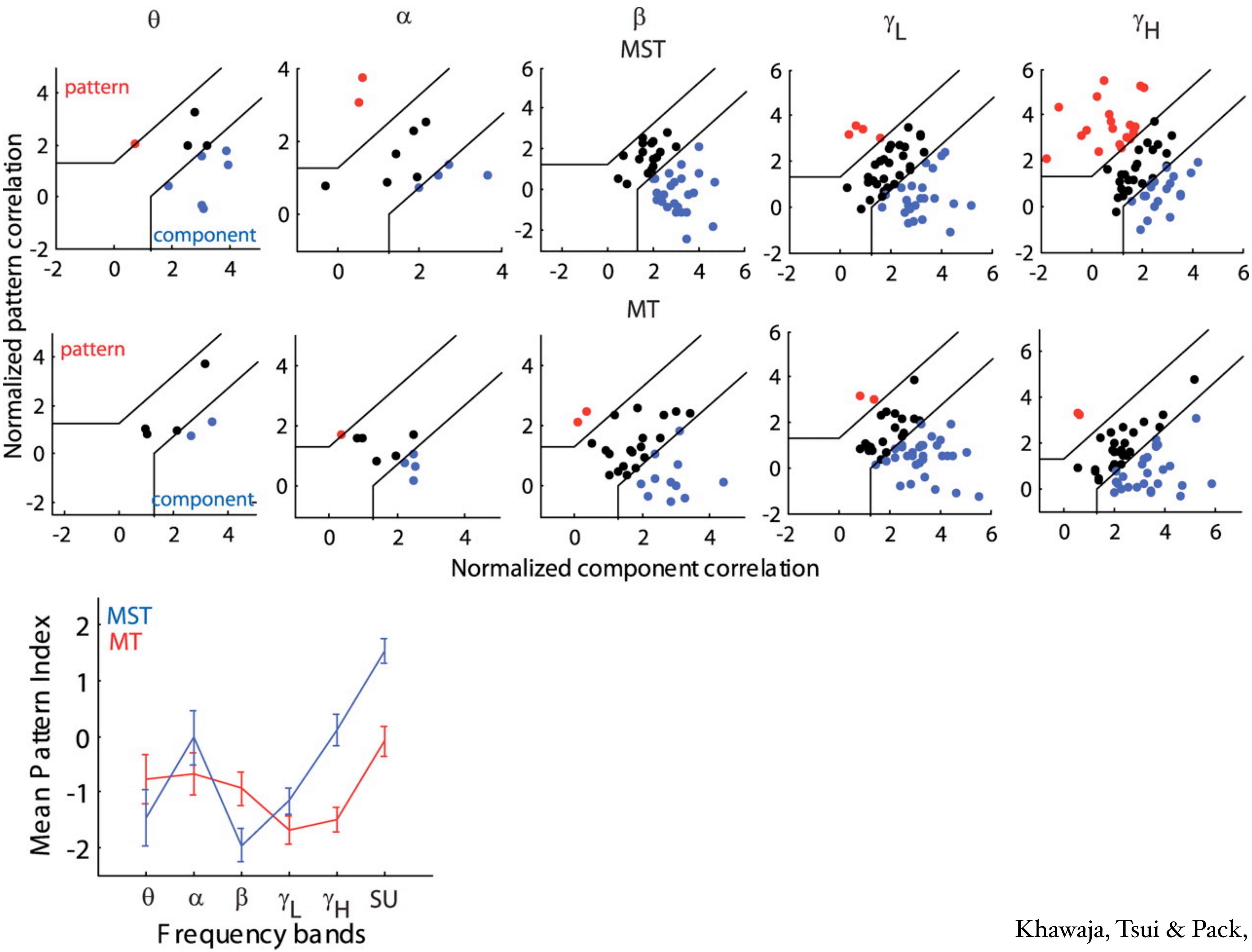
Khawaja, Tsui & Pack, 2009

Local field potentials may reveal stages in pattern computation



Khawaja, Tsui & Pack, 2009

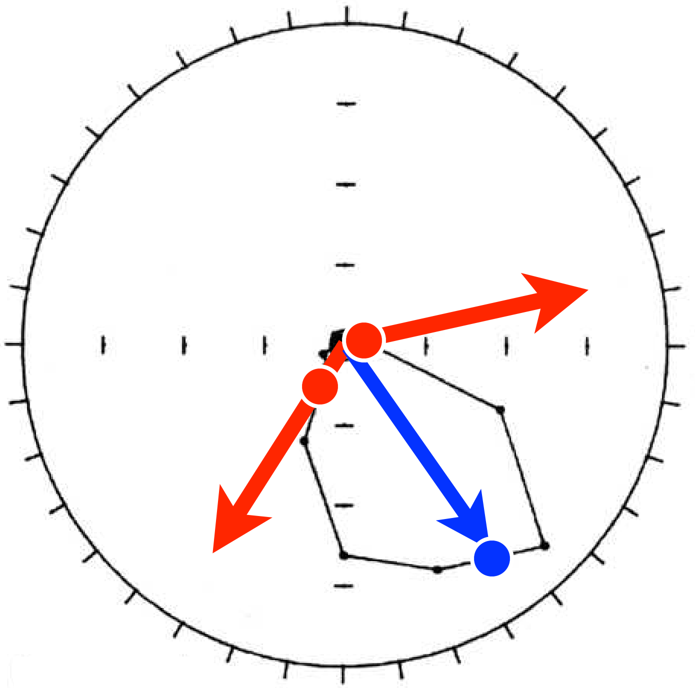
Local field potentials may reveal stages in pattern computation



