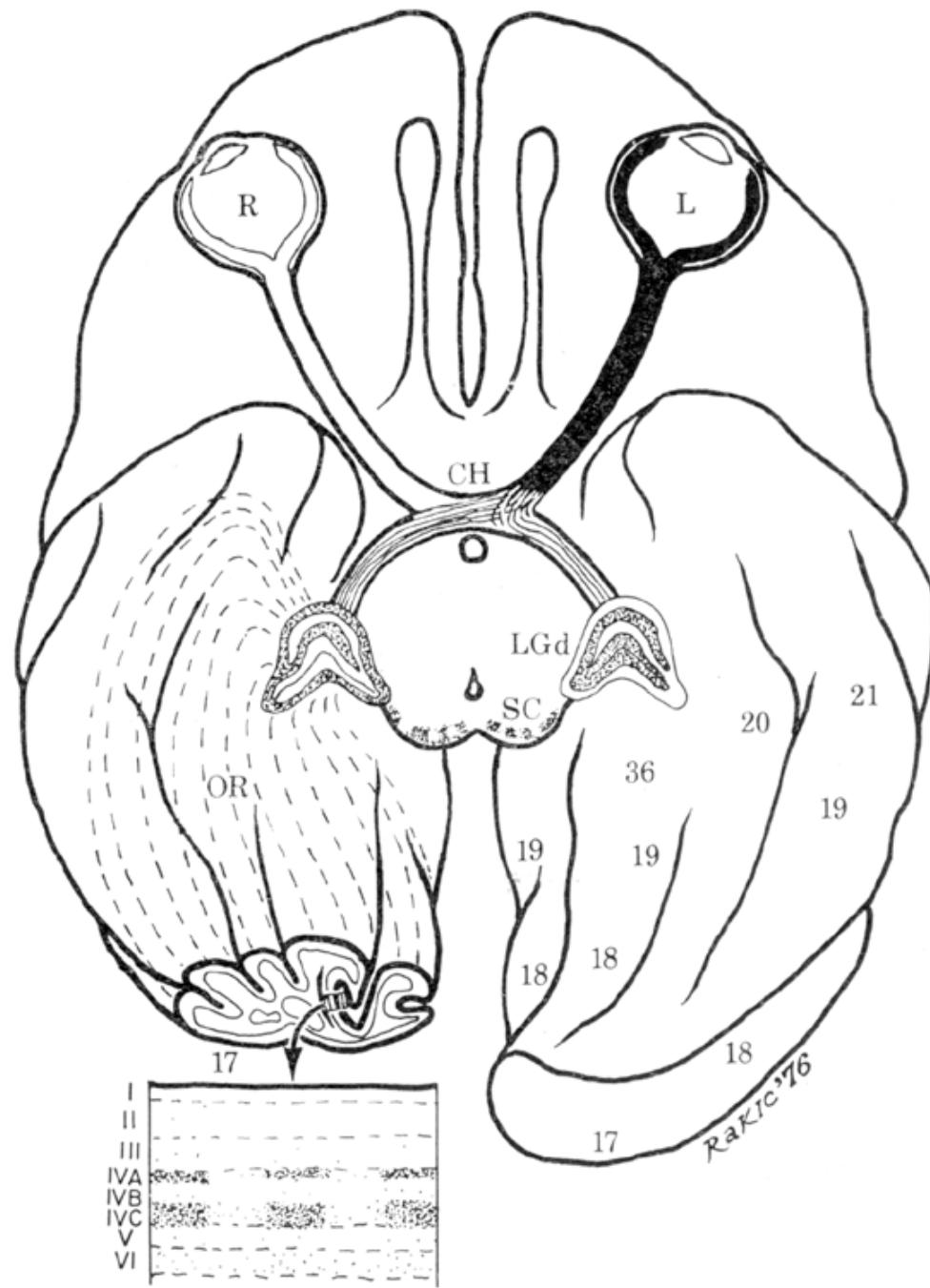


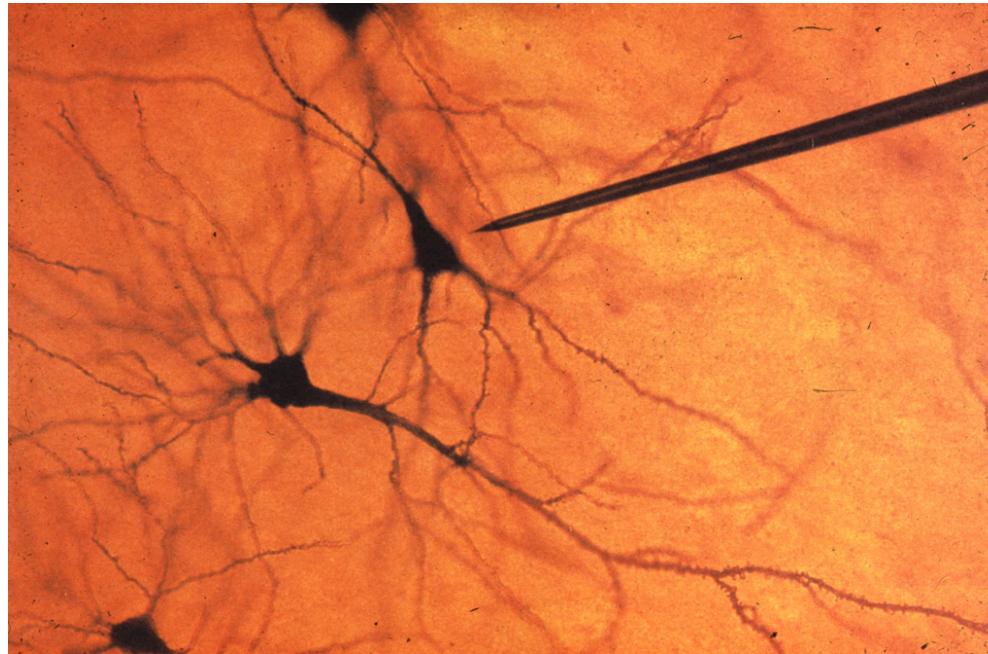
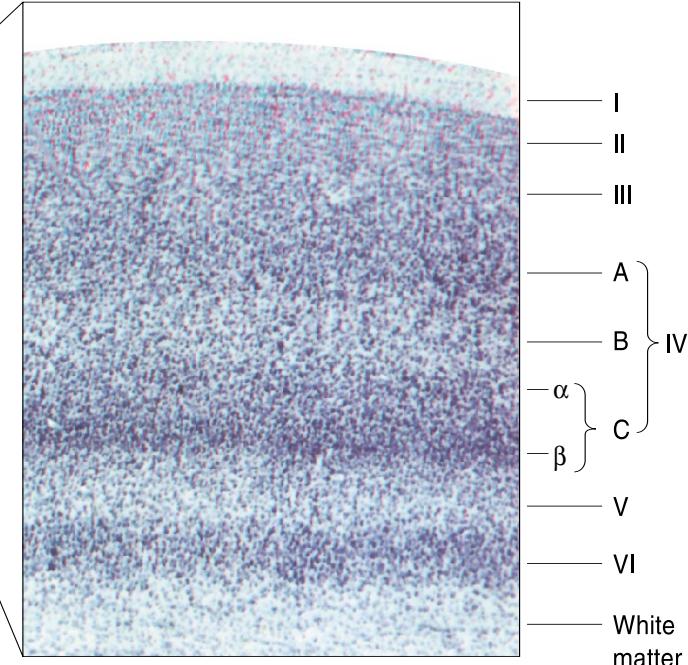
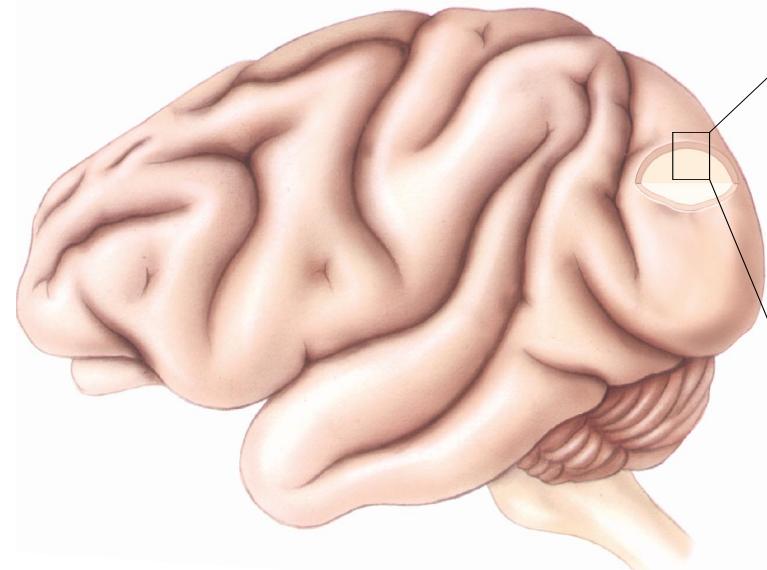
# Cortical processing of visual motion signals

J. Anthony Movshon

Computational Modeling of Neuronal Systems, 25 October 2007

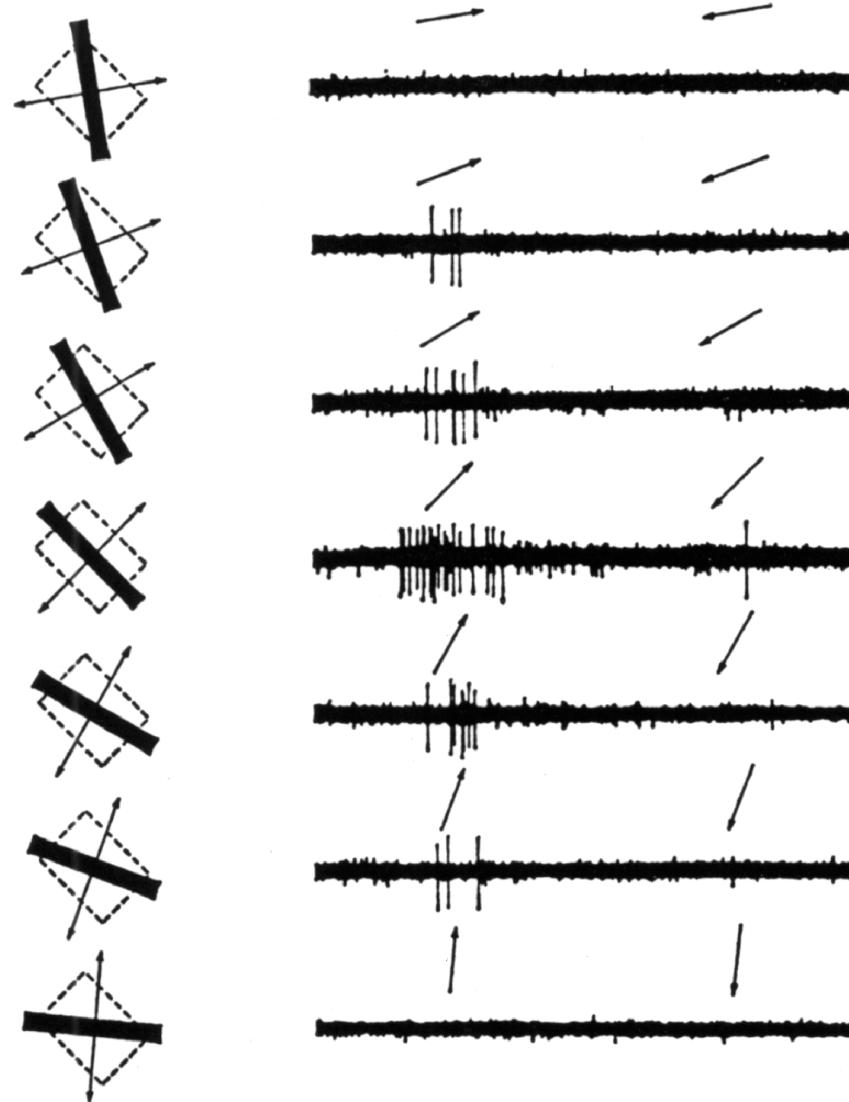






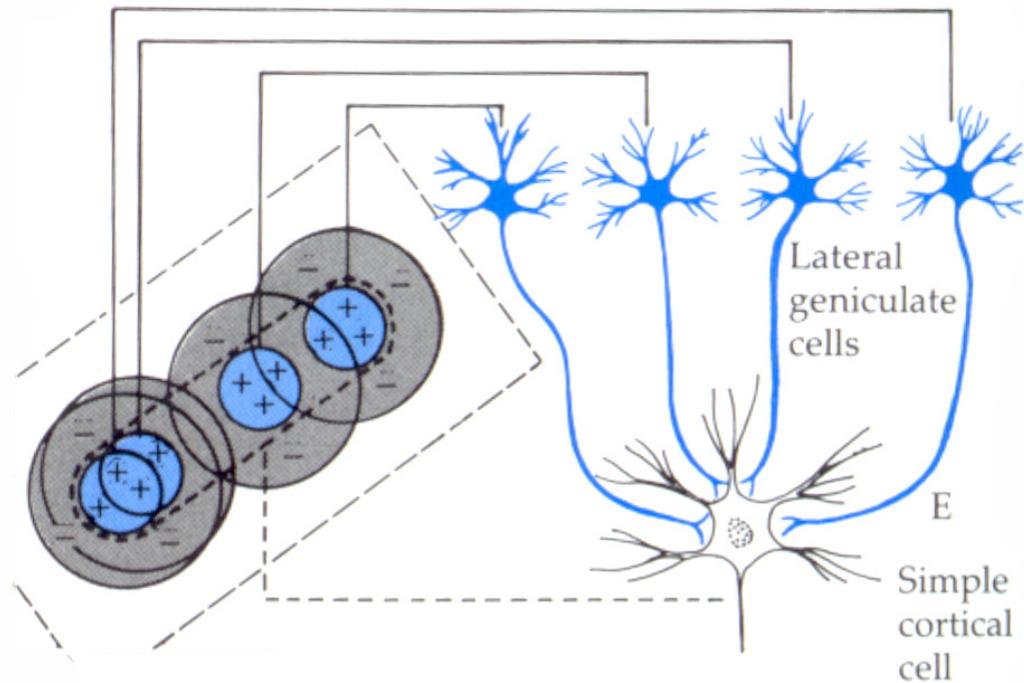
David Hubel and Torsten Wiesel

V1



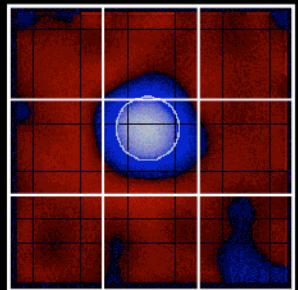
Hubel & Wiesel, 1968

SIMPLE

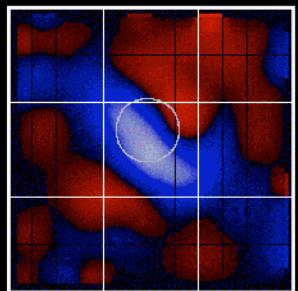


Hubel and Wiesel, 1962

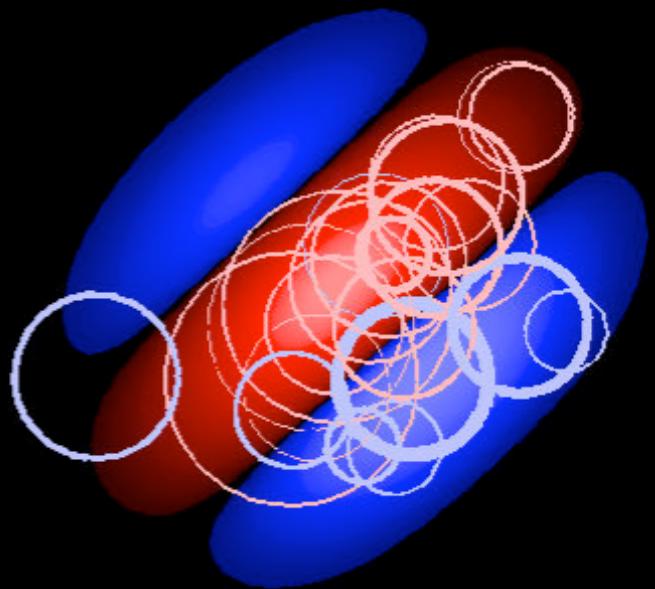
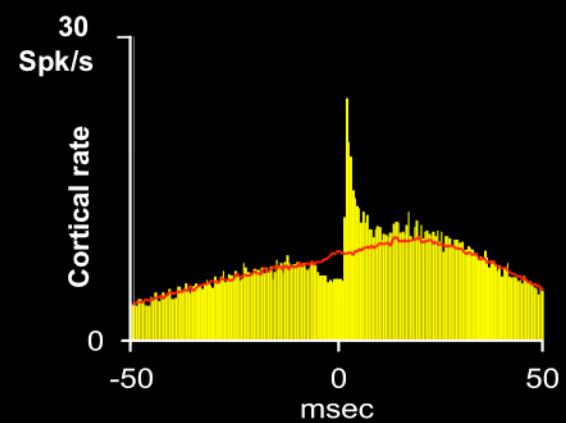
LGN RF



Cortex RF

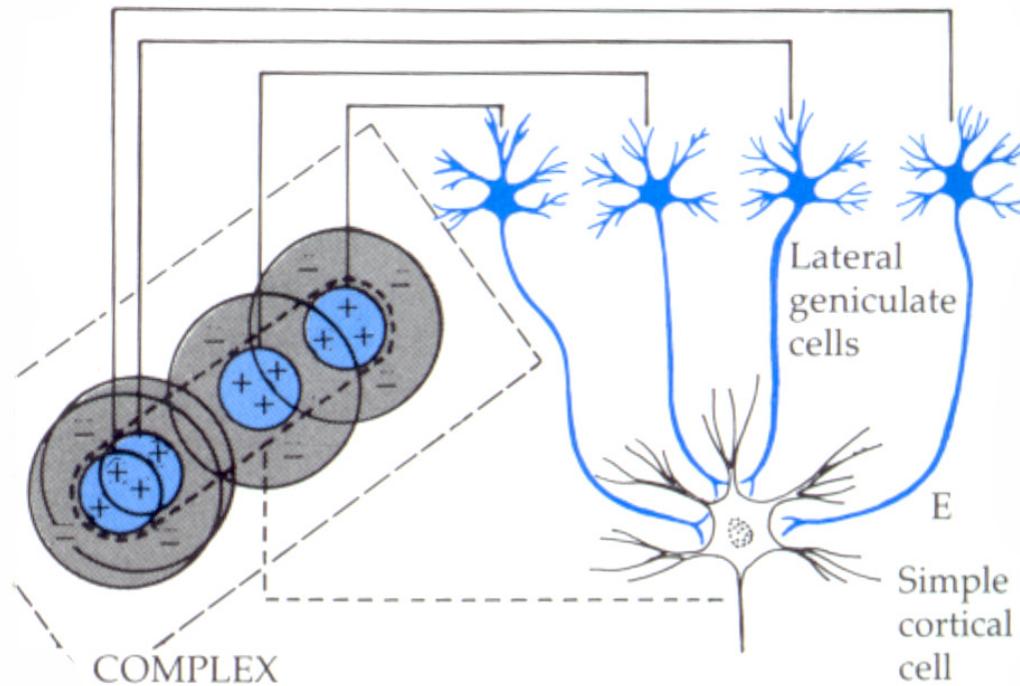


1.6°

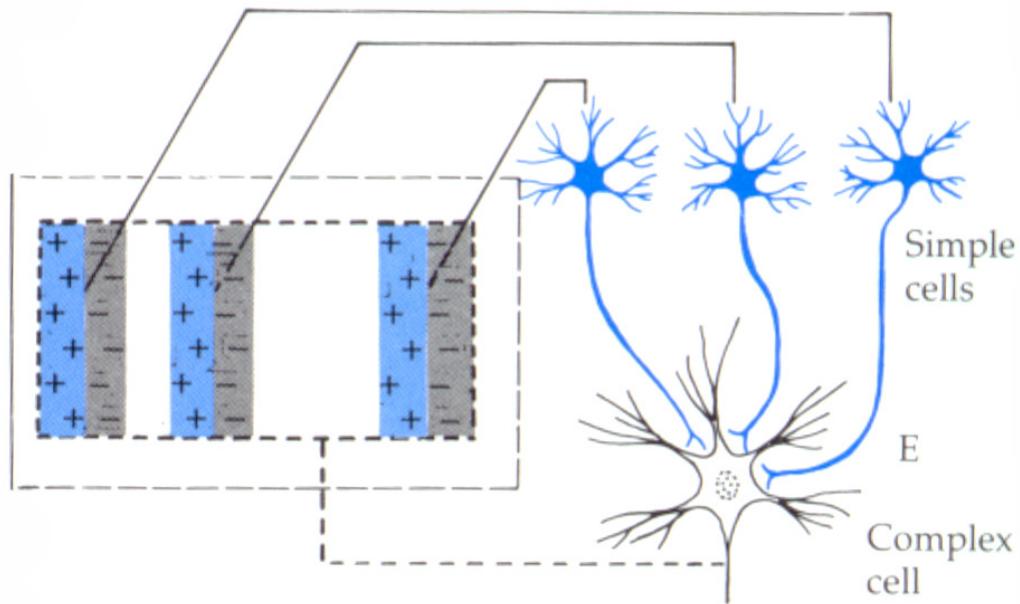


Alonso, Usrey & Reid, 2001

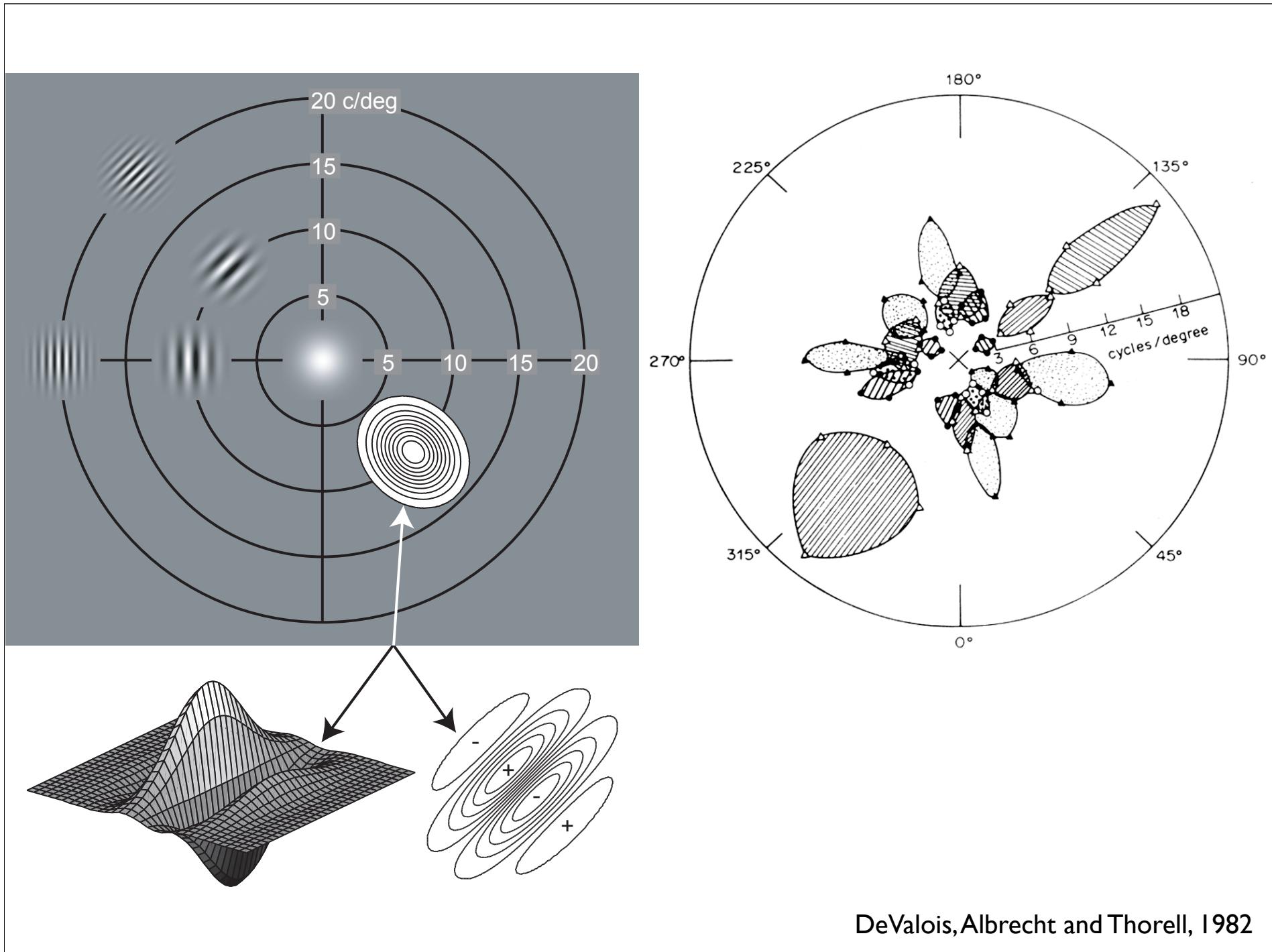
SIMPLE

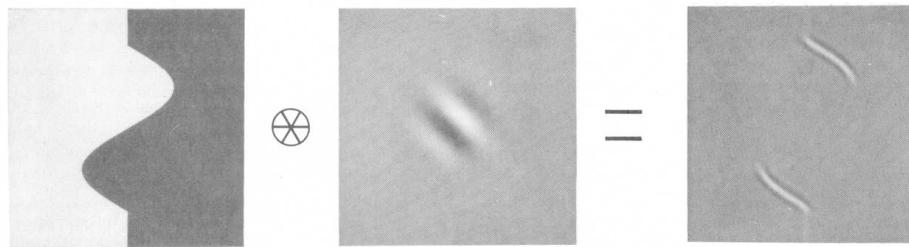
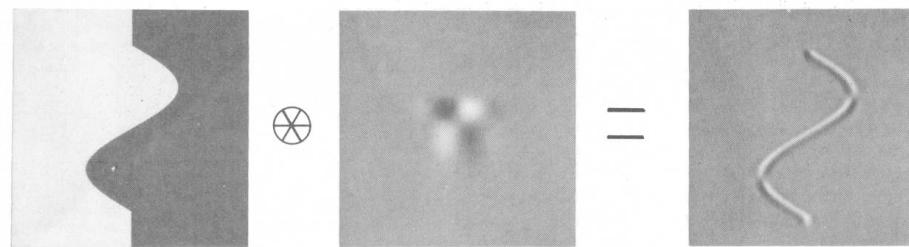
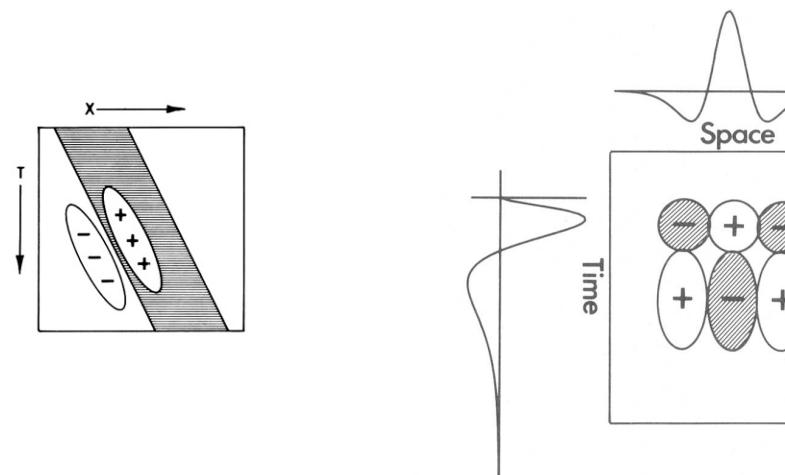
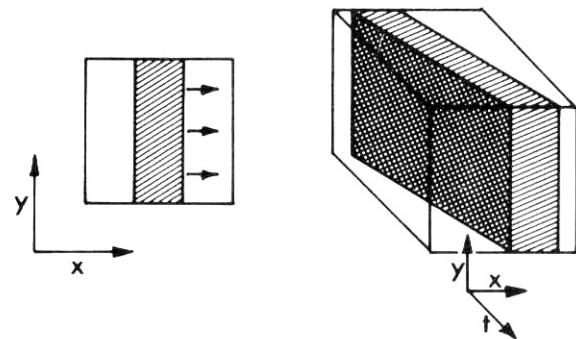


COMPLEX

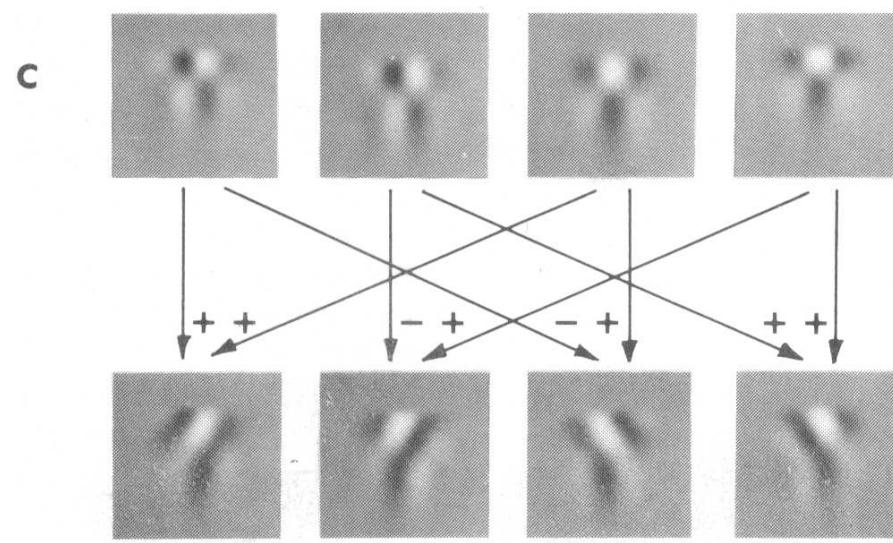
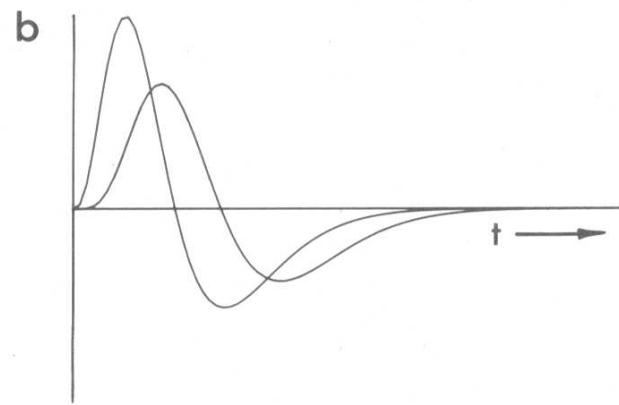
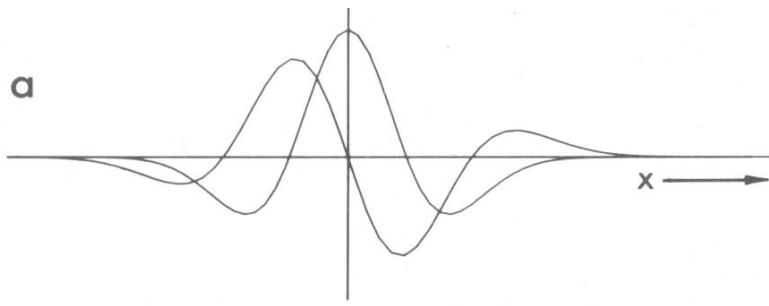


Hubel and Wiesel, 1962

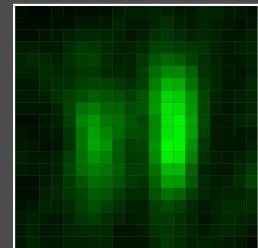
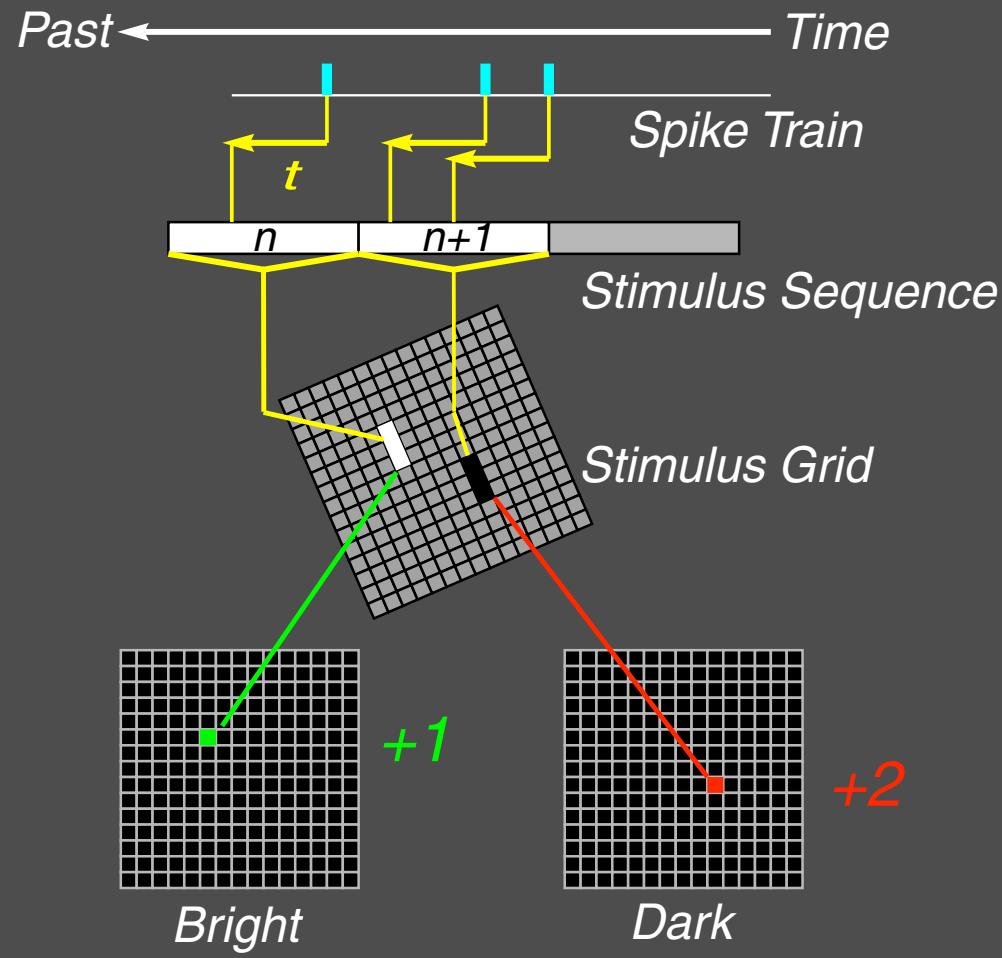




