Cortical processing of visual motion signals

J. Anthony Movshon

Figure 10.12  
Cytoarchitecture of the striate cortex. The tissue has been Nissl-stained to show cell bodies, which appear as dots. (Source: Adapted from Hubel, 1988, p. 97.)
DeAngelis, Ohzawa & Freeman, 1995
Carandini, Heeger and Movshon, 1997
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
Grating patch diameter (deg)

Response (imp/sec)

Suppression

Optimal diameter

Surround diameter

Cavanaugh, Bair and Movshon, 2002
Surround contrast

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Value</th>
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<tbody>
<tr>
<td>□</td>
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<td>□</td>
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<td>○</td>
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</tbody>
</table>

Response (imp/sec)

Contrast

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
John Maunsell, after Peter Lennie

after Felleman & Van Essen, 1991
Adelson & Bergen, 1990
Movshon & Newsome, 1996
Movshon & Newsome, 1996
Movshon, Adelson, Gizzi & Newsome, 1985

Grating response

Predicted plaid response
Grating responses  

V1 cell

Plaid responses

MT component cell

MT pattern cell

Movshon, Adelson, Gizzi & Newsome, 1985
 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
Movshon, Adelson, Gizzi & Newsome, 1985

Hubel & Wiesel, 1962
Retinal image

Moving image

Simoncelli & Heeger, 1998
Recovering and validating the model:
1. A rich test set

Simoncelli & Heeger, 1998
Component cell

Pattern cell

Rust, Mante, Simoncelli & Movshon, 2006
Component cell

Pattern cell

Rust, Mante, Simoncelli & Movshon, 2006
Direction-interaction: Gratings
Direction-interaction:
Plaids
**Direction-interaction:**

*One common component*
Direction-interaction:
Common axis
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

Spike-triggered analysis

Stimulus → Time

Firing rate

L → N
DeAngelis, Ohzawa & Freeman, 1995
Evaluation of LN functional models

Spike-triggered analysis

Stimulus

Time

Firing rate

L → N
MT functional model

Direction-selective V1 cells

Stimulus → Spike-triggered analysis

Spike-triggered analysis

Firing rate

L → N
MT functional model

V1 DS cells

Gain control

MT cell

Stimulus

Direction

Firing rate
**Gain control in V1: the untuned component**

Heeger, 1992

Carandini, Heeger & Movshon, 1997
Gain control in V1: the tuned component

Gain control in V1: the tuned component
MT functional model

Two components: tuned and untuned (within and outside the receptive field)

V1 DS cells

Tuning

Gain control

MT cell

Stimulus

Direction

Firing rate
Gain control in V1

Tuned surround suppression

Untuned local suppression

Division

Nonlinearity

Firing rate
MT functional model:
the characterization stimulus
MT functional model

V1 DS cells

MT cell

Firing rate
MT functional model

V1 DS cells

MT cell

Rust, Mante, Simoncelli & Movshon, 2006
Performance of the MT functional model

Data

Predictions

Rust, Mante, Simoncelli & Movshon, 2006
Performance of the MT functional model
Recovered model elements

Data

V1 gain control

Model

MT linear weights

Connection weights

Preferred direction of V1 input neuron
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
Contributions of model components

Data
Prediction
Contributions of model components

V1 input alone
TUNING
NORMALIZATION
FEEDFORWARD INPUTS
EXCITATION INHIBITION

Contributions of model components

MT excitation

Data
Prediction
Contributions of model components

MT inhibition
TUNING
NORMALIZATION
-4
FEEDFORWARD
INPUTS
EXCITATION
INHIBITION

Contributions of model components

V1 normalization

Data
Prediction
Contributions of tuned normalization

Convergent excitation and inhibition

Divisive normalization signal

Prediction
Local and global model elements

Stimulus → Direction → V1 DS cells → MT cell → Firing rate