Khawaja, Tsui & Pack, 2009

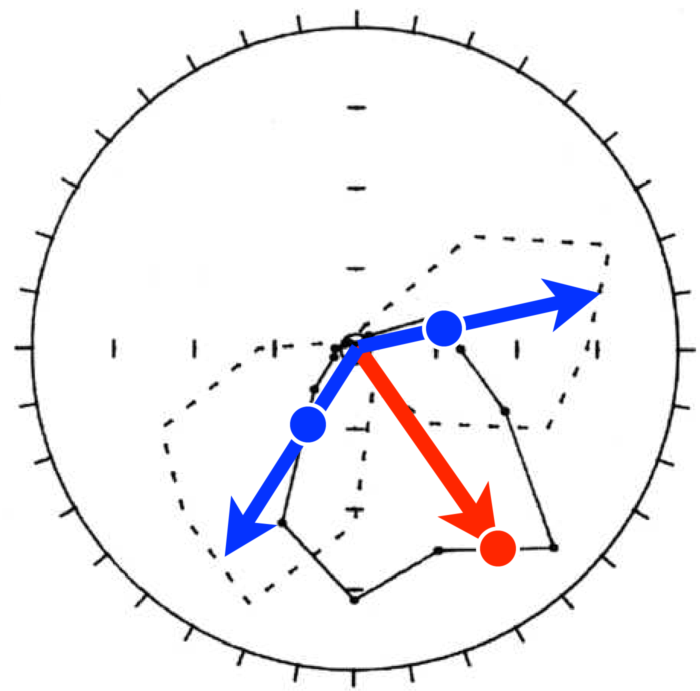
MT pattern cell

Grating responses



Components of the optimal plaid

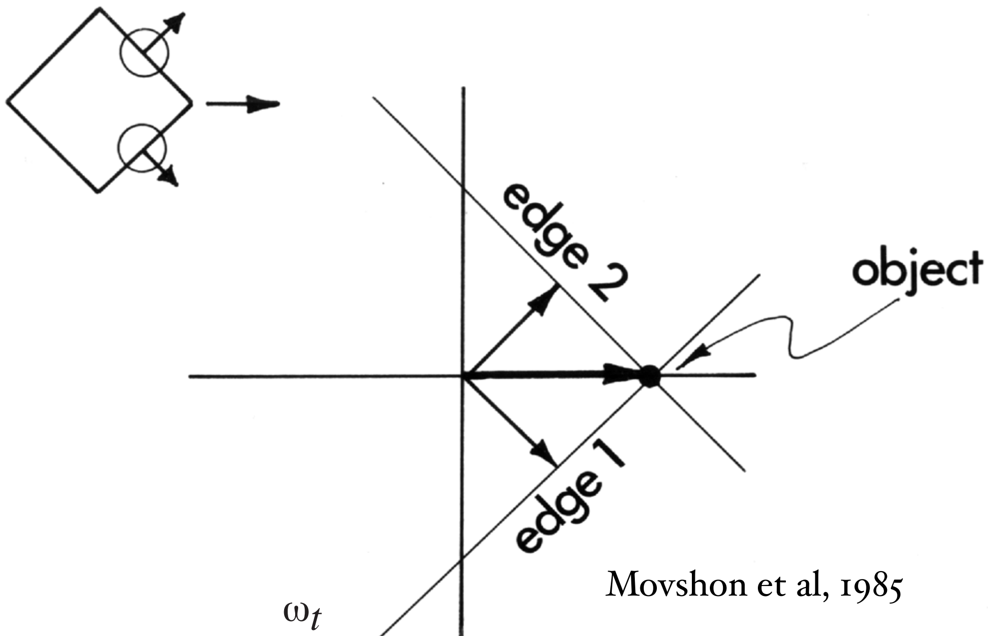
Plaid responses



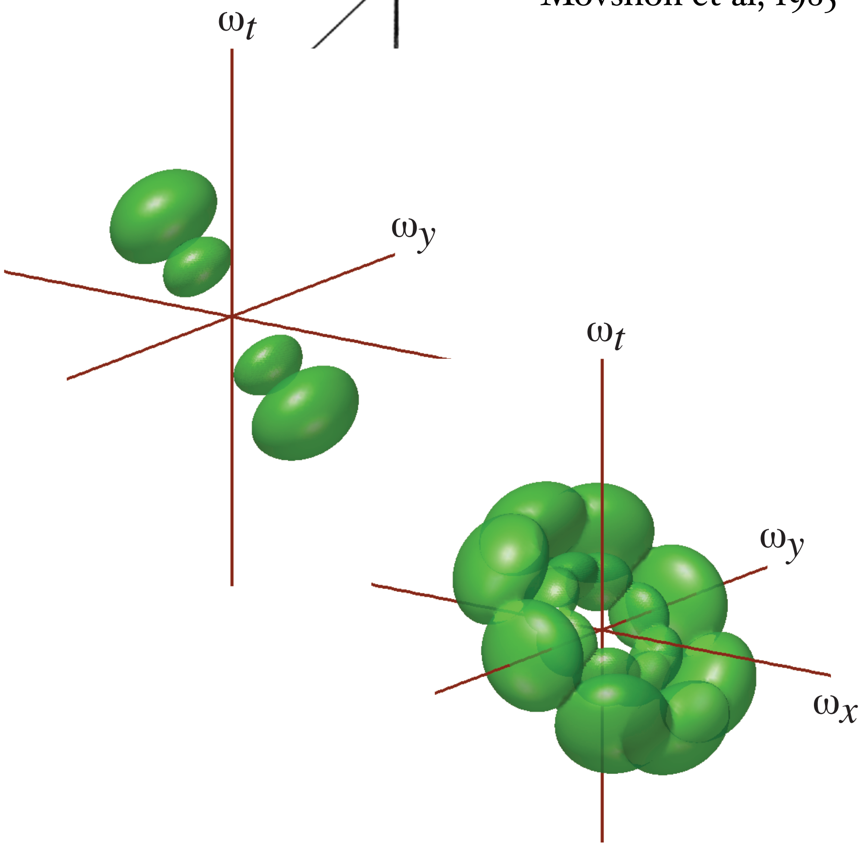
Plaids containing the optimal grating

Movshon, Adelson, Gizzi & Newsome, 1985

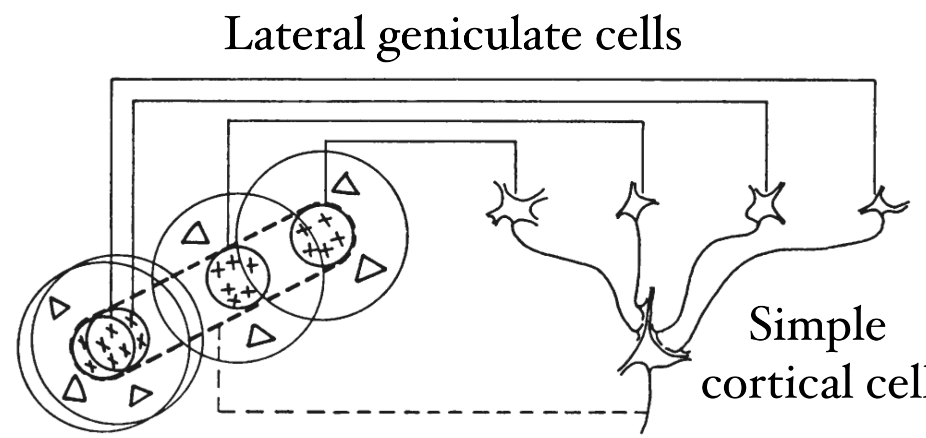
In search of a simple model



Movshon et al, 1985

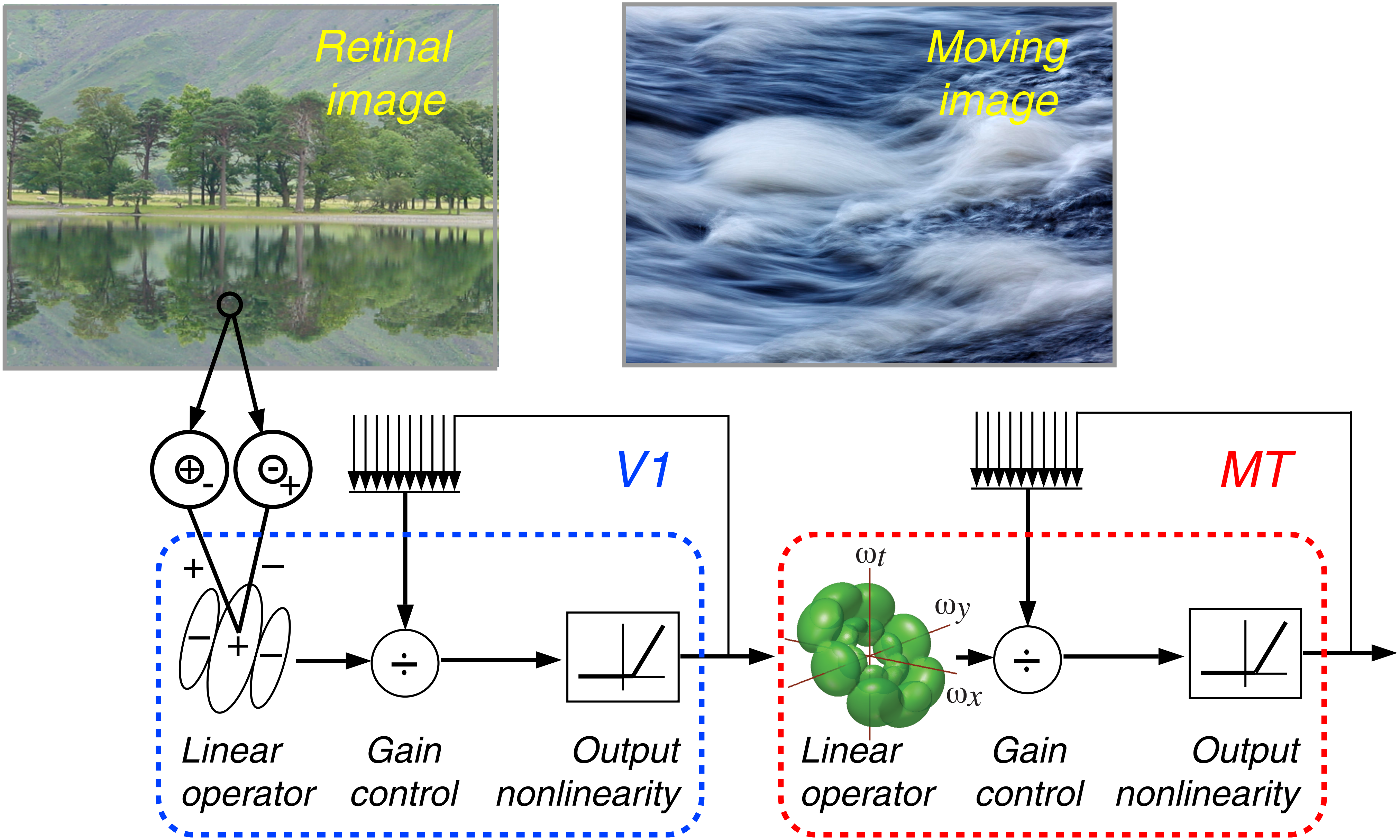


Simoncelli & Heeger., 1998



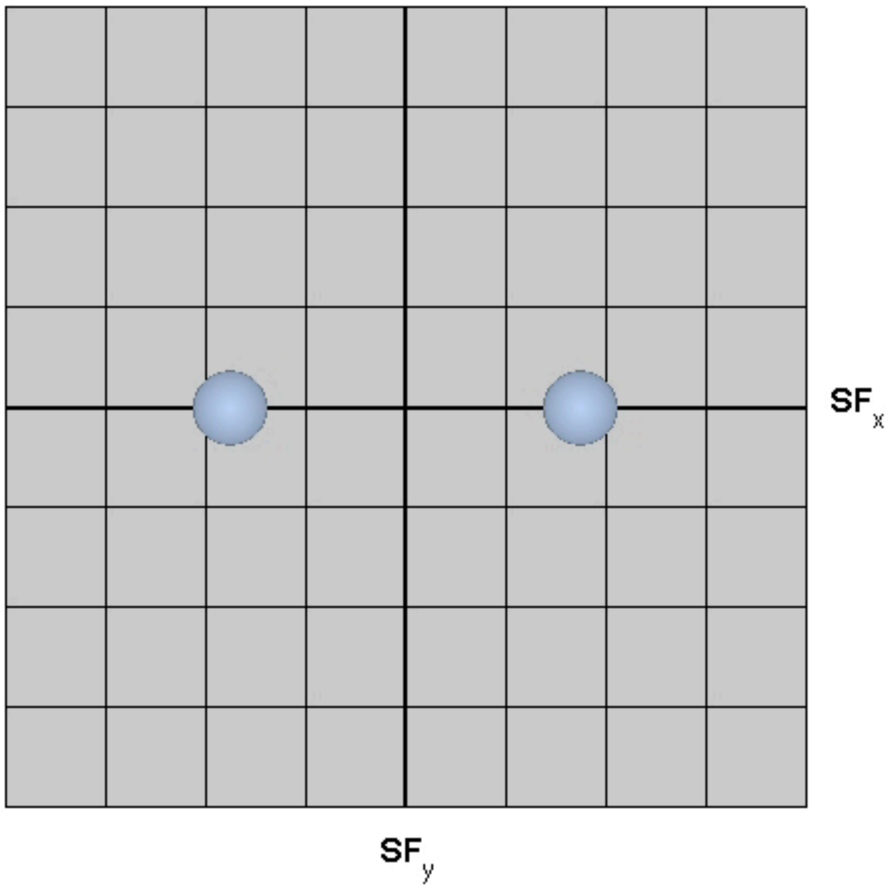
Hubel & Wiesel, 1962

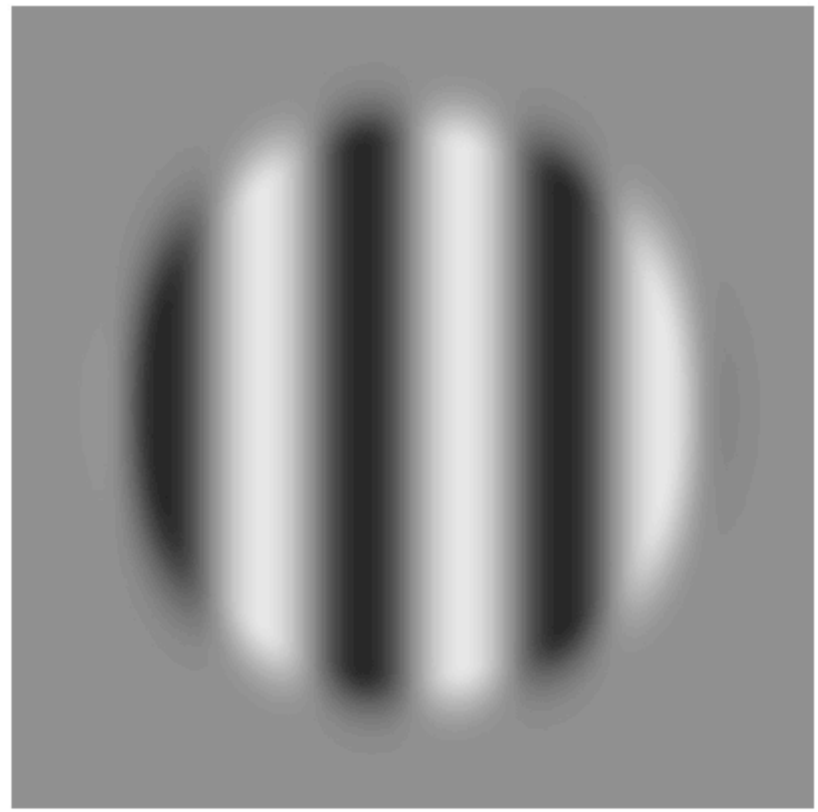
A simple and (mostly) feedforward model



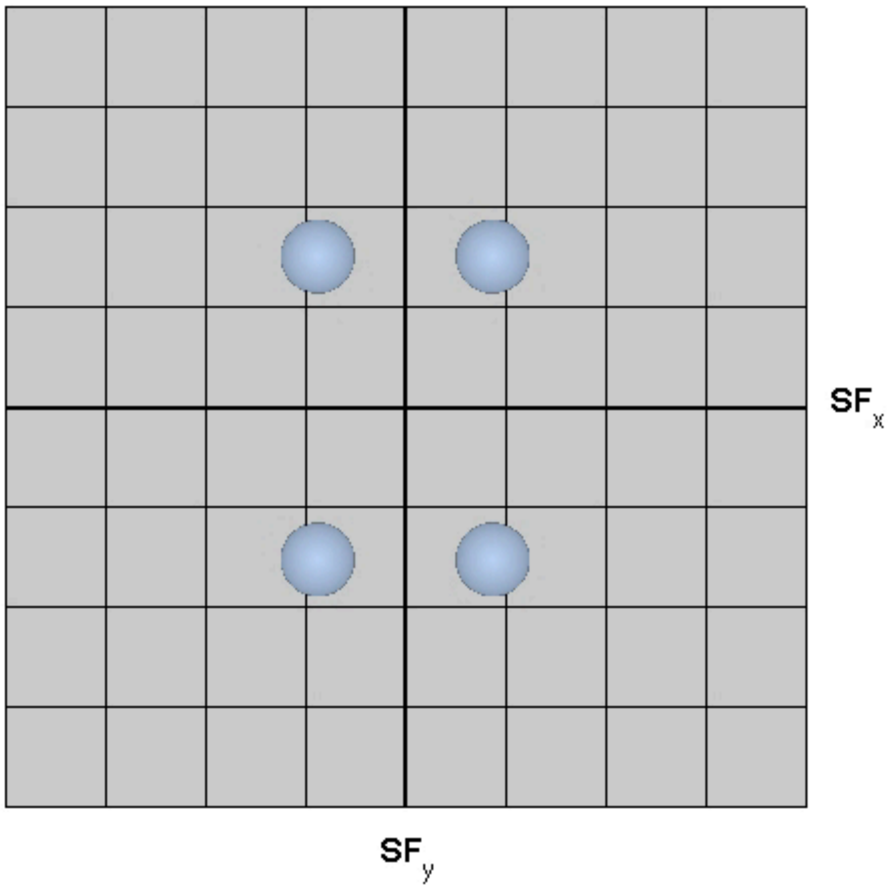
Simoncelli & Heeger., 1998

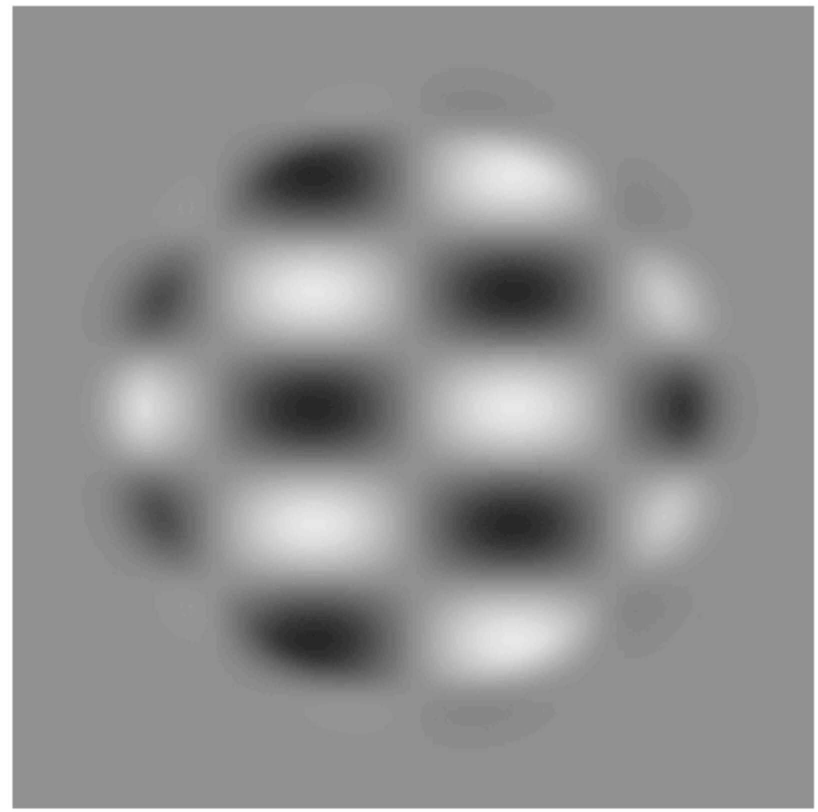
1D motion stimuli: gratings



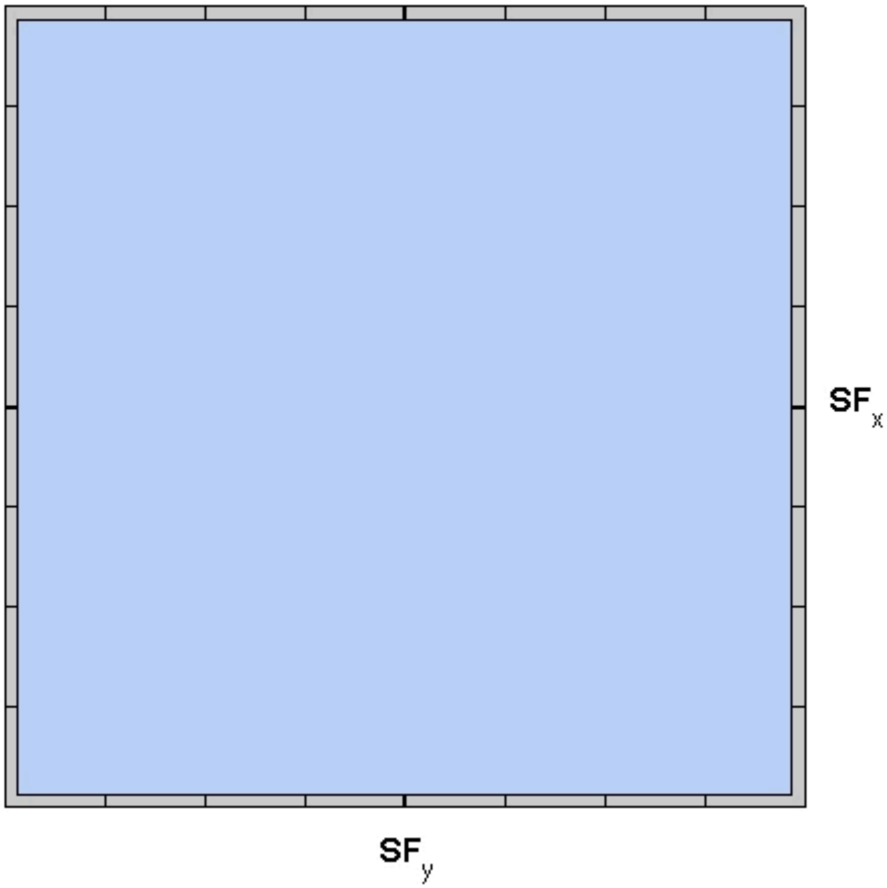


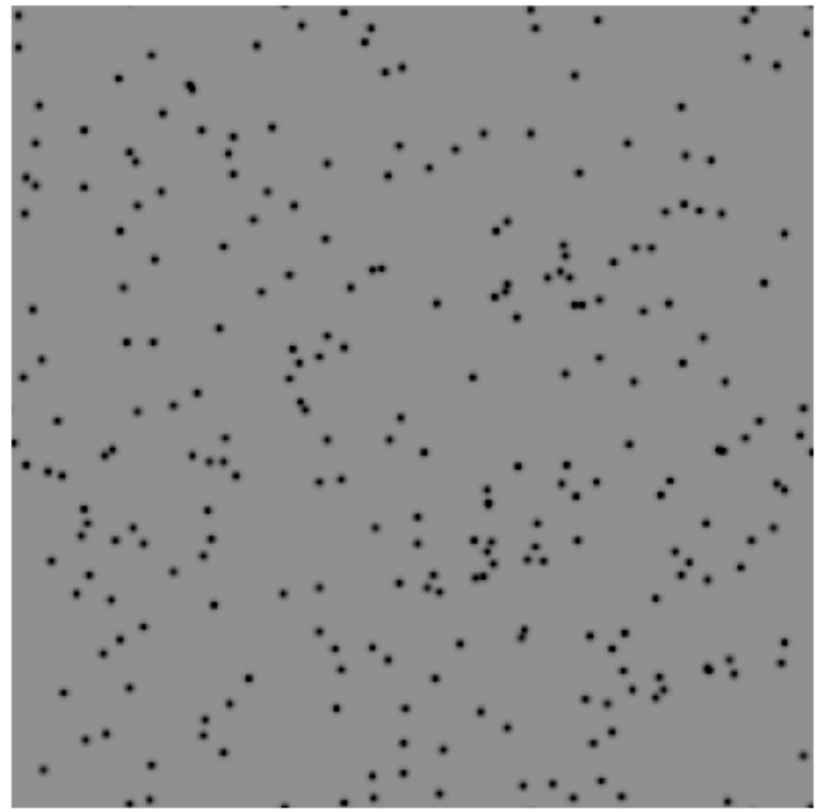
2D motion stimuli: plaids



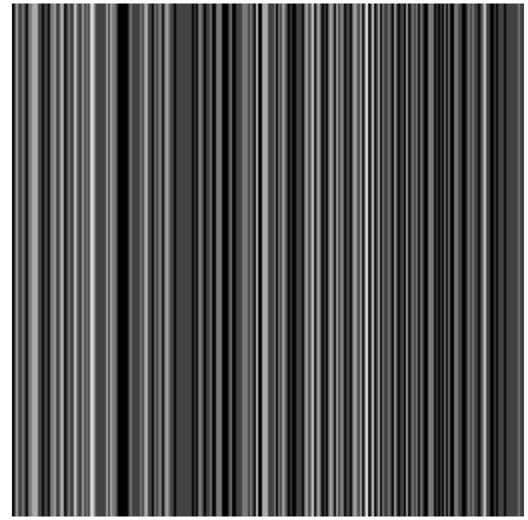


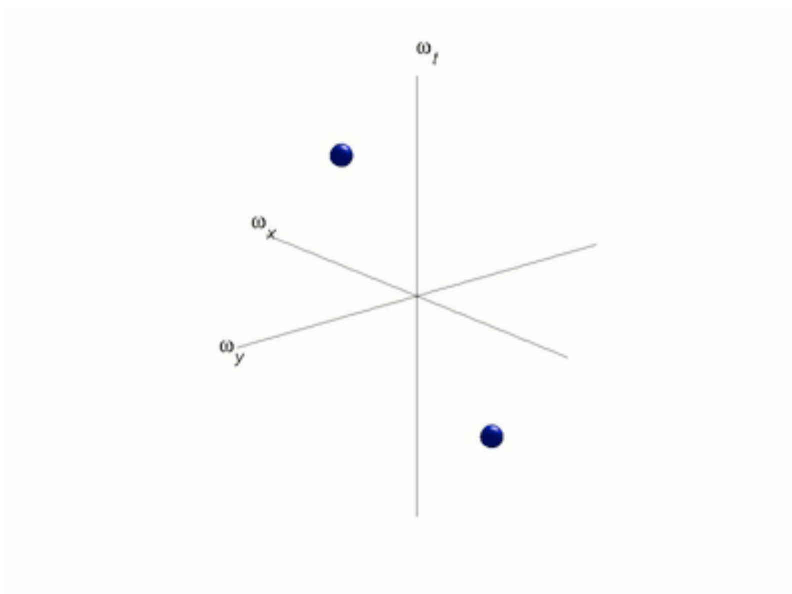
2D motion stimuli: textures

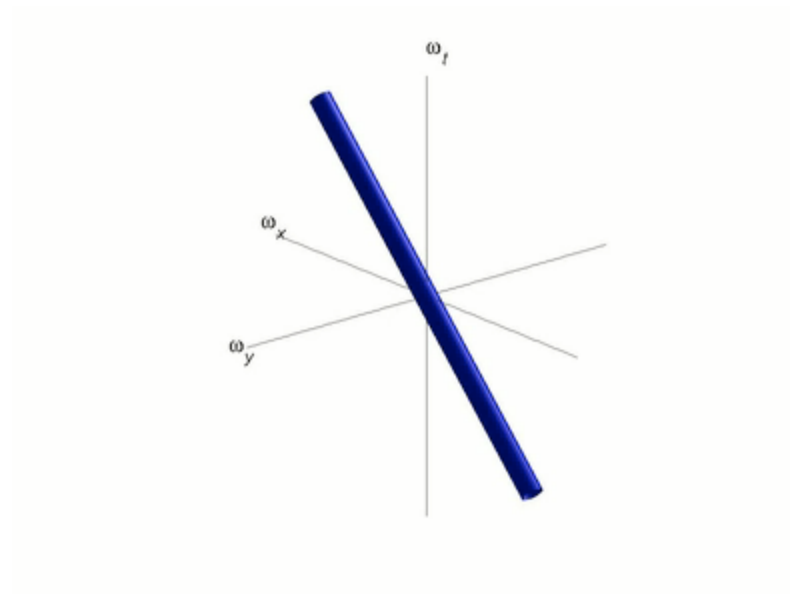


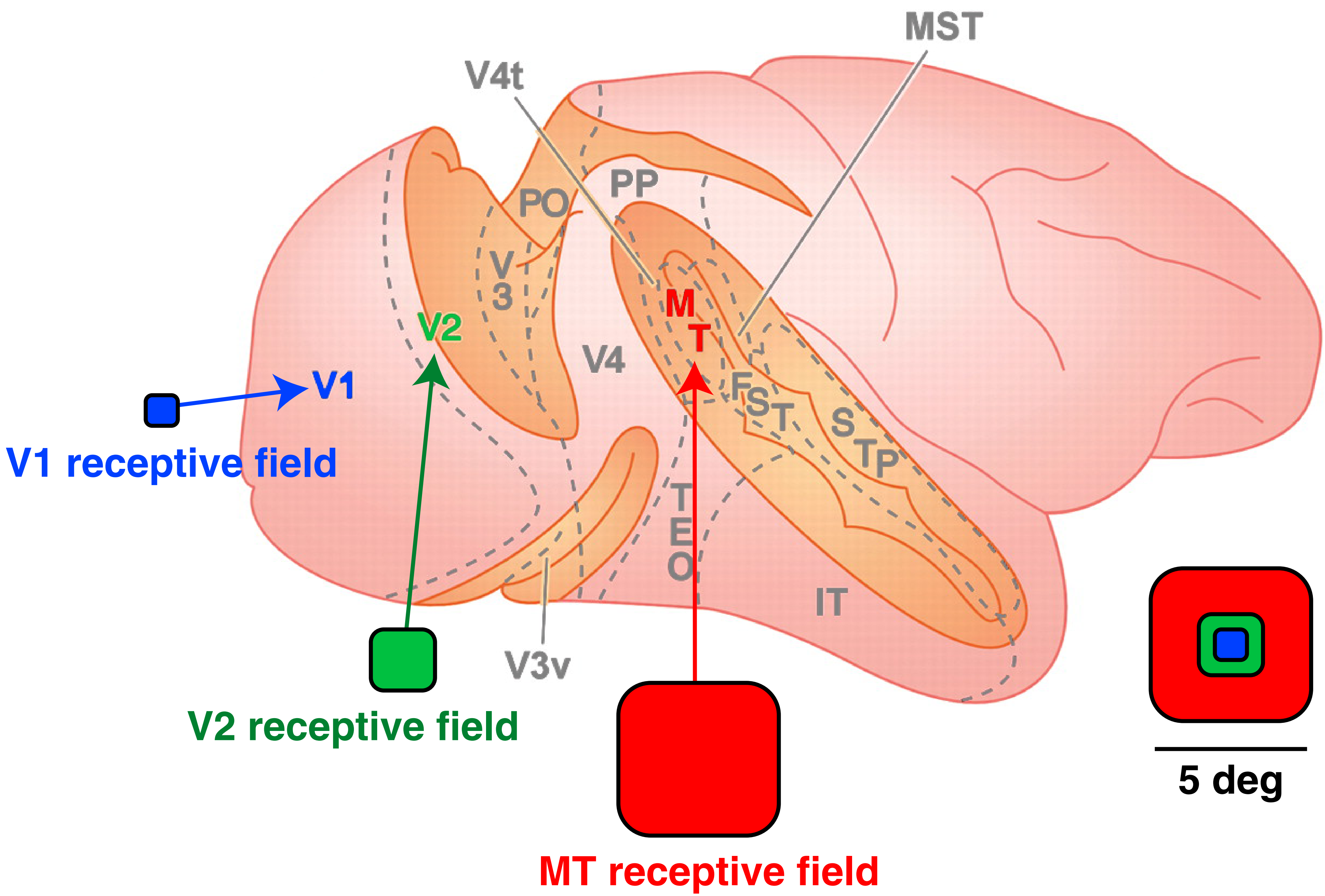


1D motion stimuli








MST
V4t
PP
PO
V3
V2
V1
V4
MT
FST
STP
TEO
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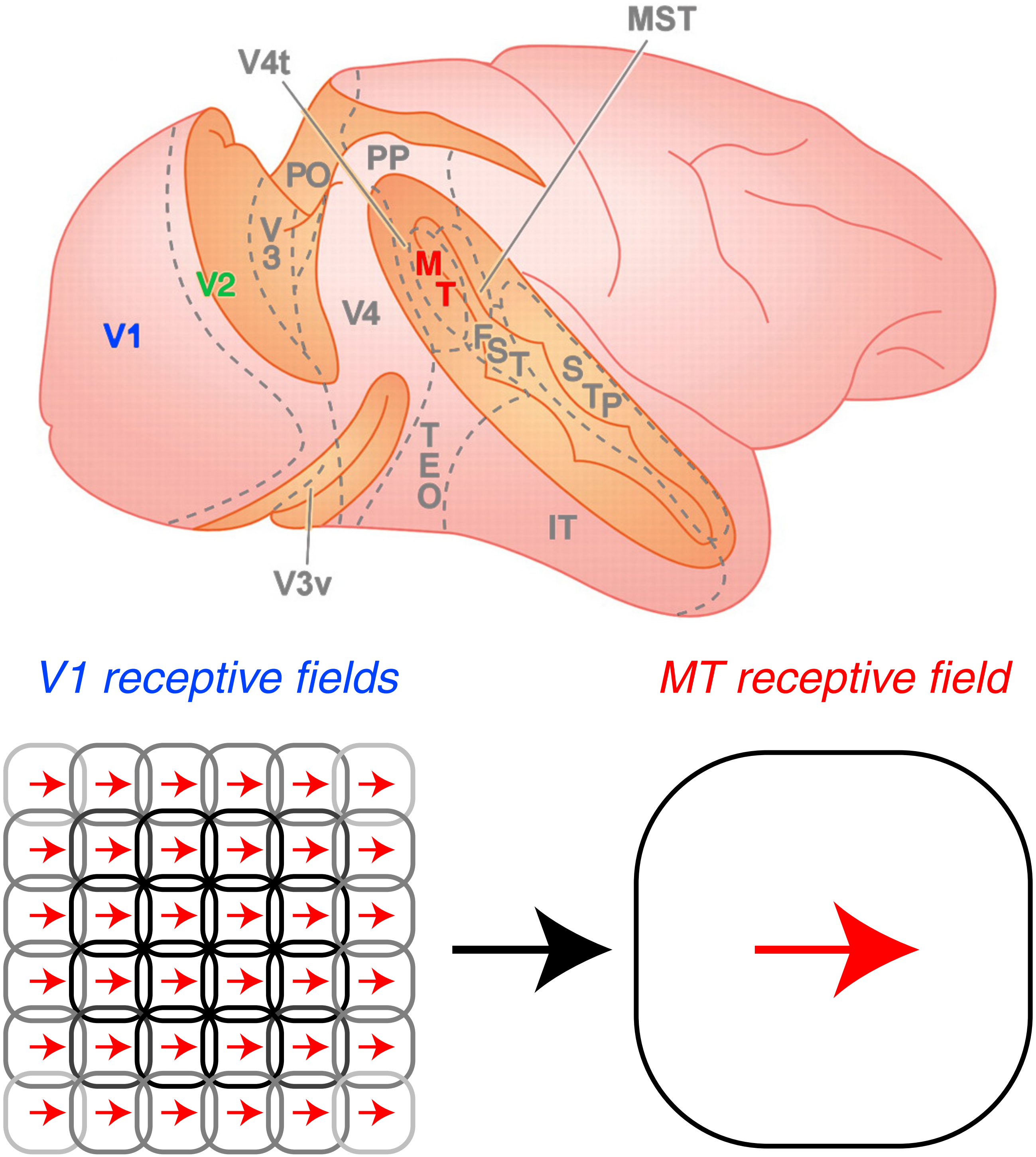
V3v
V1 receptive field
V2 receptive field
MT receptive field
5 deg