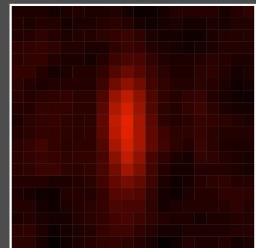
Adelson & Bergen, 1985



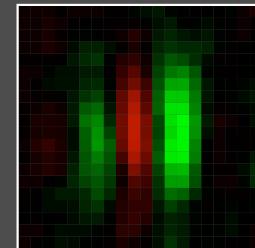
Adelson & Bergen, 1985



*Bright*

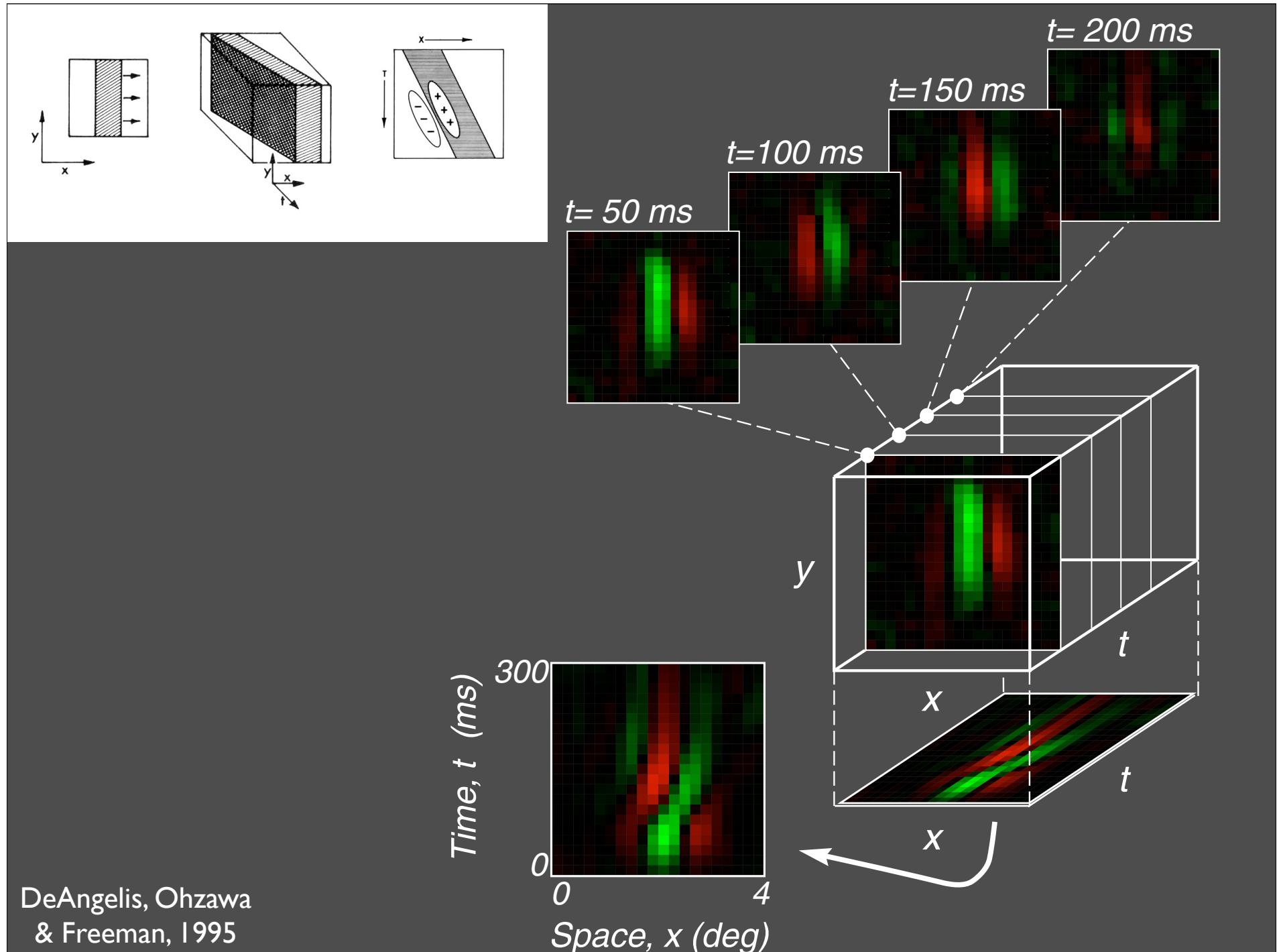


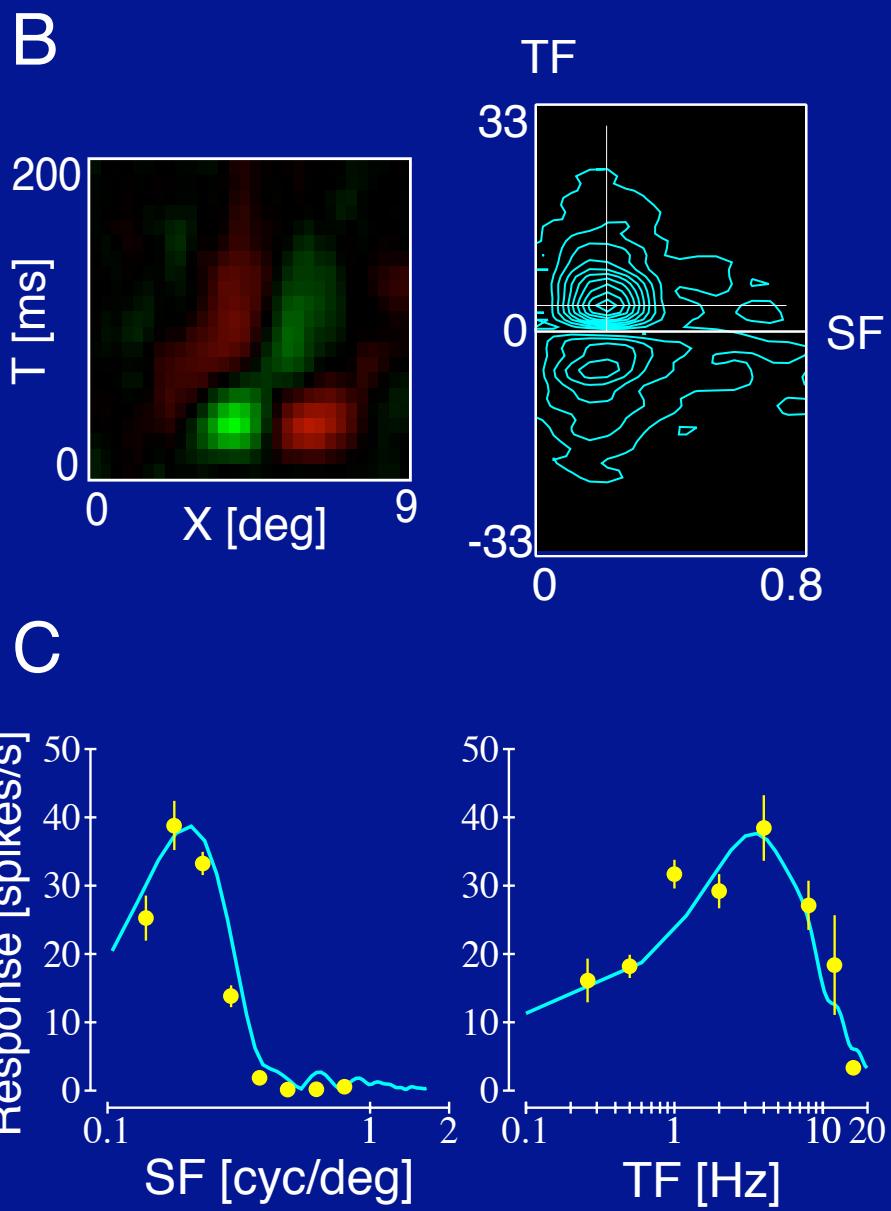
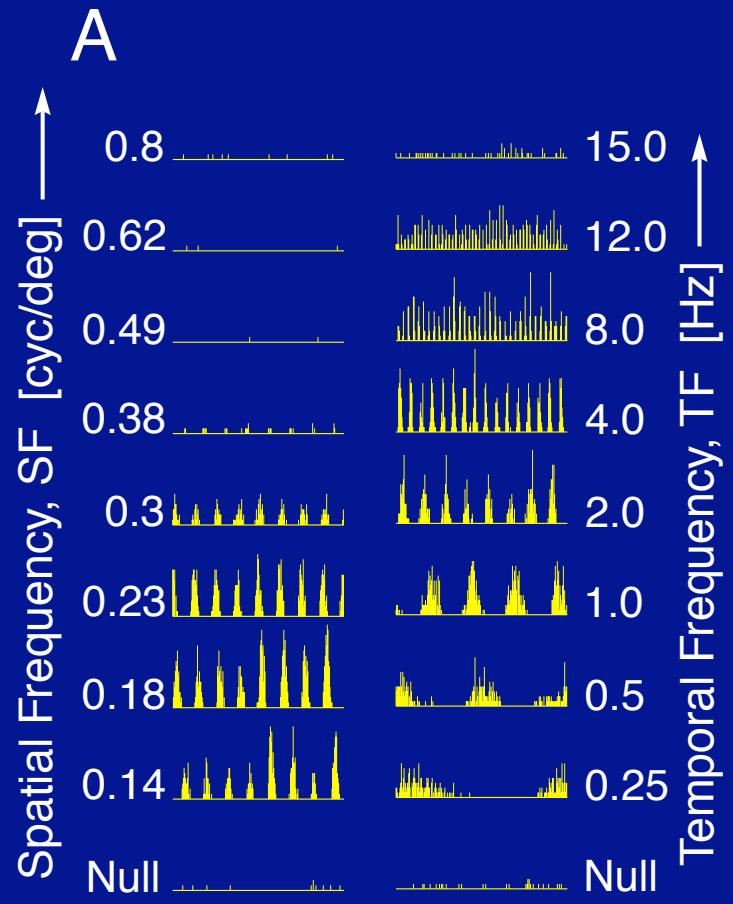
*Dark*



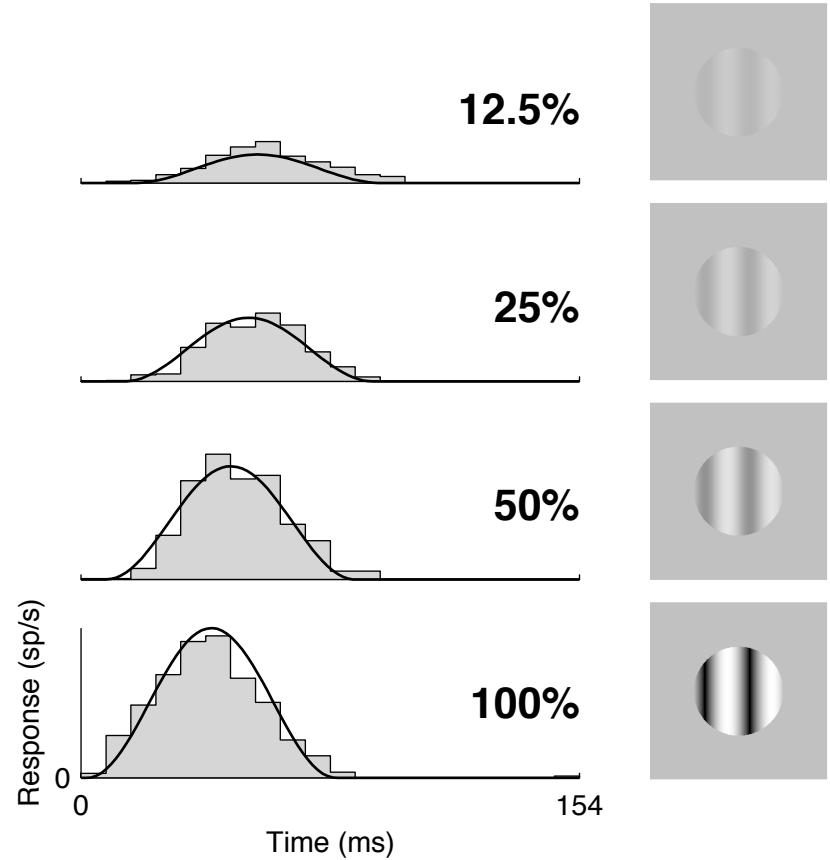
*Difference*

Greg DeAngelis

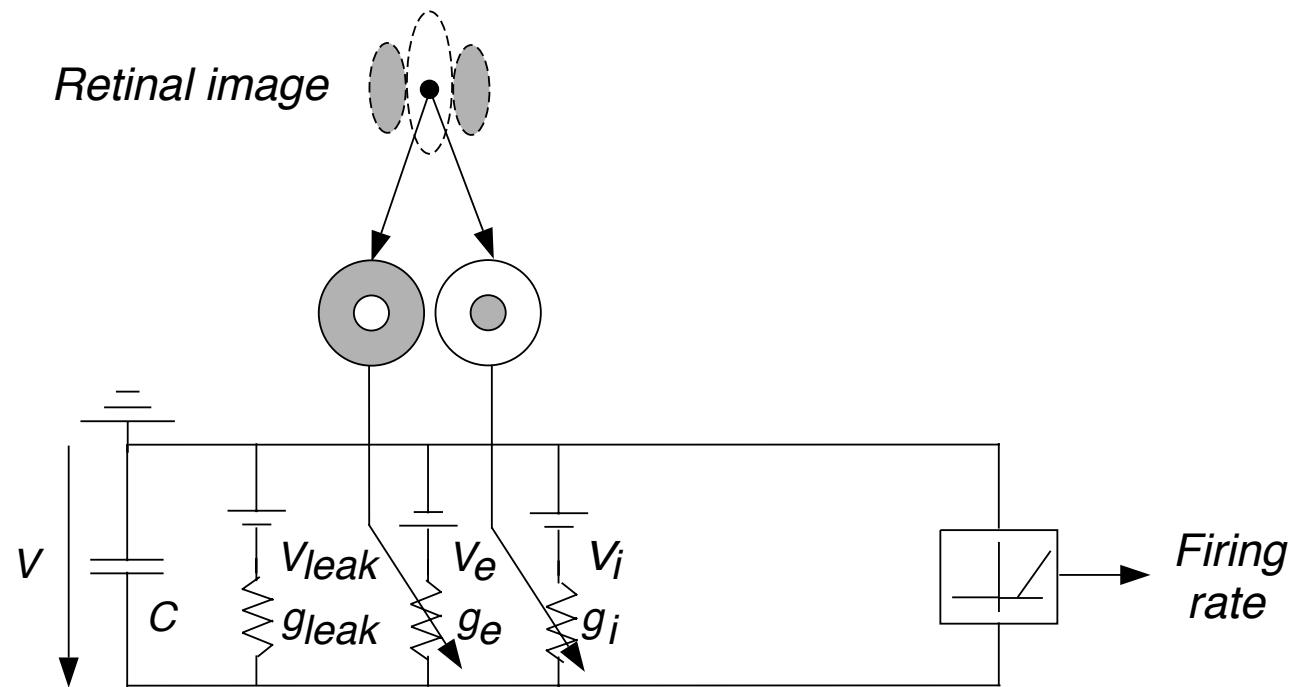




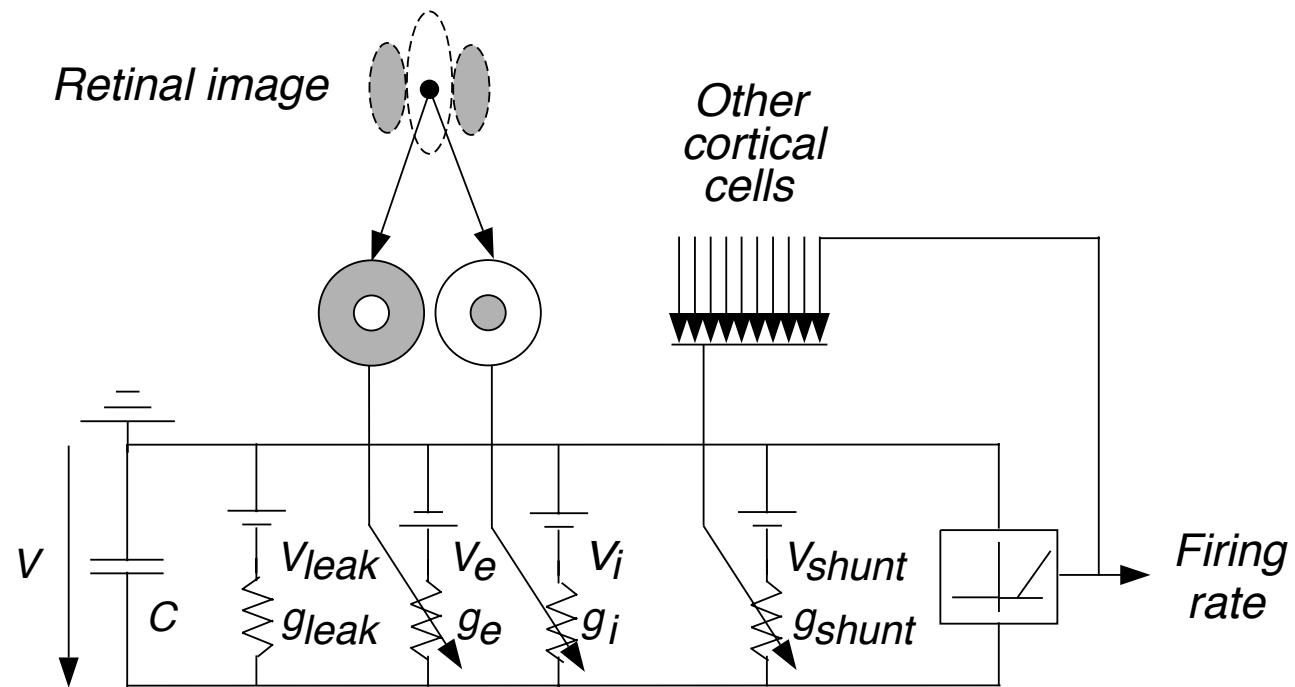
DeAngelis, Ohzawa  
& Freeman, 1995



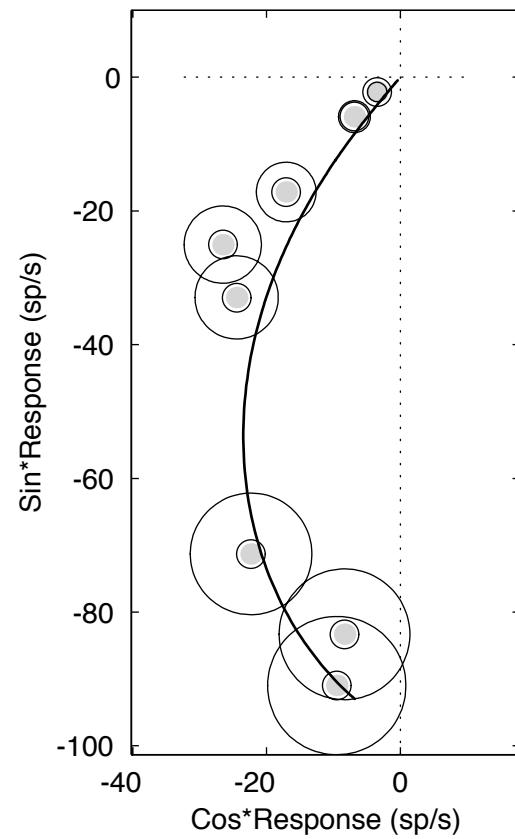
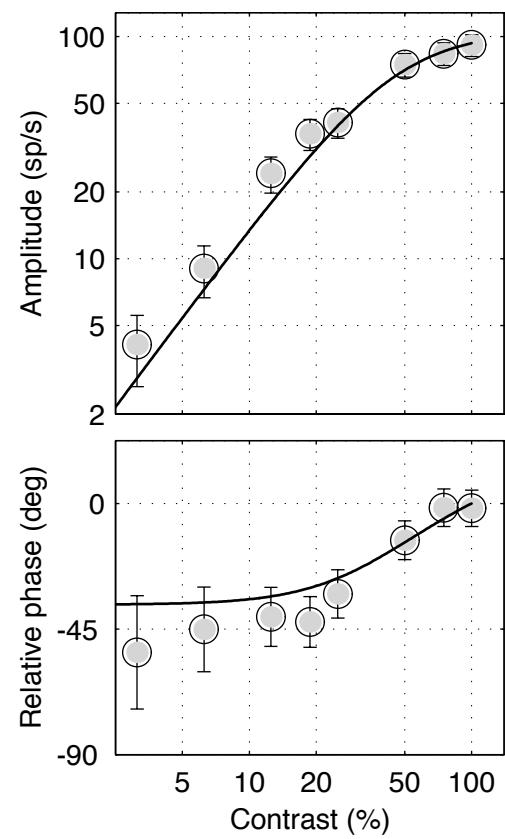
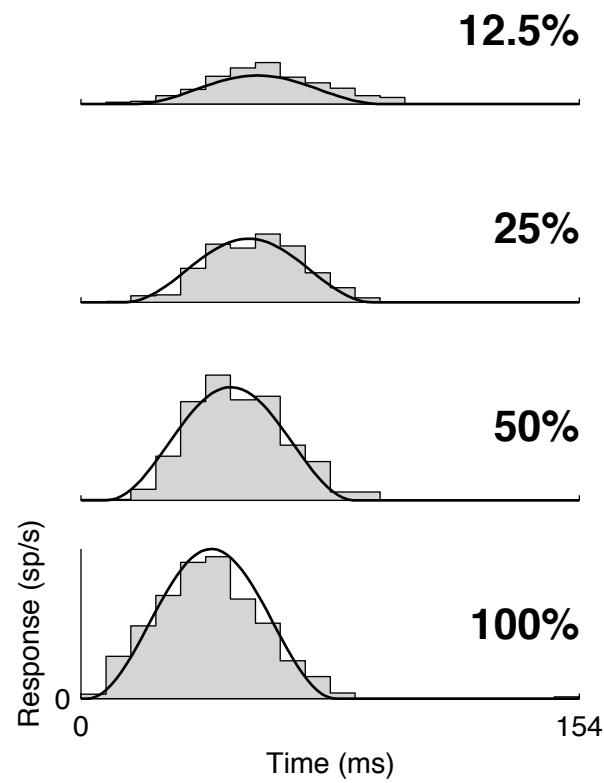
Carandini, Heeger and Movshon, 1997



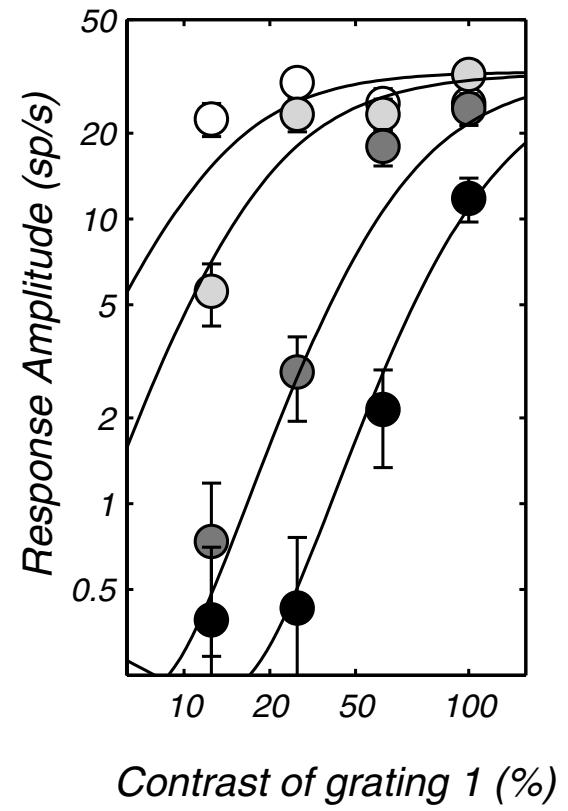
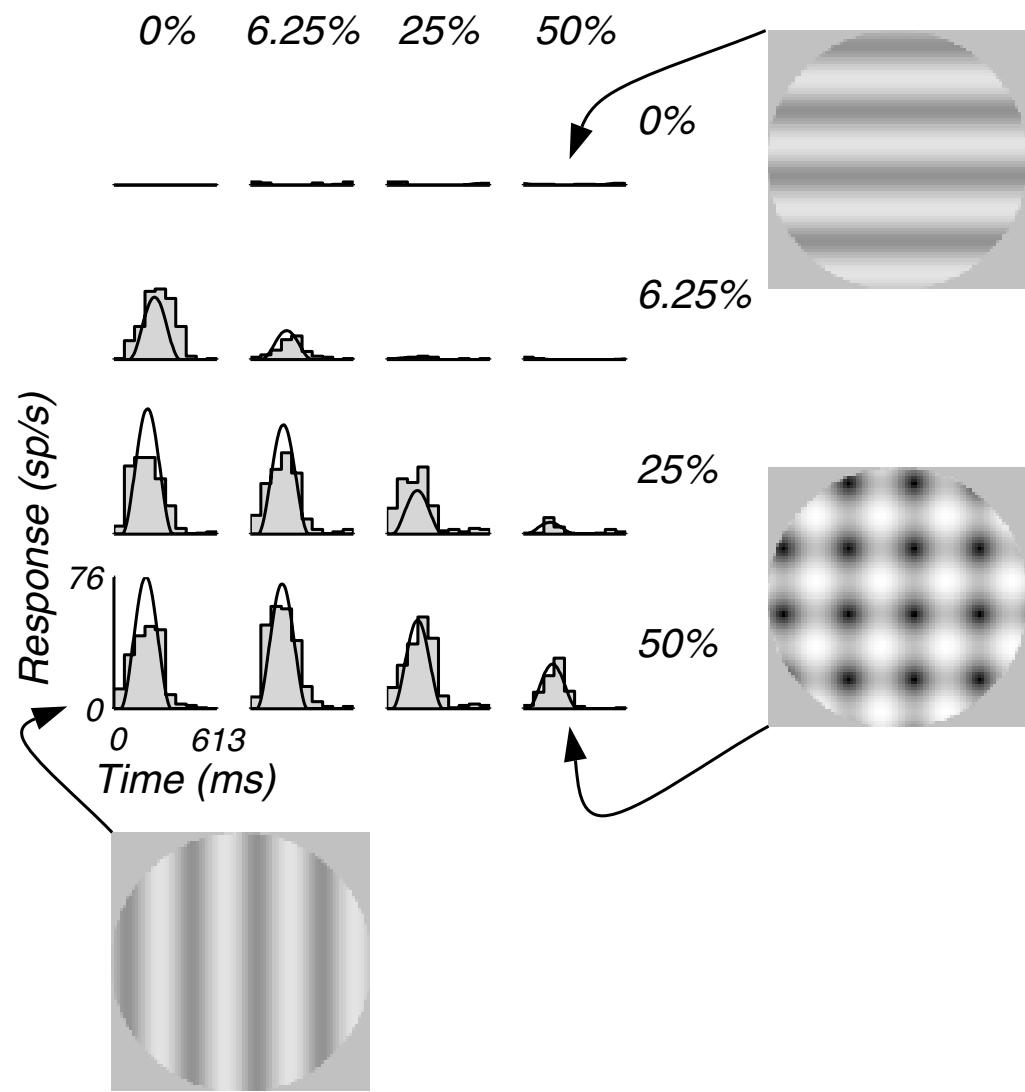
Carandini and Heeger, 1994



Carandini and Heeger, 1994



Carandini, Heeger and Movshon, 1997

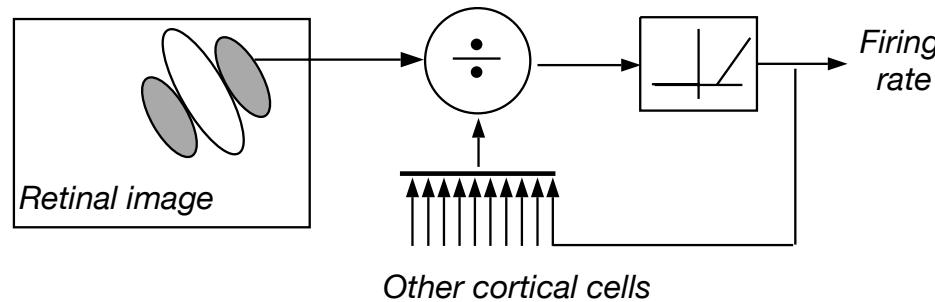


Carandini, Heeger and Movshon, 1997

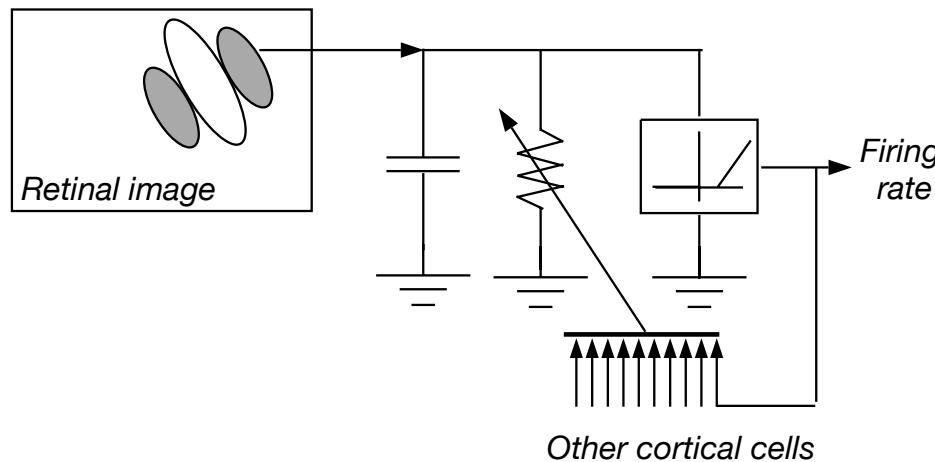
### *The linear model of simple cells*



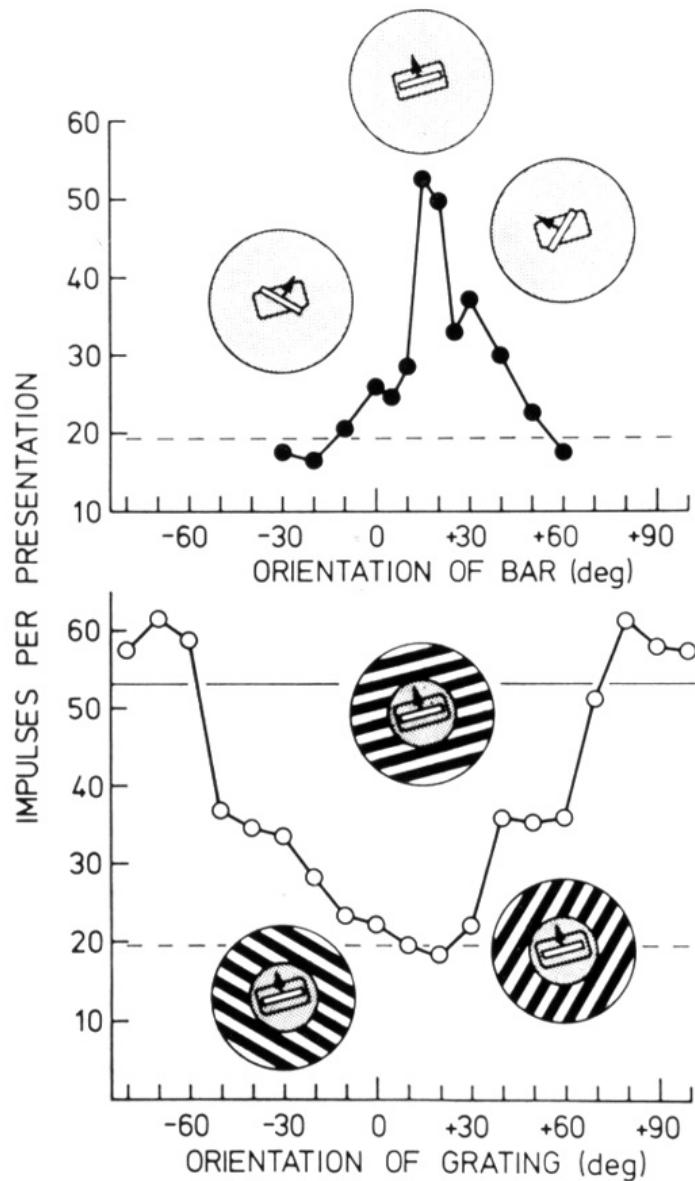
### *The normalization model of simple cells*



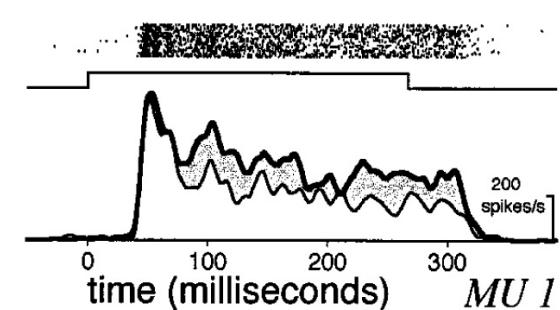
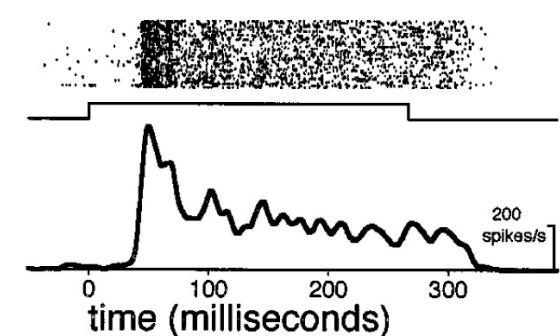
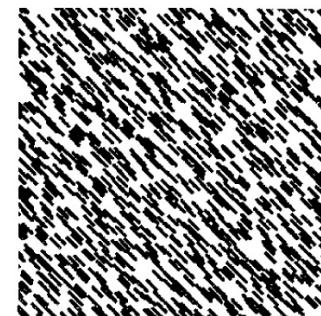
### *RC circuit implementation*