MST
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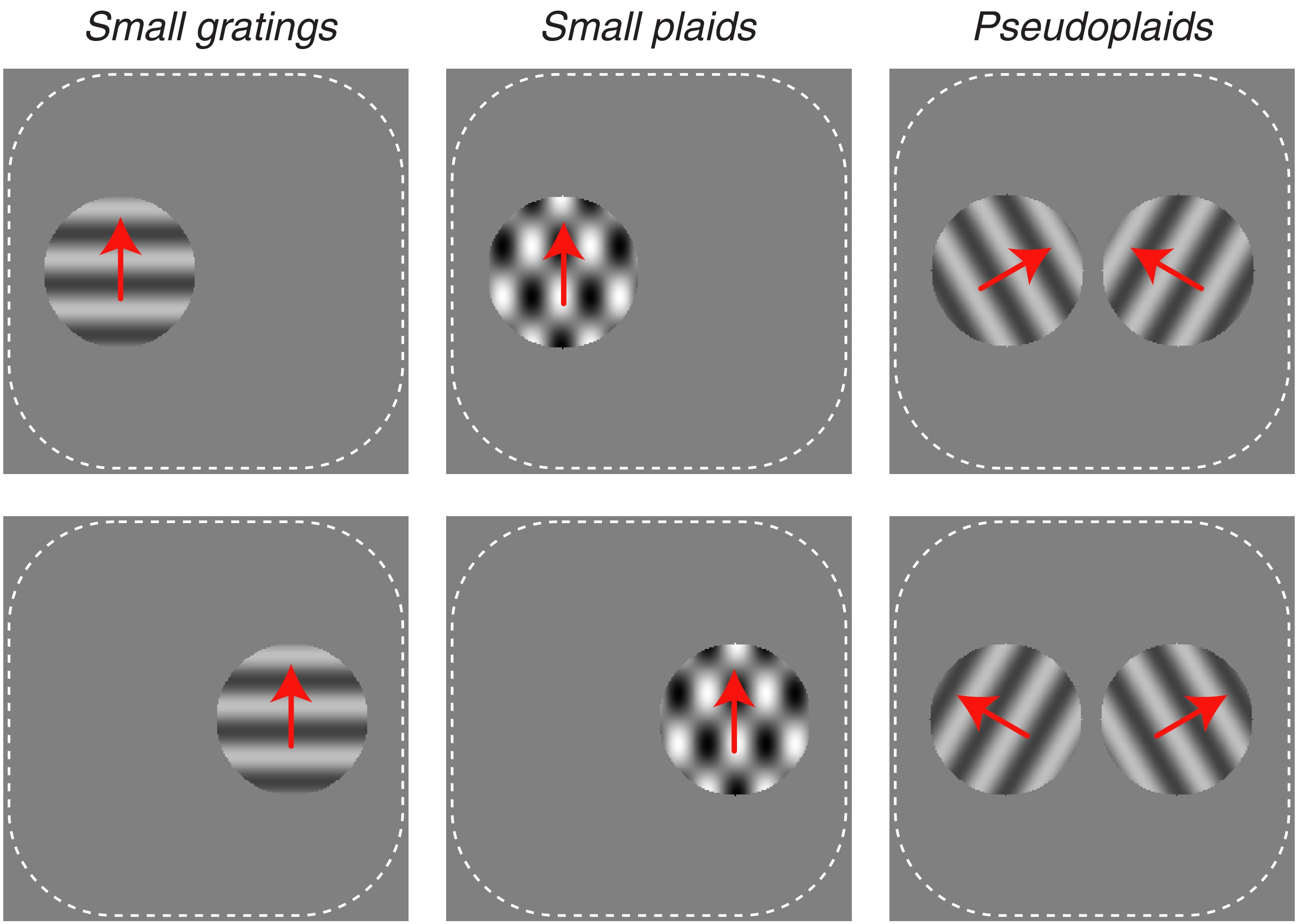
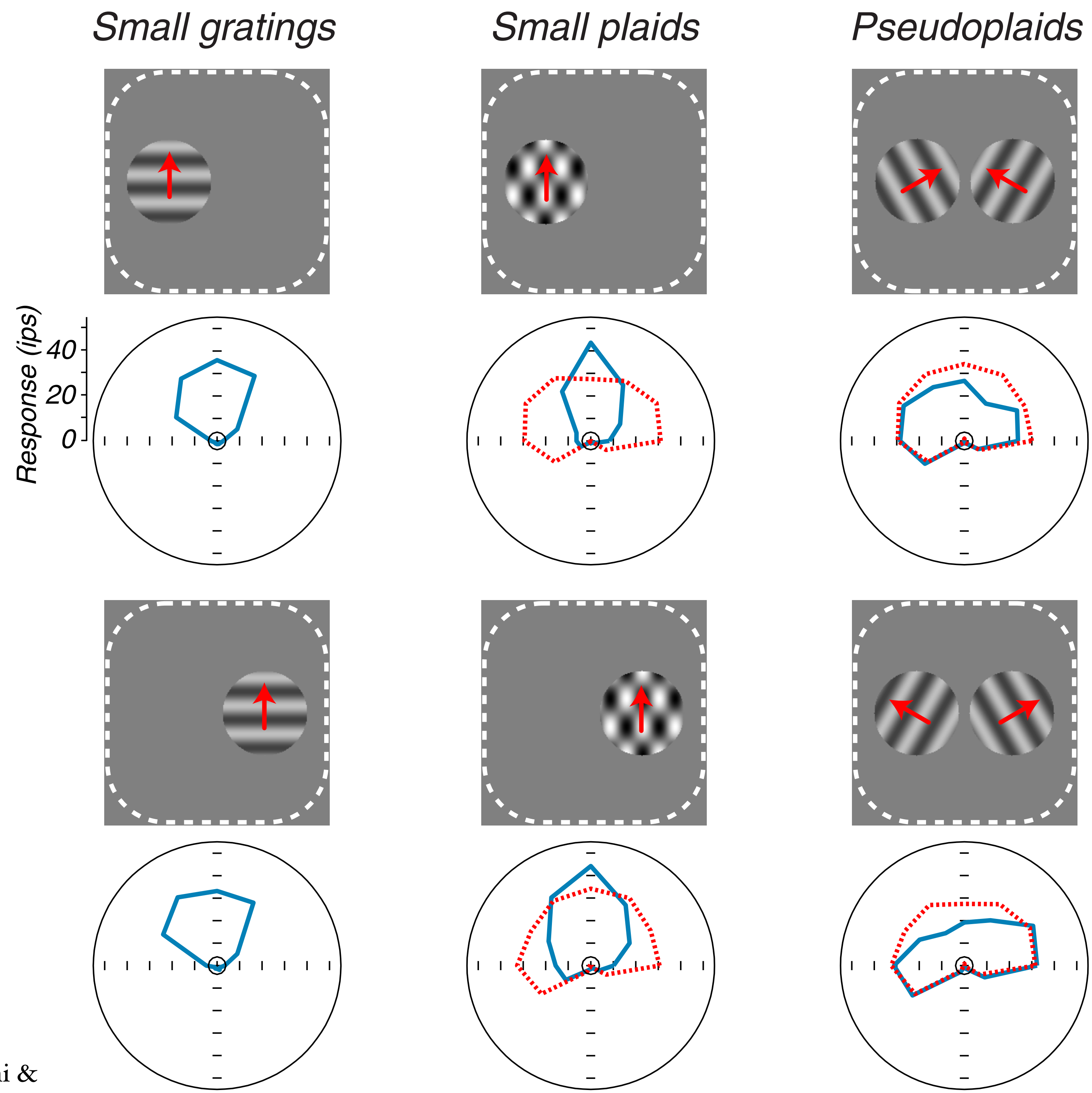
V3v
V1 receptive fields
MT receptive field

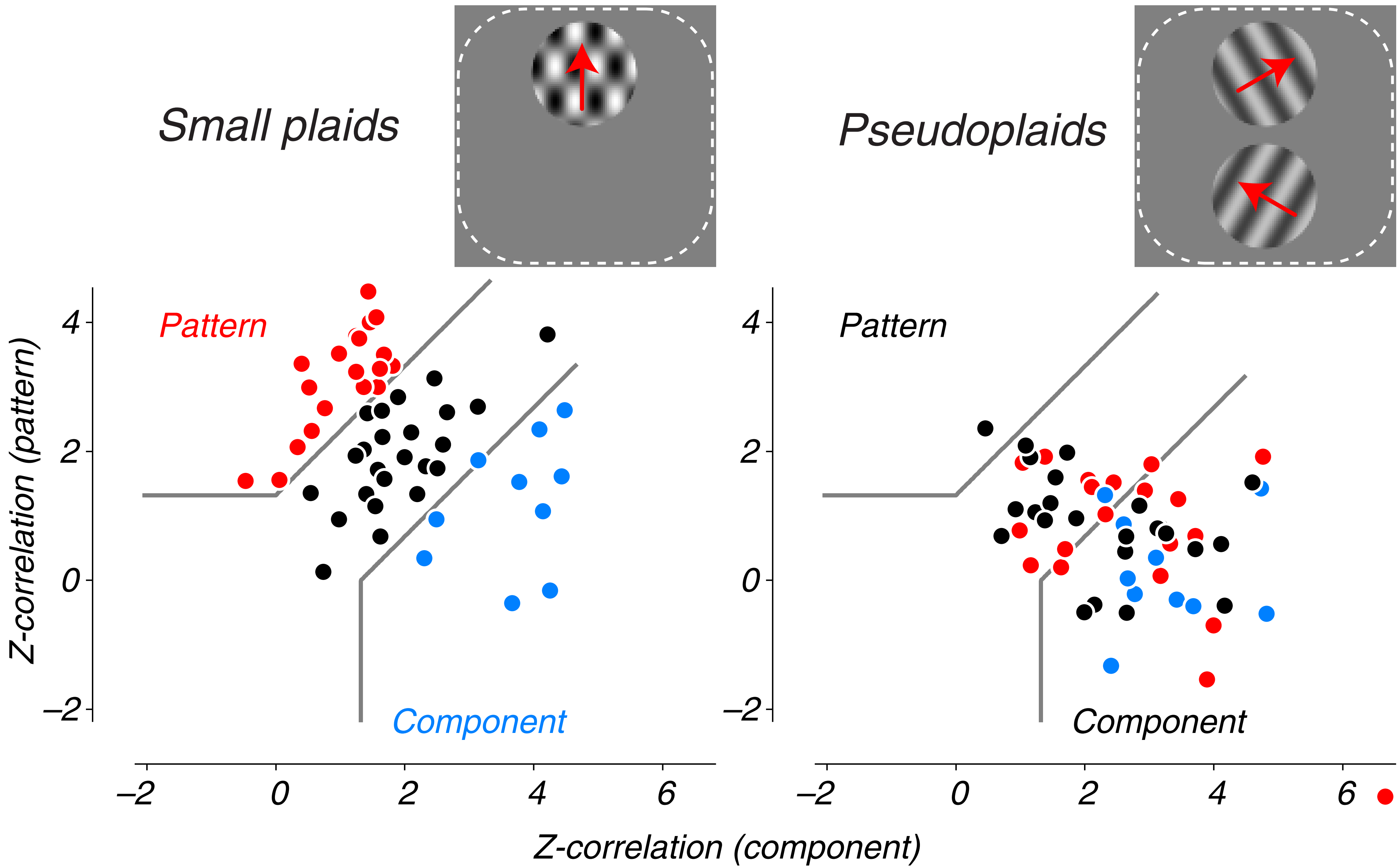
Is pattern motion computed globally?



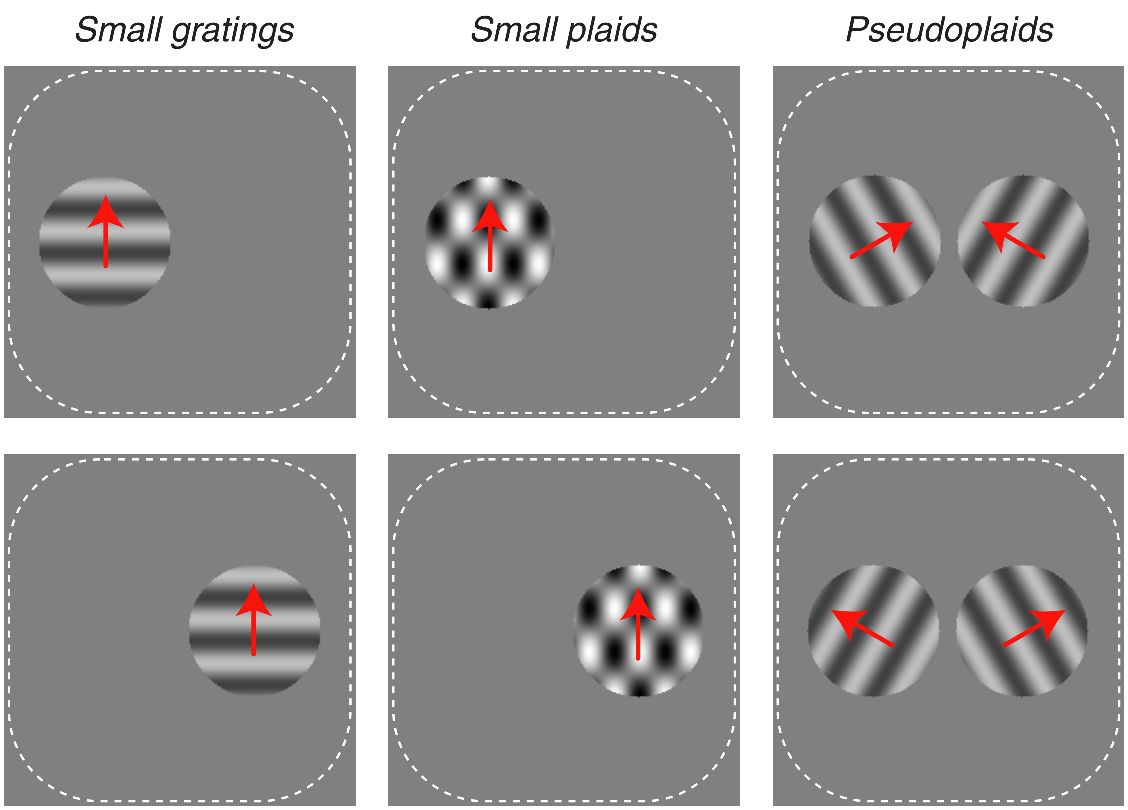
Majaj, Carandini & Movshon, 2007



Majaj, Carandini & Movshon, 2007



Majaj, Carandini & Movshon, 2007



Pattern motion is computed locally

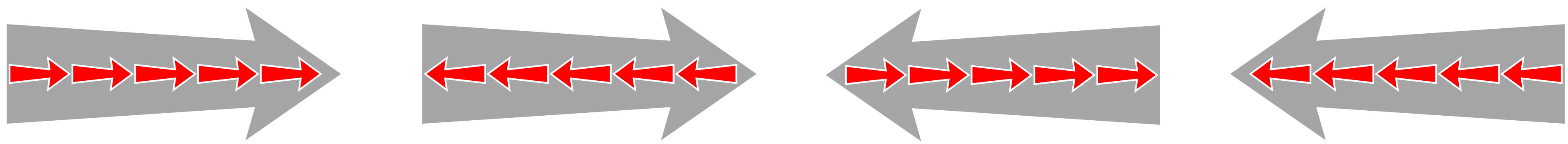
How do local and global motion signals interact?