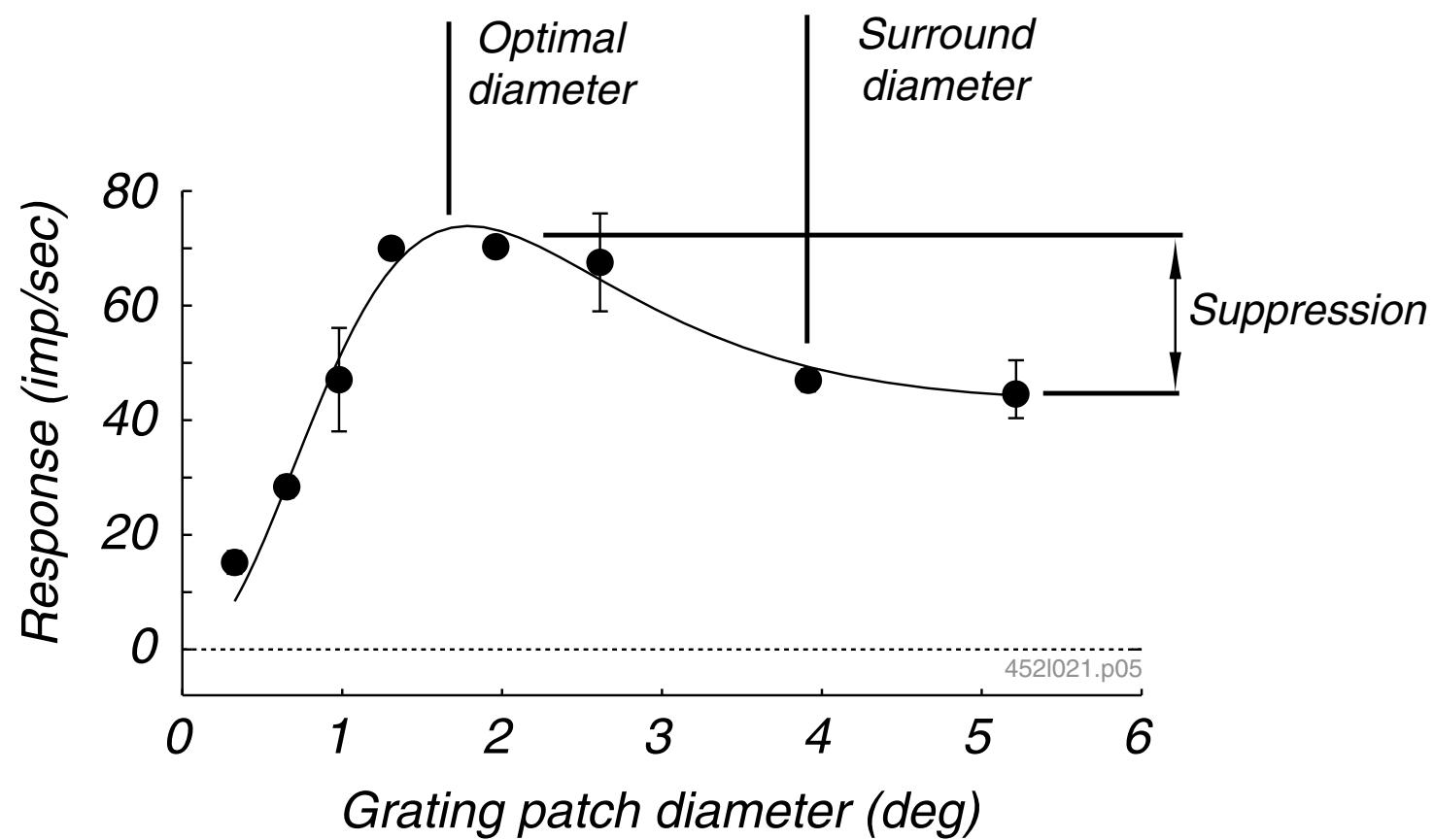
Carandini, Heeger and Movshon, 1997



Blakemore and Tobin, 1972



Zipser, Lamme and Schiller, 1996

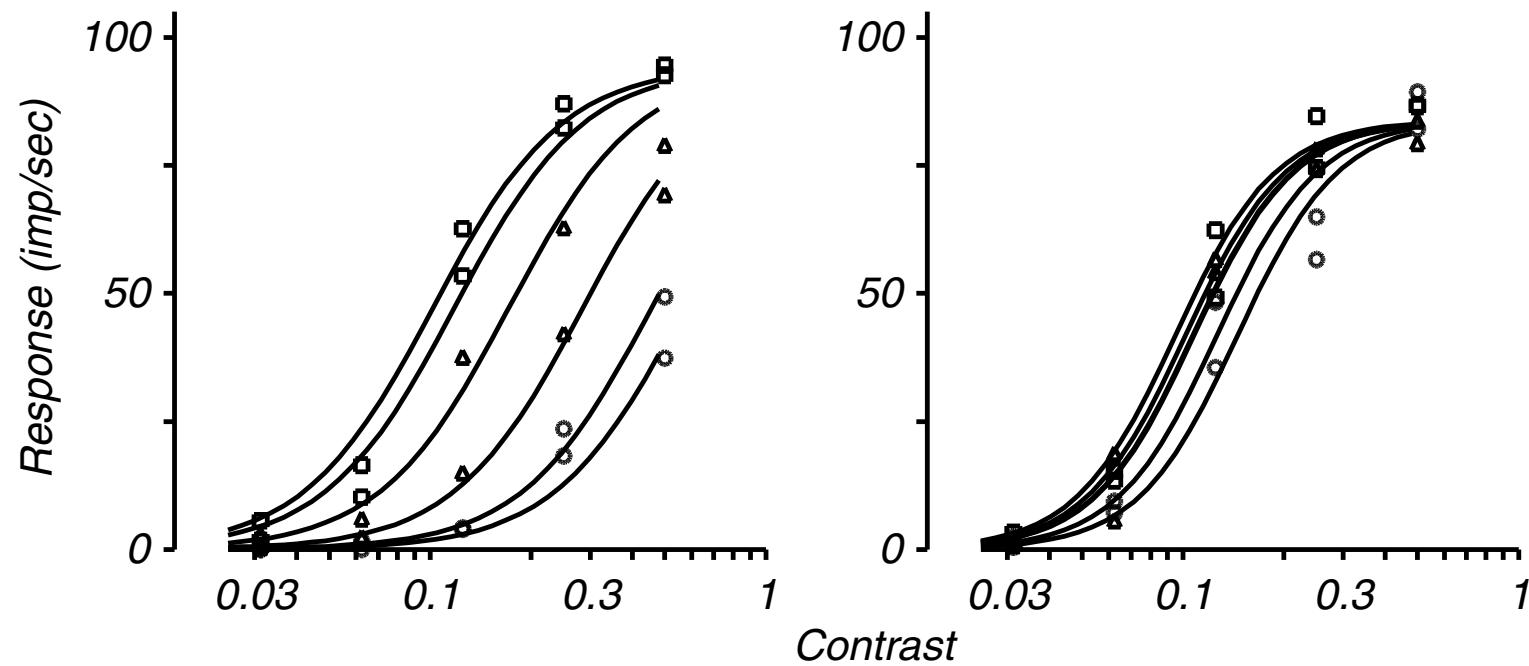
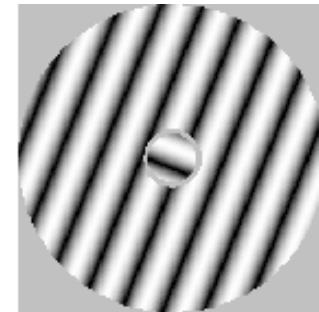


Cavanaugh, Bair and Movshon, 2002

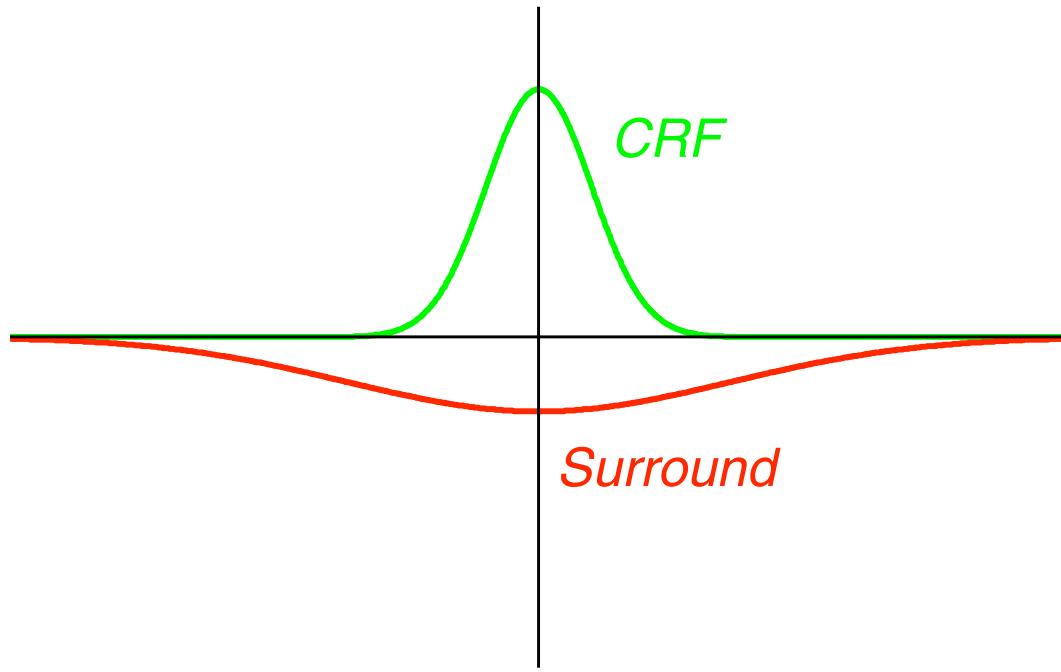
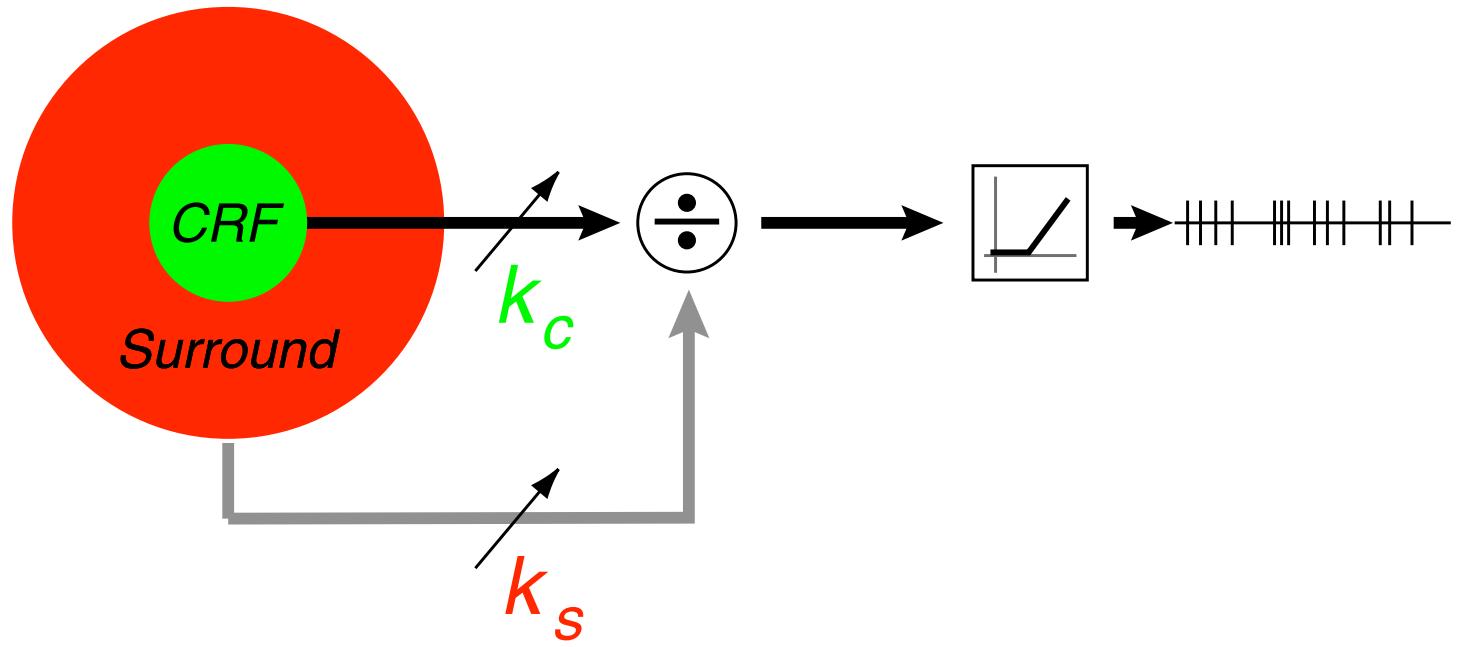


*Surround contrast*

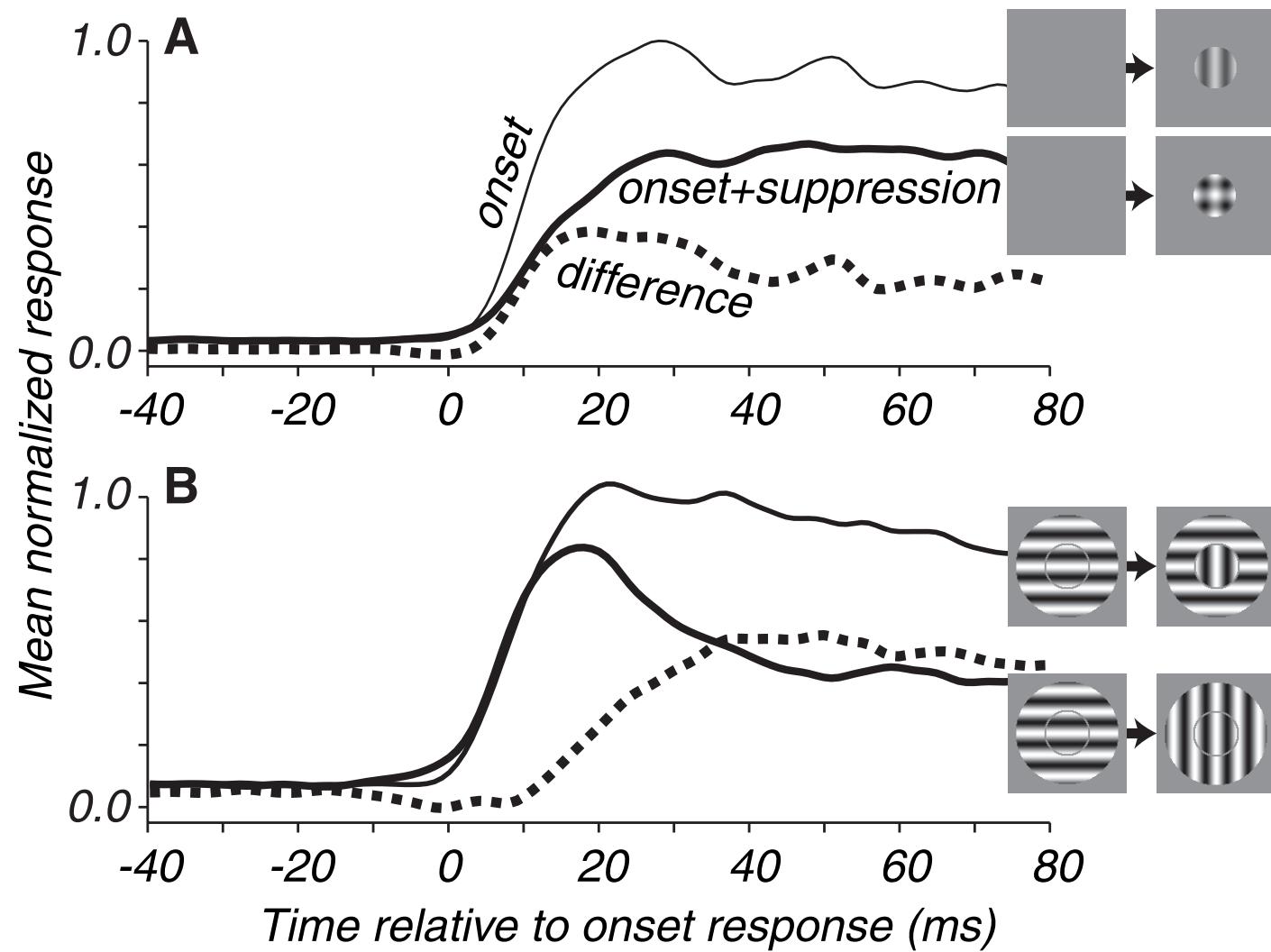
- 0
- 0.03
- △ 0.06
- △ 0.13
- 0.25
- 0.5

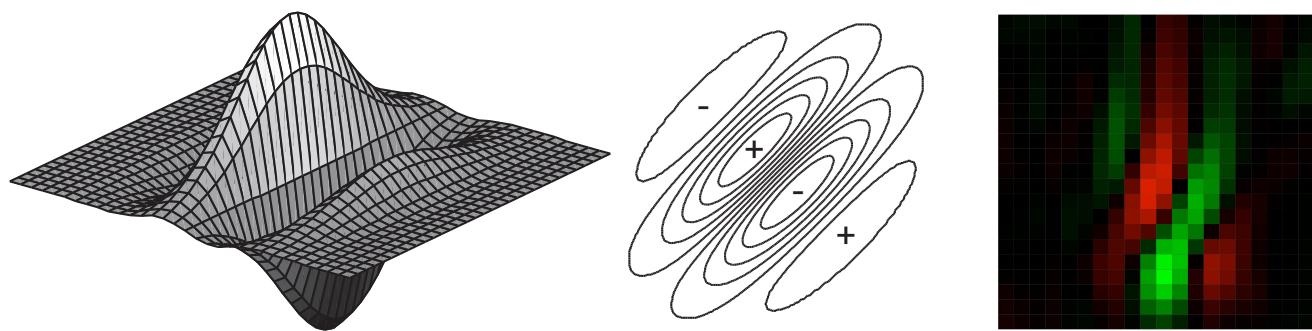


Cavanaugh, Bair and Movshon, 2002



Cavanaugh, Bair and Movshon, 2002

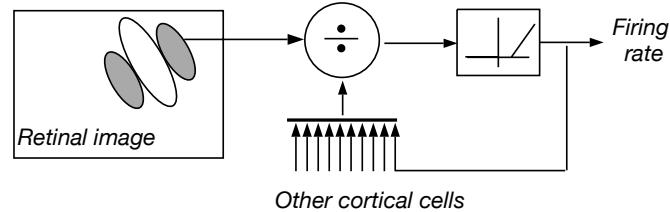




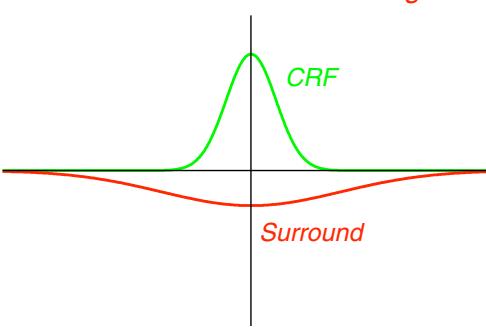
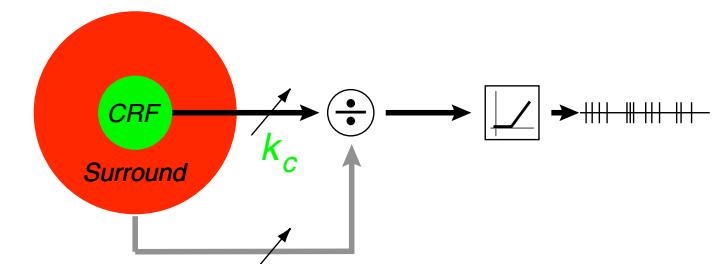
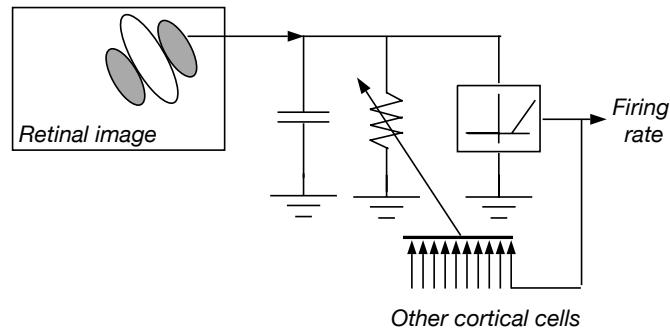
*The linear model of simple cells*

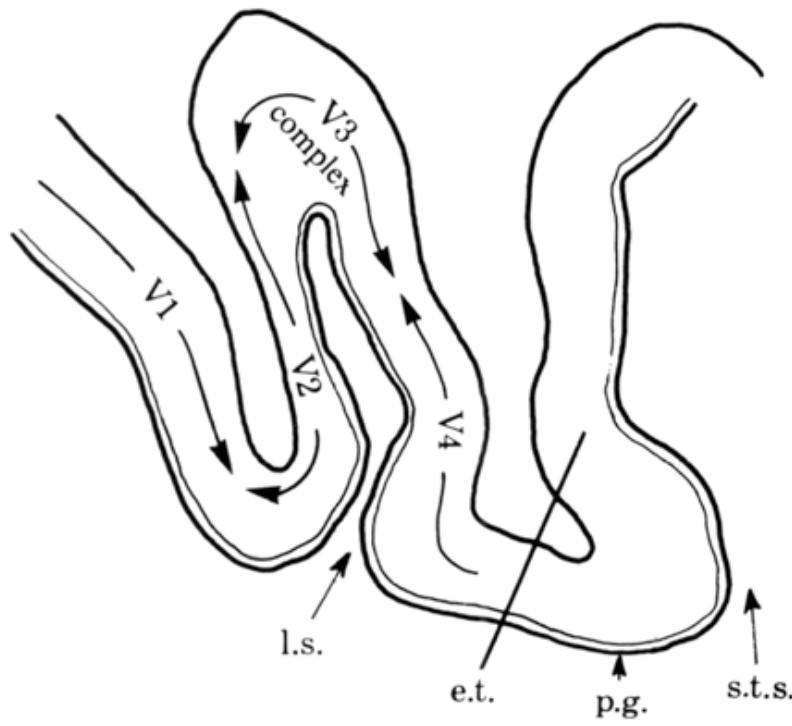
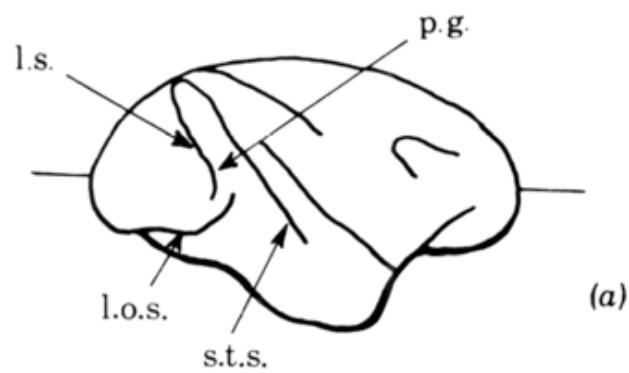
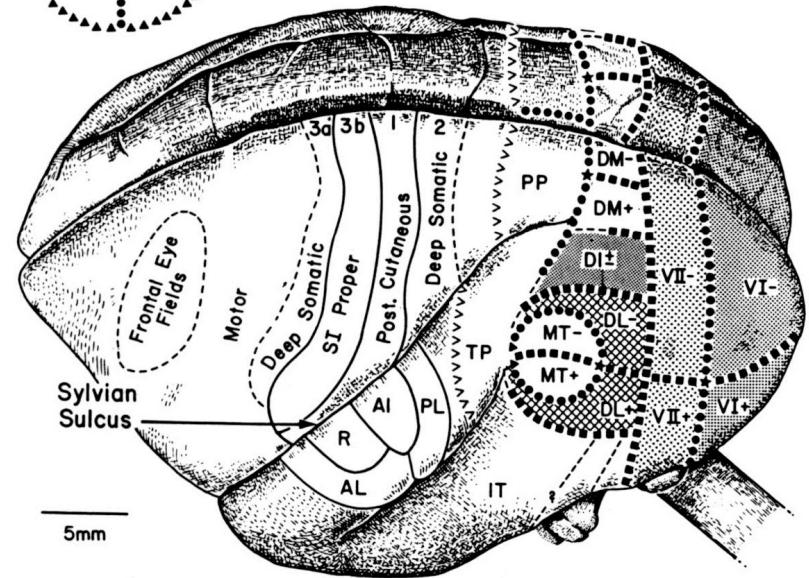
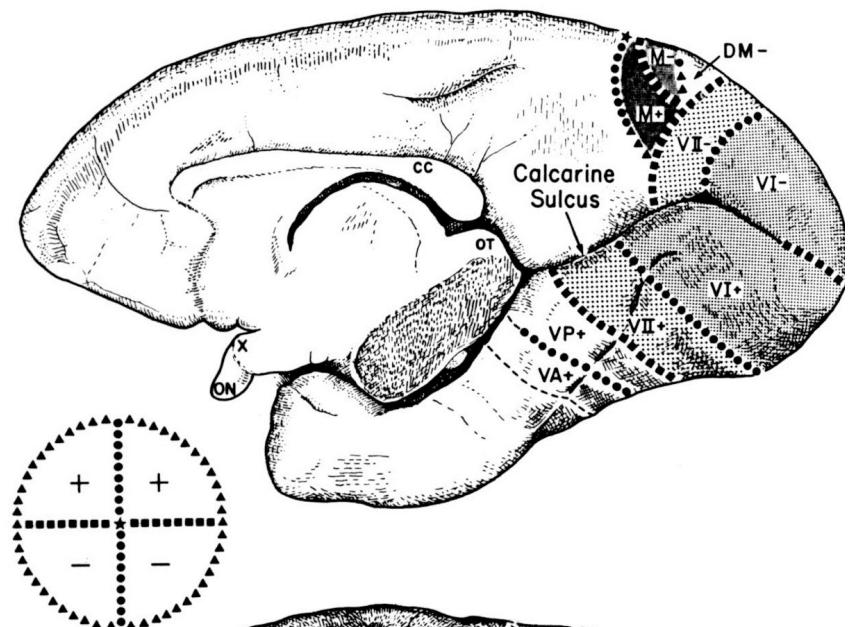


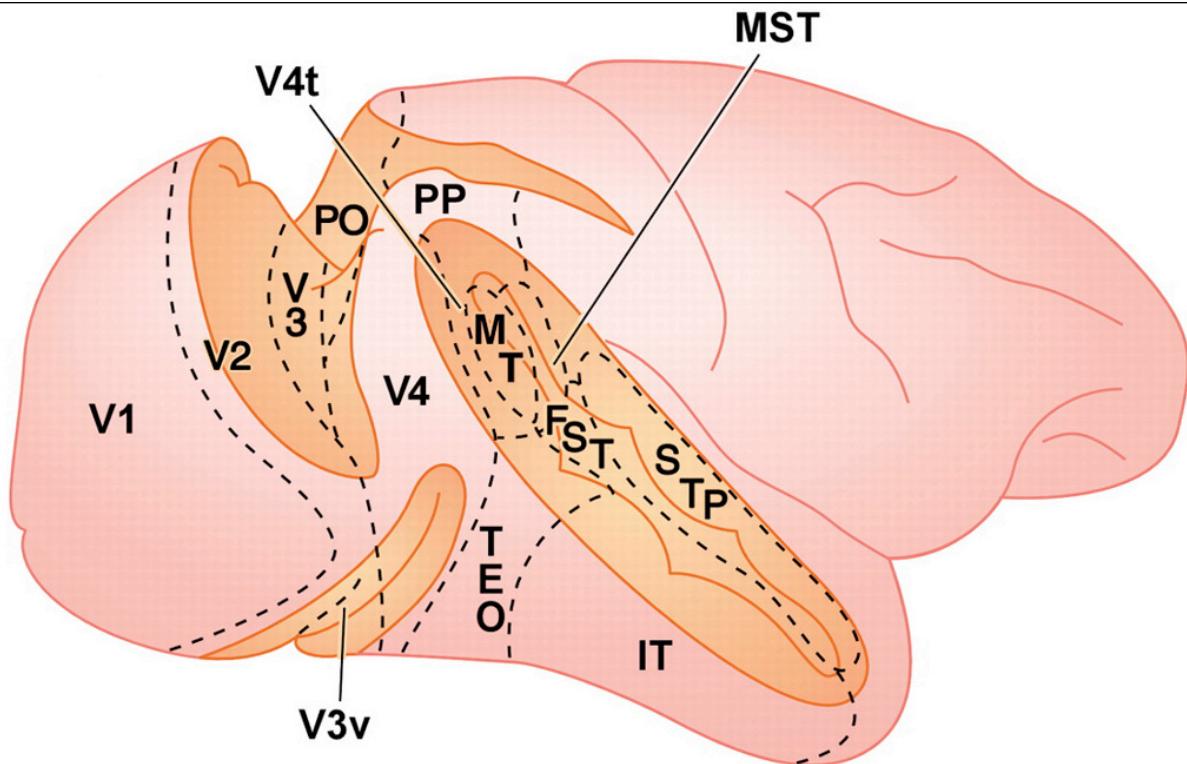
*The normalization model of simple cells*



*RC circuit implementation*







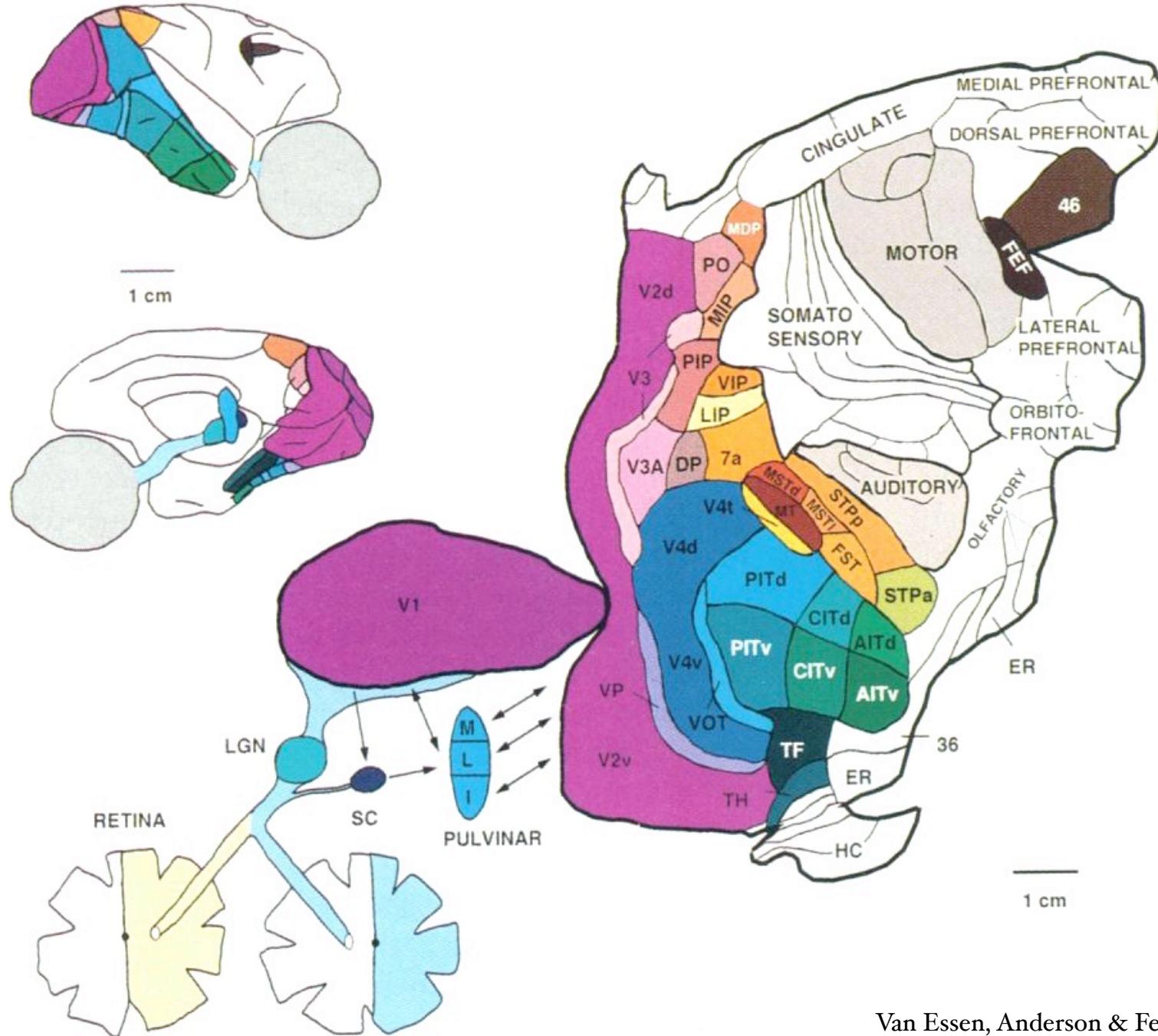
*Dorsal pathway*  
*Space, motion, action*