Global preferred
Local preferred

Global preferred
Local null

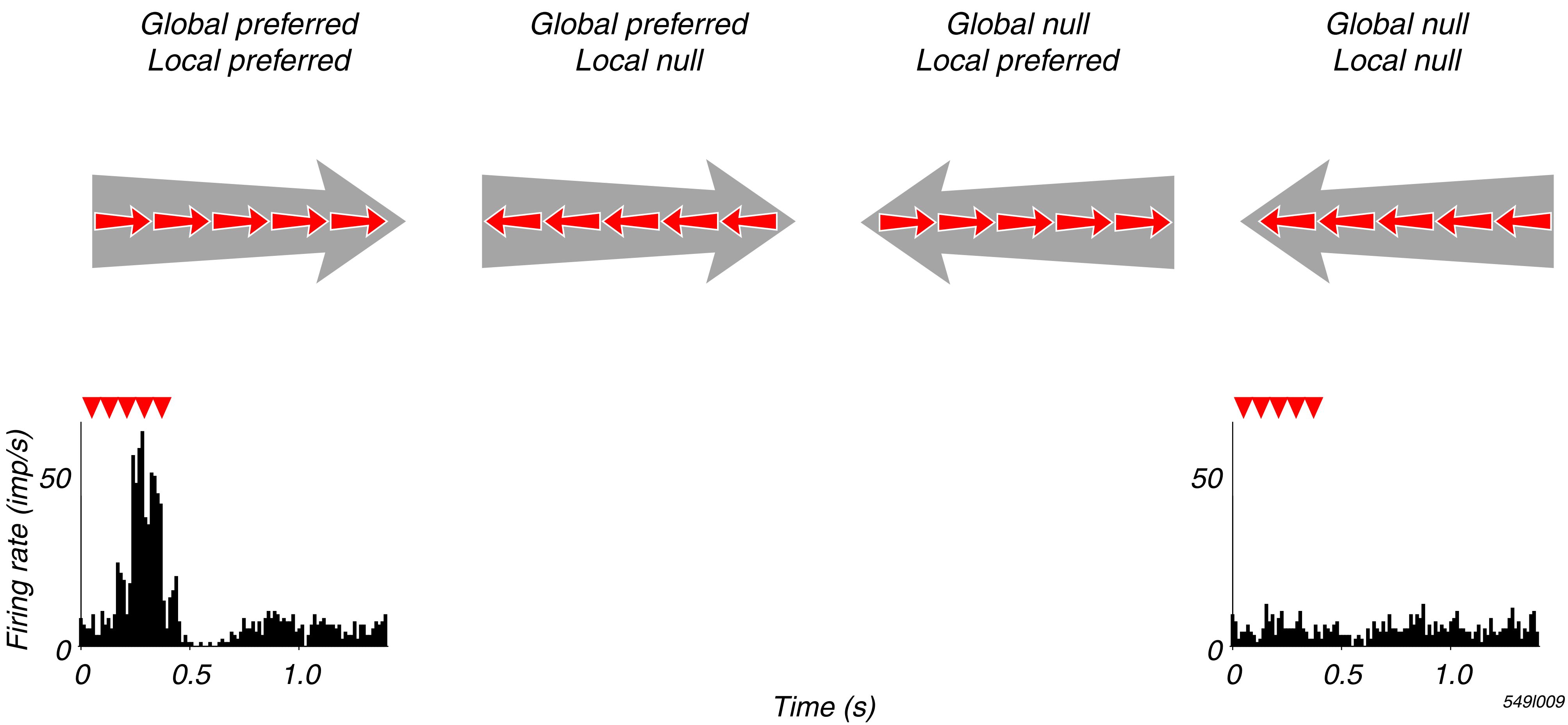
Global null
Local preferred

Global null
Local null



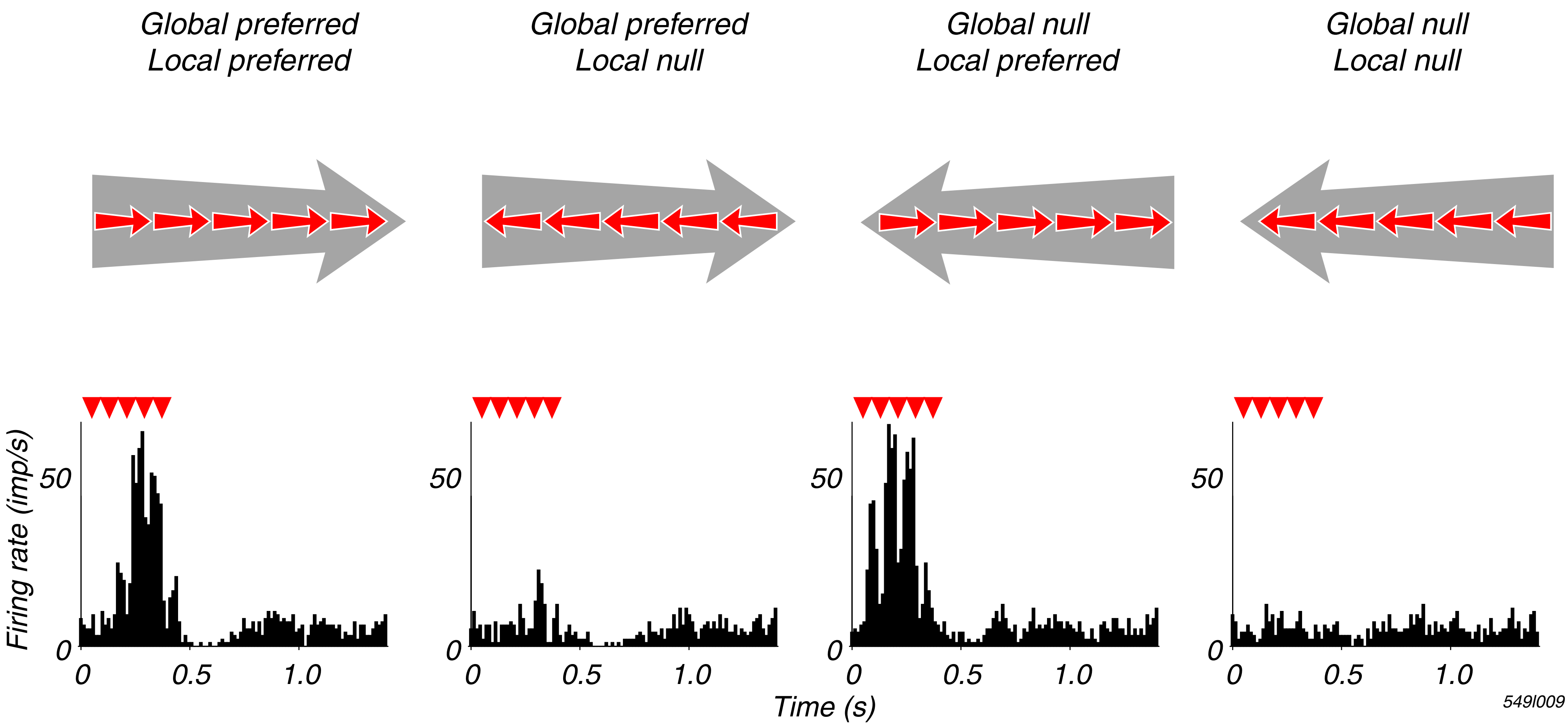
Hedges, Gartshteyn, Kohn, Rust, Shadlen, Newsome & Movshon, 2011

How do local and global motion signals interact?

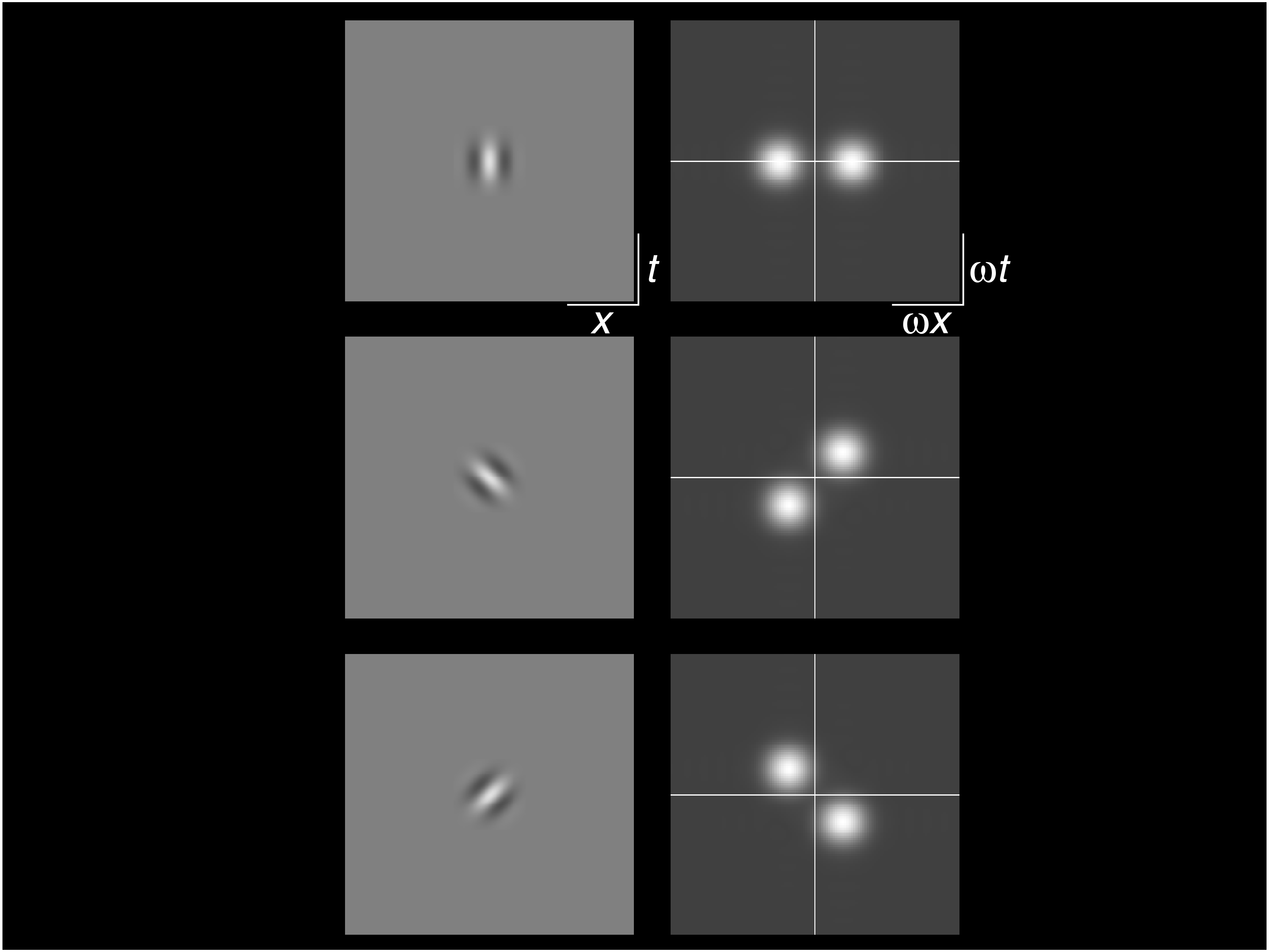


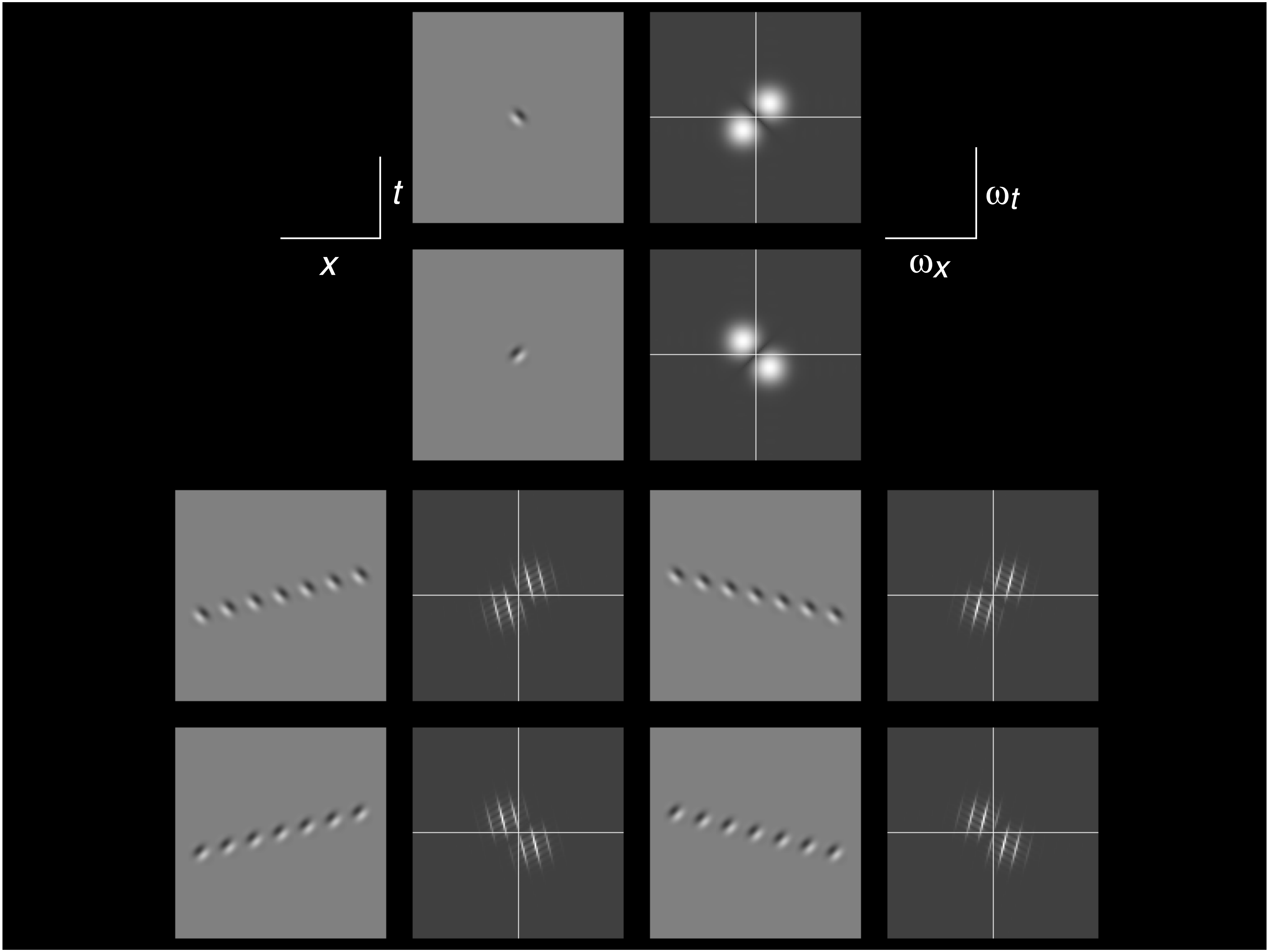
Hedges, Gartshteyn, Kohn, Rust, Shadlen, Newsome & Movshon, 2011

How do local and global motion signals interact?

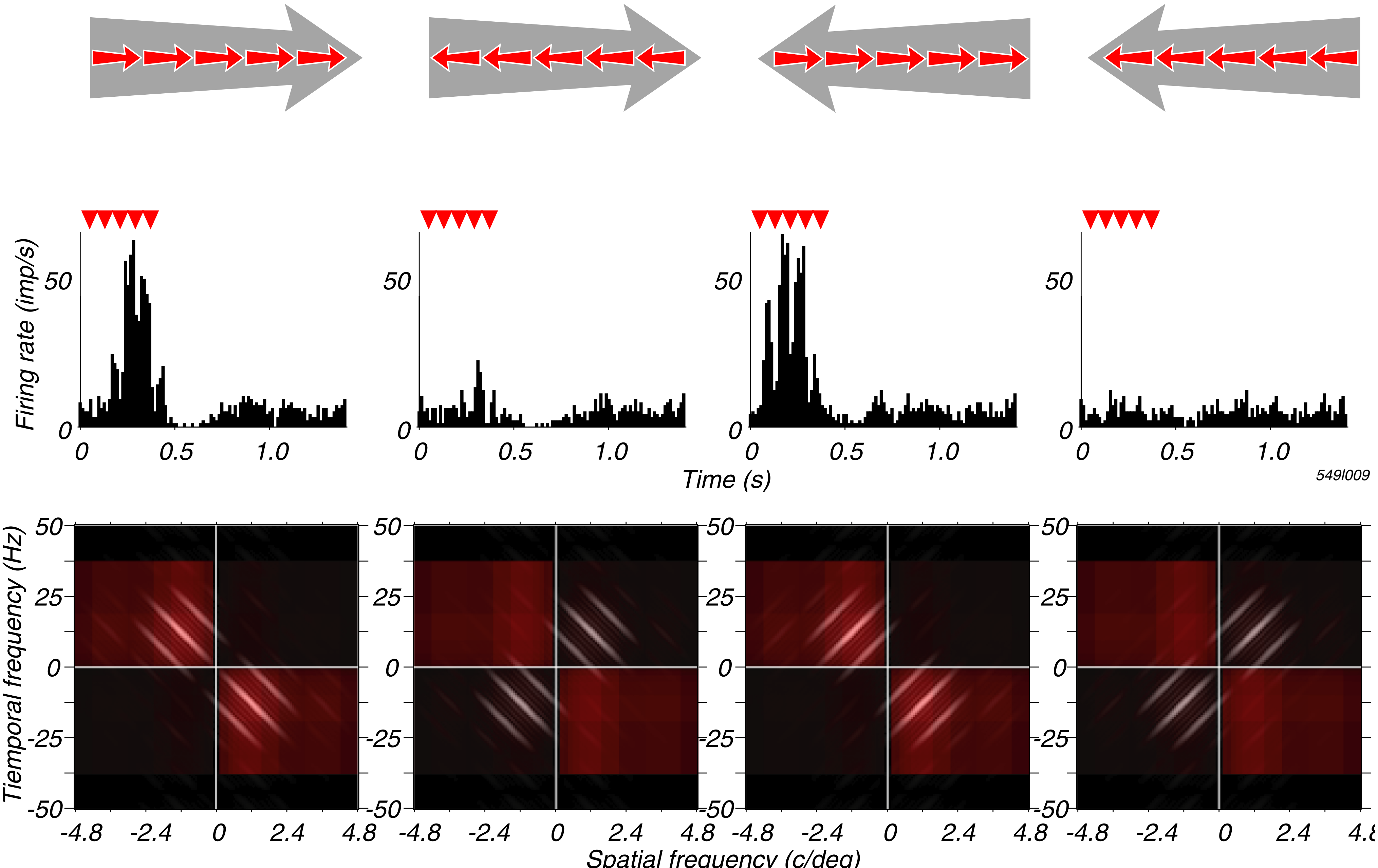


Hedges, Gartshteyn, Kohn, Rust, Shadlen, Newsome & Movshon, 2011

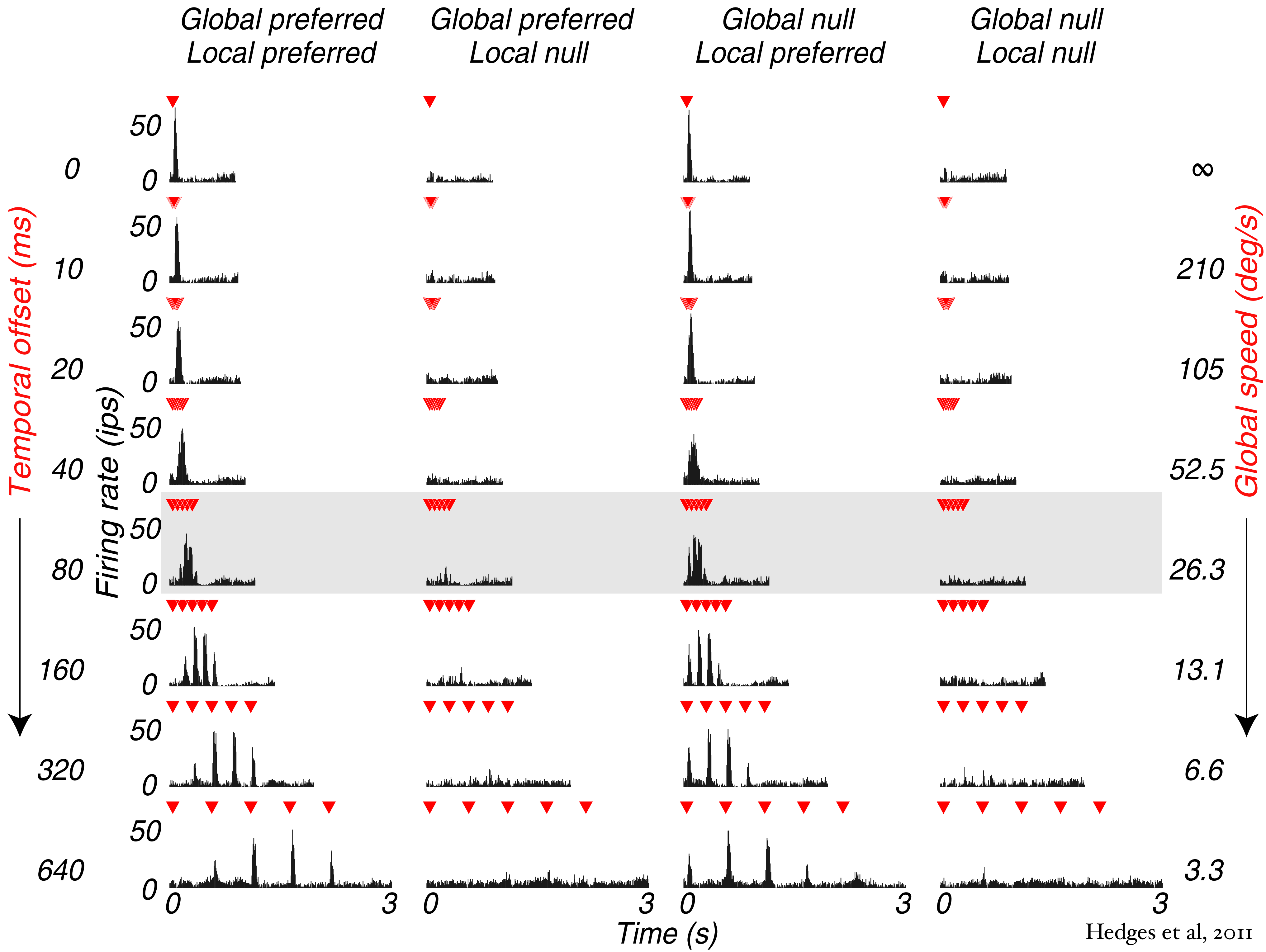

t
x
ωt
ωx


t
x
ωt
ωx

How do local and global motion signals interact?

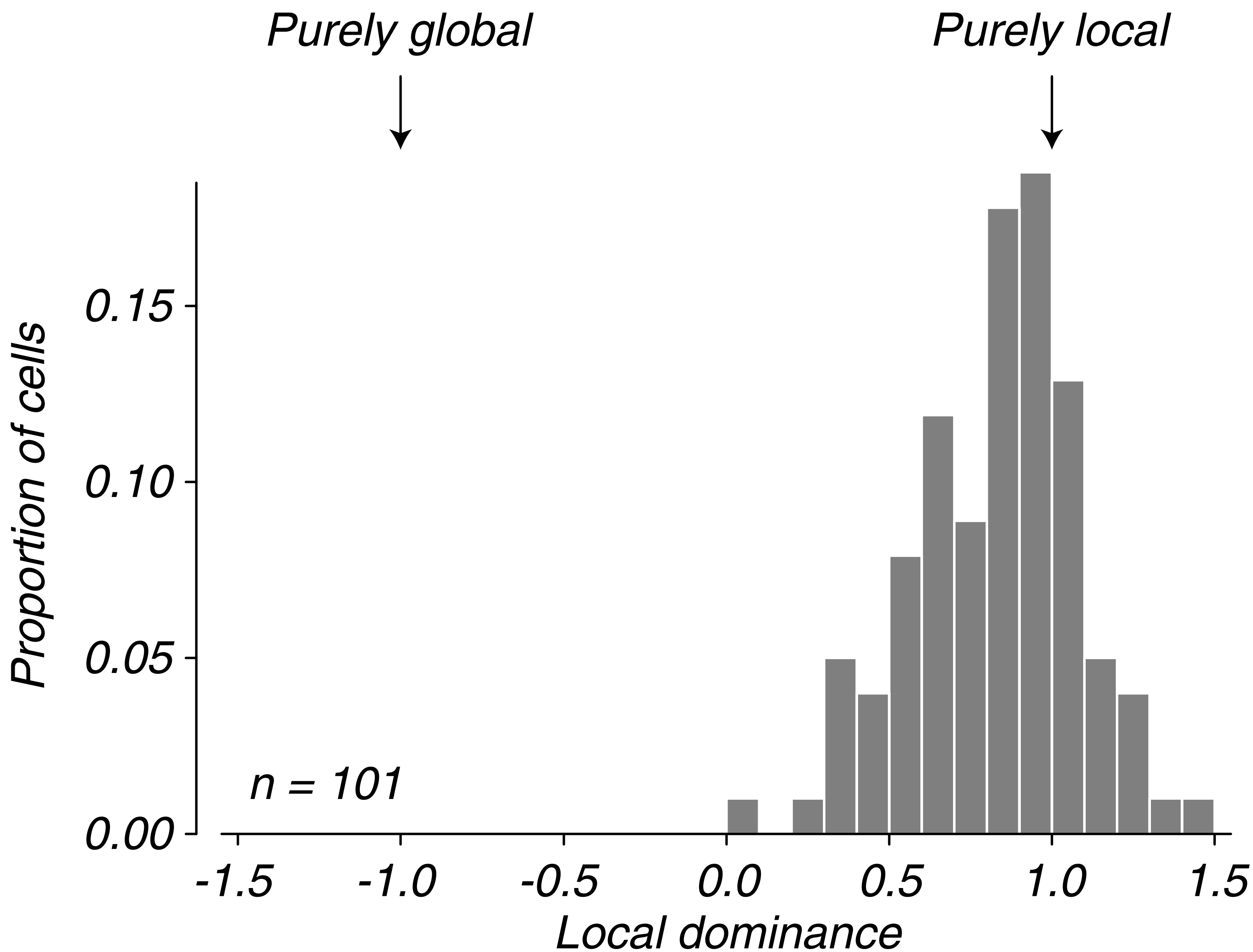


Hedges et al, 2011

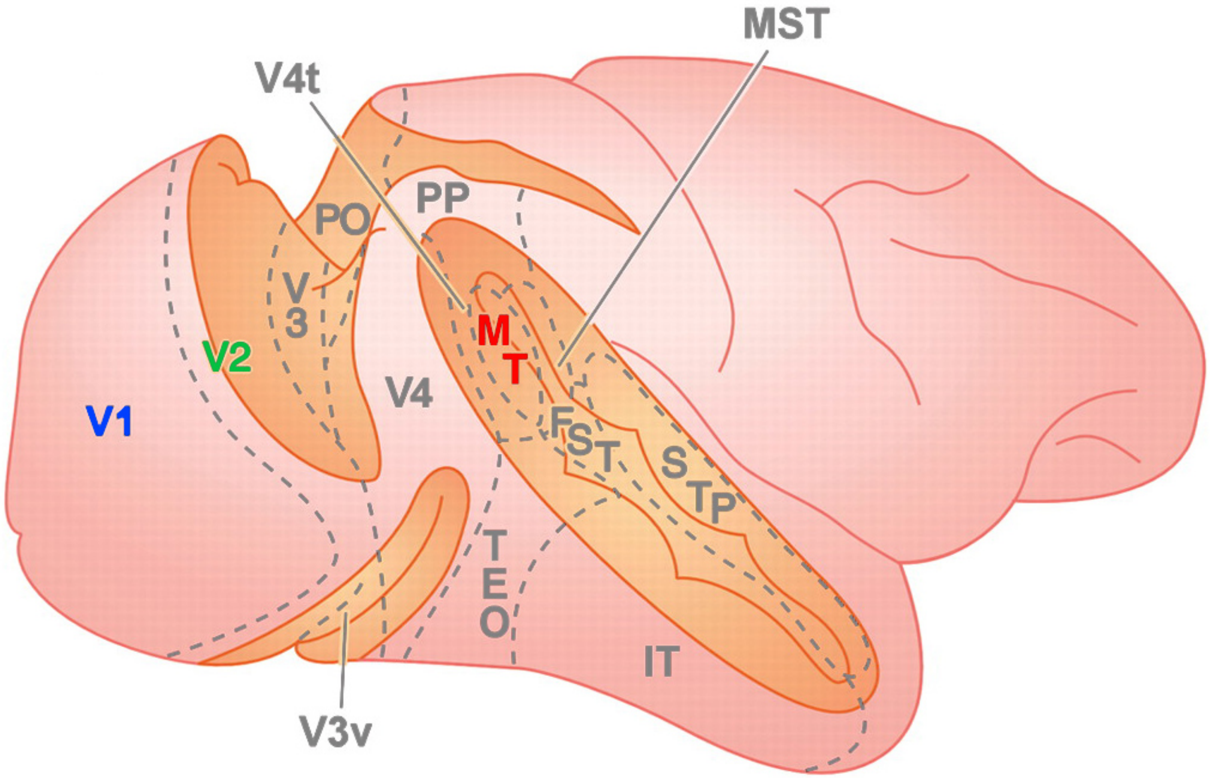


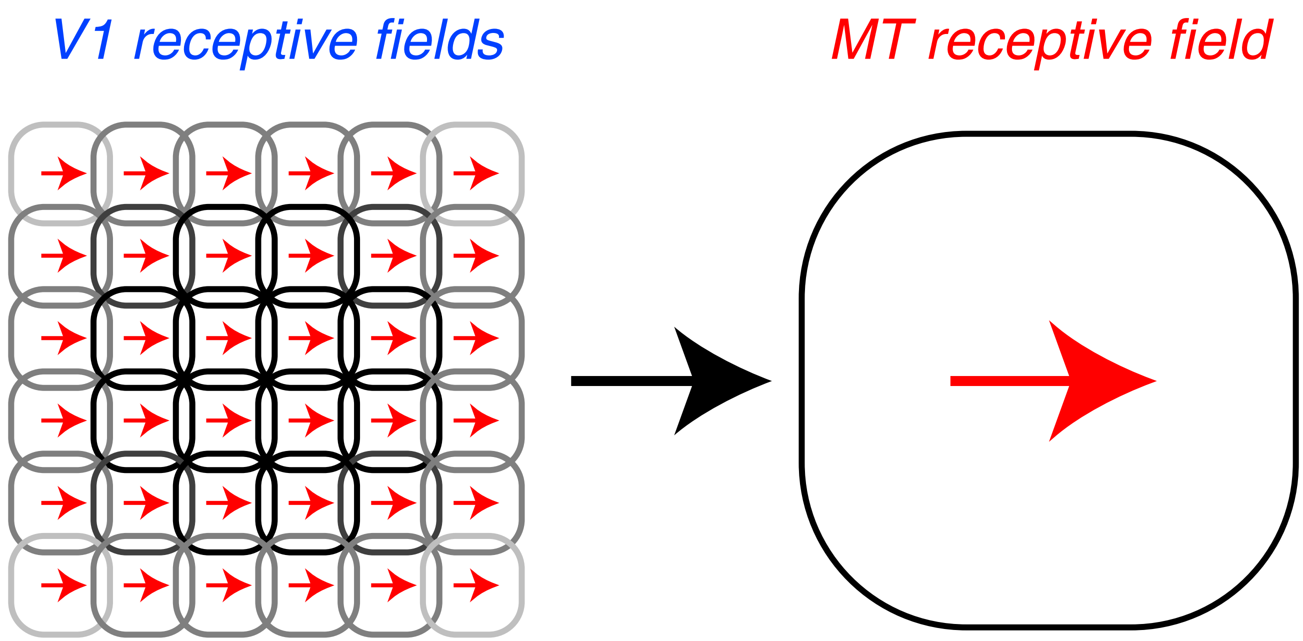
Global preferred
Local preferred
Global preferred
Local null
Global null
Local preferred
Global null
Local null
Temporal offset (ms)
0
10
20
40
80
160
320
640
Firing rate (ips)
50
0
Global speed (deg/s)
∞
210
105
52.5
26.3
13.1
6.6
3.3
0
3
Time (s)
Hedges et al, 2011

How do local and global motion signals interact?

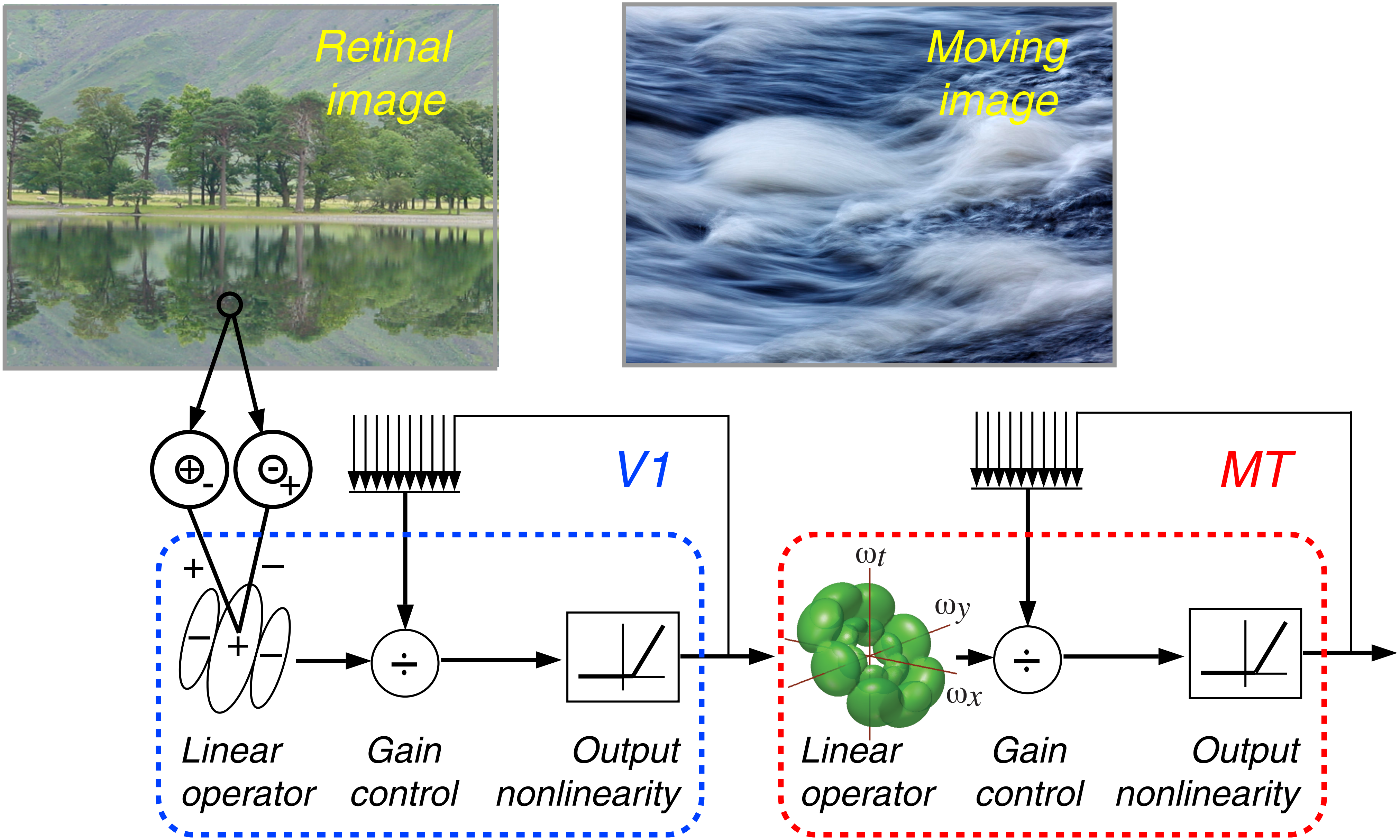


Hedges, Gartshteyn, Kohn, Rust, Shadlen, Newsome & Movshon, 2011

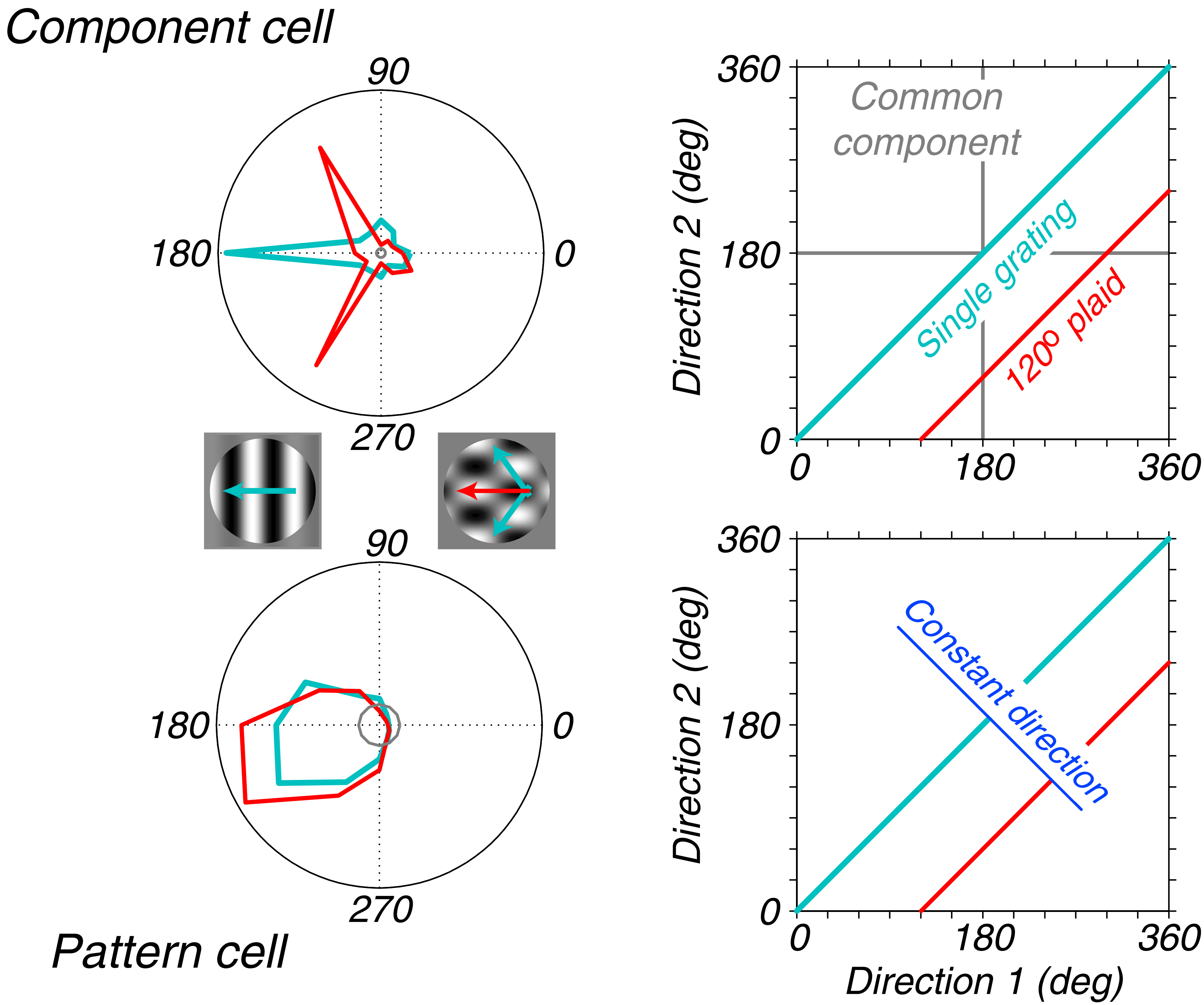

MST
V4t
PO
PP
V3
V2
V1
V4
MT
FST
STP
TEO
IT
V3v


V1 receptive fields
MT receptive field

A simple and (mostly) feedforward model

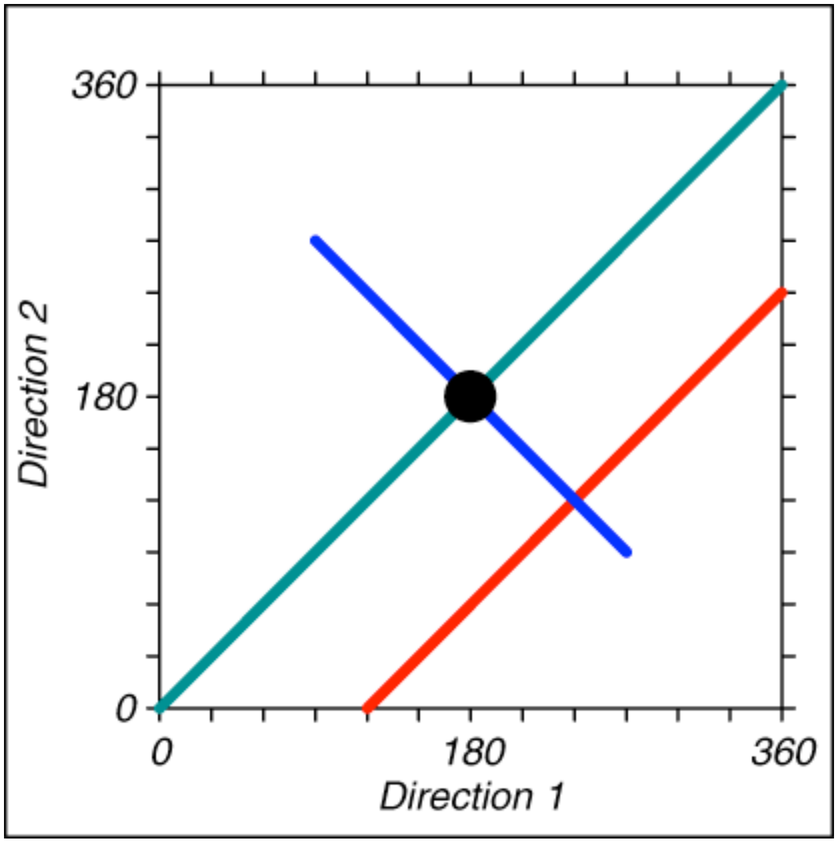


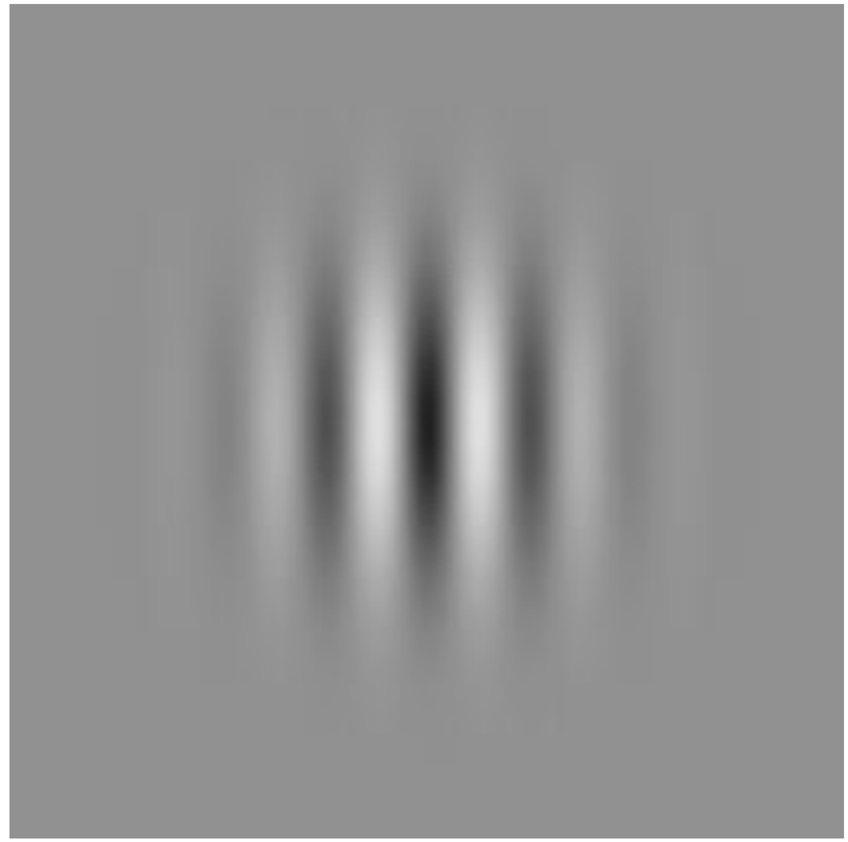
Simoncelli & Heeger, 1998; Rust, Mante, Simoncelli & Movshon, 2006