*Ventral pathway*  
*Form, recognition, memory*

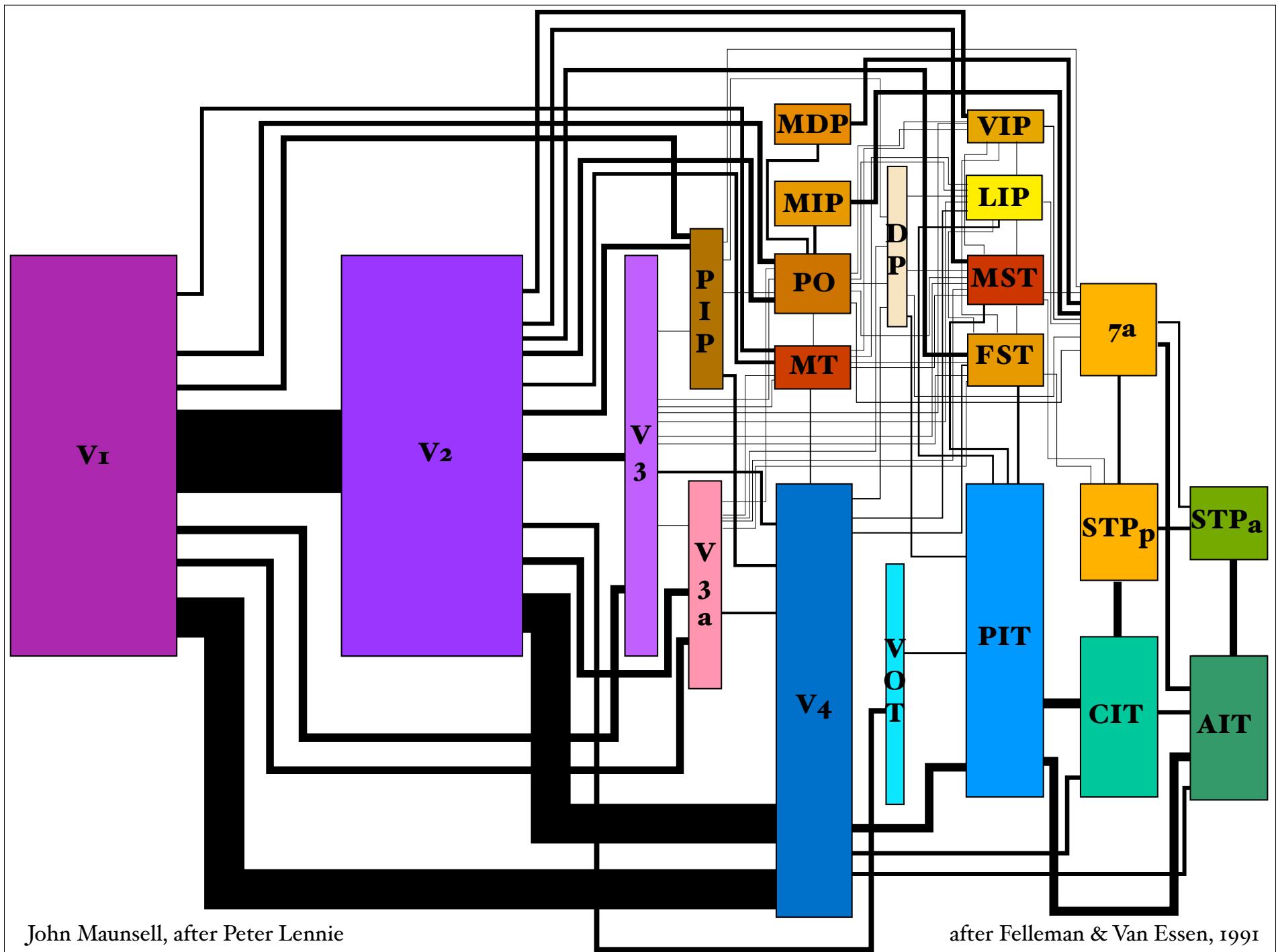


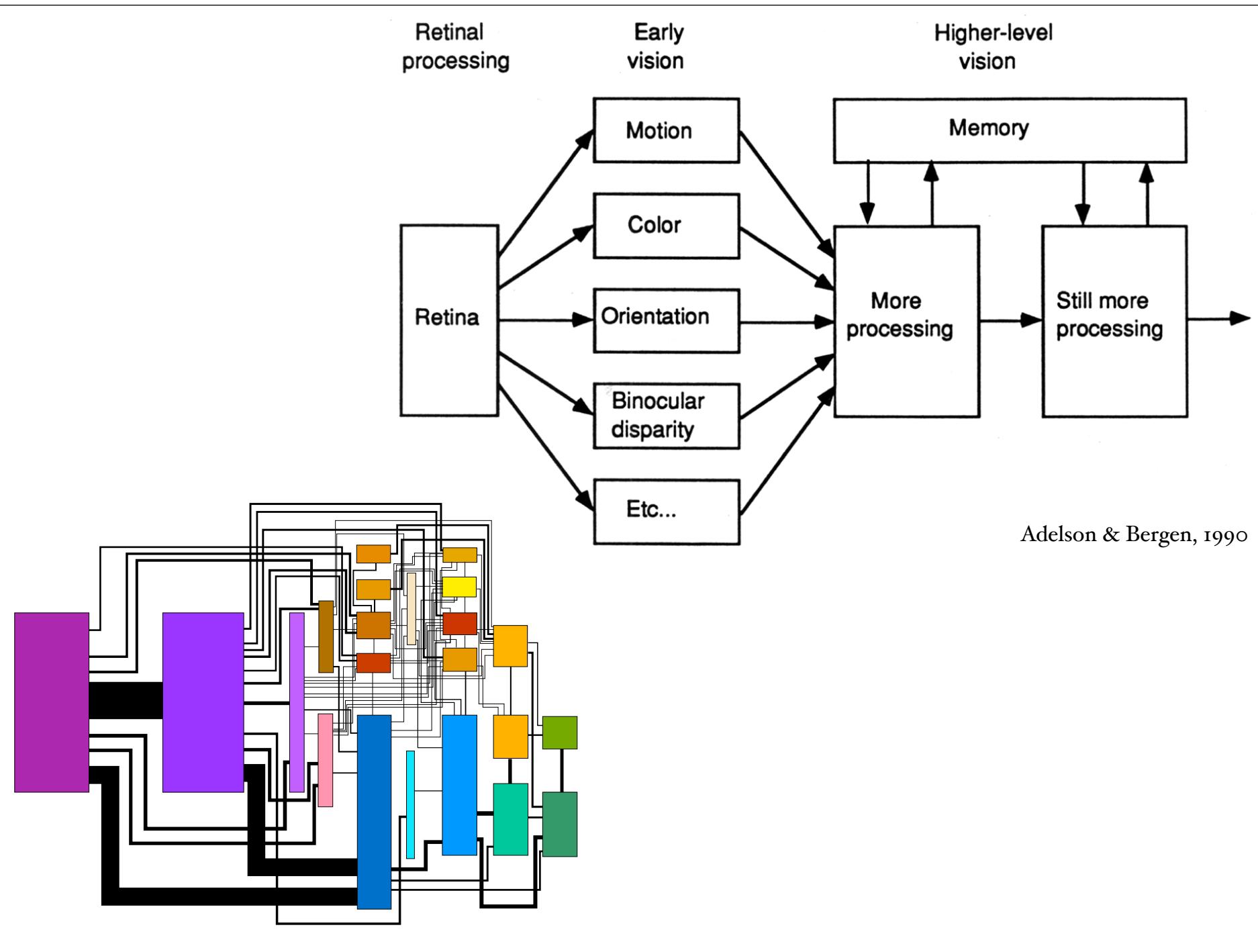
Ungerleider & Mishkin, 1982

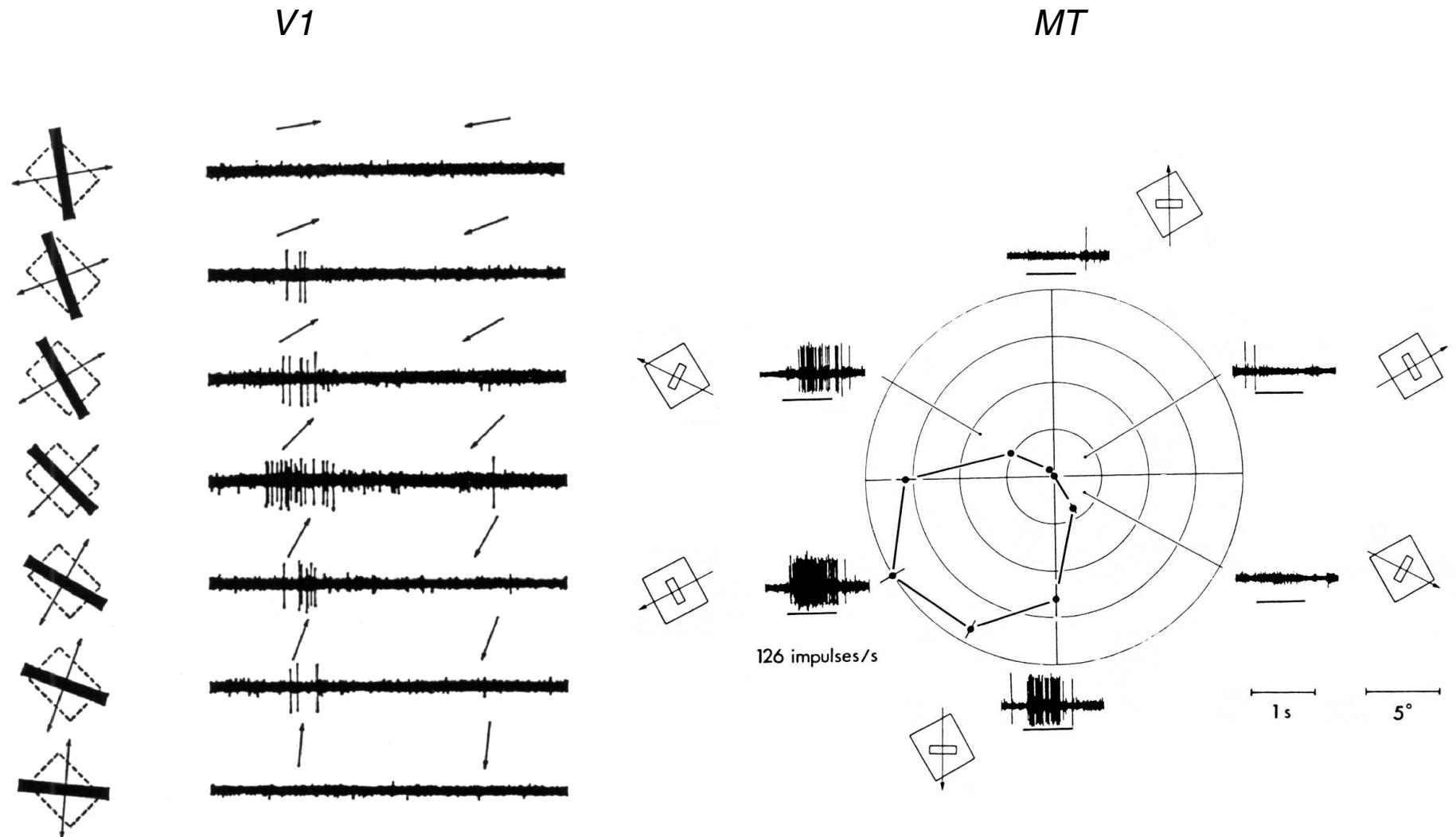




Van Essen, Anderson & Felleman, 1992

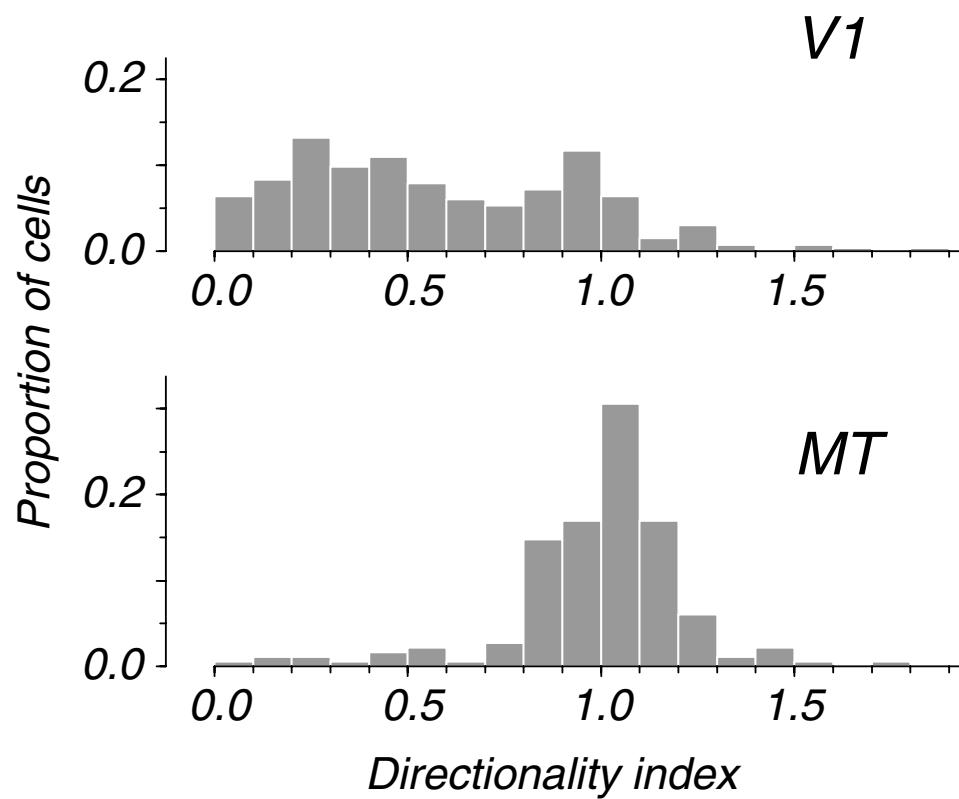


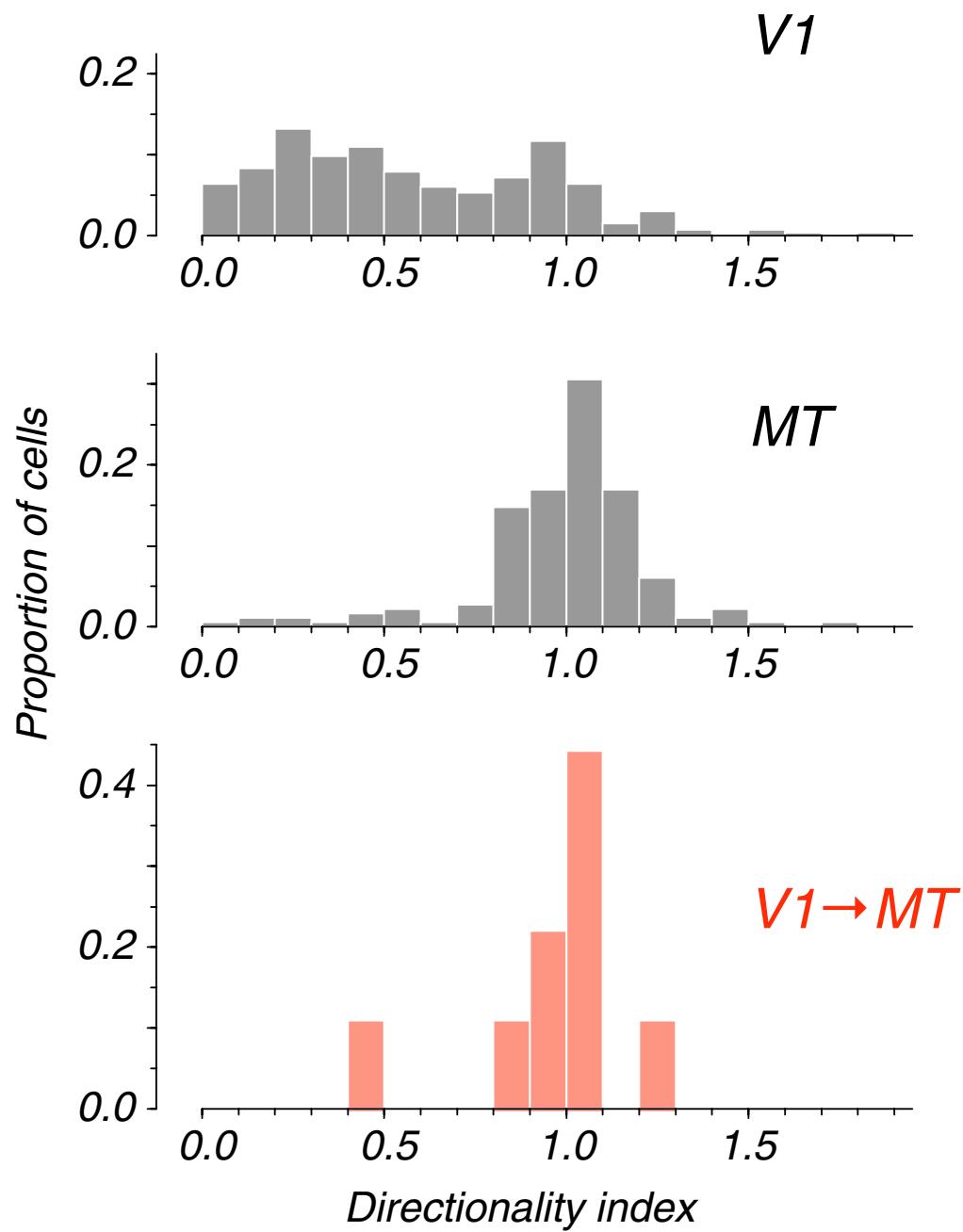




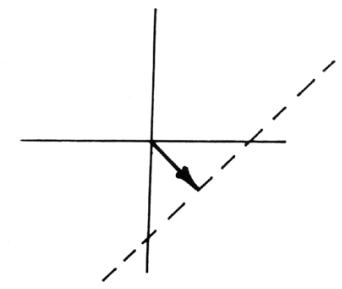
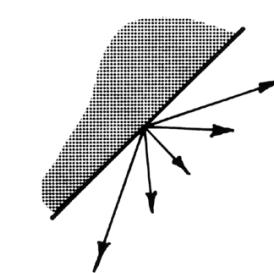
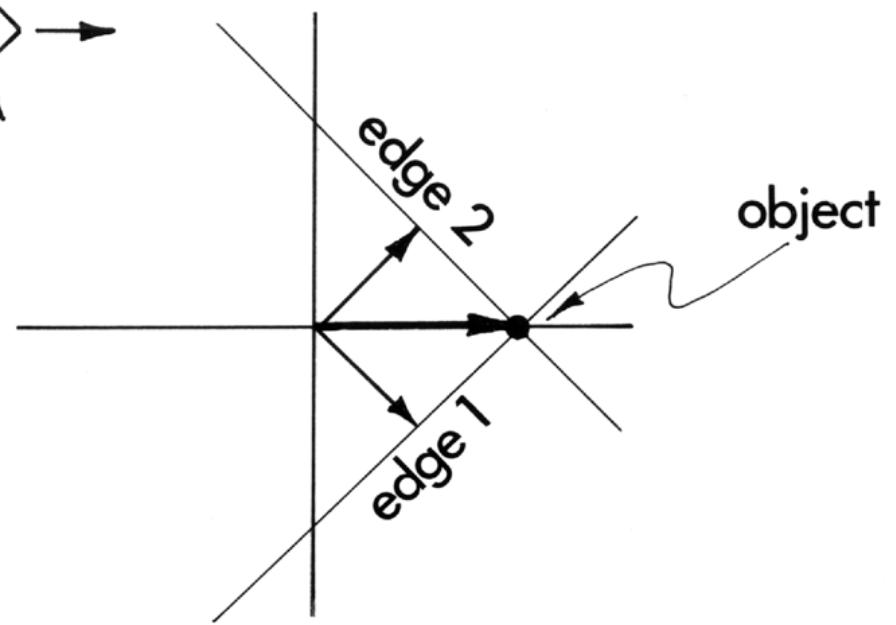
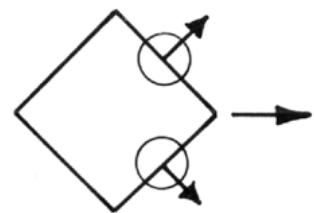
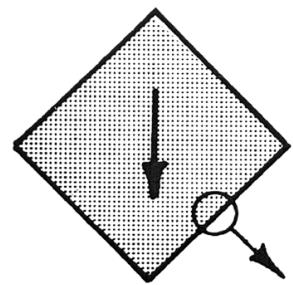
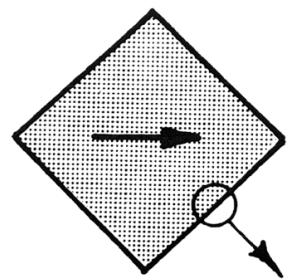
Hubel & Wiesel, 1968

Maunsell & Van Essen, 1983

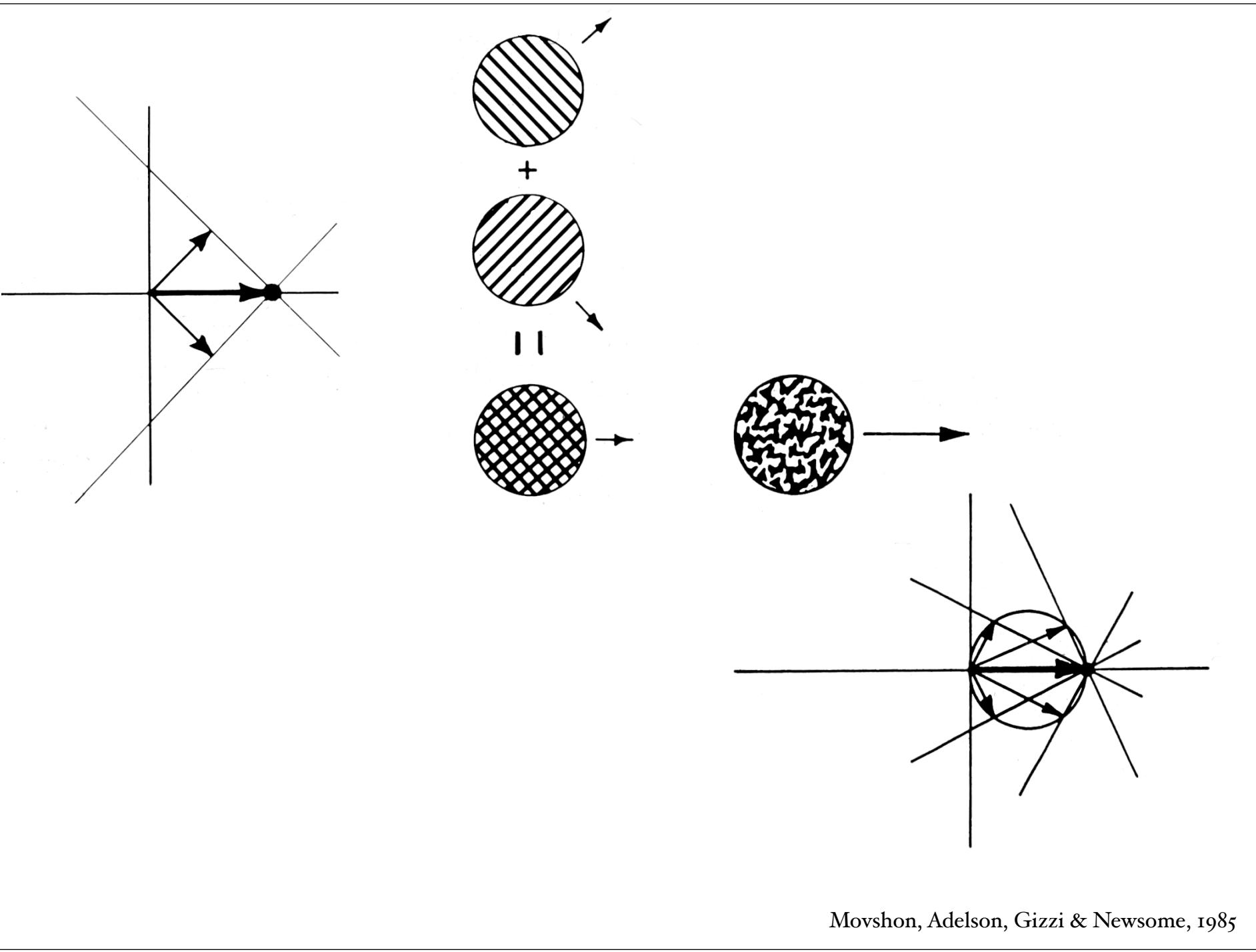




Movshon & Newsome, 1996

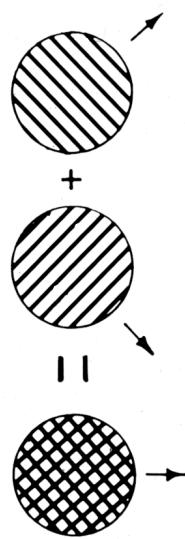
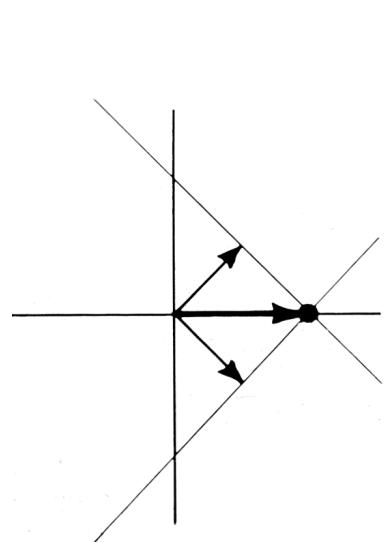


Movshon, Adelson, Gizzi & Newsome, 1985

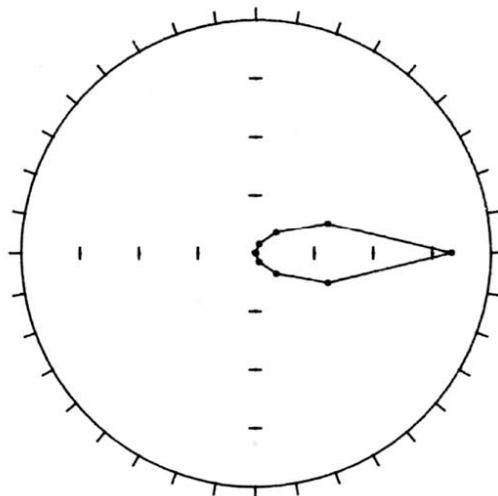


*Gratings, plaids, and coherent motion*

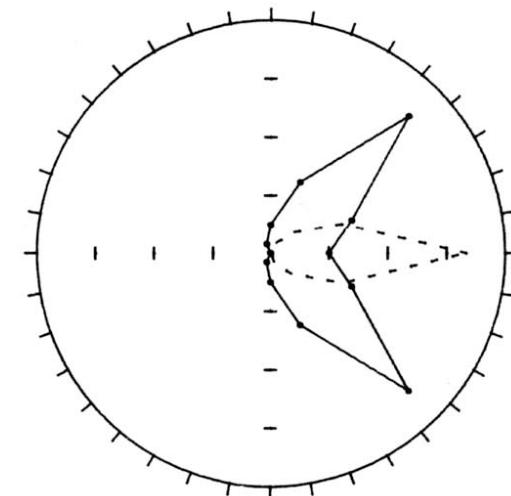




*Grating response*



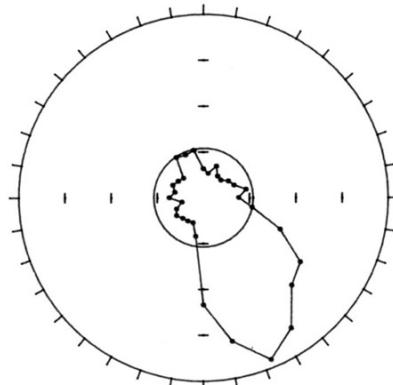
*Predicted plaid response*



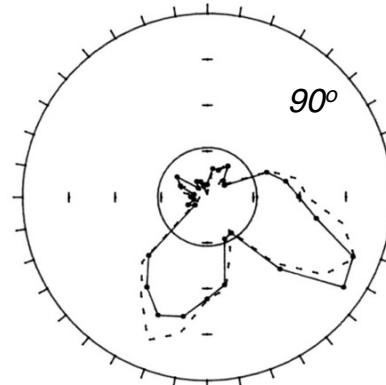
Movshon, Adelson, Gizzi & Newsome, 1985

*V1 cell*

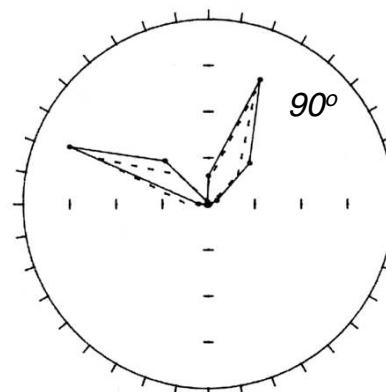
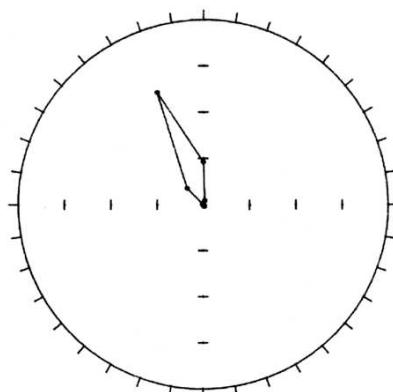
*Grating responses*



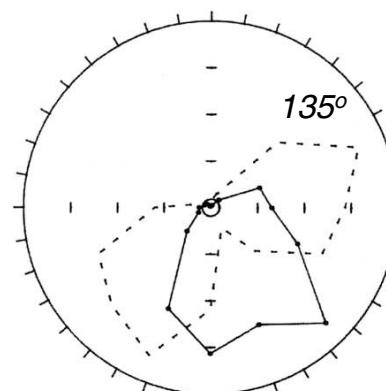
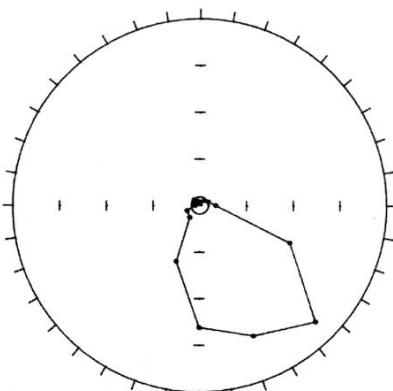
*Plaid responses*

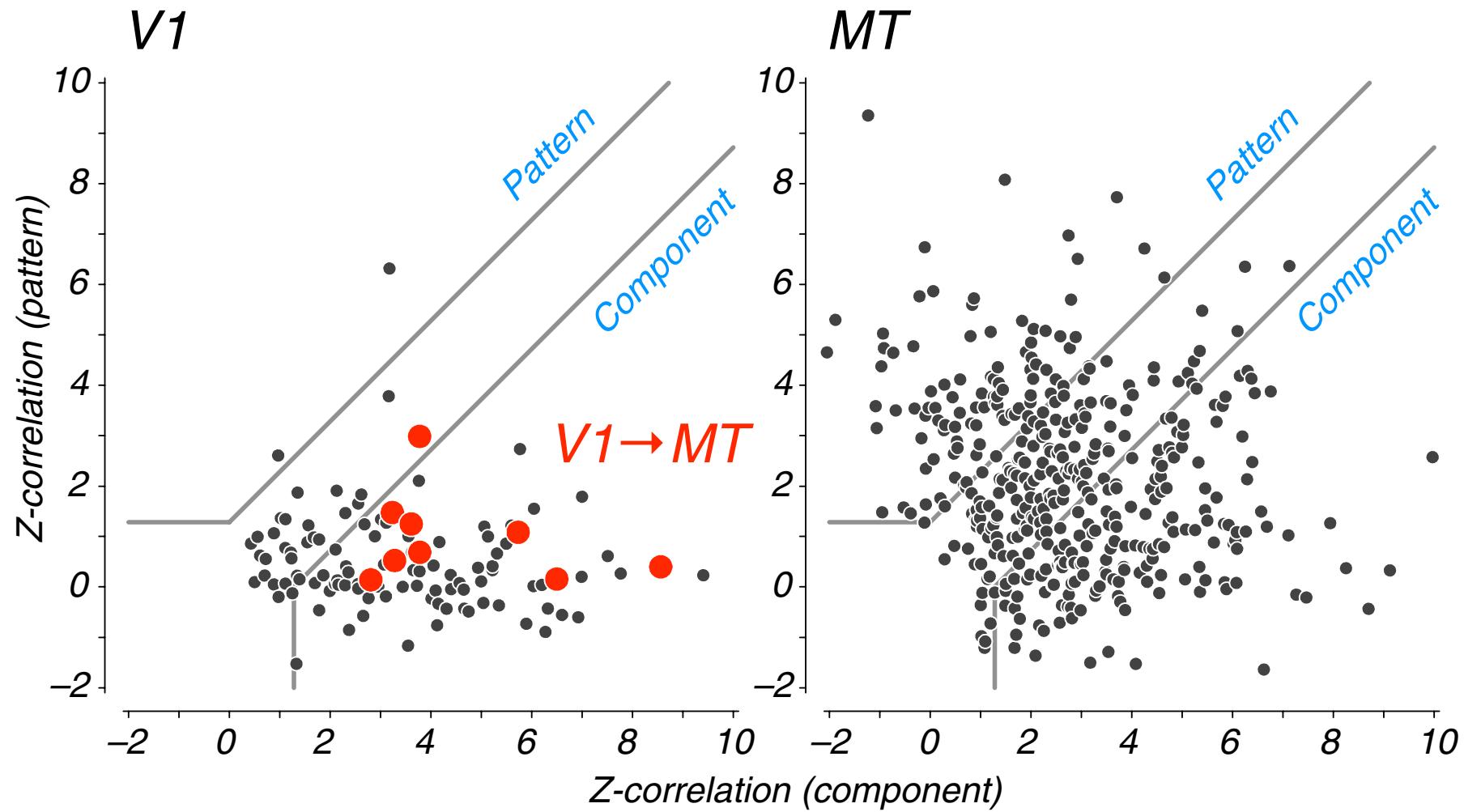


*MT component cell*



*MT pattern cell*

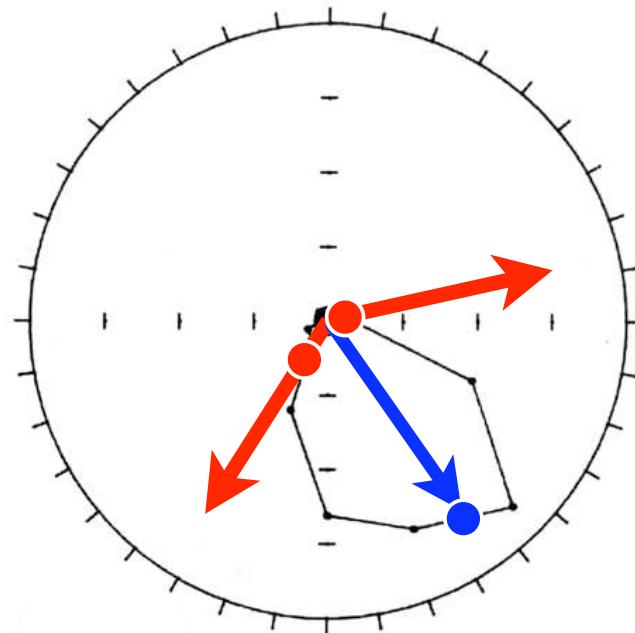




Movshon & Newsome, 1996

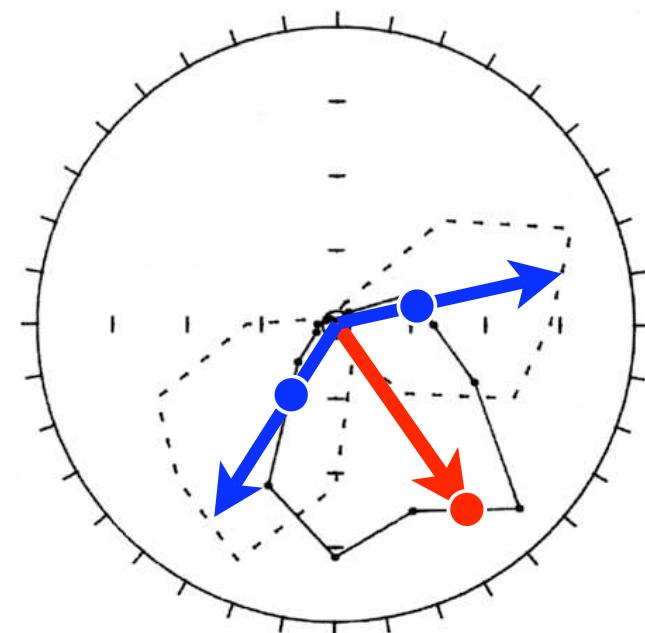
*MT pattern cell*

*Grating responses*

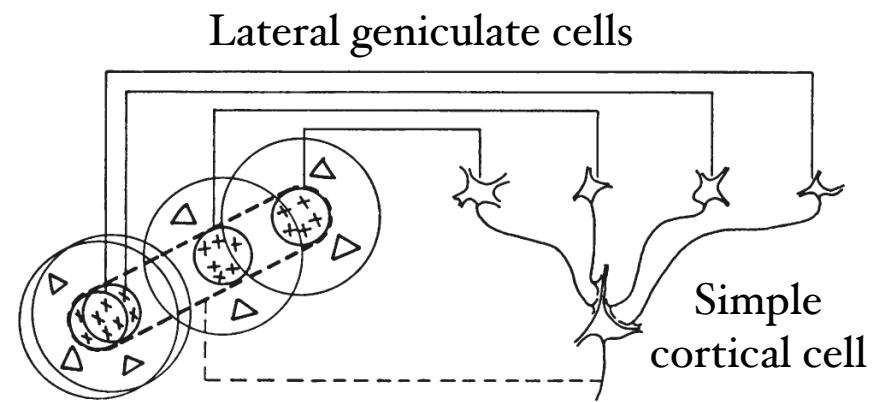
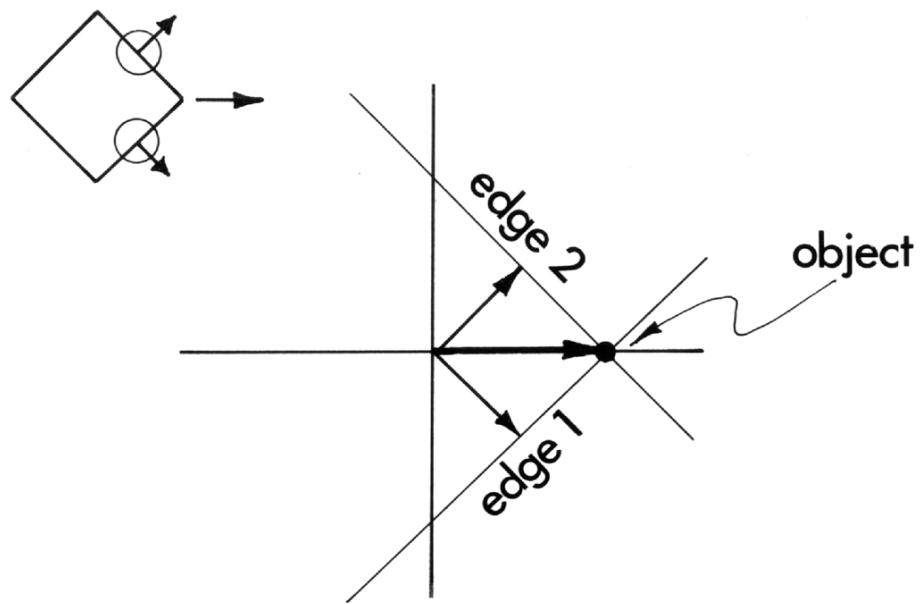