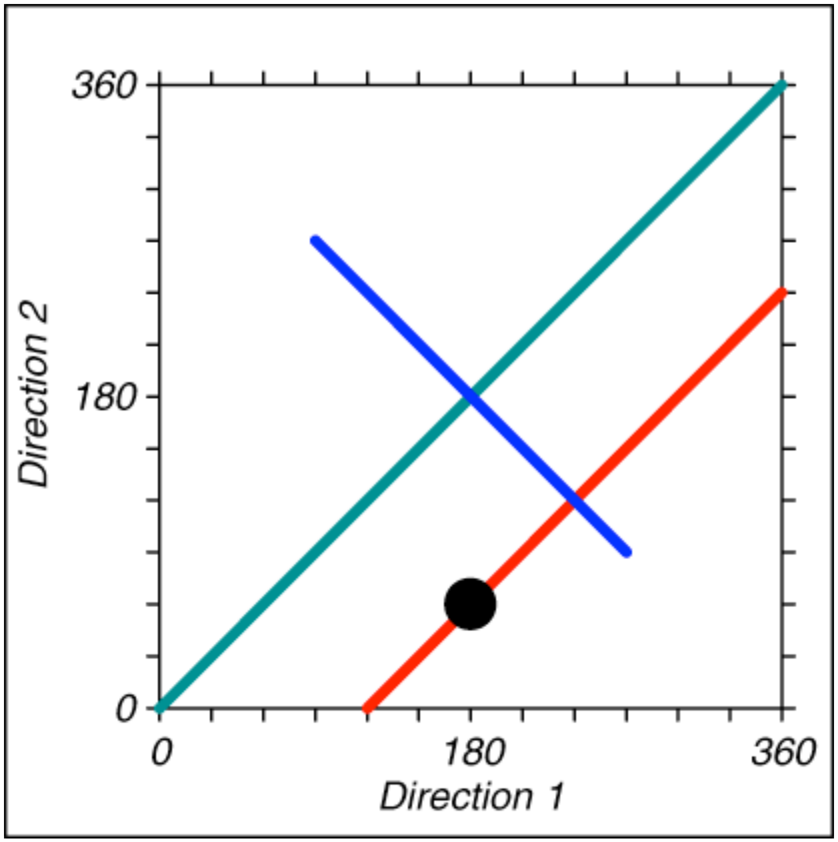
Rust, Mante, Simoncelli & Movshon, 2006

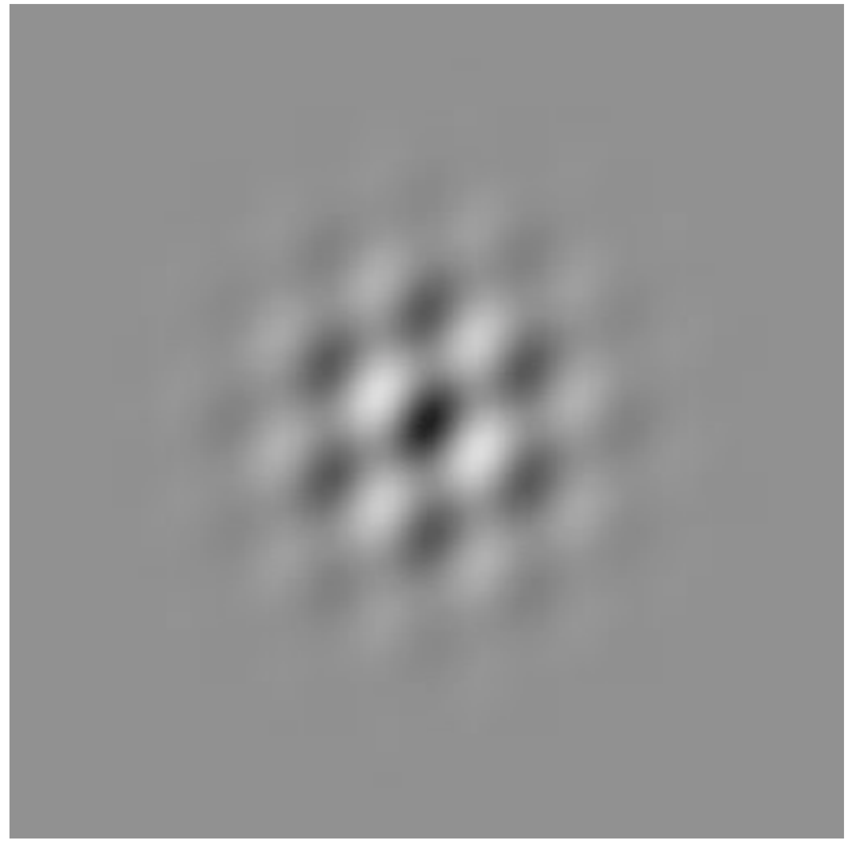
Direction-interaction:
Gratings



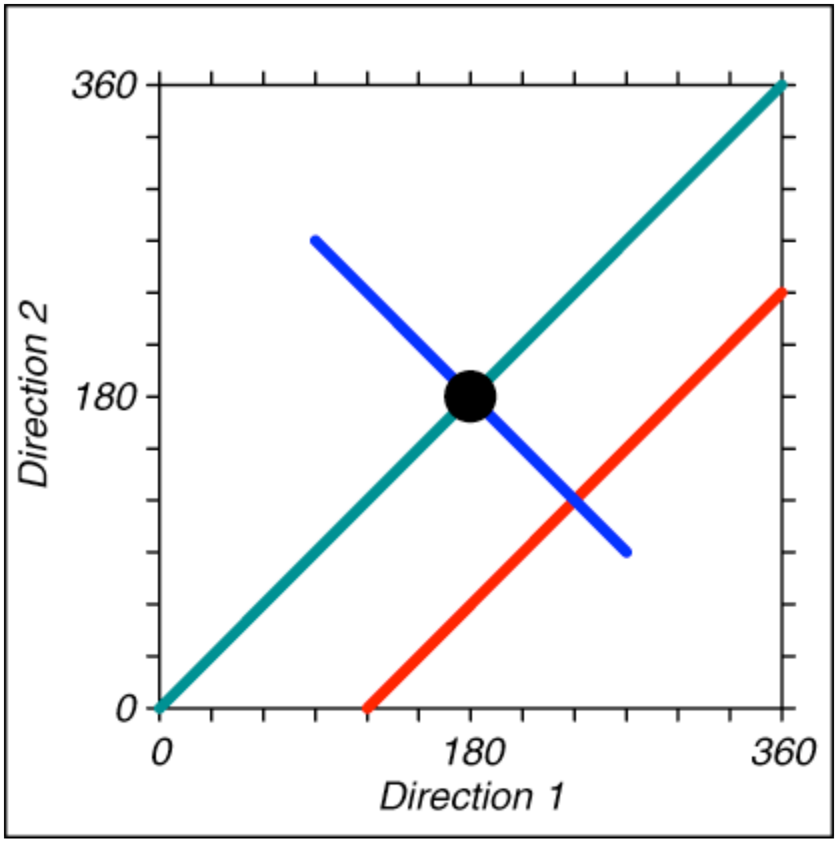


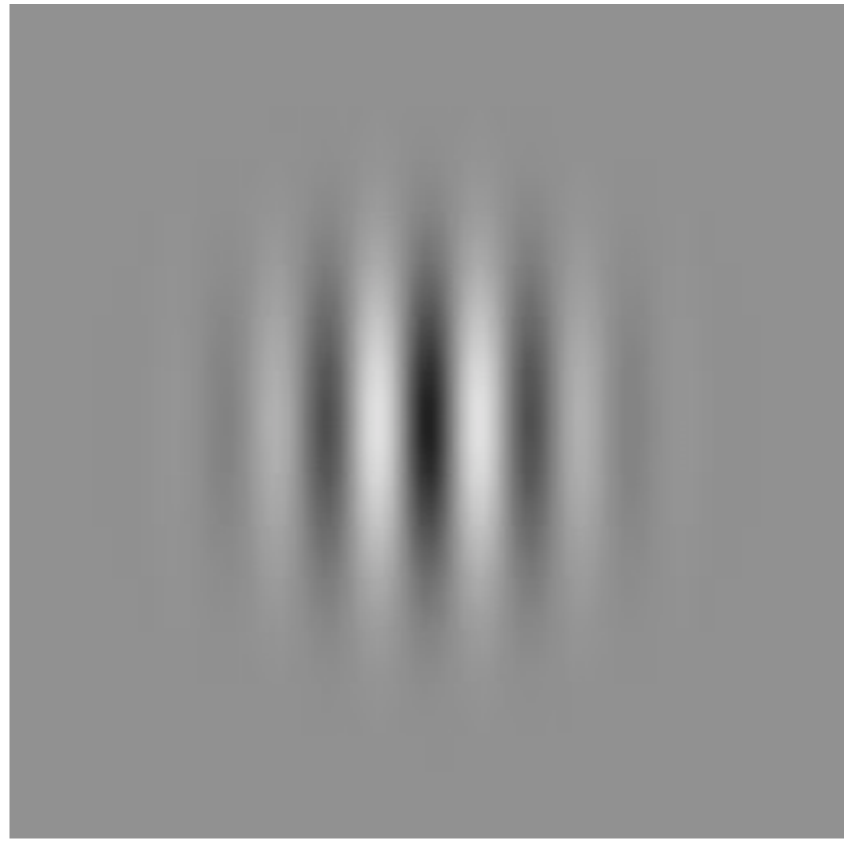
Direction-interaction:
Plaids



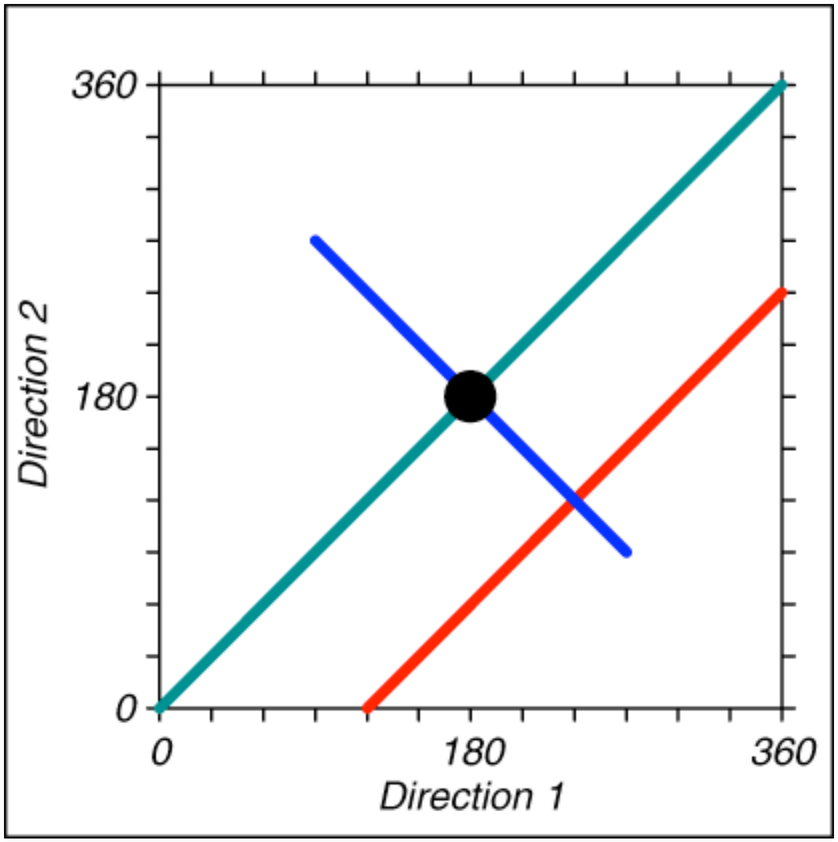


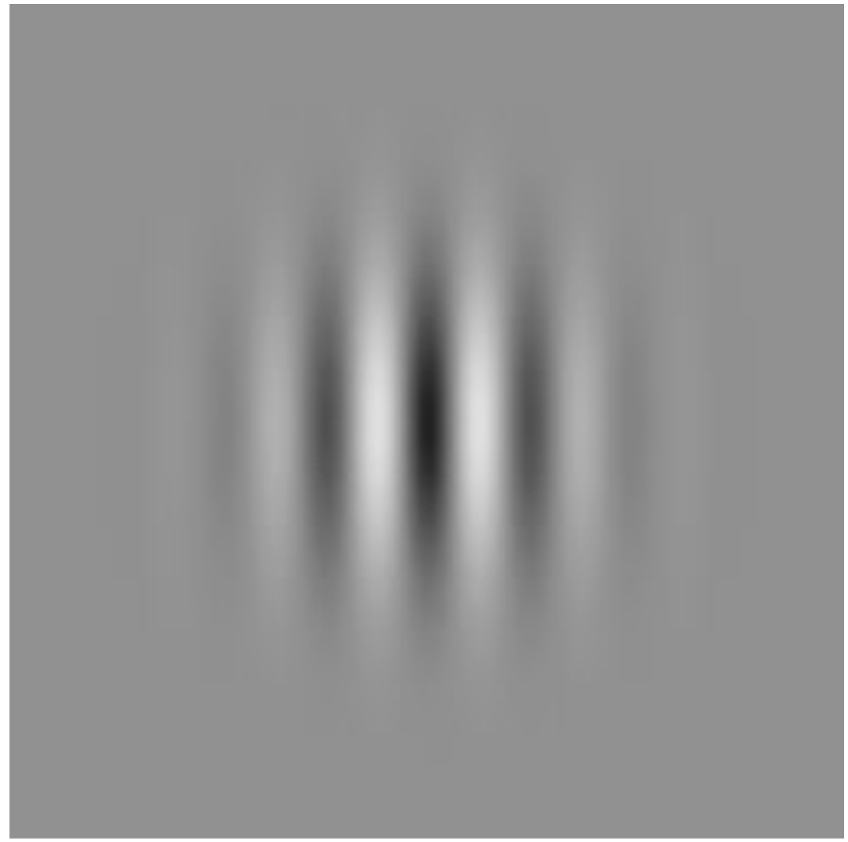
Direction-interaction:
One common component