*Components of the optimal plaid*

*Plaid responses*

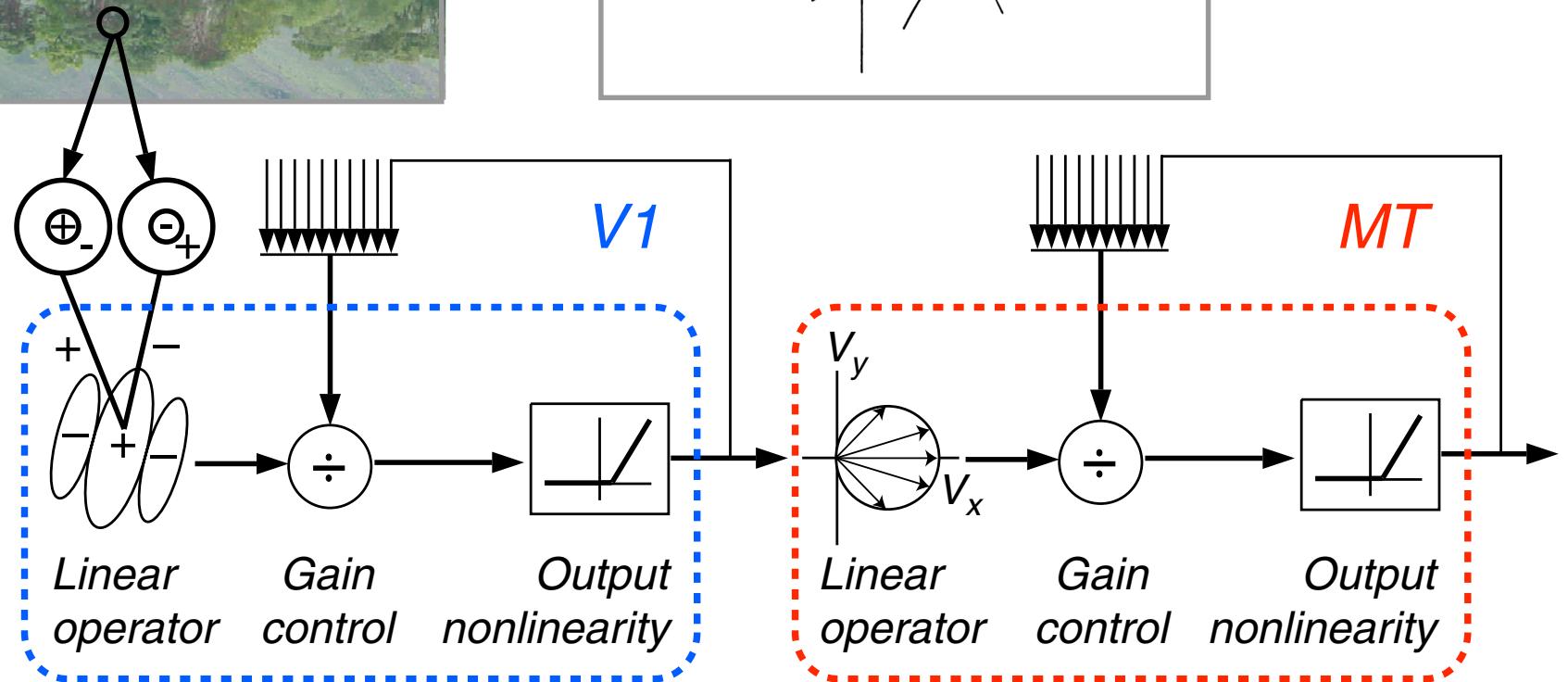
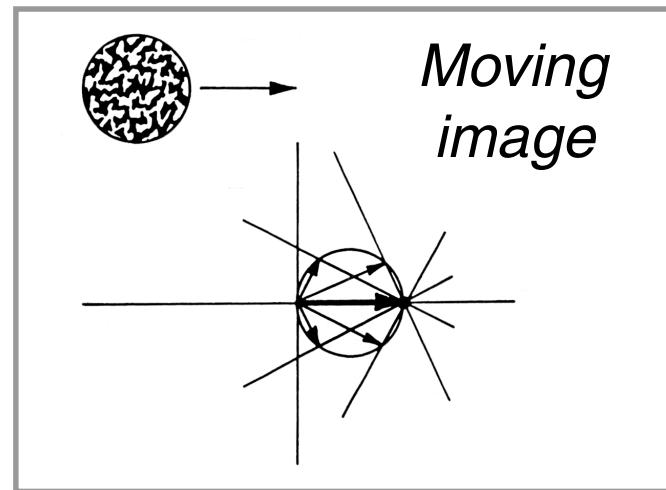
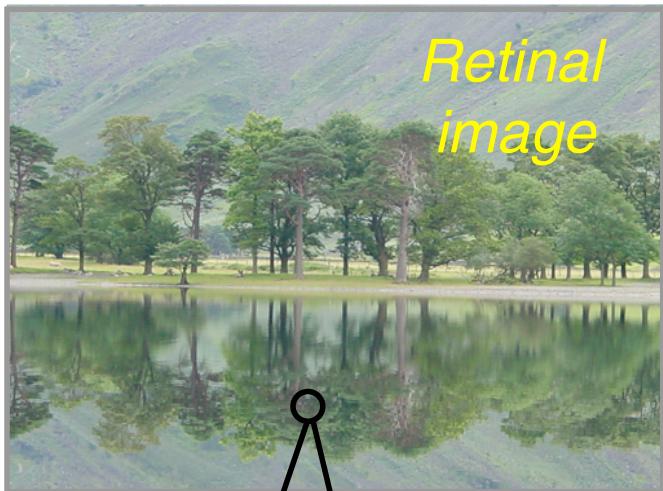


*Plaids containing the optimal grating*



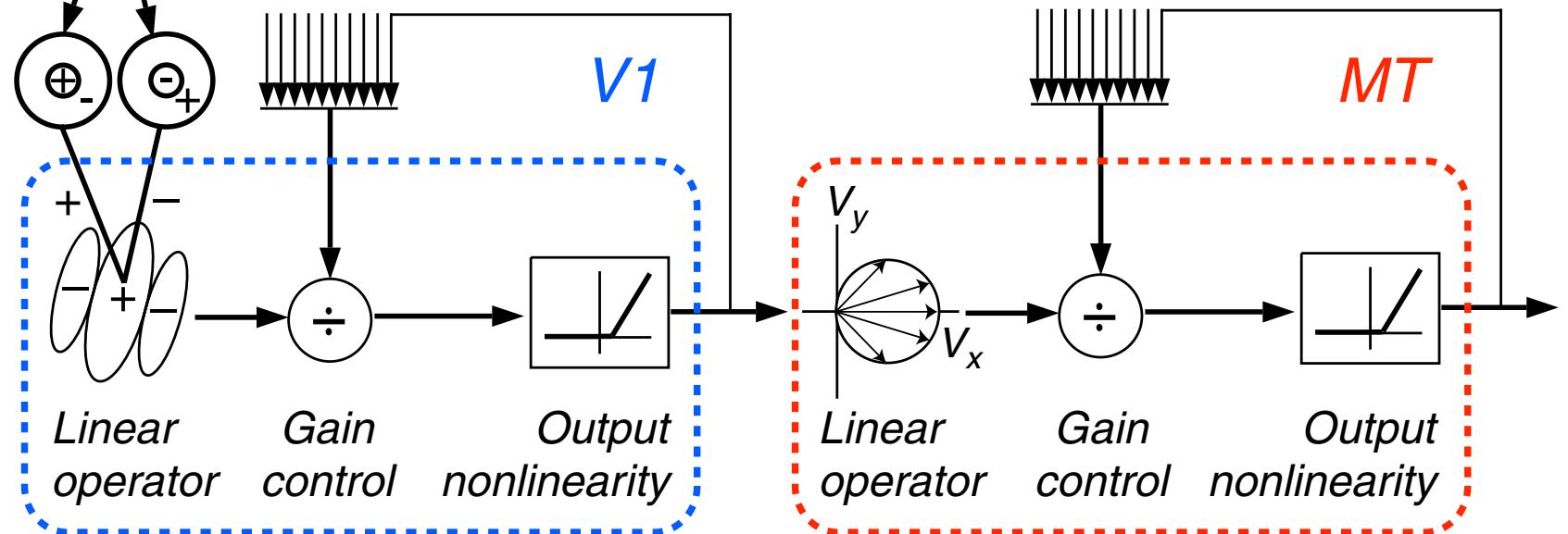
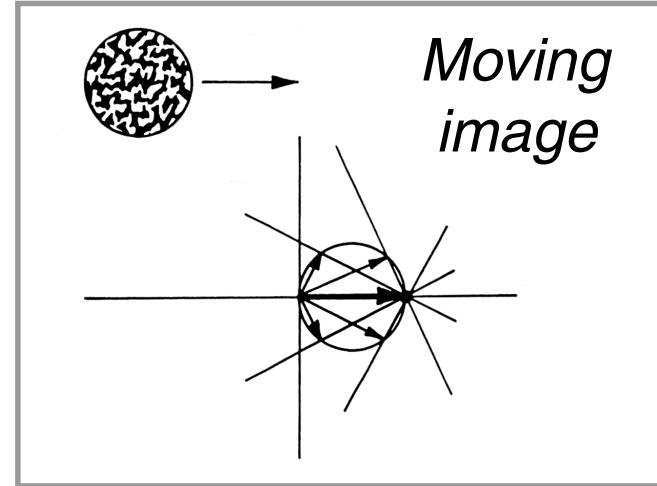
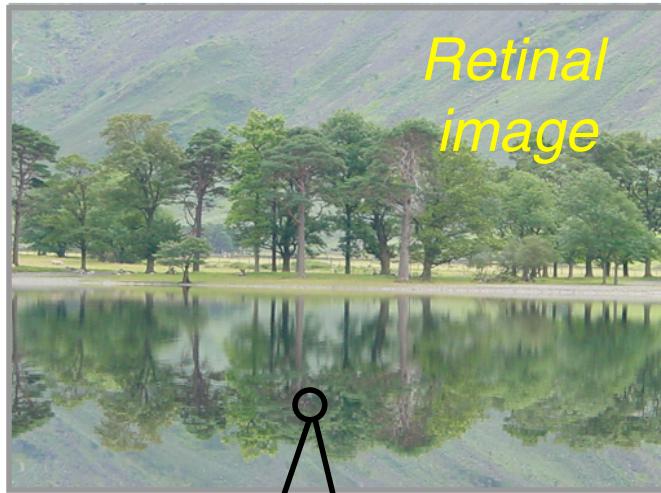
Movshon, Adelson, Gizzi & Newsome, 1985

Hubel & Wiesel, 1962



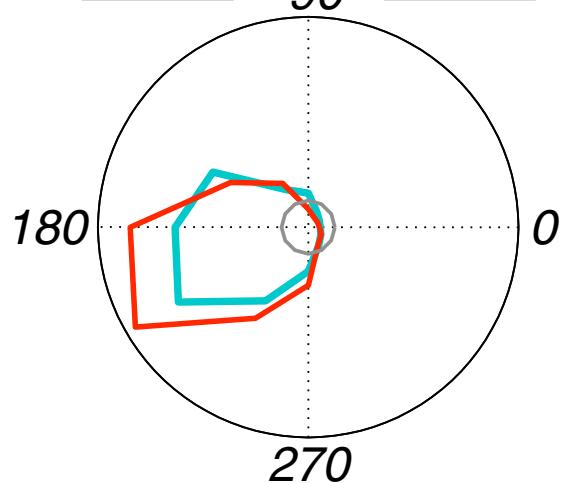
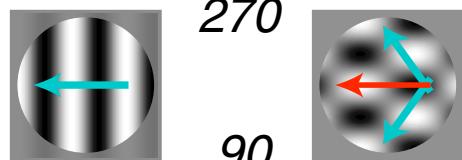
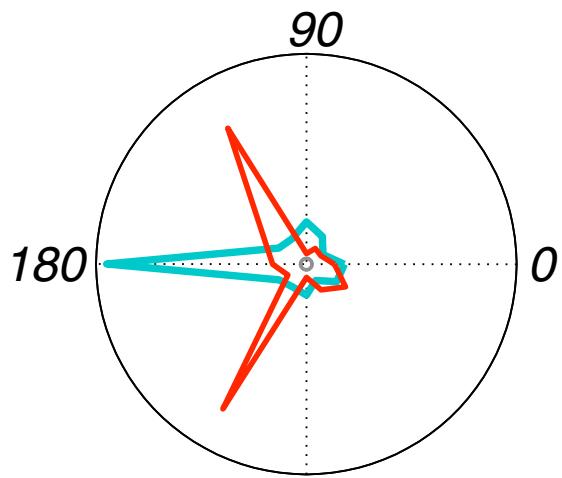
Simoncelli & Heeger, 1998

*Recovering and validating the model:*  
1. A rich test set



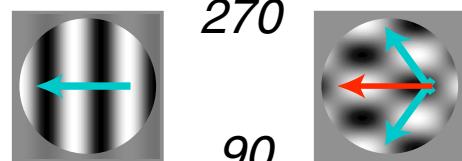
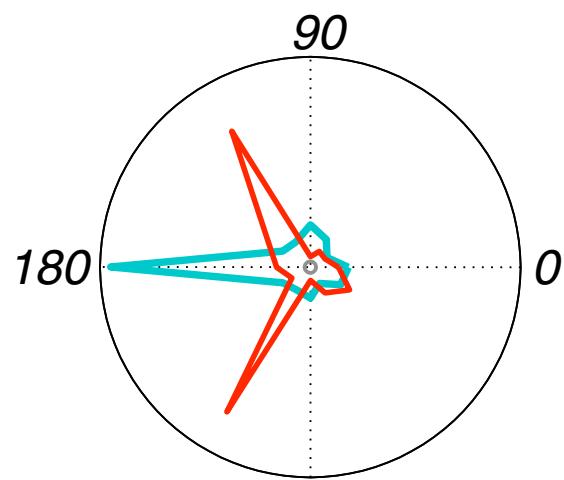
Simoncelli & Heeger, 1998

*Component cell*

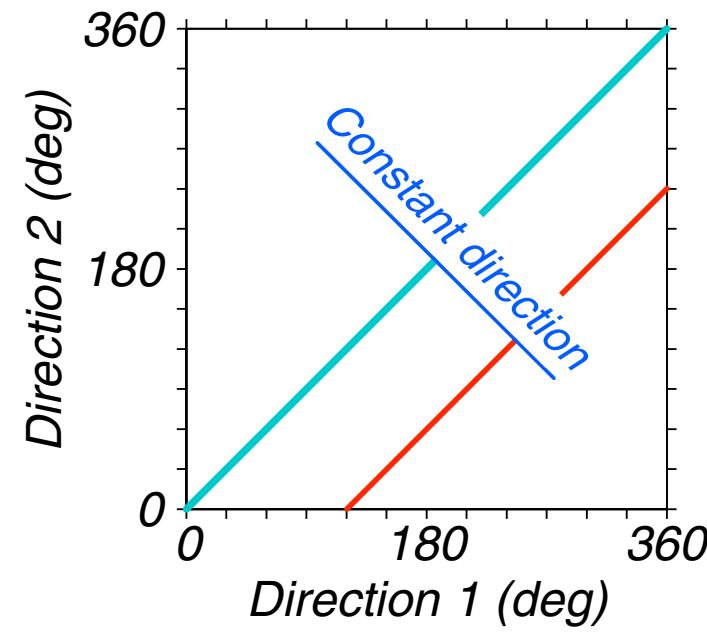
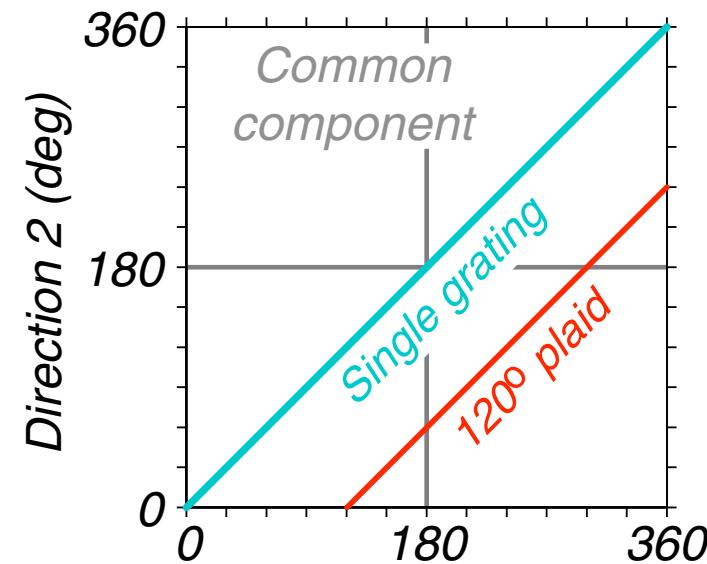
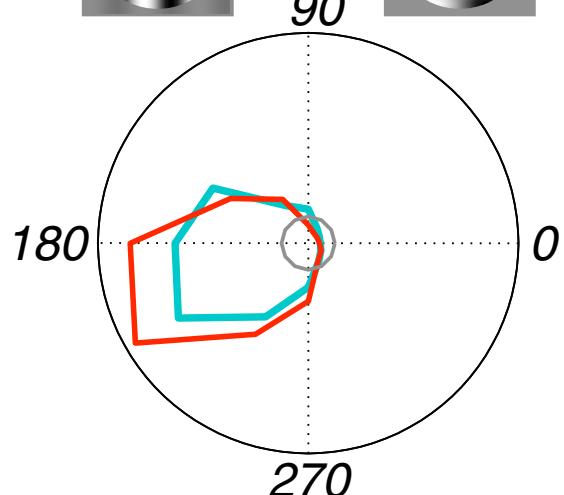


*Pattern cell*

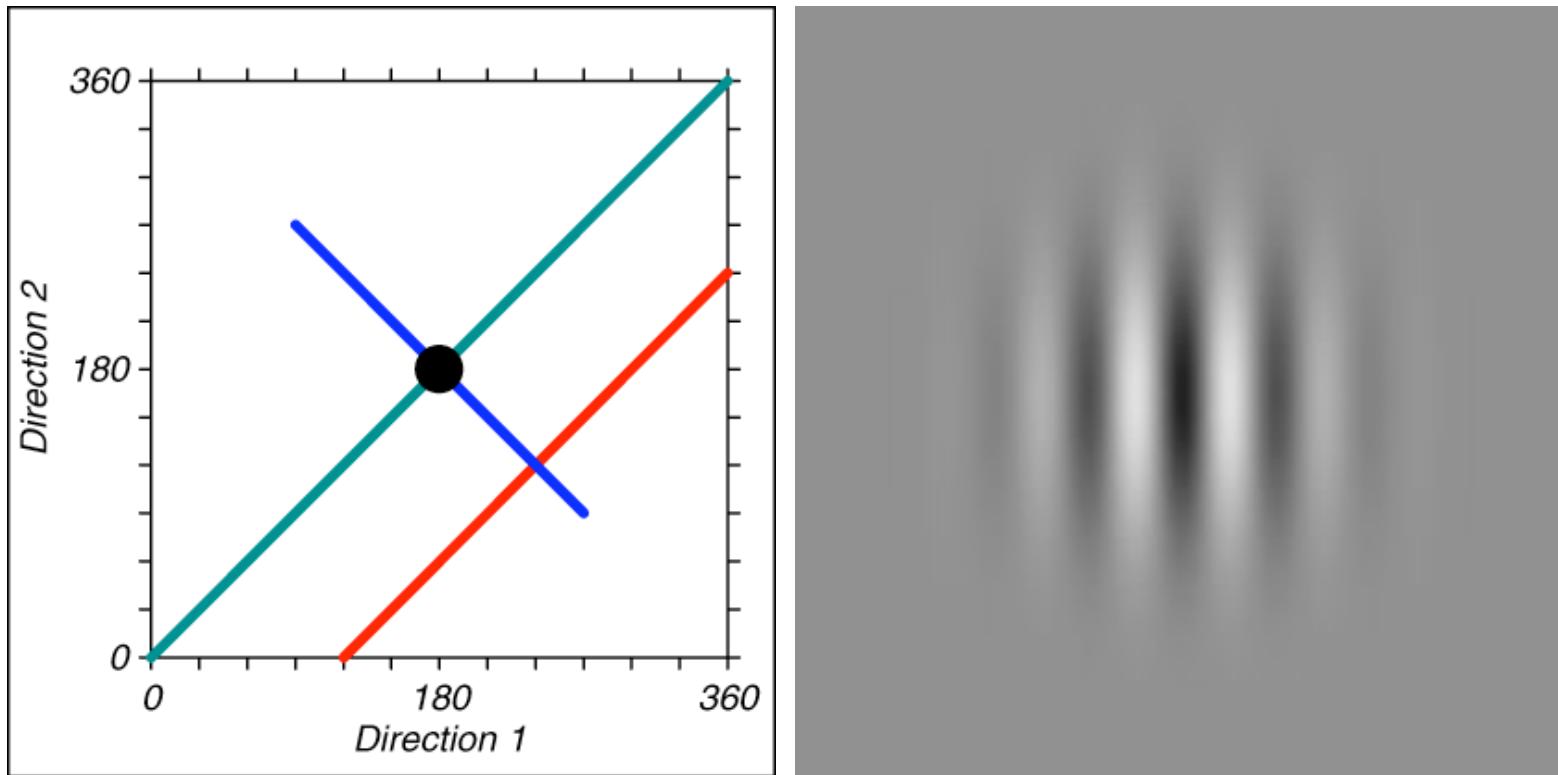
## *Component cell*



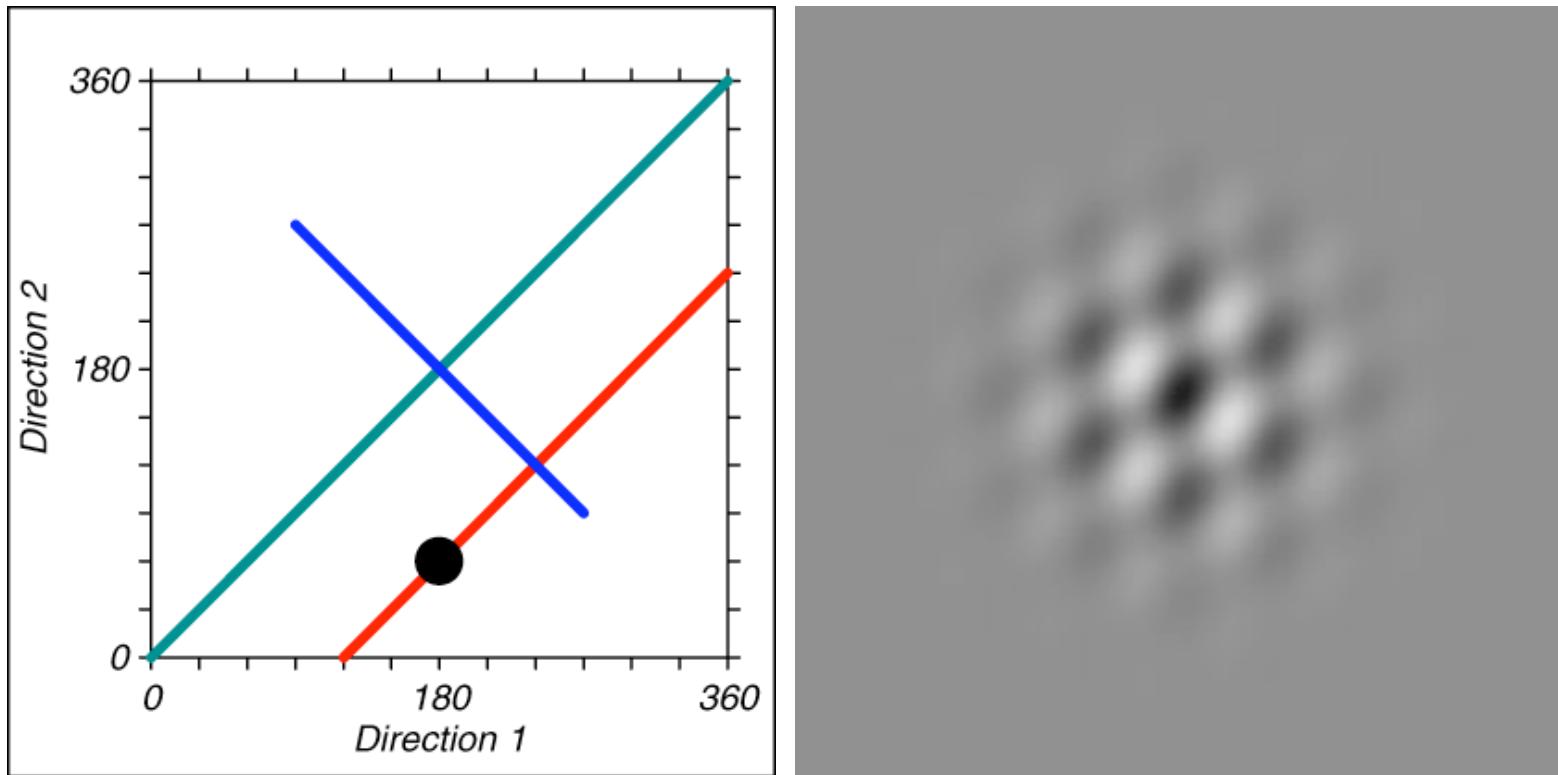
## *Pattern cell*



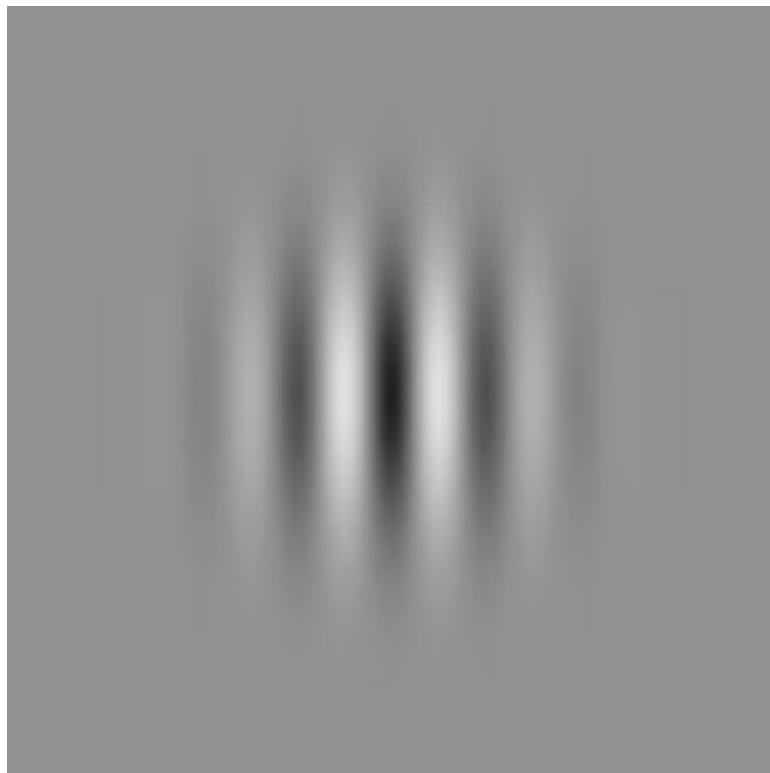
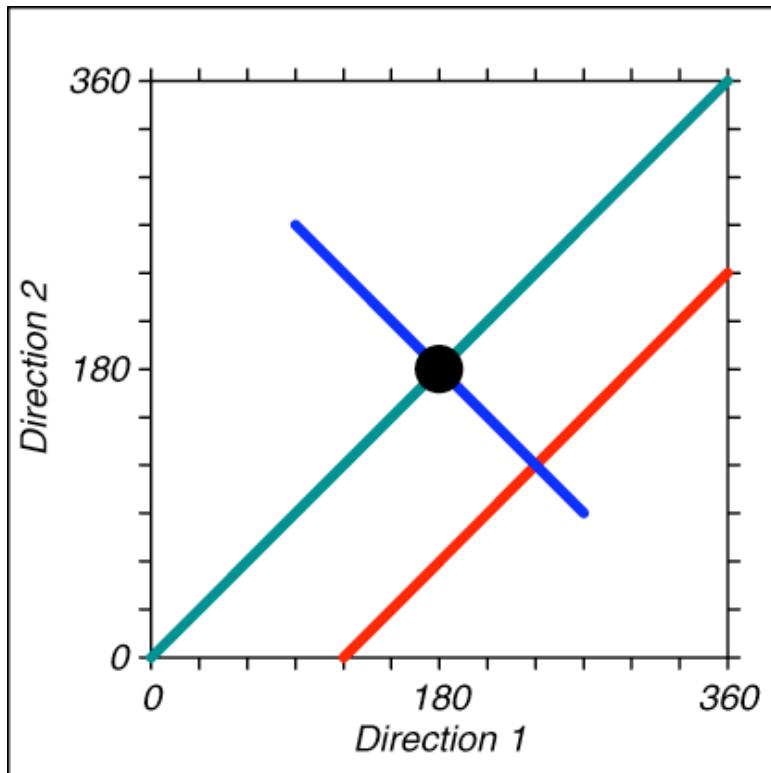
*Direction-interaction:  
Gratings*



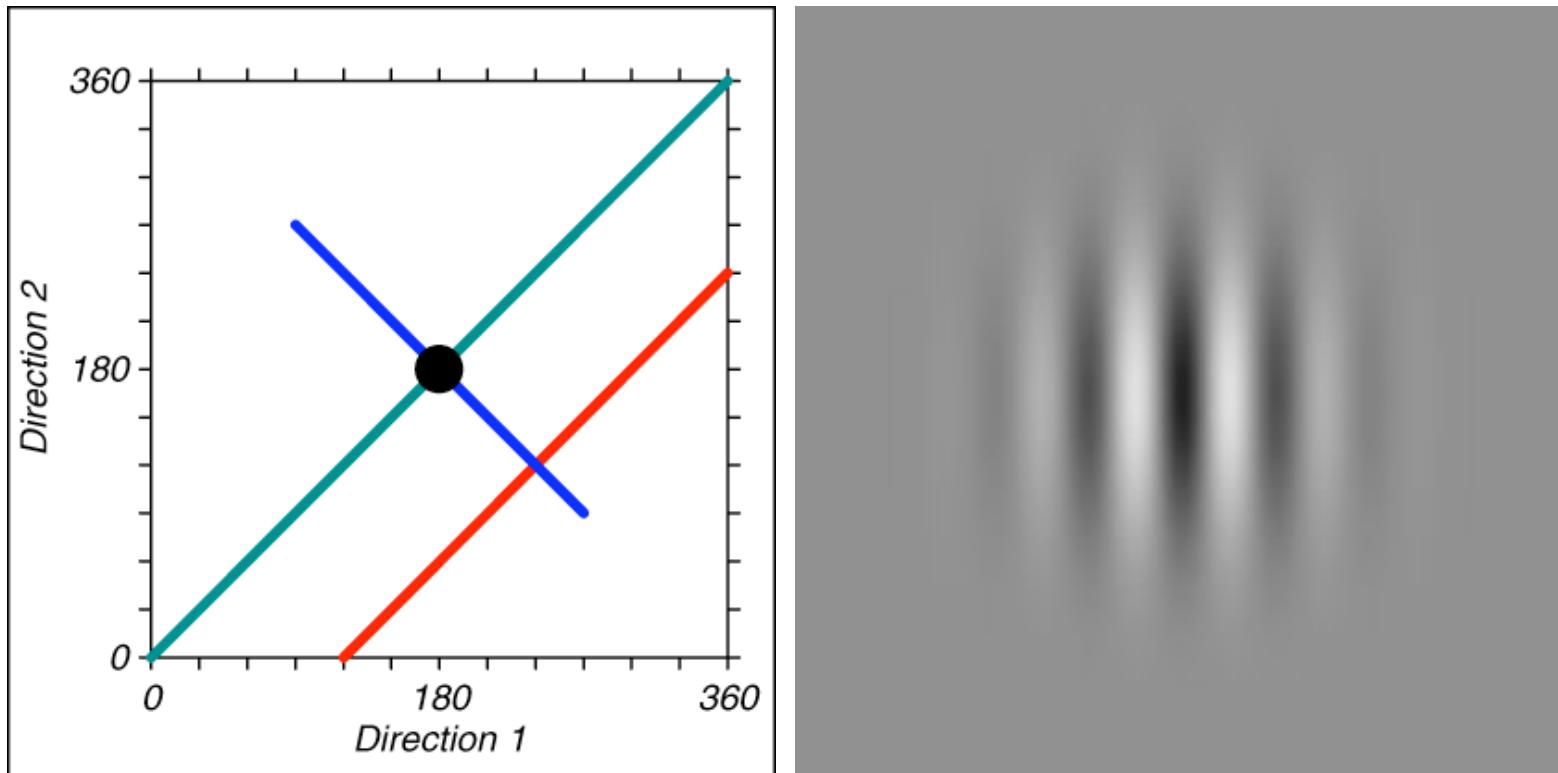
*Direction-interaction:*  
*Plaids*

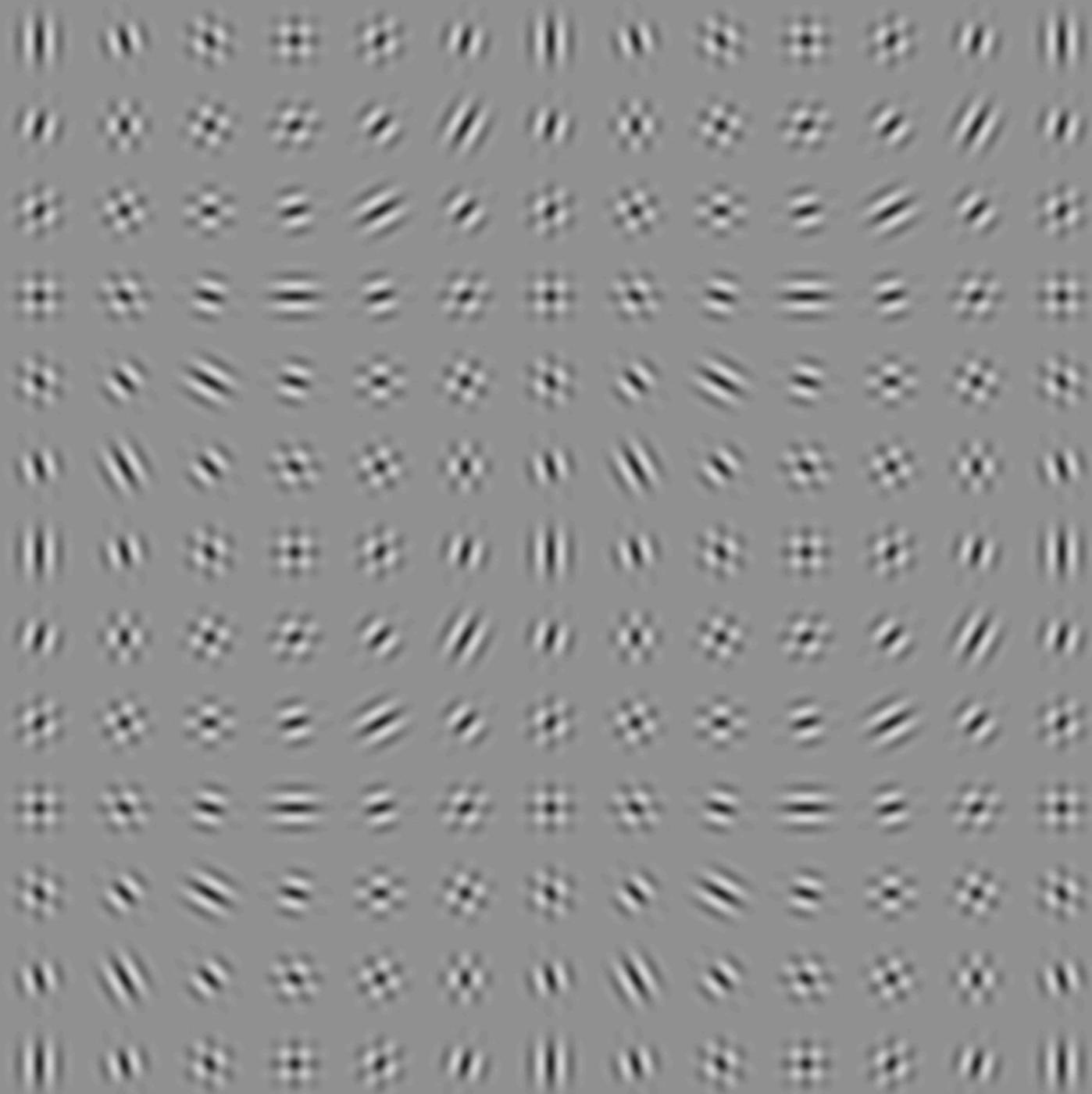


*Direction-interaction:  
One common component*

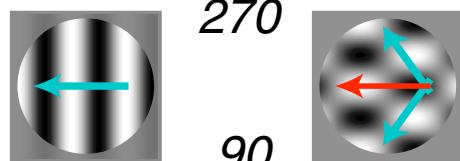
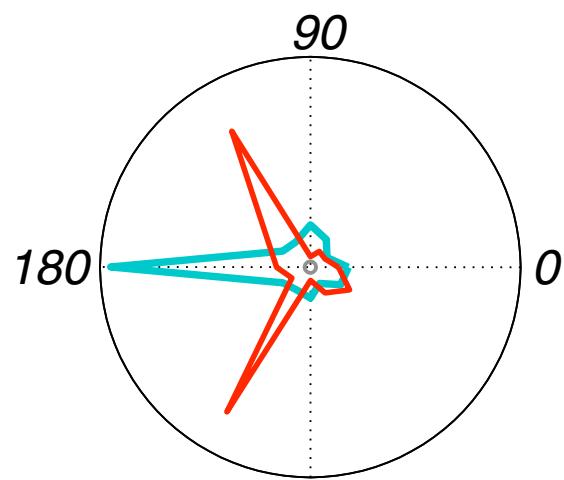


*Direction-interaction:  
Common axis*

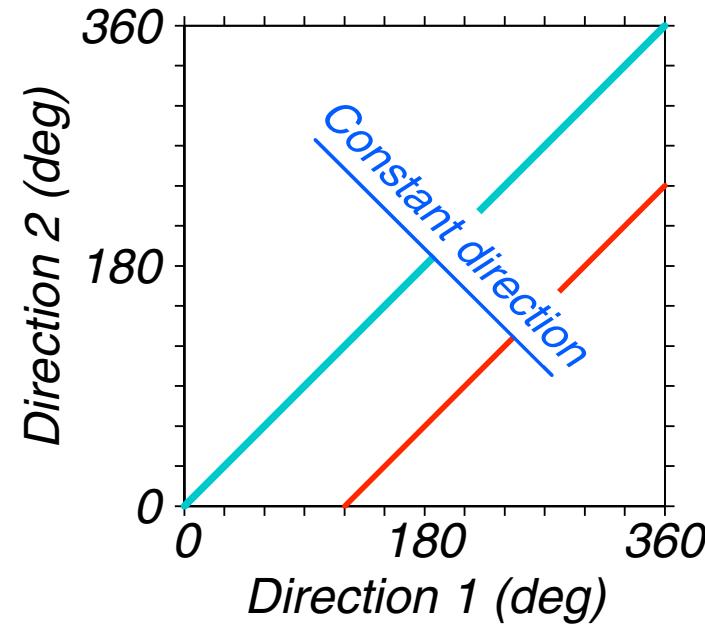
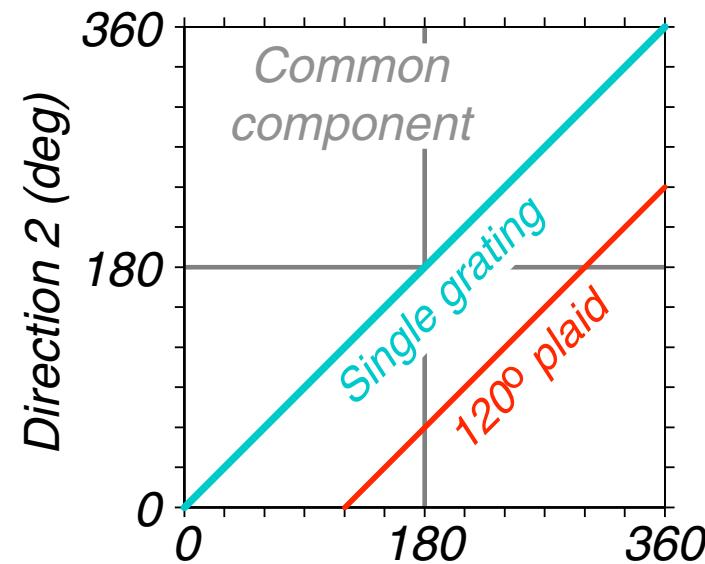
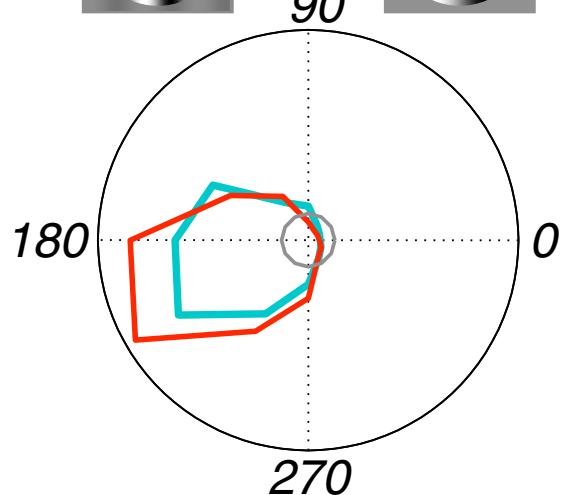




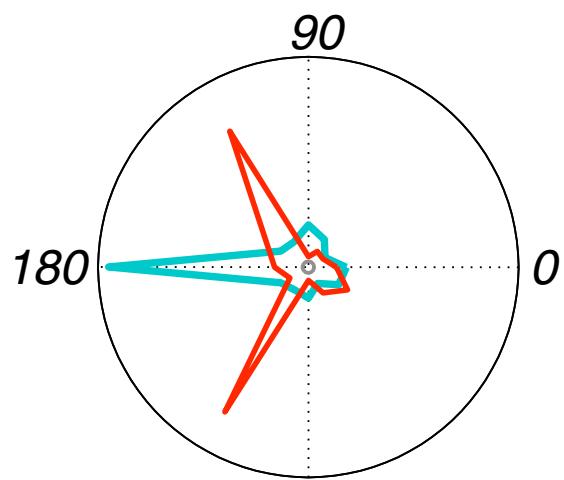
## *Component cell*



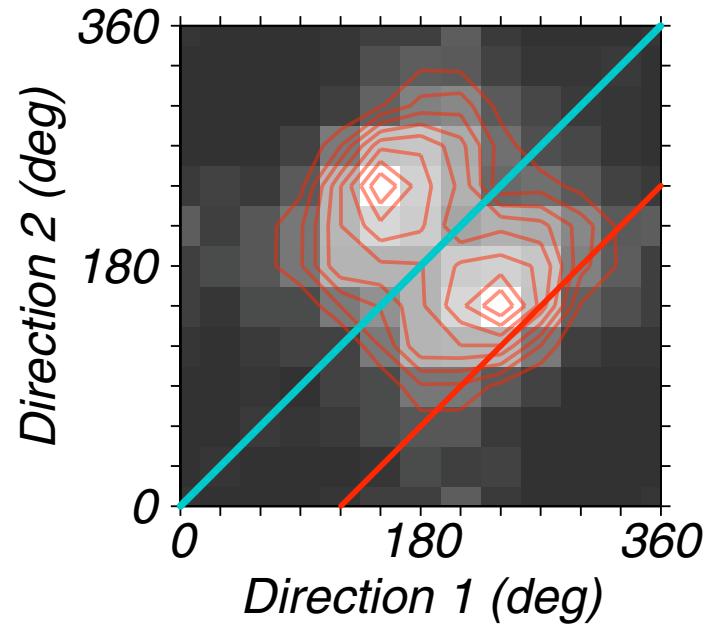
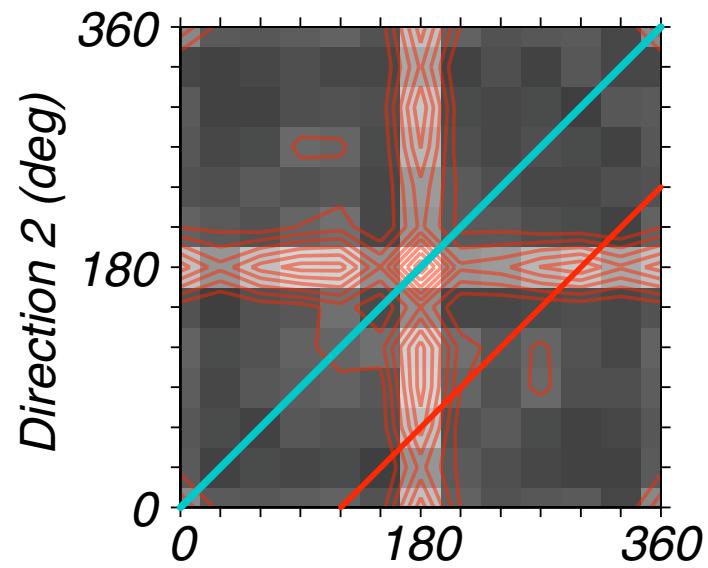
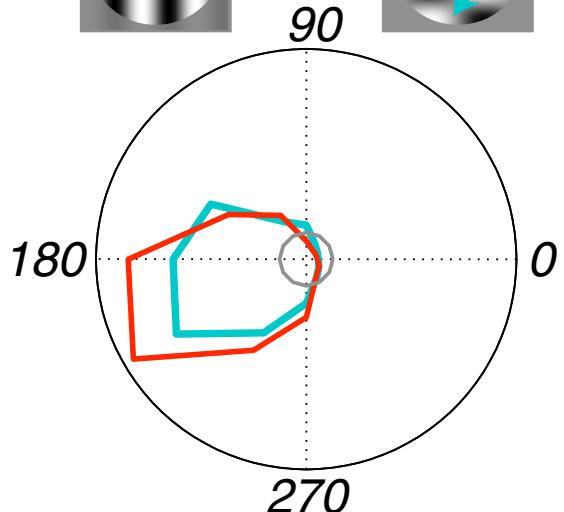
## *Pattern cell*



## *Component cell*



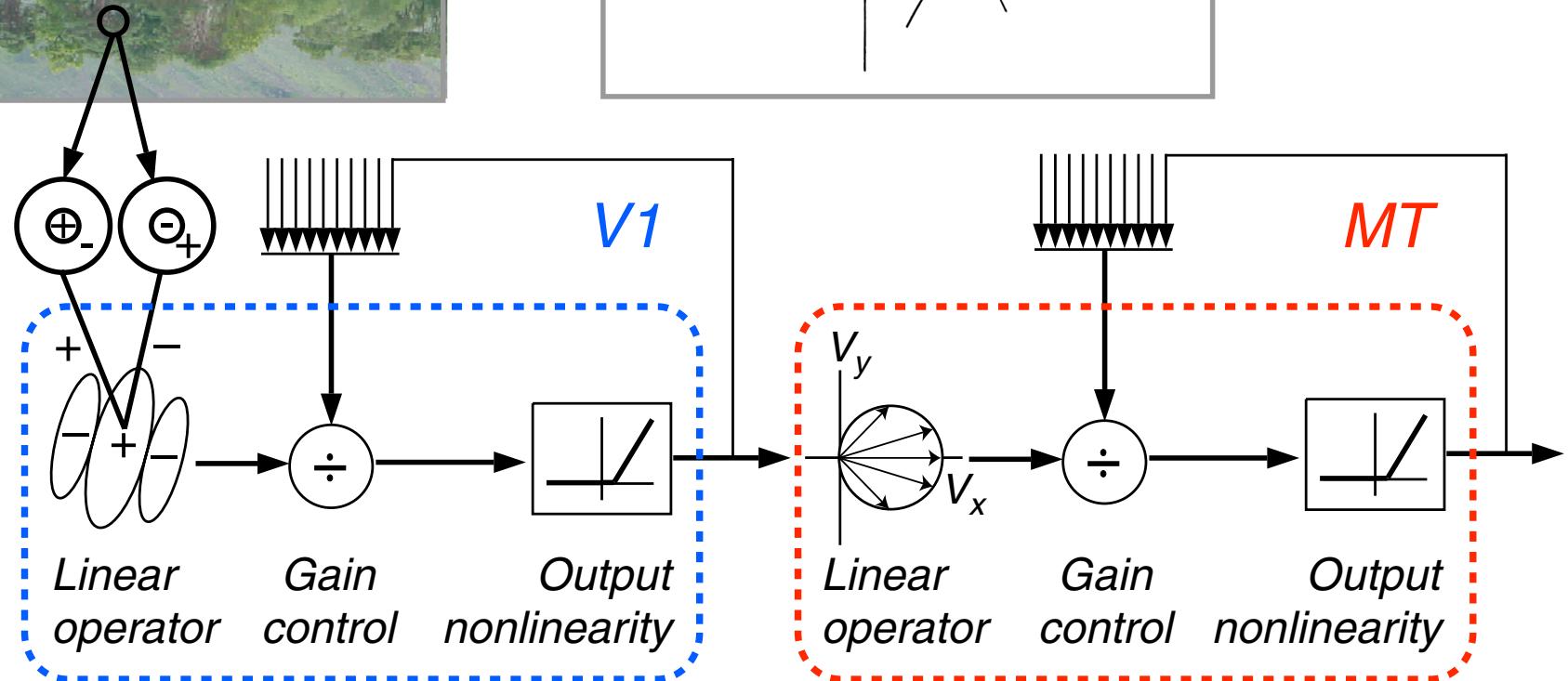
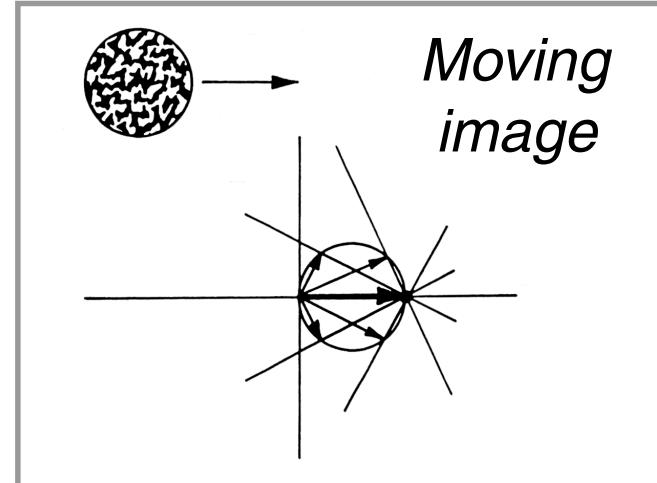
## *Pattern cell*



Rust, Mante, Simoncelli & Movshon, 2006

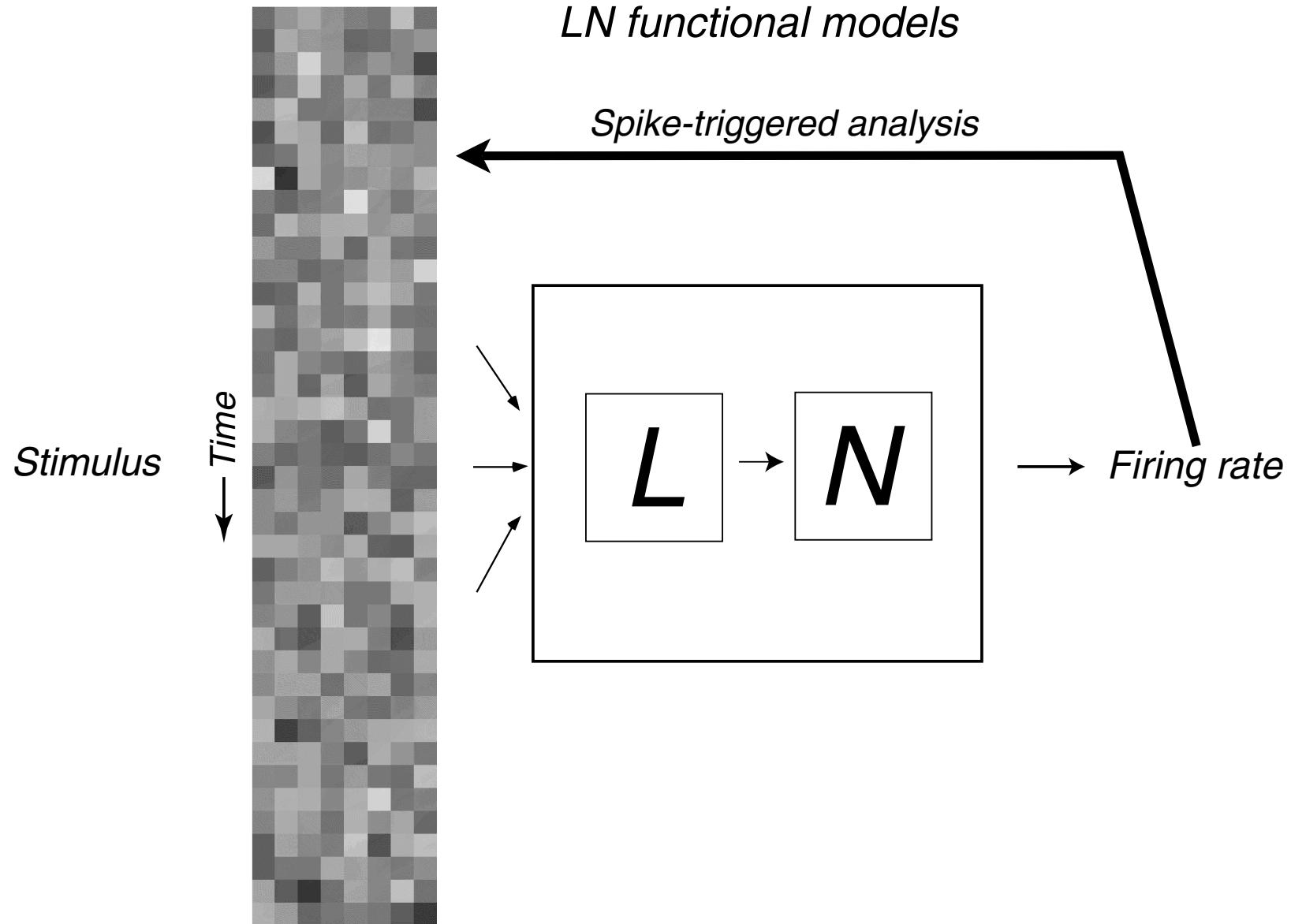
## *Recovering and validating the model:*

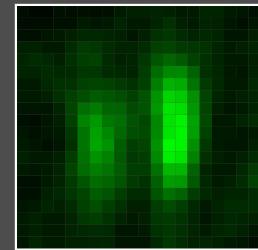
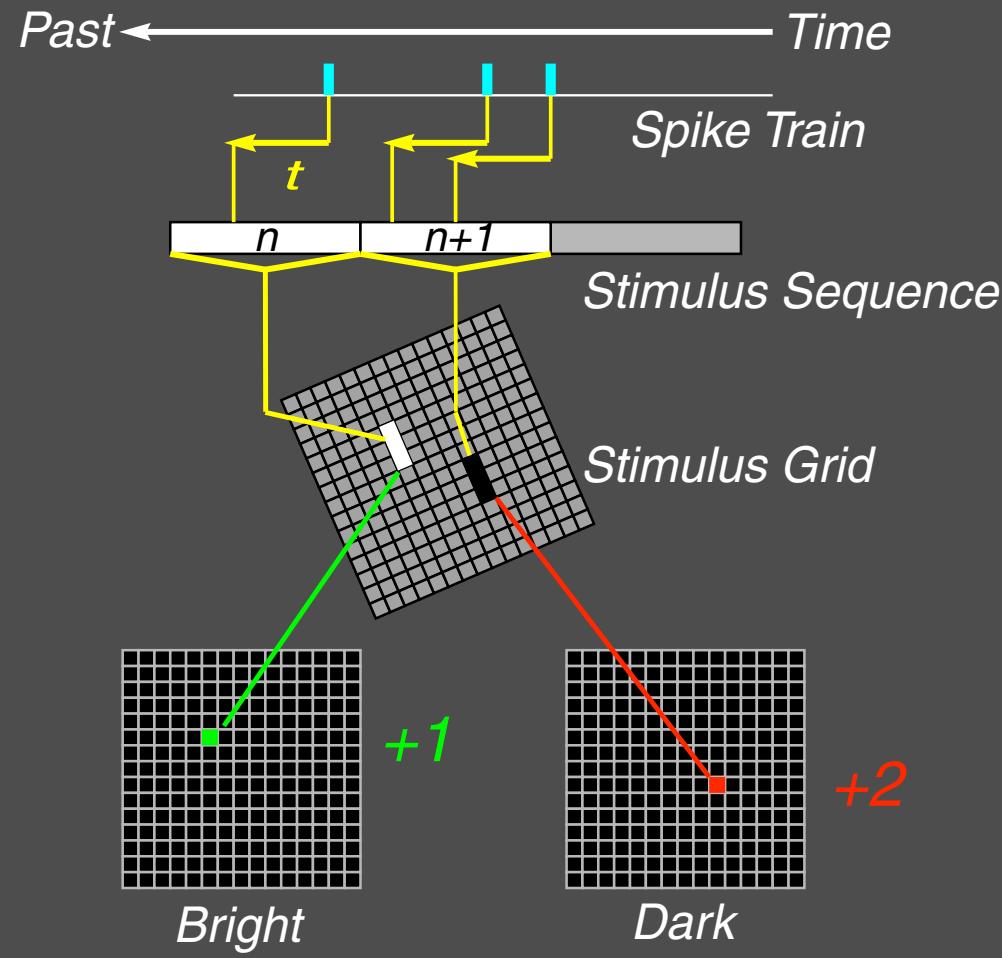
- 1. A rich test set*
- 2. An evaluation method*