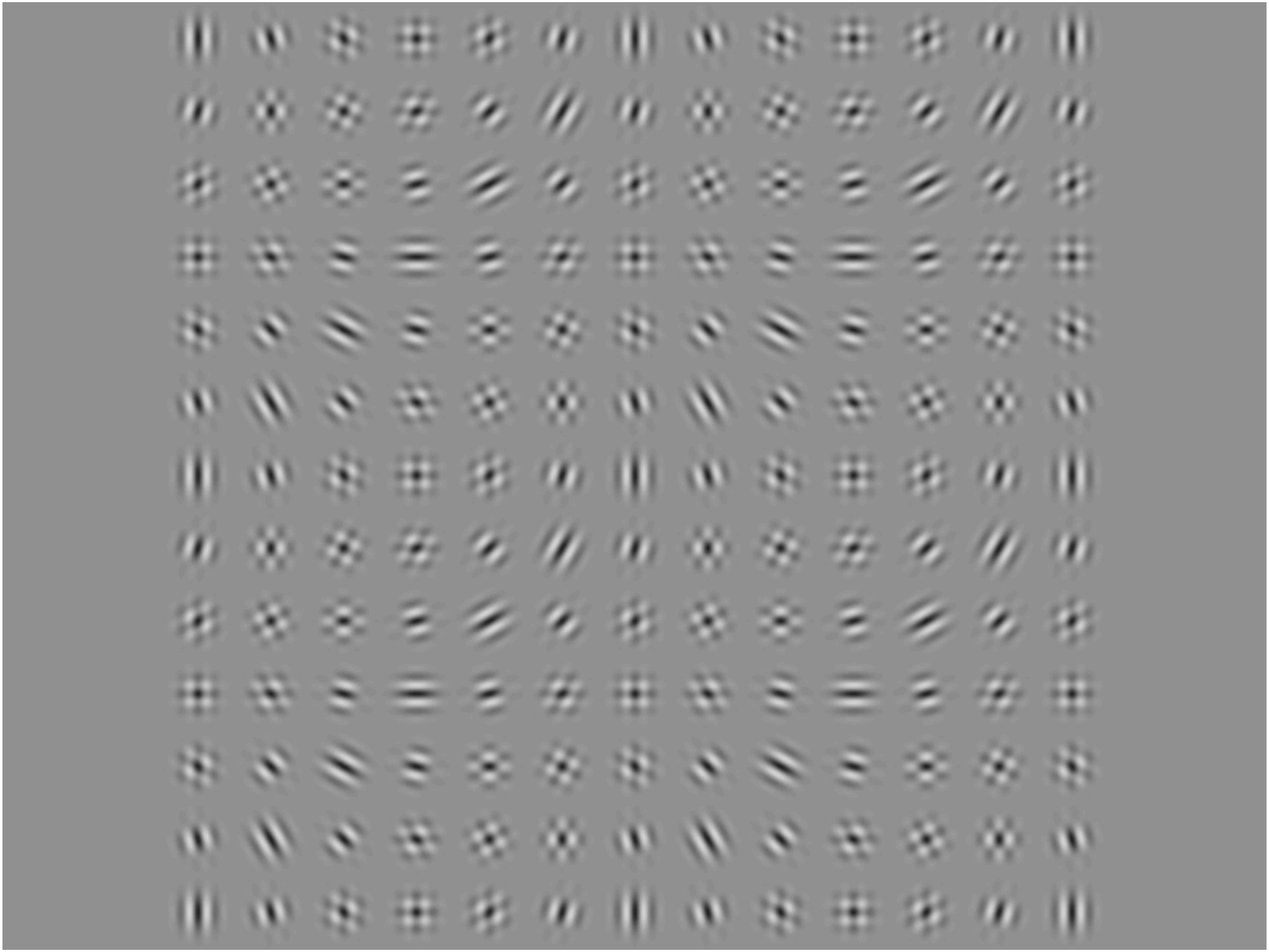


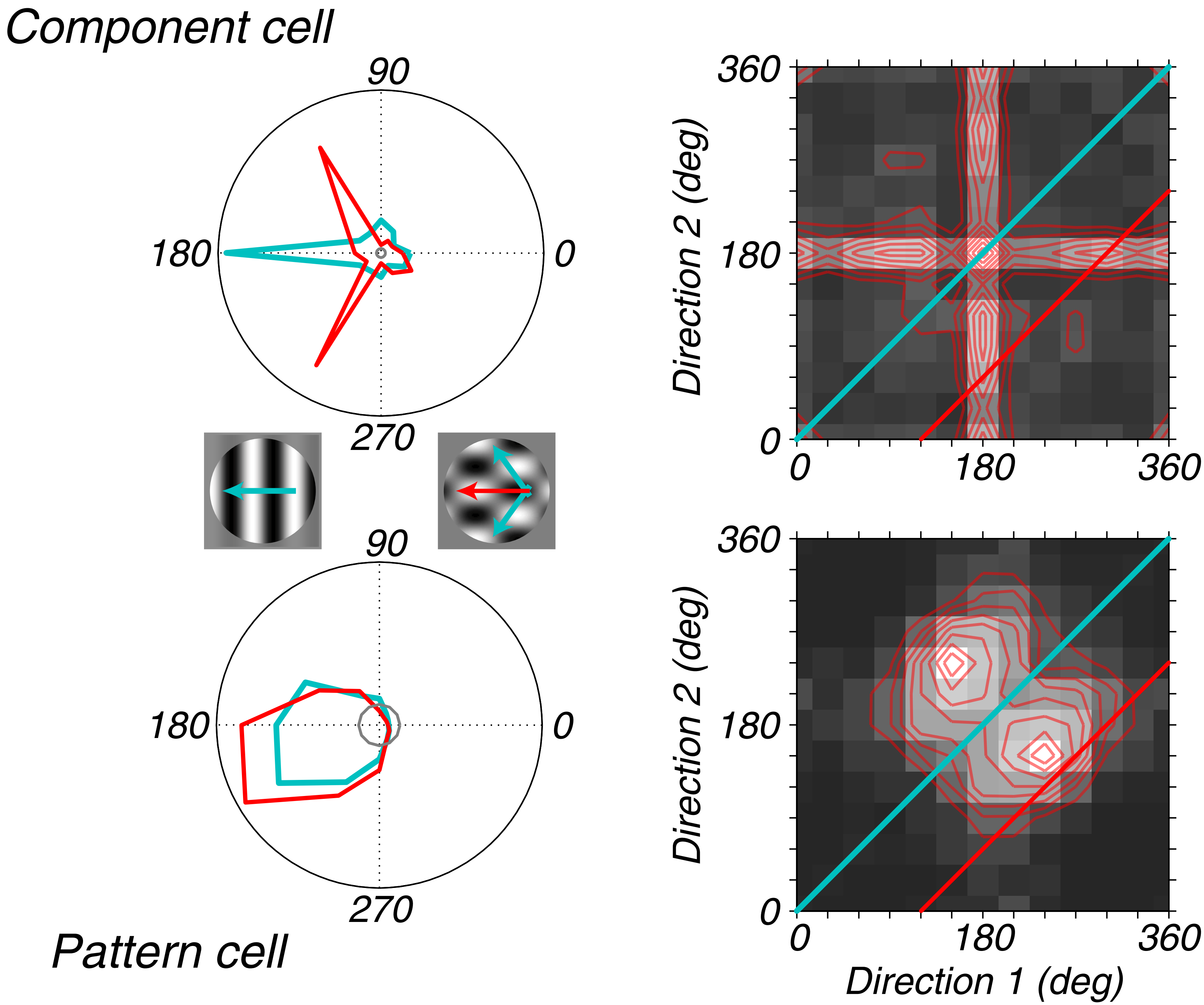


Direction-interaction:
Common axis

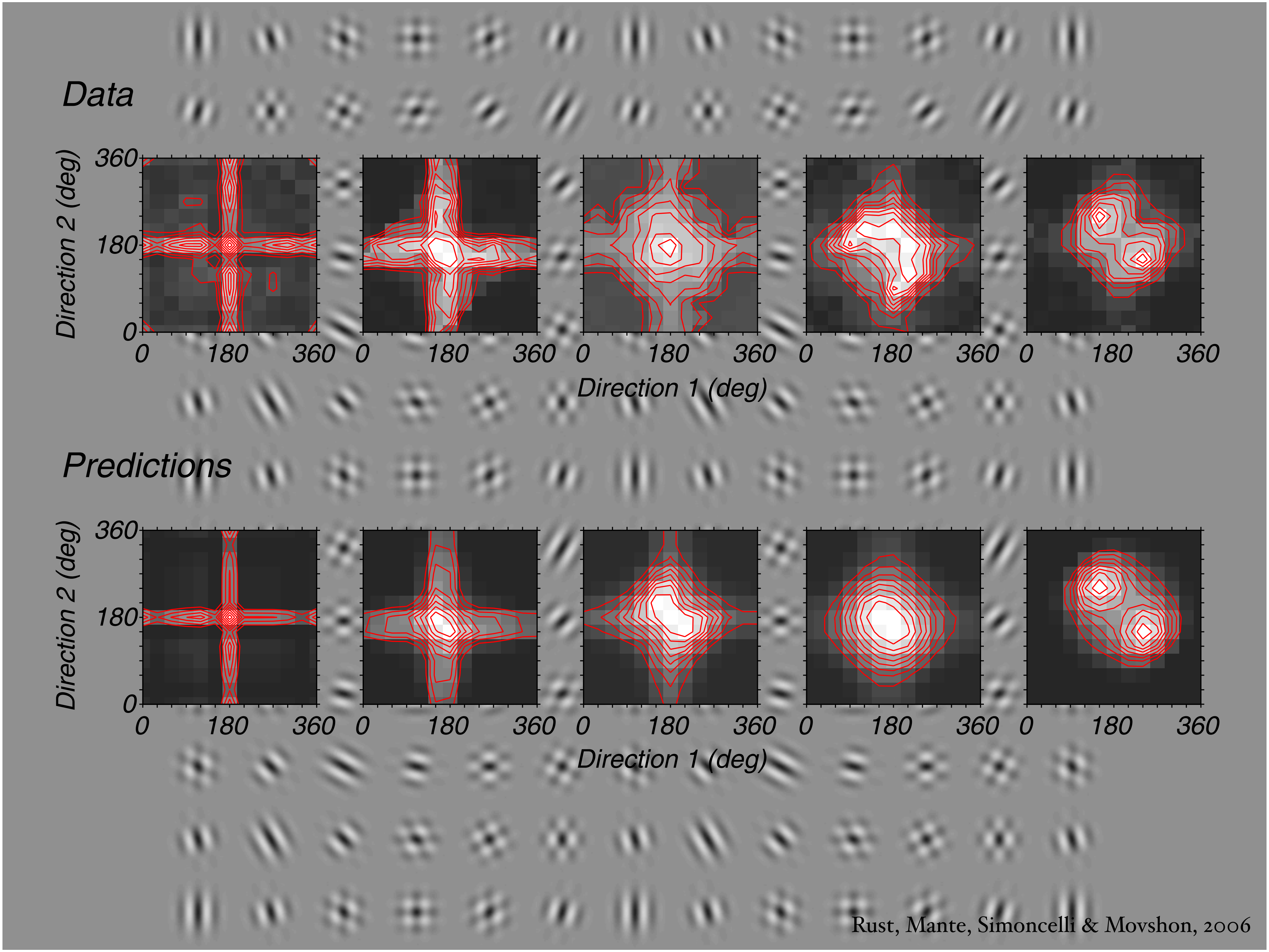


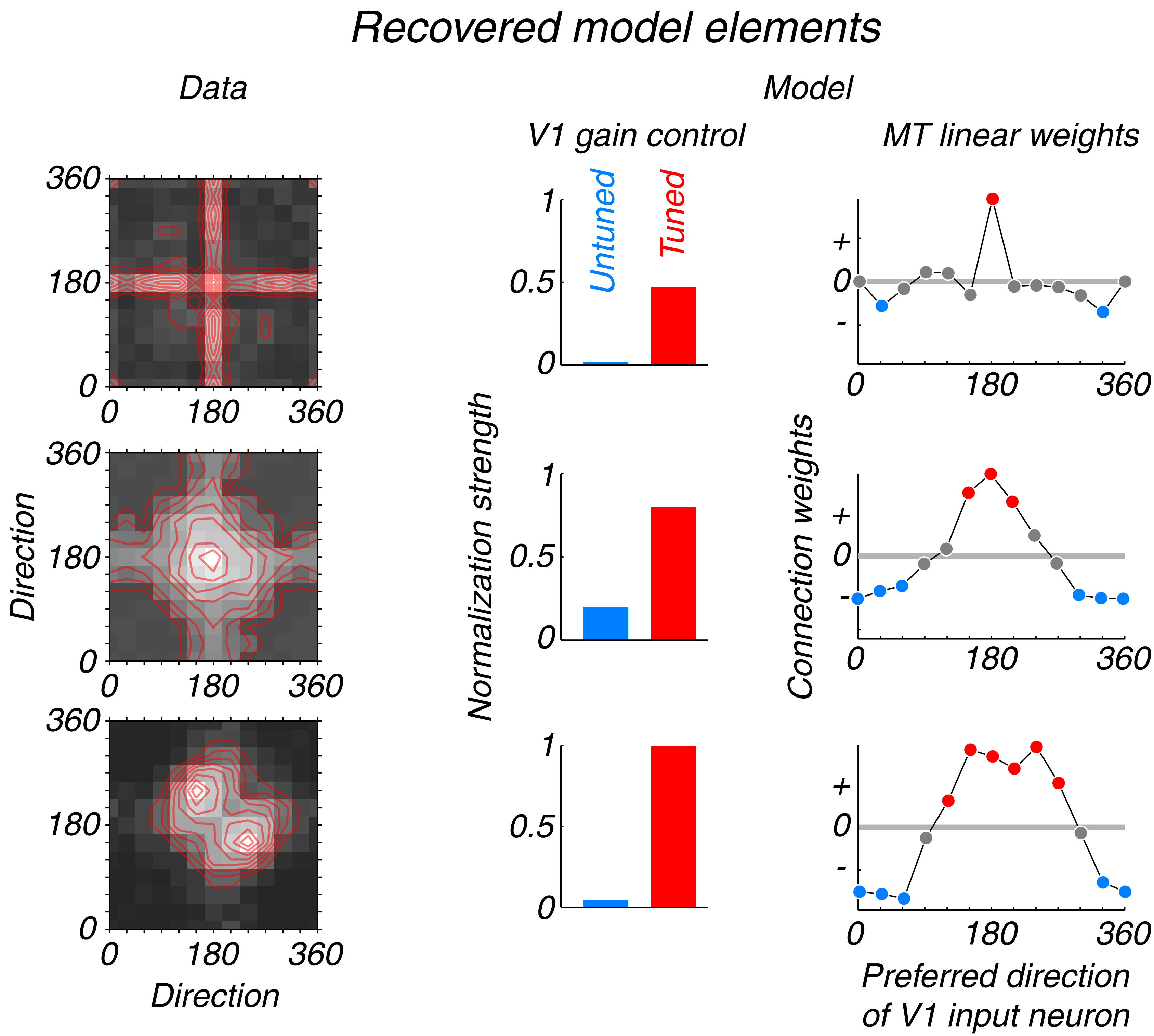






Rust, Mante, Simoncelli & Movshon, 2006

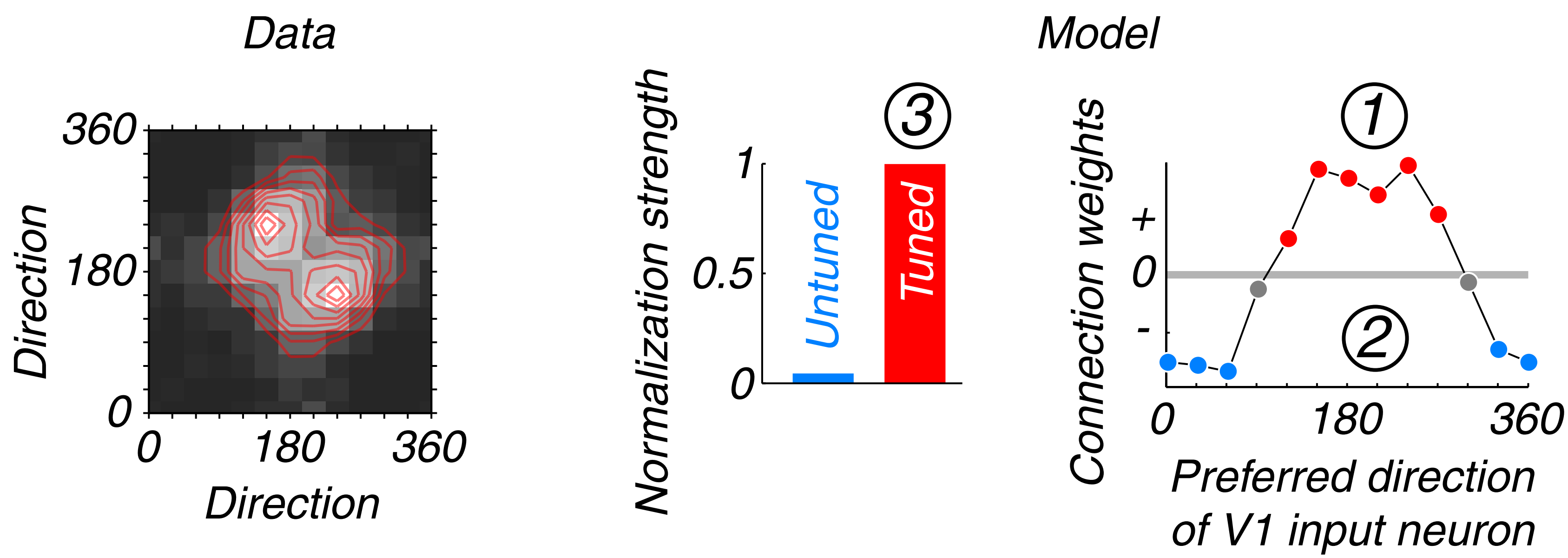

Data
Direction 2 (deg)
360
180
0
0 180 360
Direction 1 (deg)
Predictions
Direction 2 (deg)
360
180
0
0 180 360
Direction 1 (deg)
Rust, Mante, Simoncelli & Movshon, 2006



Recovered model elements
Data
Model
V1 gain control
MT linear weights
Untuned
Tuned
Direction
Normalization strength
Connection weights
Preferred direction of V1 input neuron
360
180
0
1
0.5
+
-

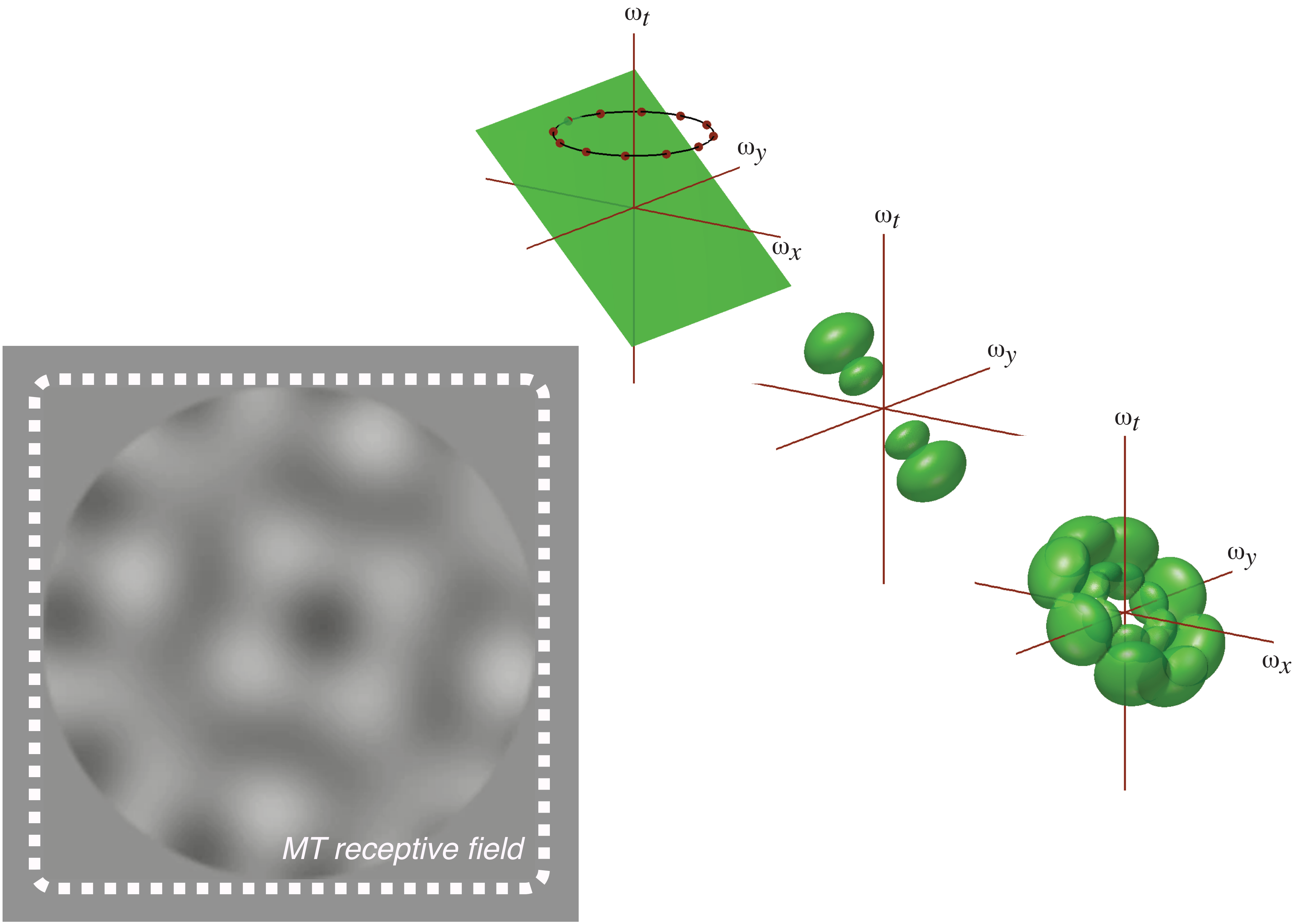
Pattern direction selectivity arises from:

1. *Broad convergence of excitatory inputs*
2. *Strong motion opponent suppression*
3. *Strong tuned gain control*