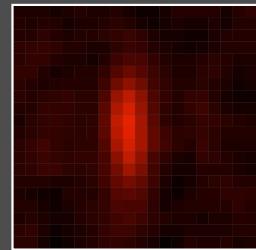
Simoncelli & Heeger, 1998

*Evaluation of  
LN functional models*

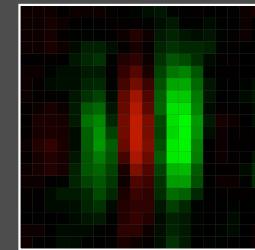




*Bright*



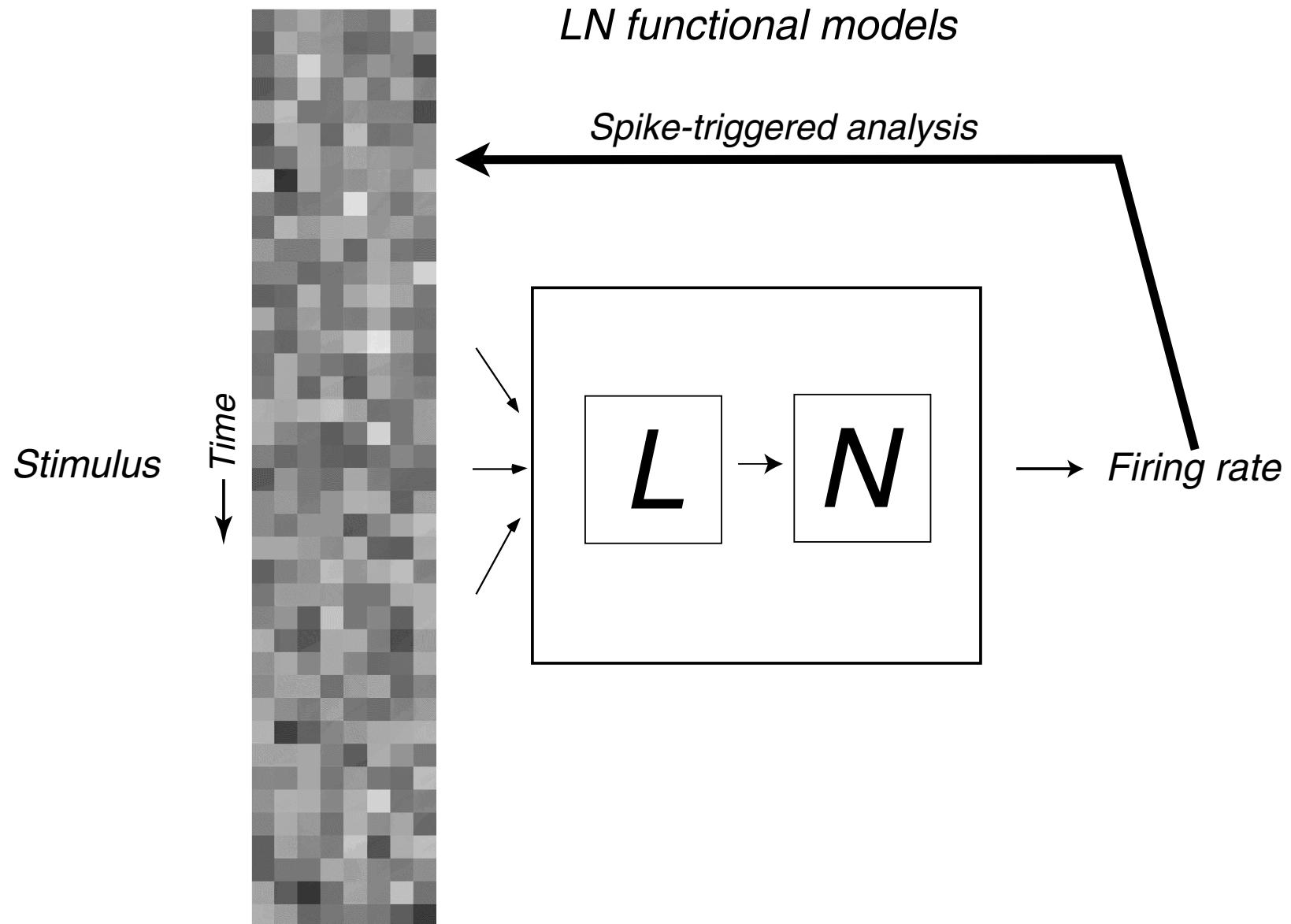
*Dark*



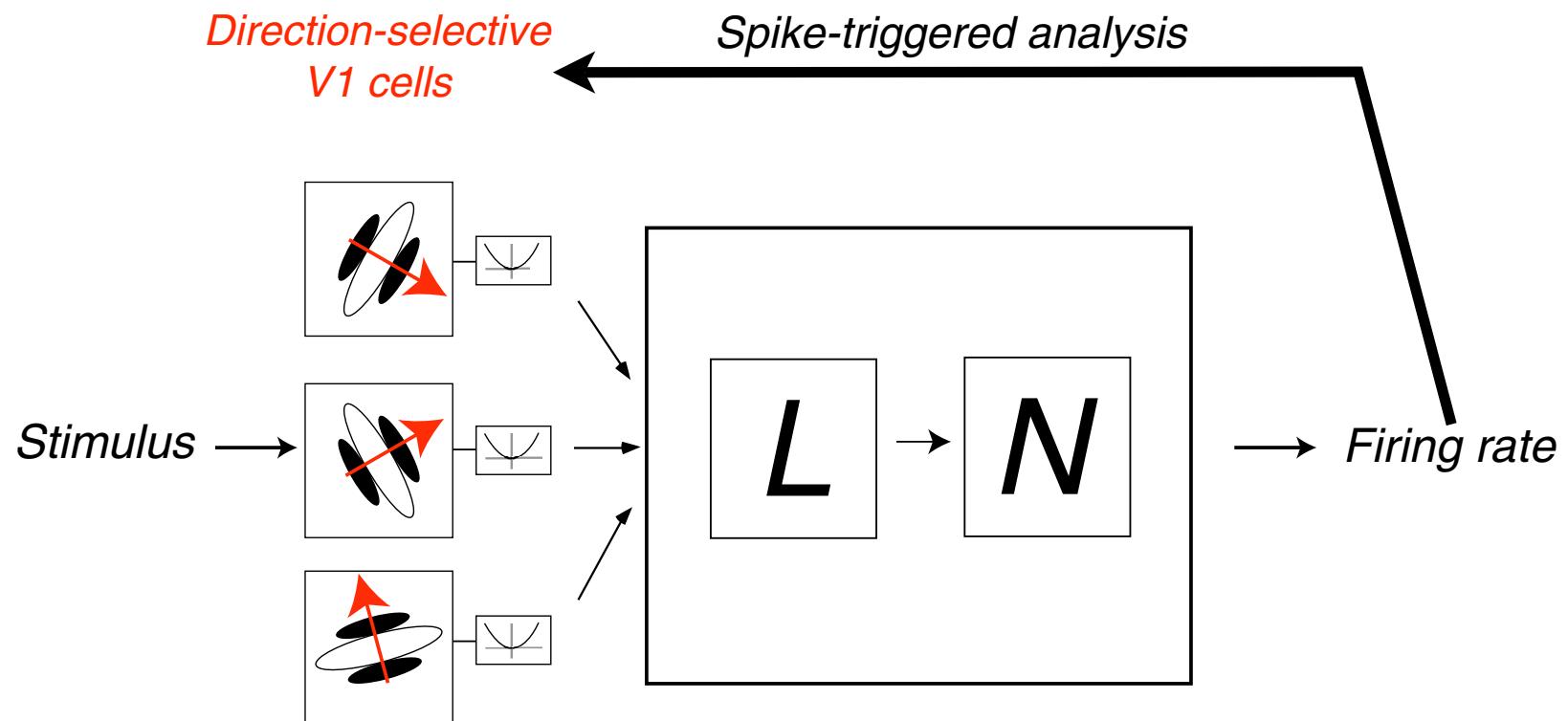
*Difference*

DeAngelis, Ohzawa  
& Freeman, 1995

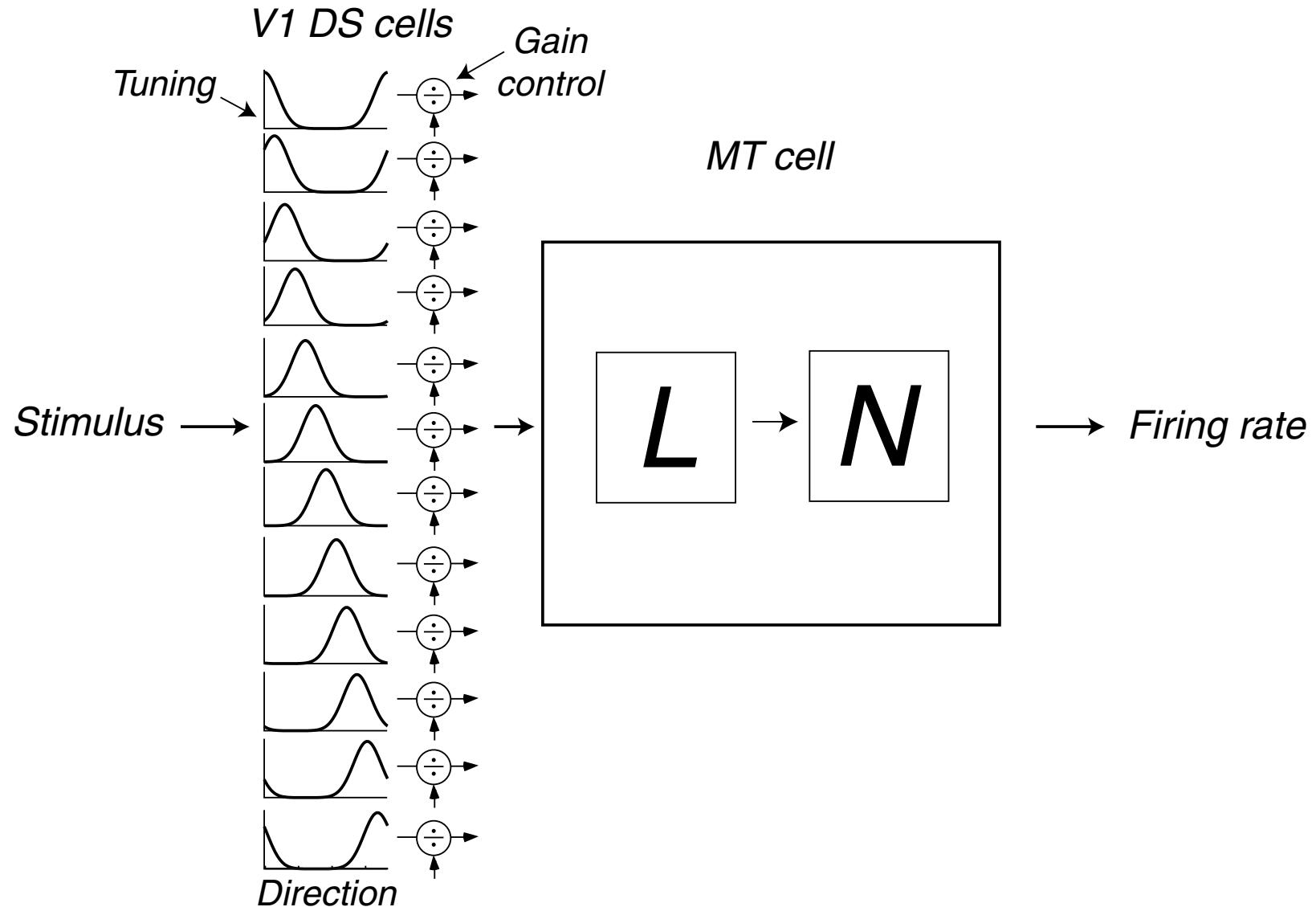
## *Evaluation of LN functional models*



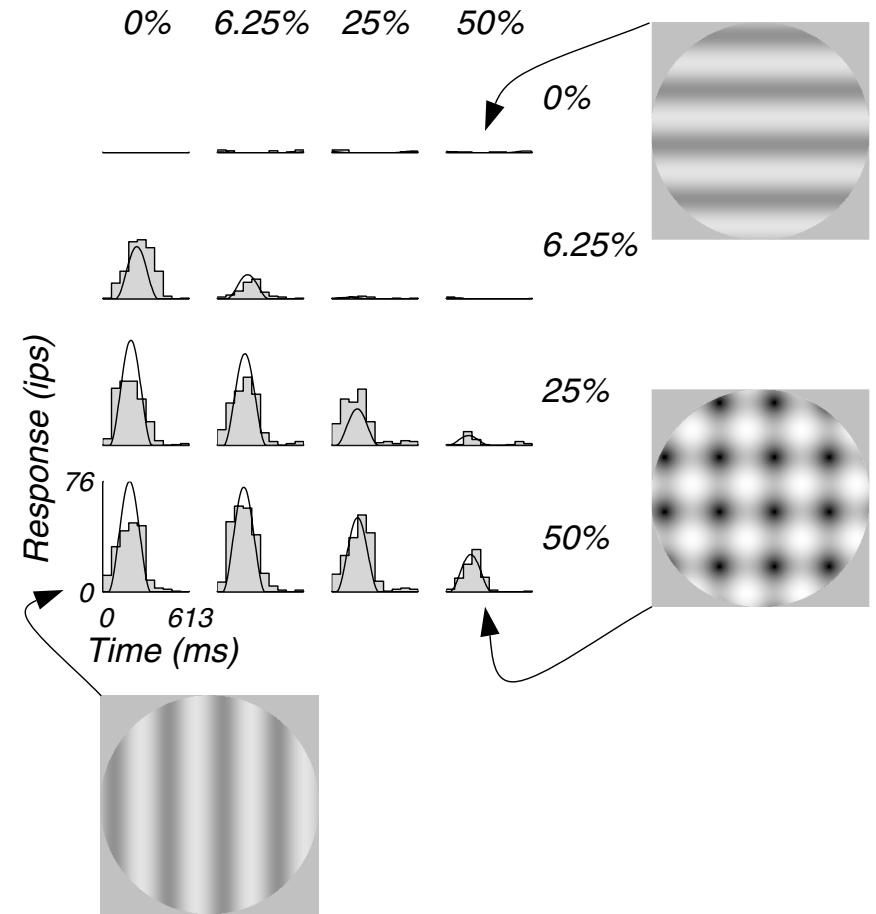
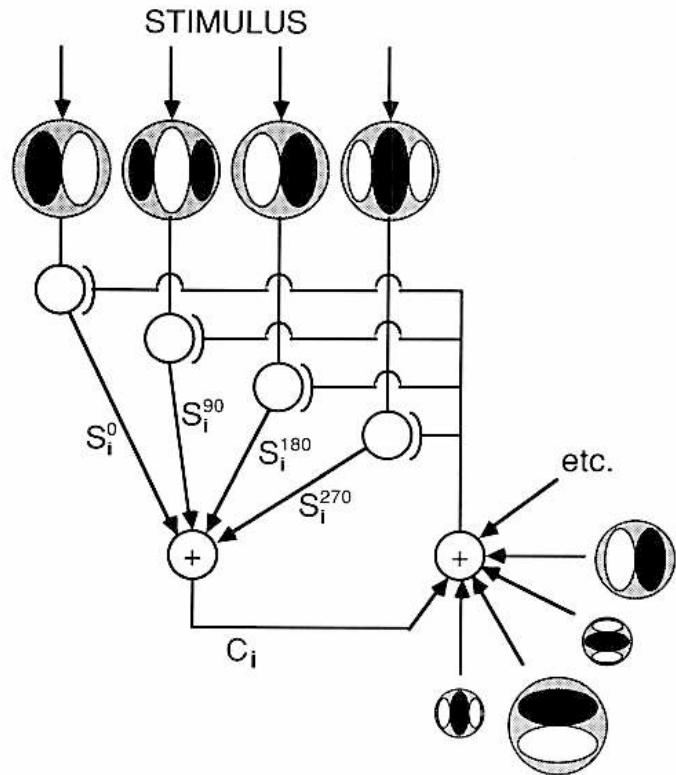
## *MT functional model*



## *MT functional model*



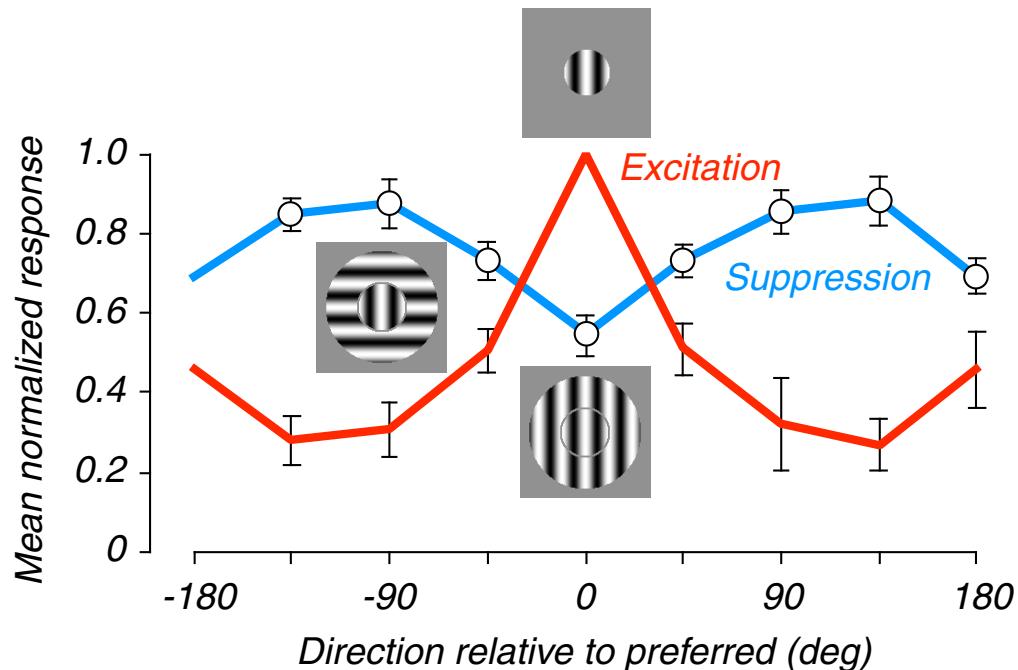
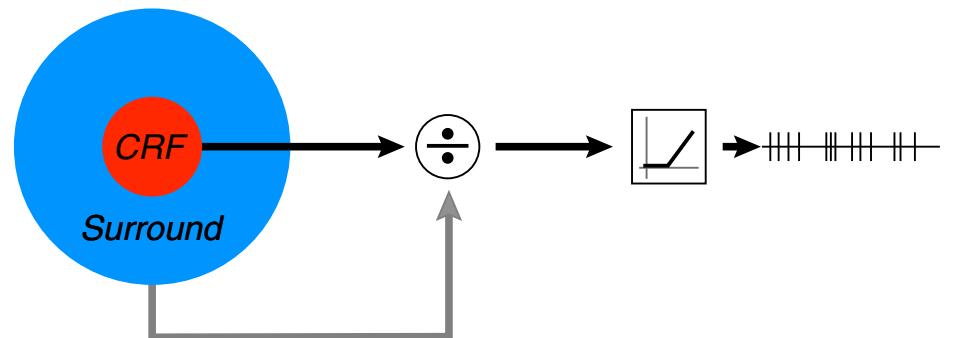
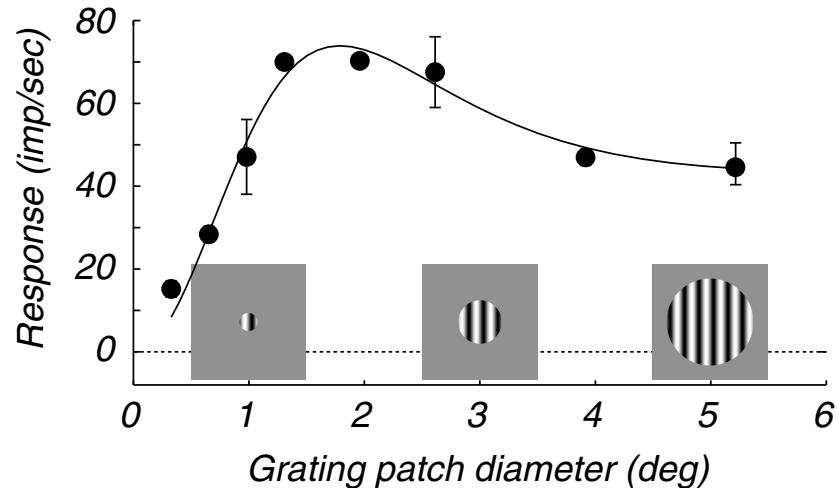
## *Gain control in V1: the untuned component*



Heeger, 1992

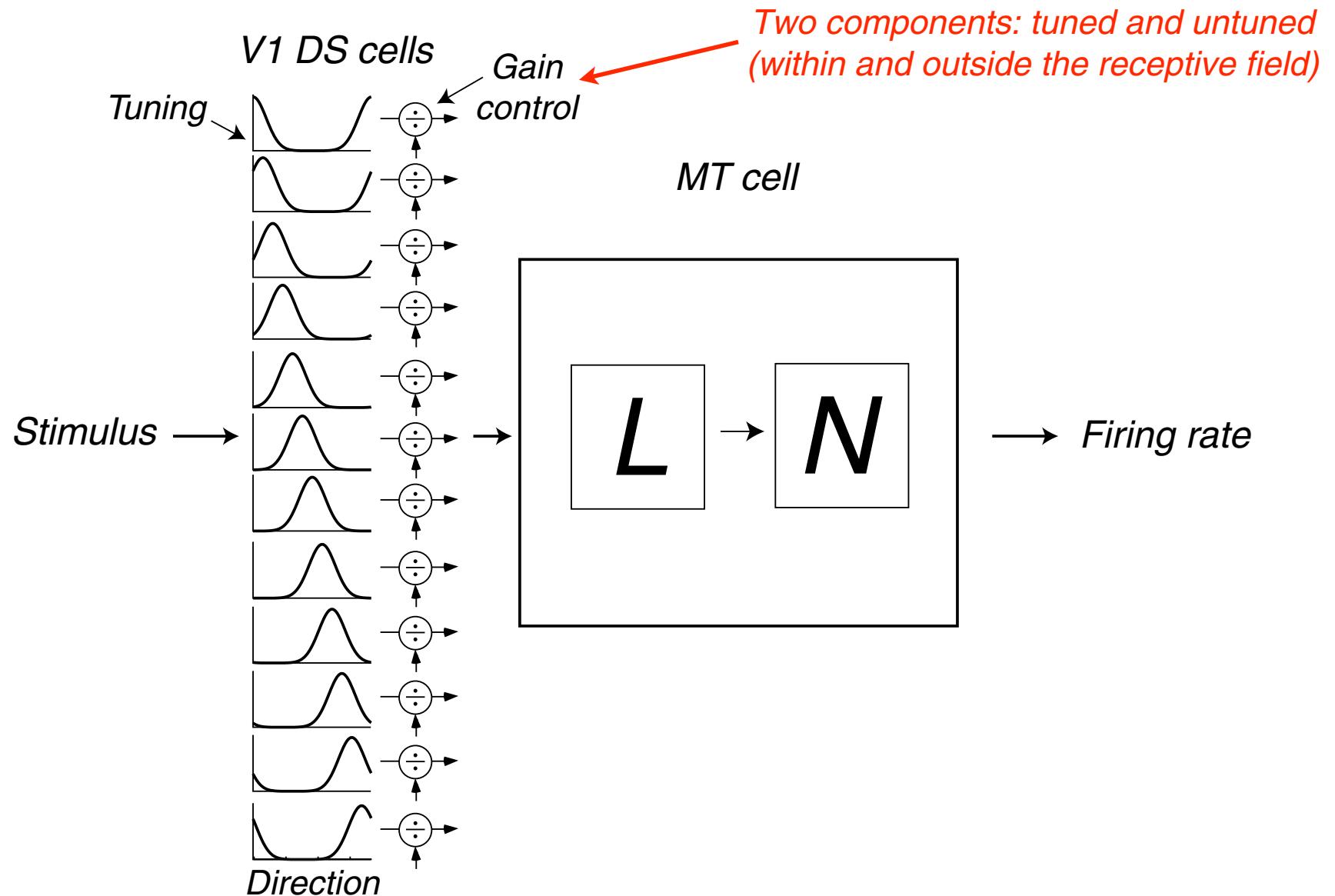
Carandini, Heeger & Movshon, 1997

## *Gain control in V1: the tuned component*

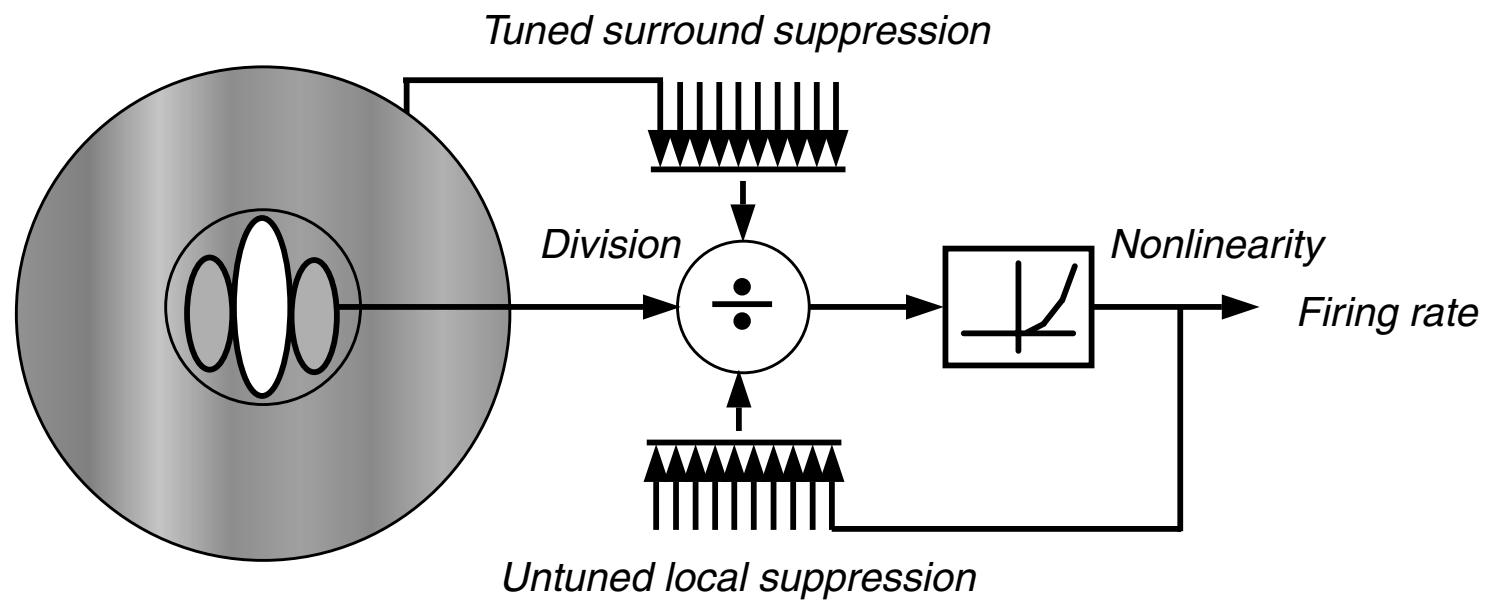


Cavanaugh, Bair & Movshon, 2002

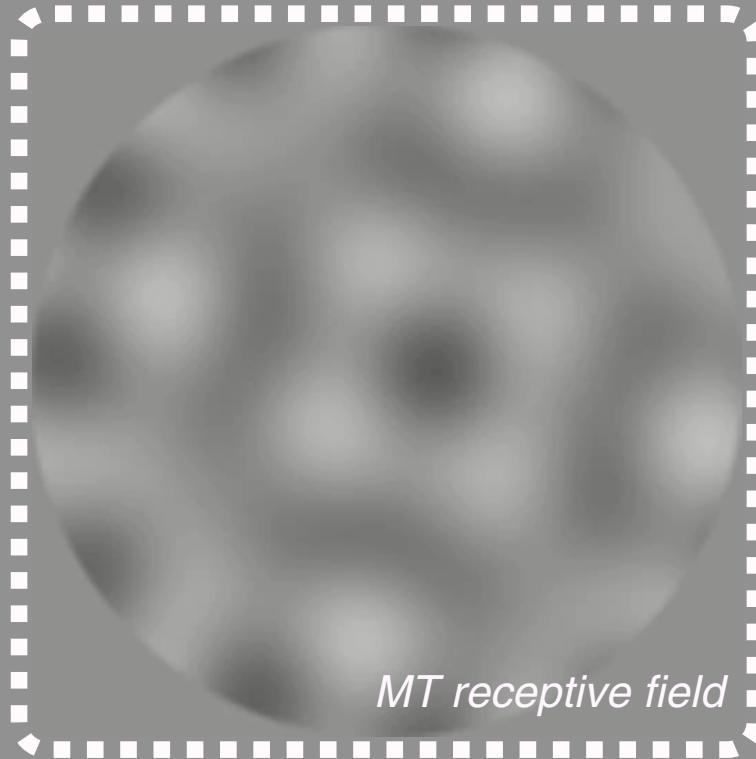
## *MT functional model*



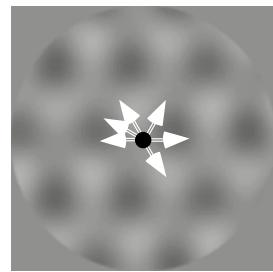
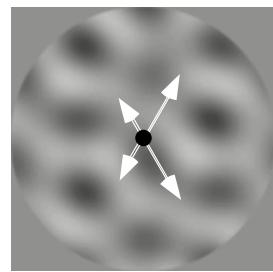
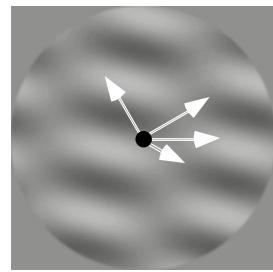
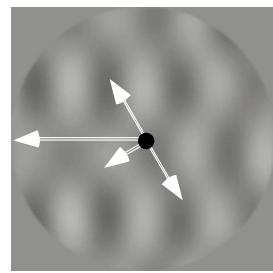
## *Gain control in V1*



*MT functional model:  
the characterization stimulus*

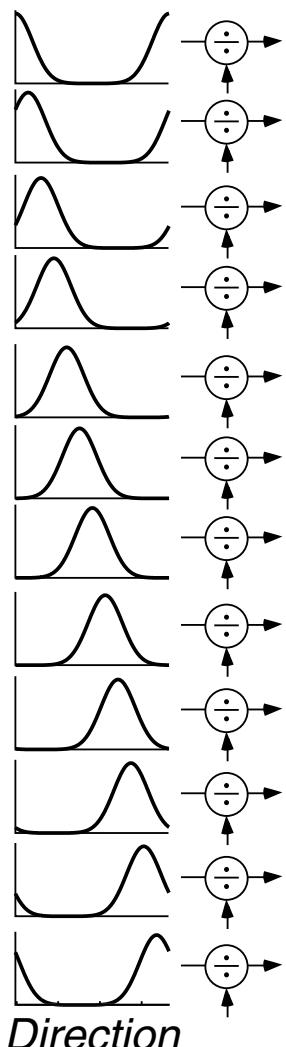


## *MT functional model*

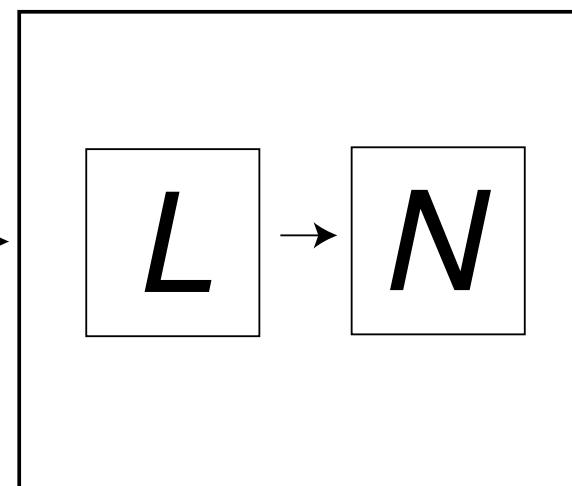


Time →

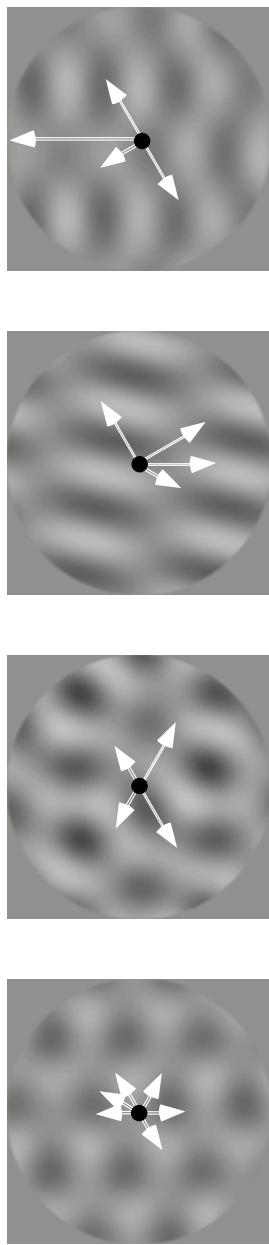
*V1 DS cells*



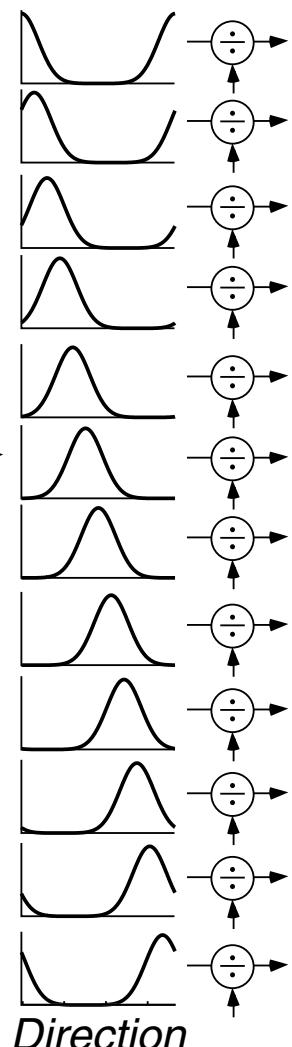
*MT cell*



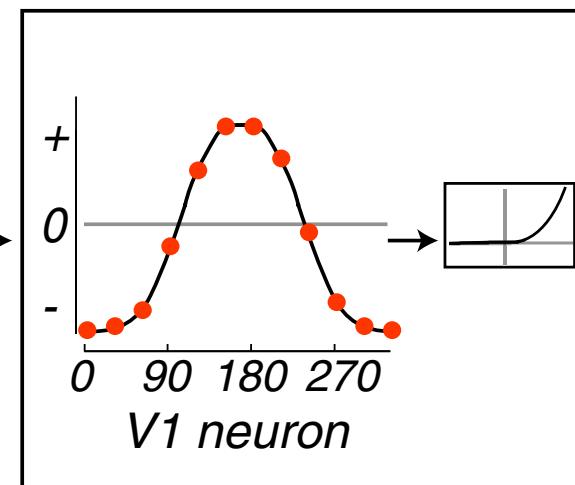
## *MT functional model*



*V1 DS cells*

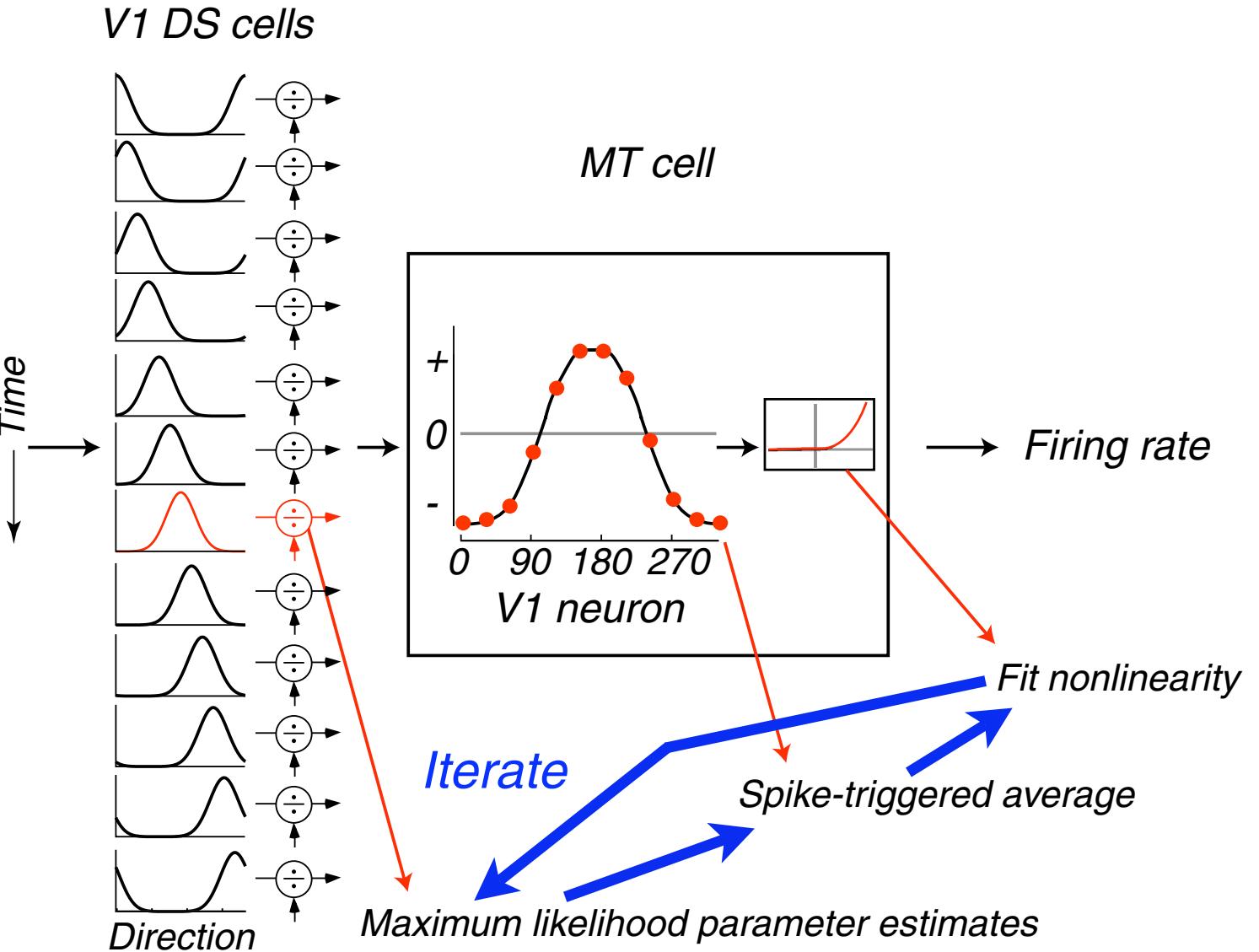
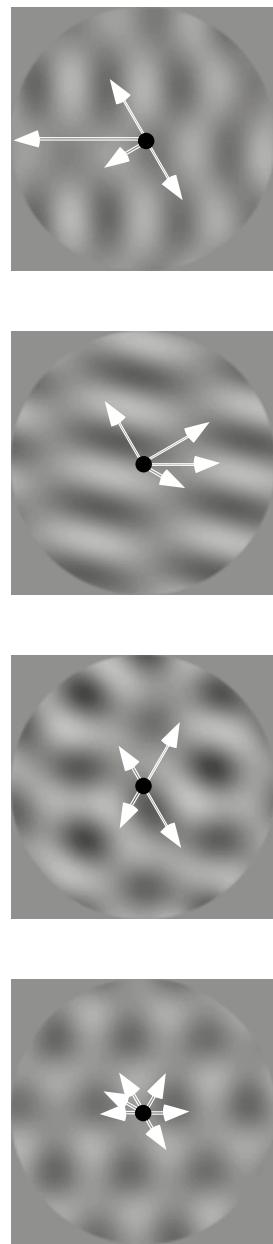


*MT cell*



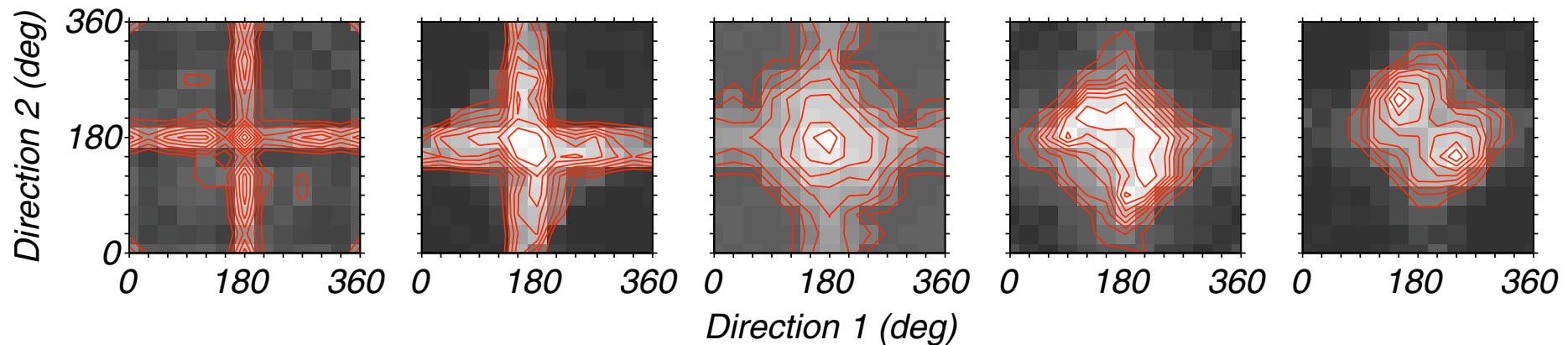
→ *Firing rate*

## *MT functional model*

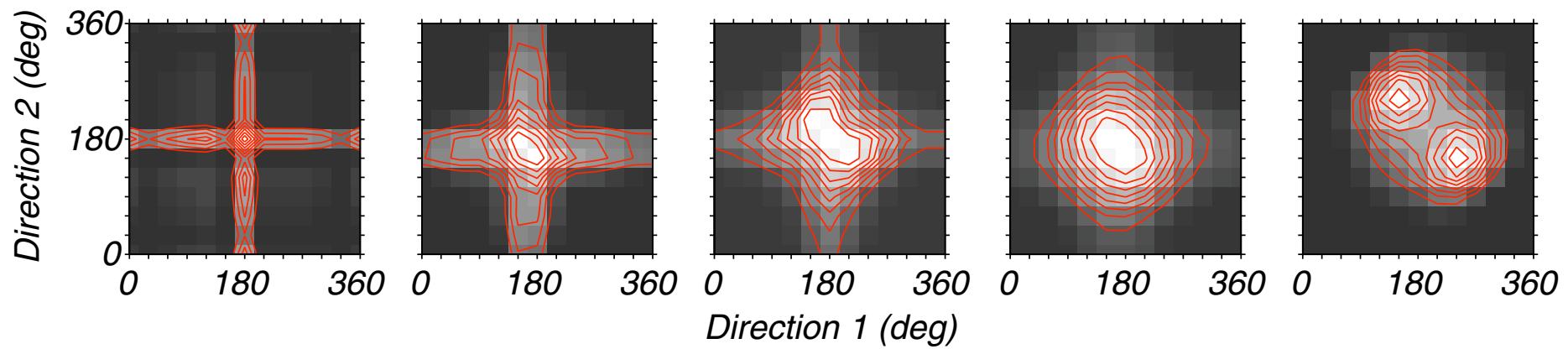


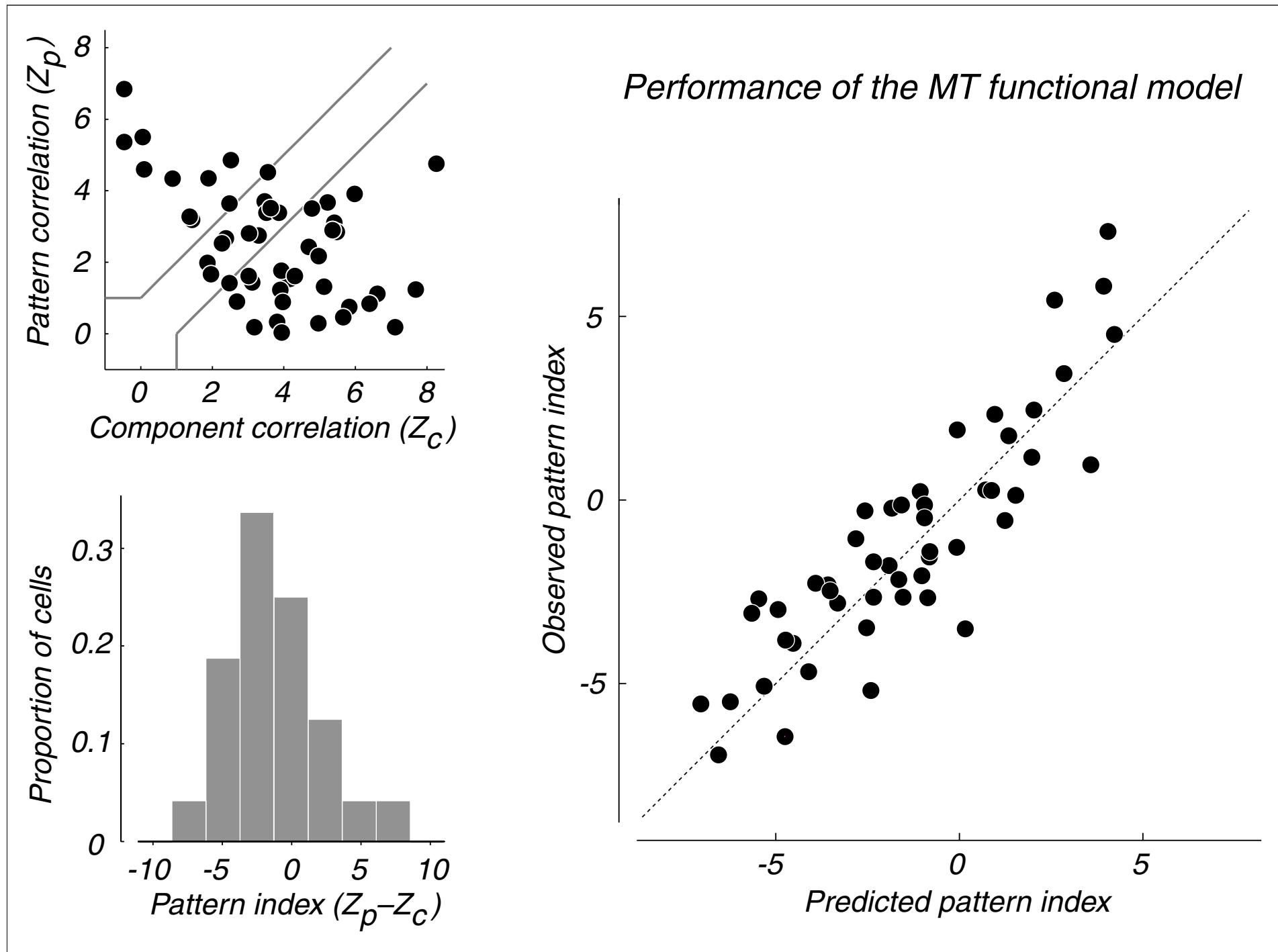
## *Performance of the MT functional model*

*Data*



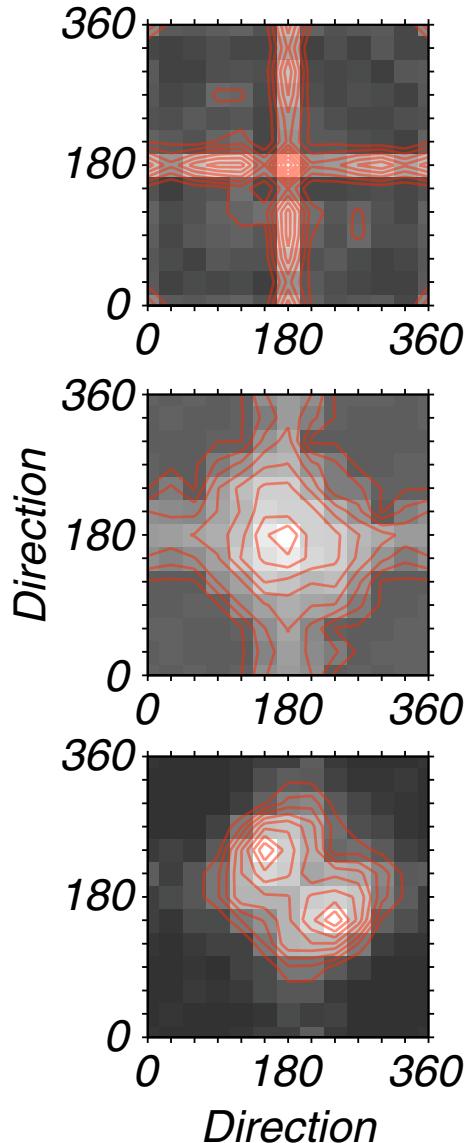
*Predictions*



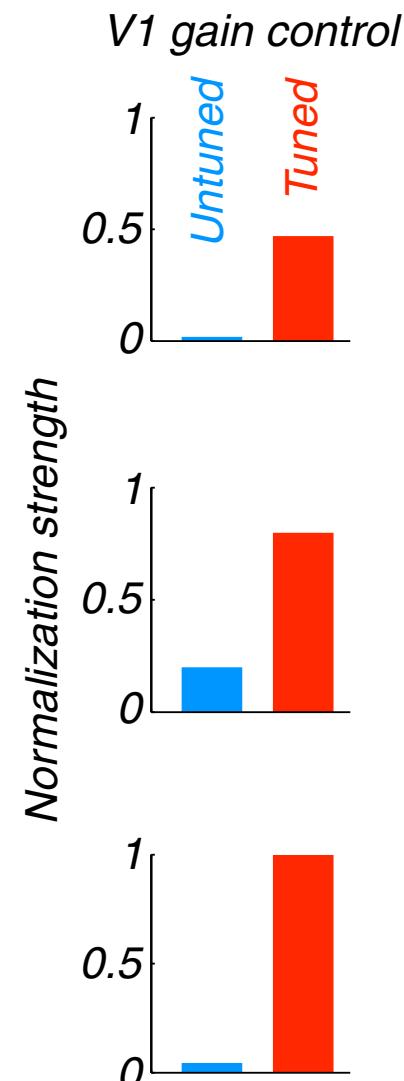


## *Recovered model elements*

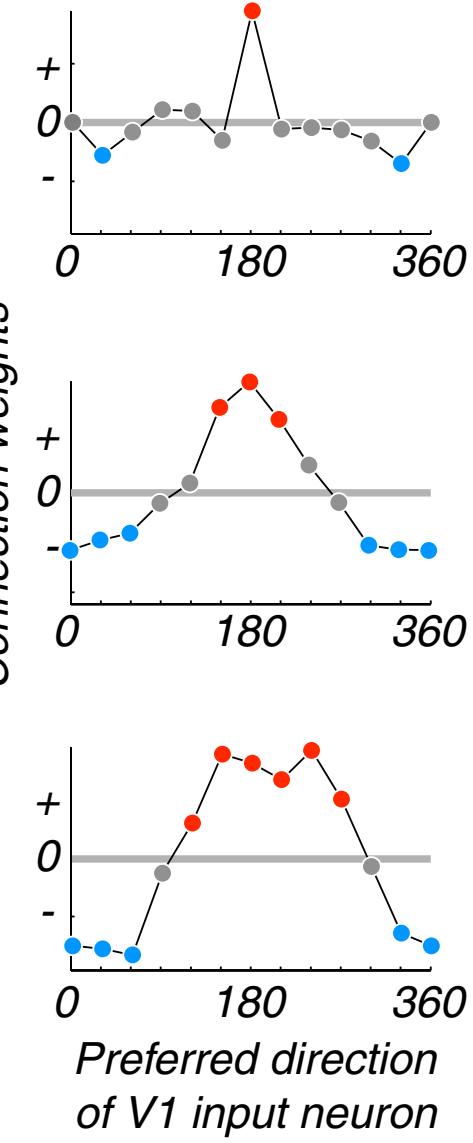
*Data*



*Model*

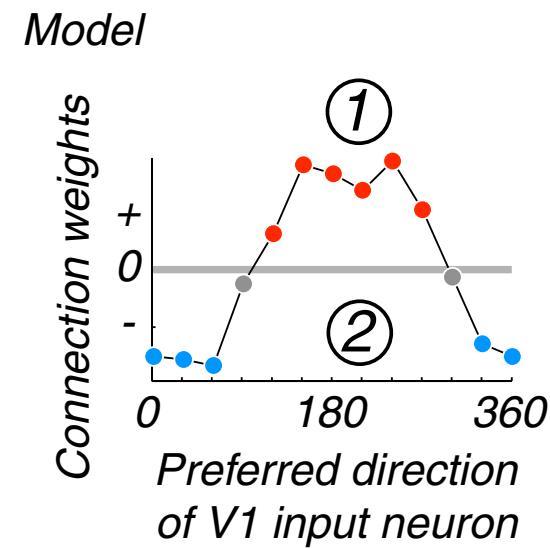
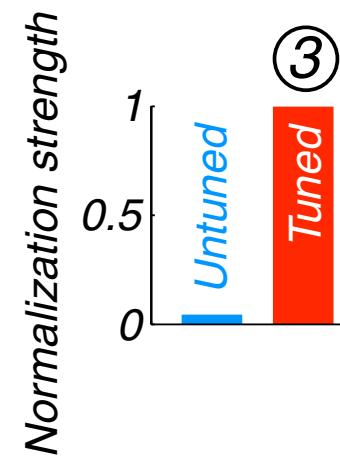
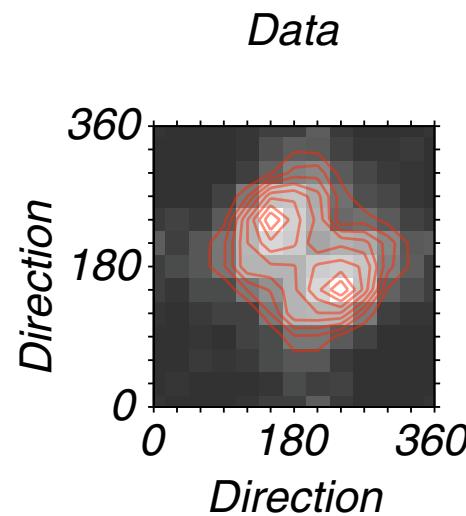


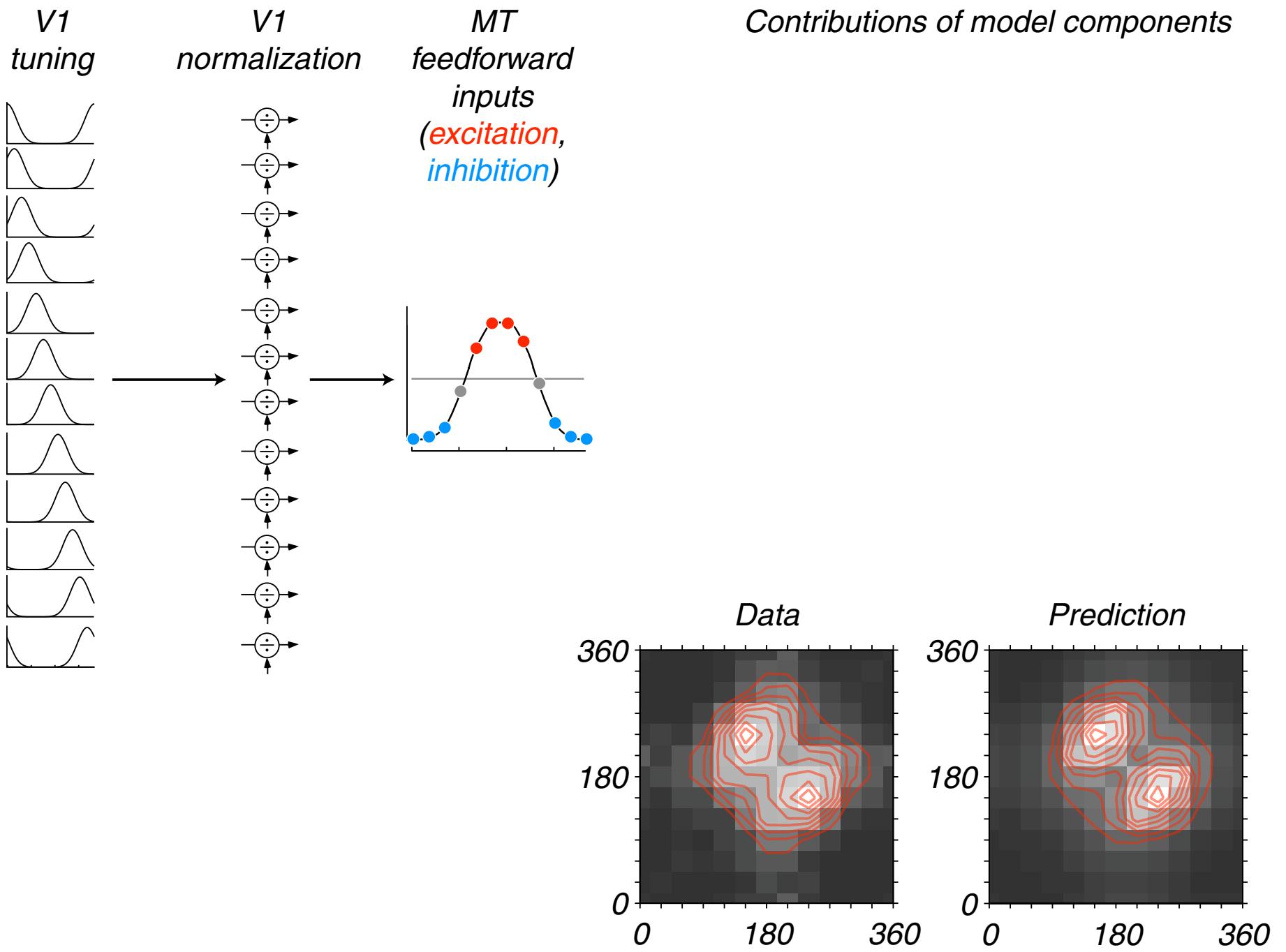
*MT linear weights*



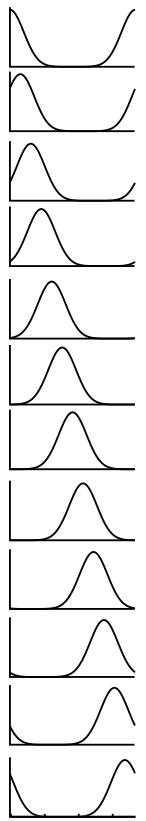
*Pattern direction selectivity arises from:*

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

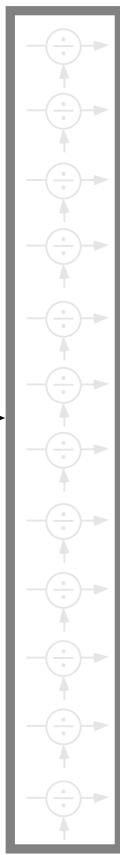




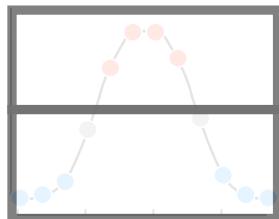
*V1*  
tuning



*V1*  
normalization

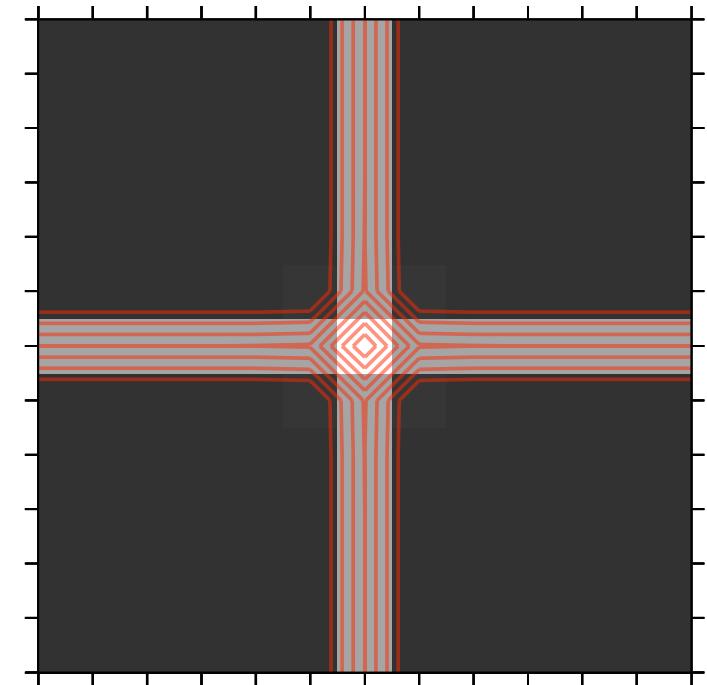


*MT*  
feedforward  
inputs  
(excitation,  
inhibition)

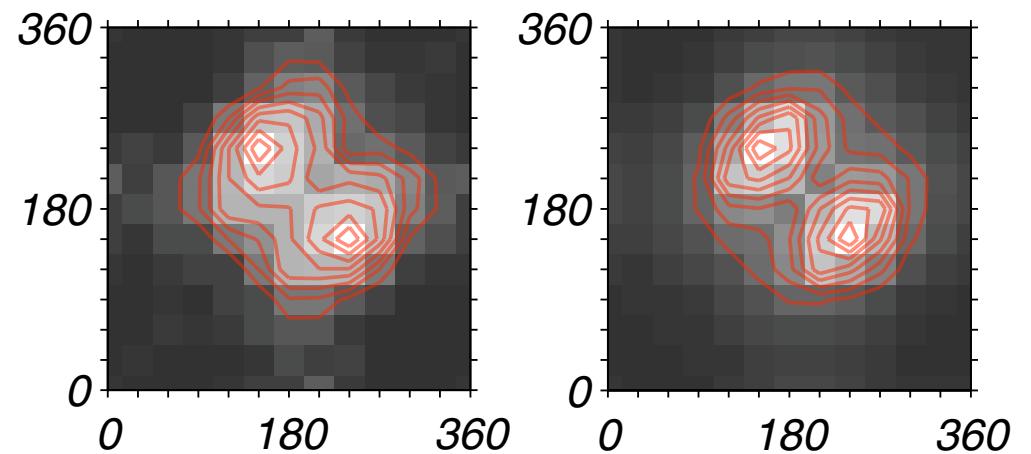


*V1 input alone*

*Contributions of model components*

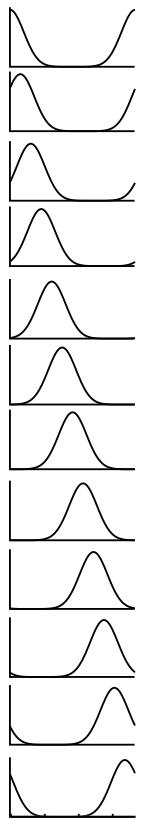


*Data*

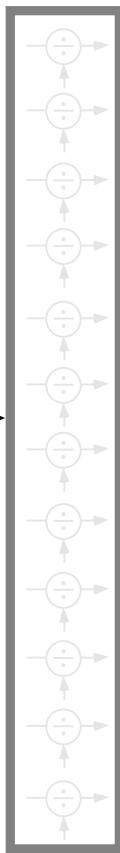


*Prediction*

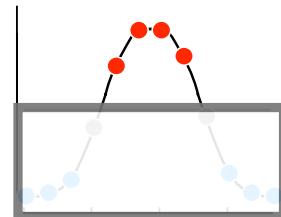
*V1*  
tuning



*V1*  
normalization

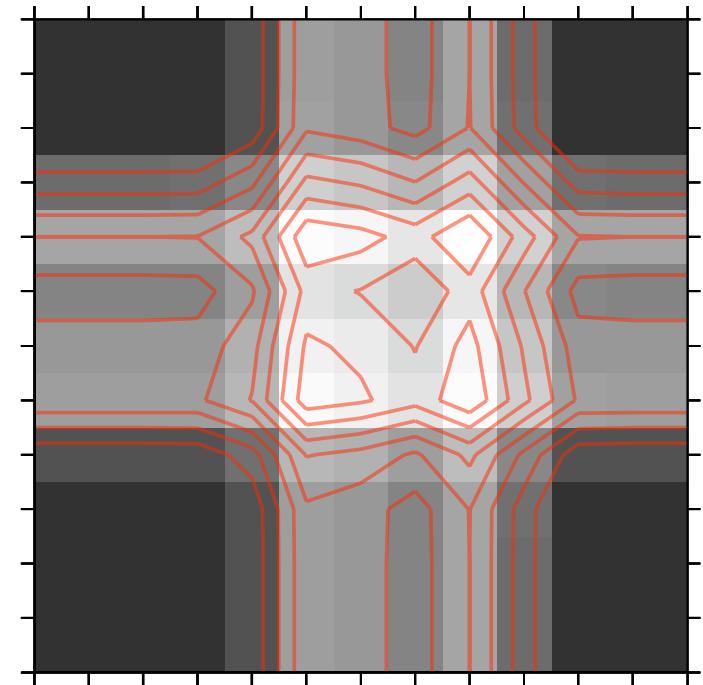


*MT*  
feedforward  
inputs  
(excitation,  
inhibition)

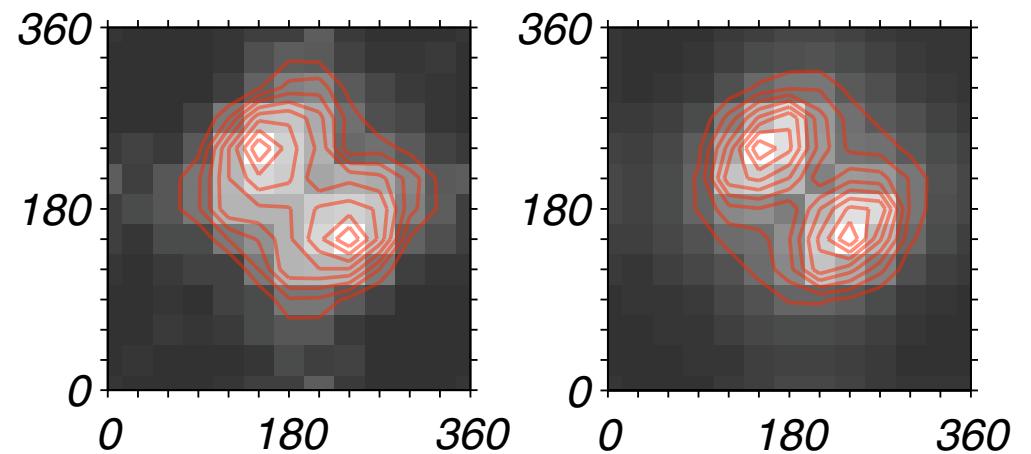


*MT excitation*

*Contributions of model components*

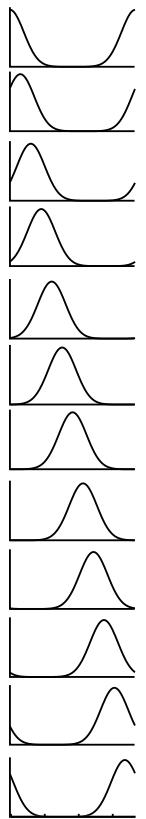


*Data*

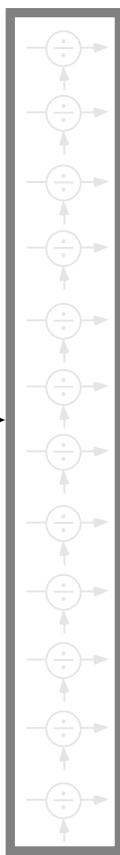


*Prediction*

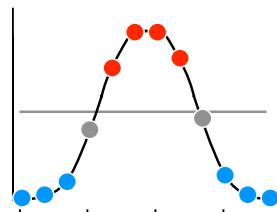
*V1*  
tuning



*V1*  
normalization

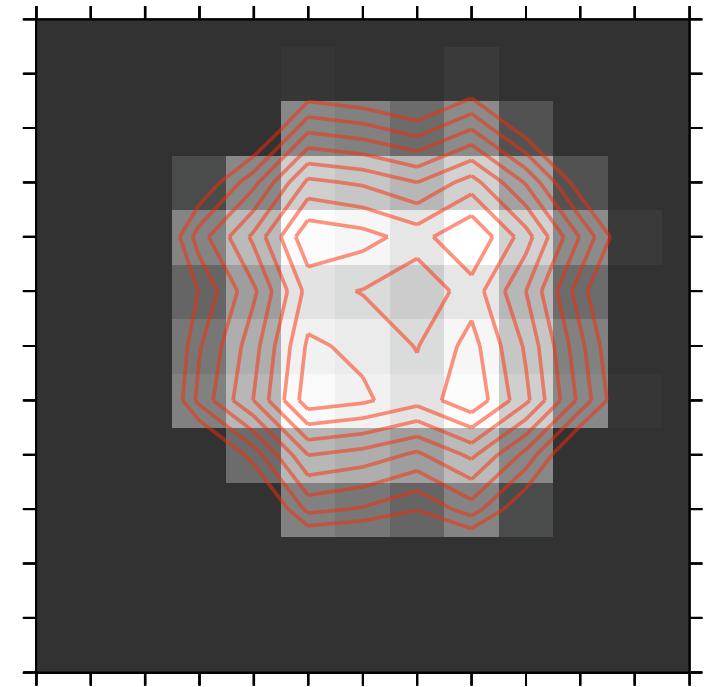


*MT*  
feedforward  
inputs  
(excitation,  
inhibition)

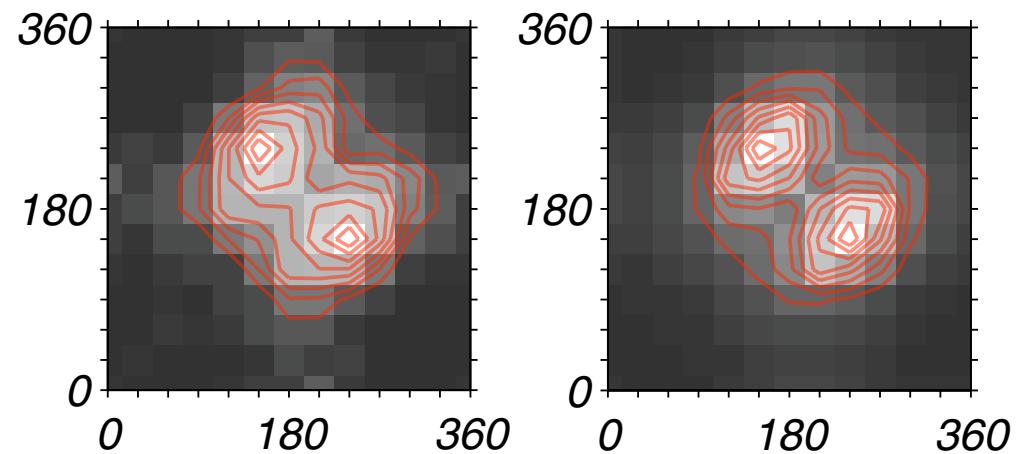


*MT inhibition*

*Contributions of model components*

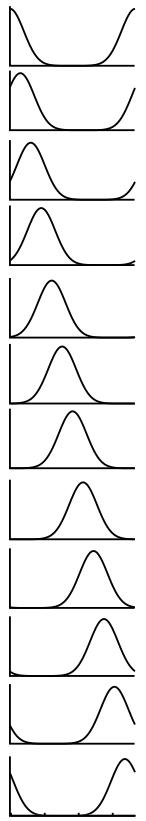


*Data*

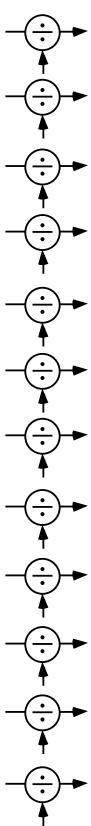


*Prediction*

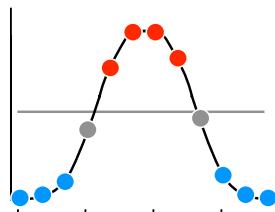
*V1*  
tuning



*V1*  
normalization

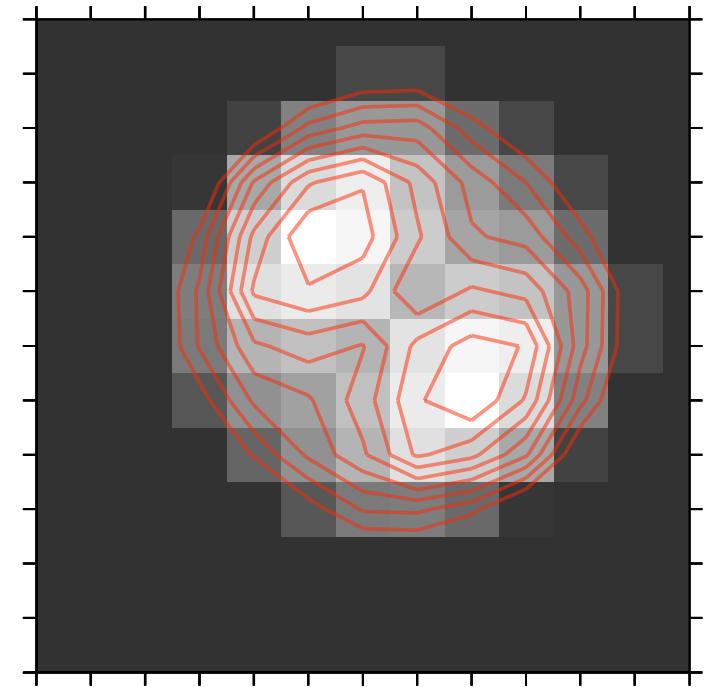


*MT*  
feedforward  
inputs  
(excitation,  
inhibition)

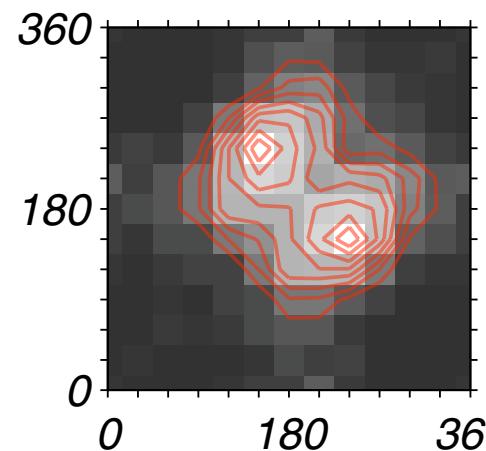


*V1 normalization*

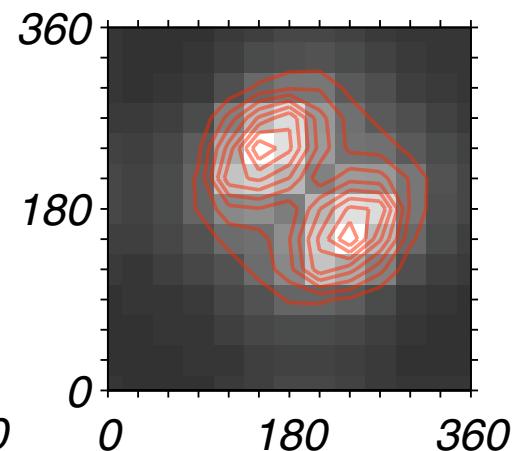
*Contributions of model components*



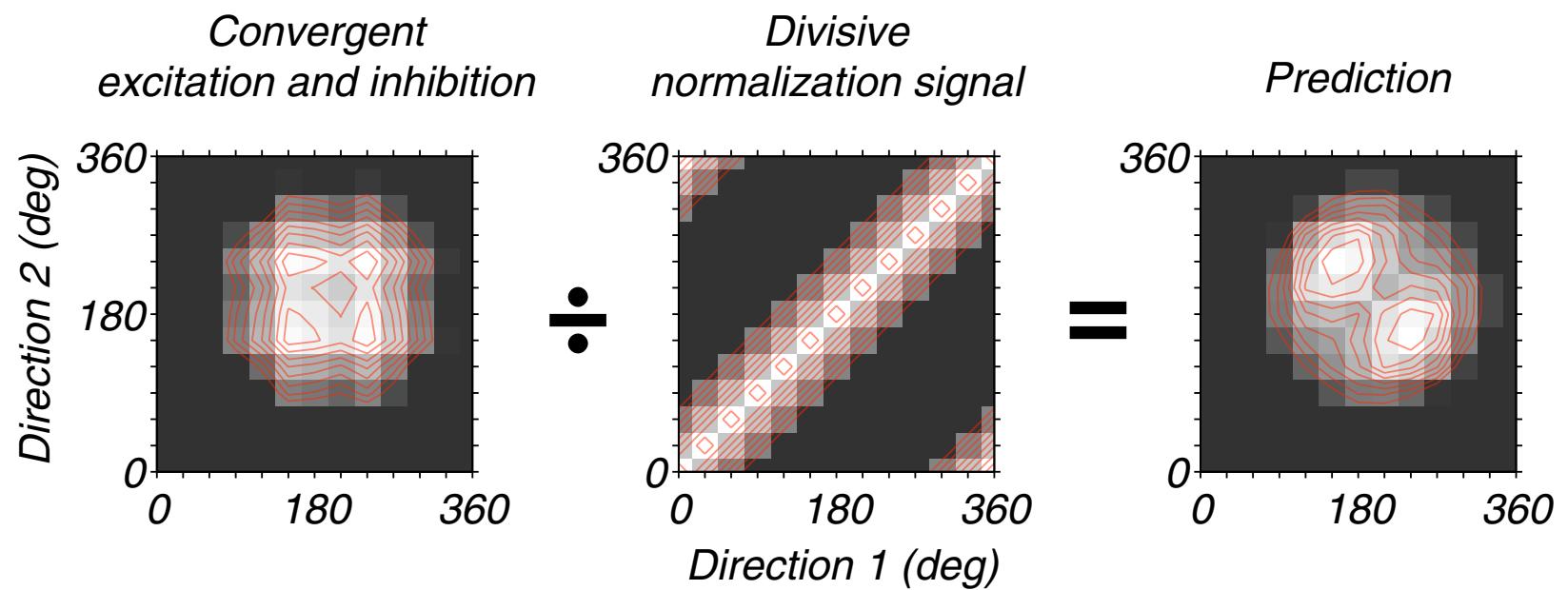
*Data*



*Prediction*



*Contributions of tuned normalization*



## *Local and global model elements*