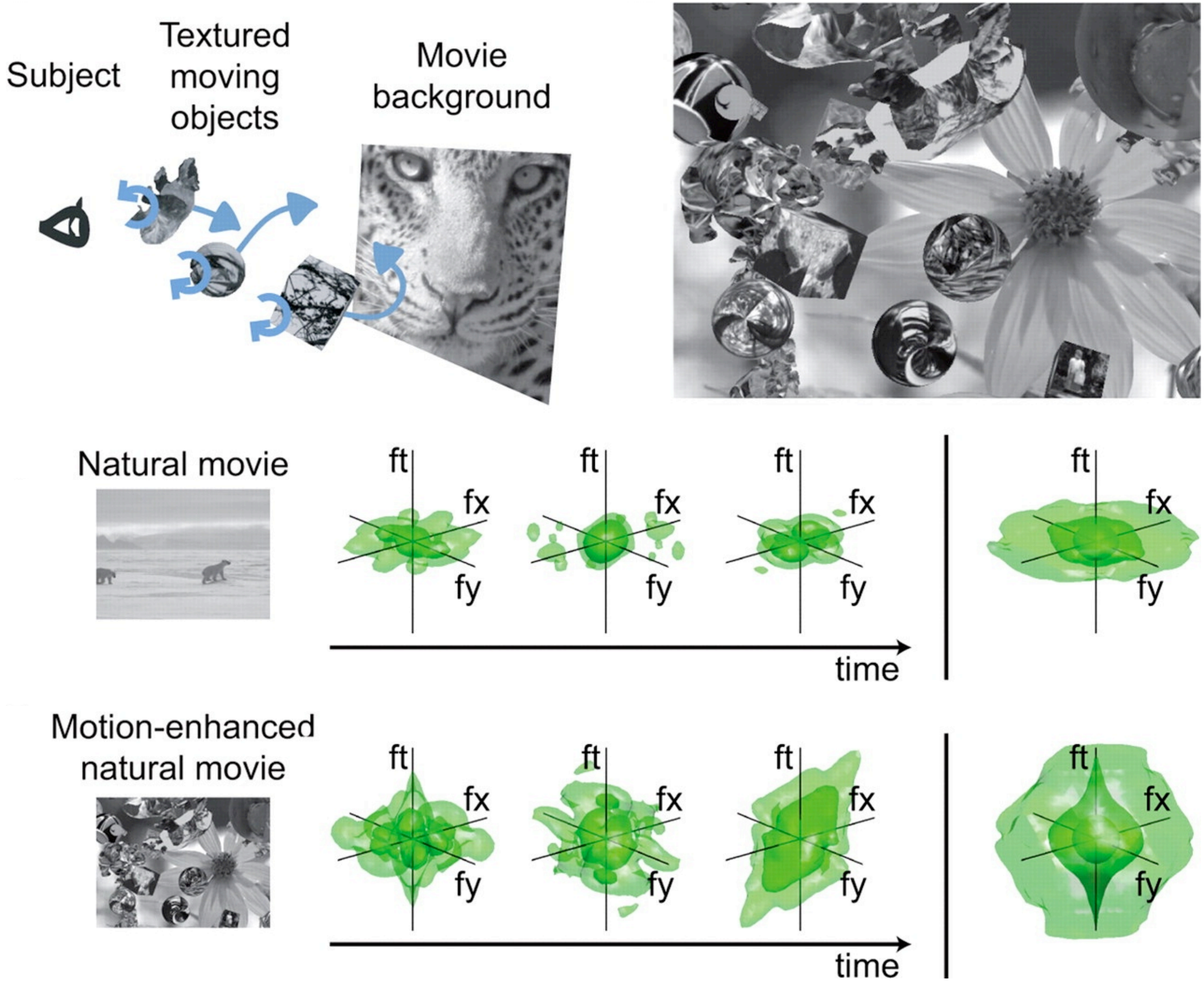


Rust, Mante, Simoncelli & Movshon, 2006

Limitations of the approach



Spatial and spectral structure of motion-enhanced natural movies

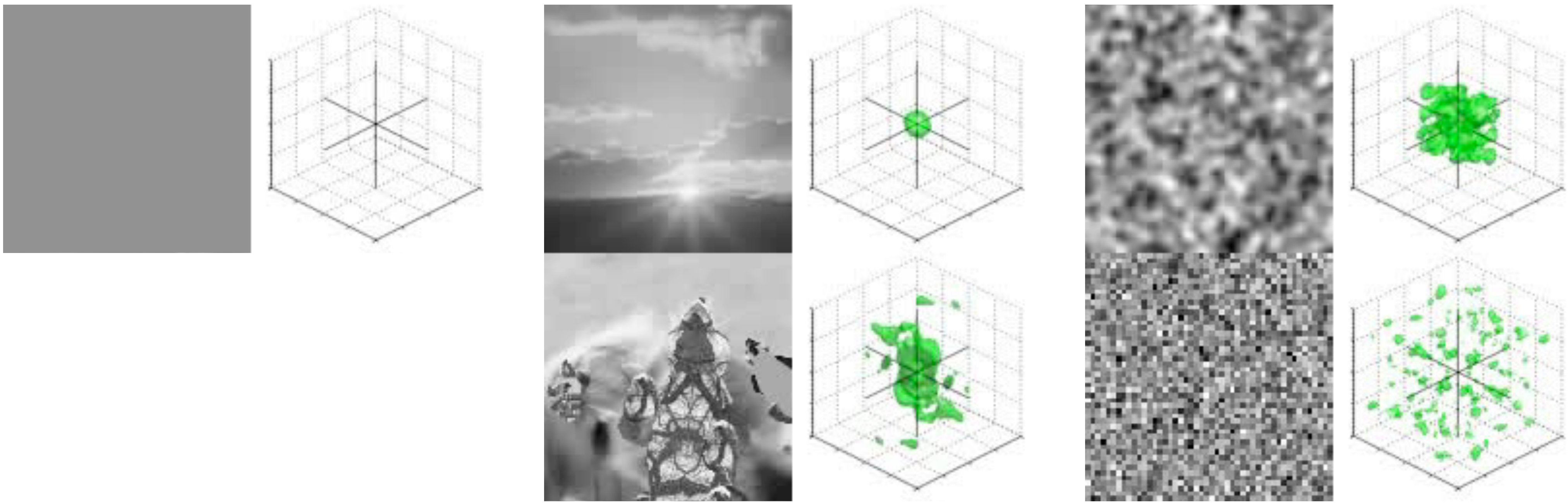


Nishimoto & Gallant, 2011

"Motion-enhanced" natural movies

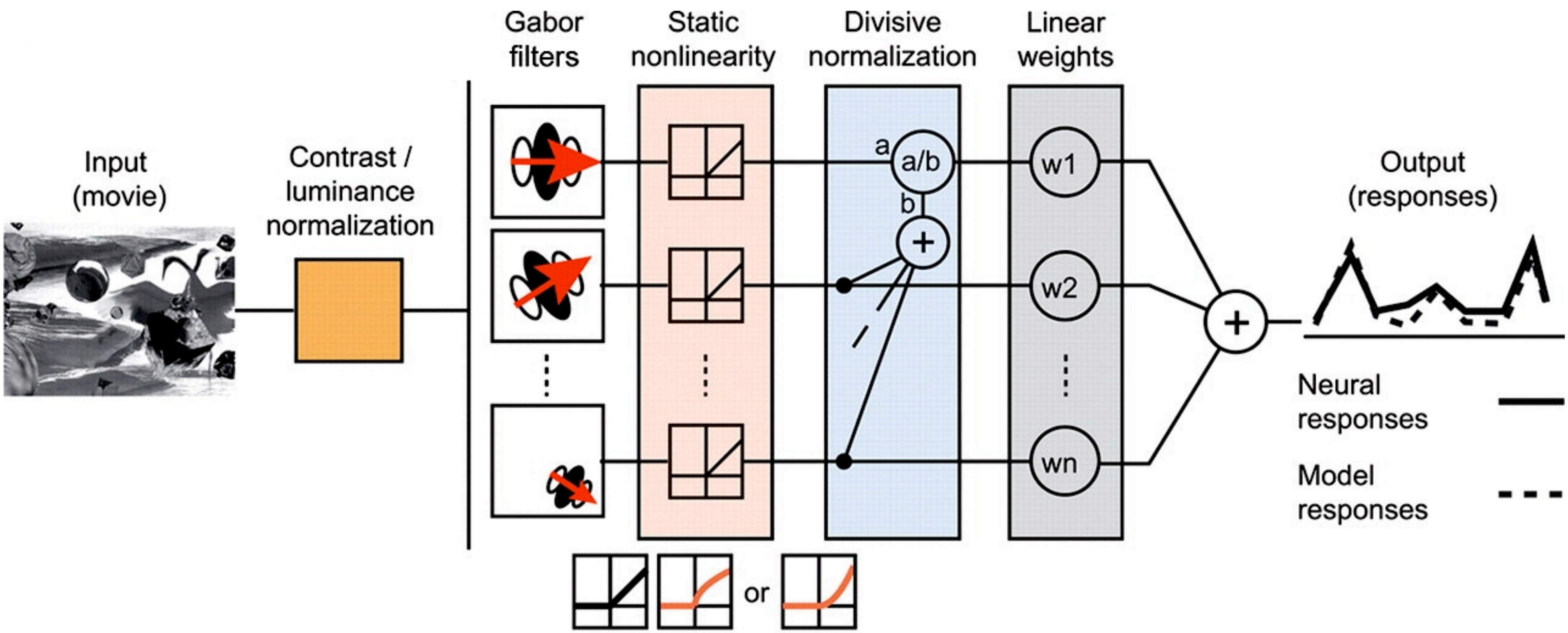
Nishimoto & Gallant, 2011

"Motion-enhanced" natural movies, and friends



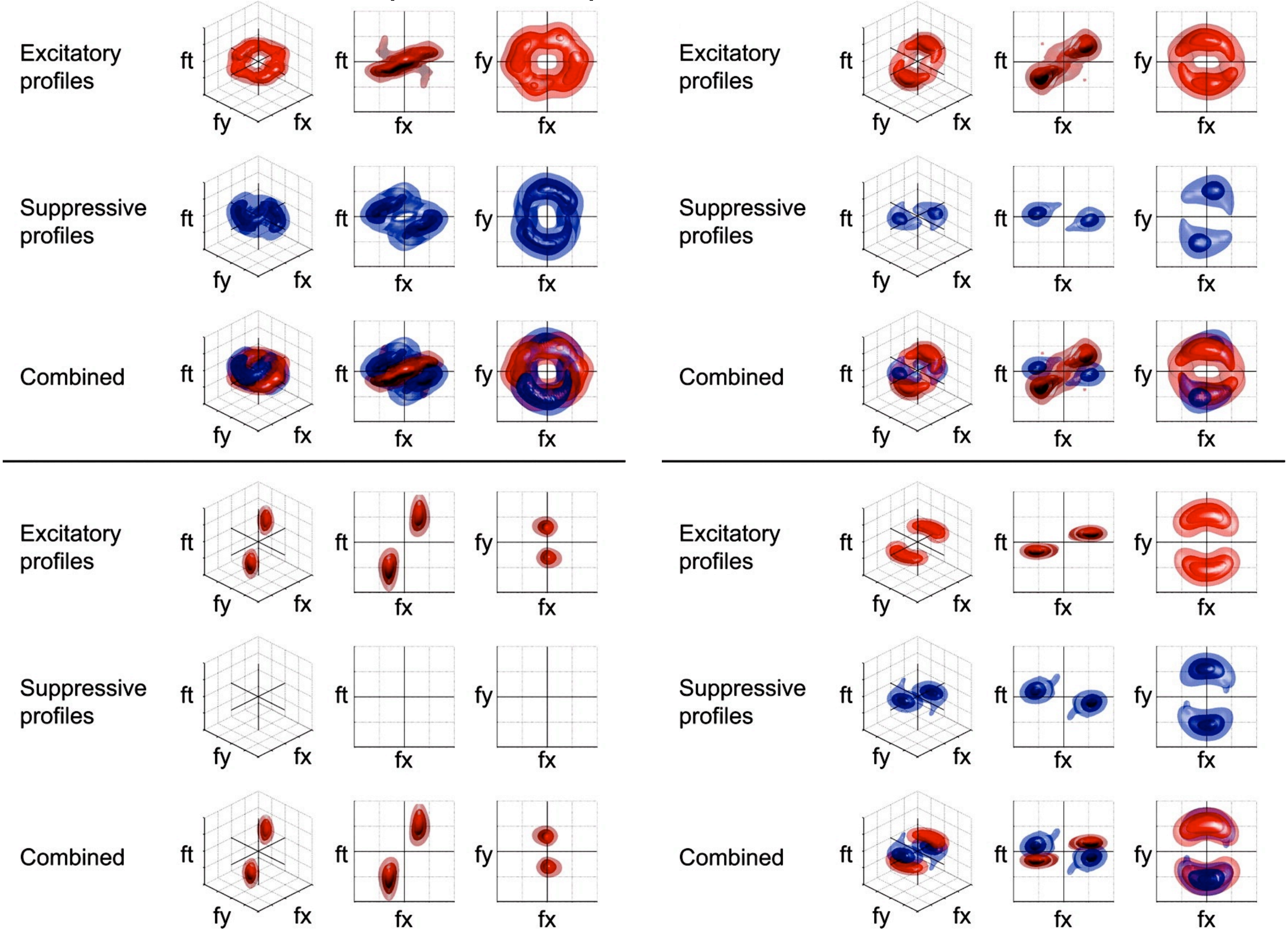
Nishimoto & Gallant, 2011

Analysis of MT neurons using a "boosted" model



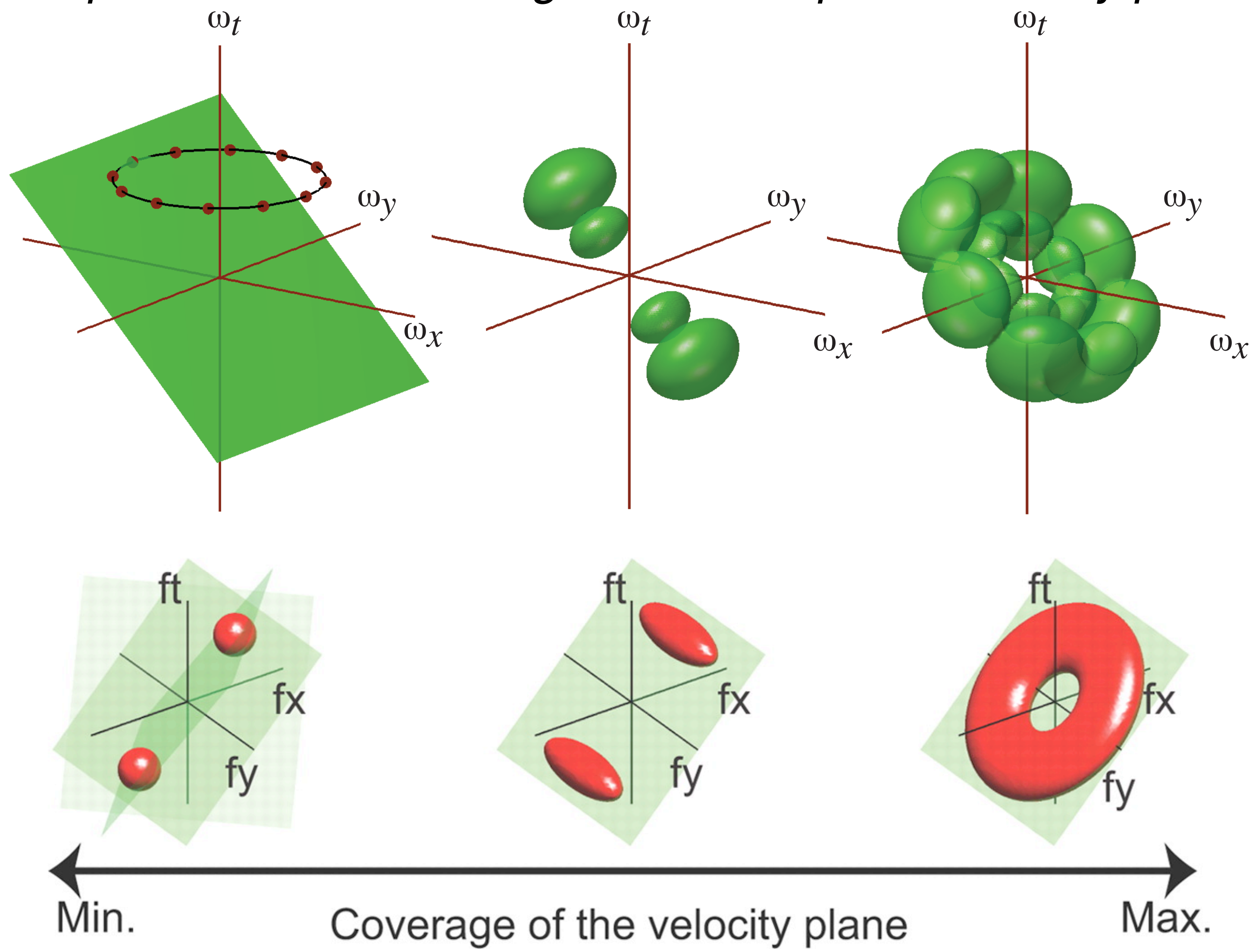
Nishimoto & Gallant, 2011

Estimated spectral receptive fields of four MT neurons



Nishimoto & Gallant, 2011

MT neurons vary in the degree to which their excitatory spectral receptive fields form a ring within the optimal velocity plane.



Nishimoto & Gallant, 2011

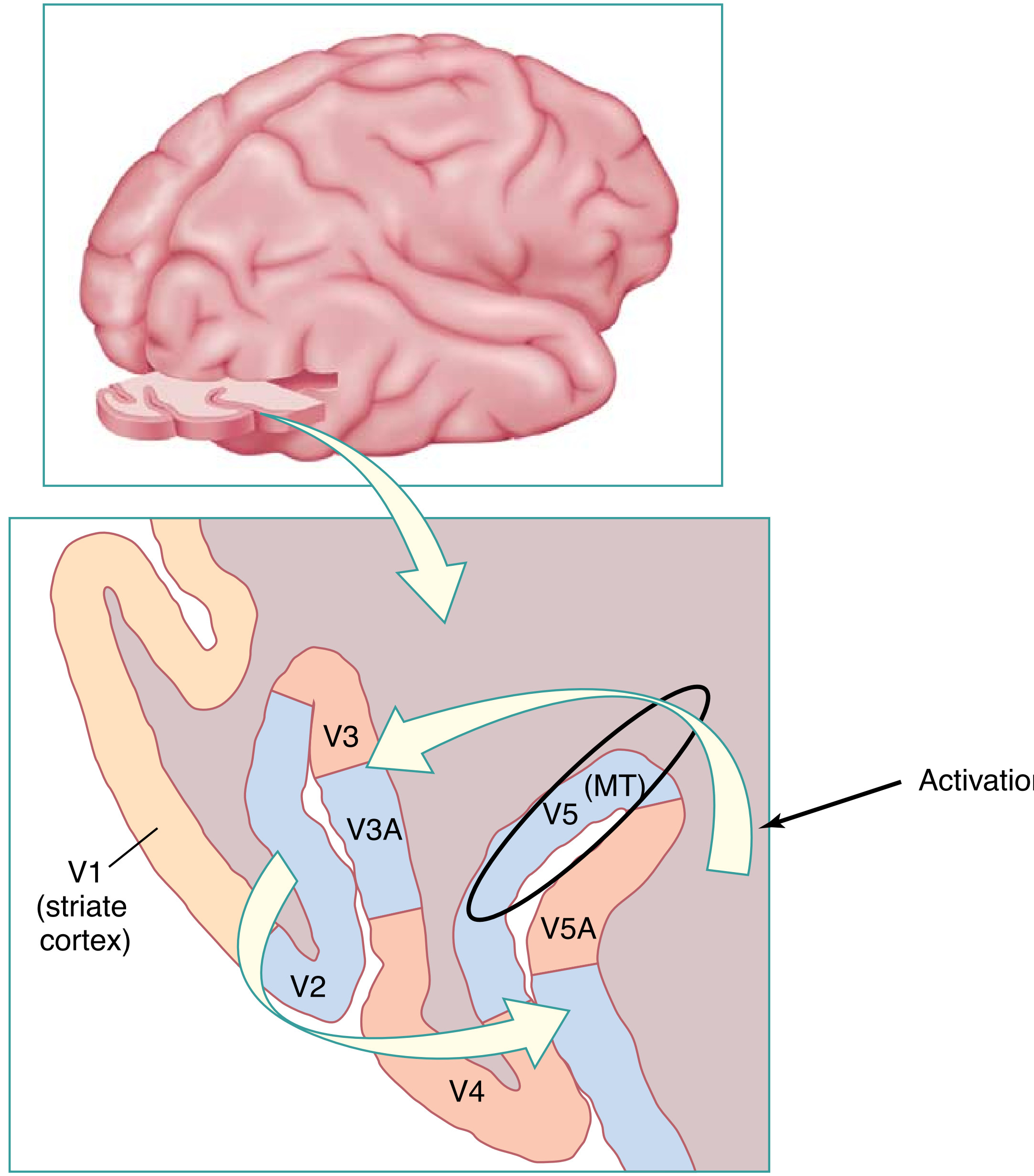
Opinion TRENDS in Cognitive Sciences Vol.9 No.2 February 2005

Two neural correlates of consciousness

Ned Block

Block's conjecture

MT is "the core phenomenal neural correlate of consciousness for the visual experiential content as of motion"



Local and global motion signals