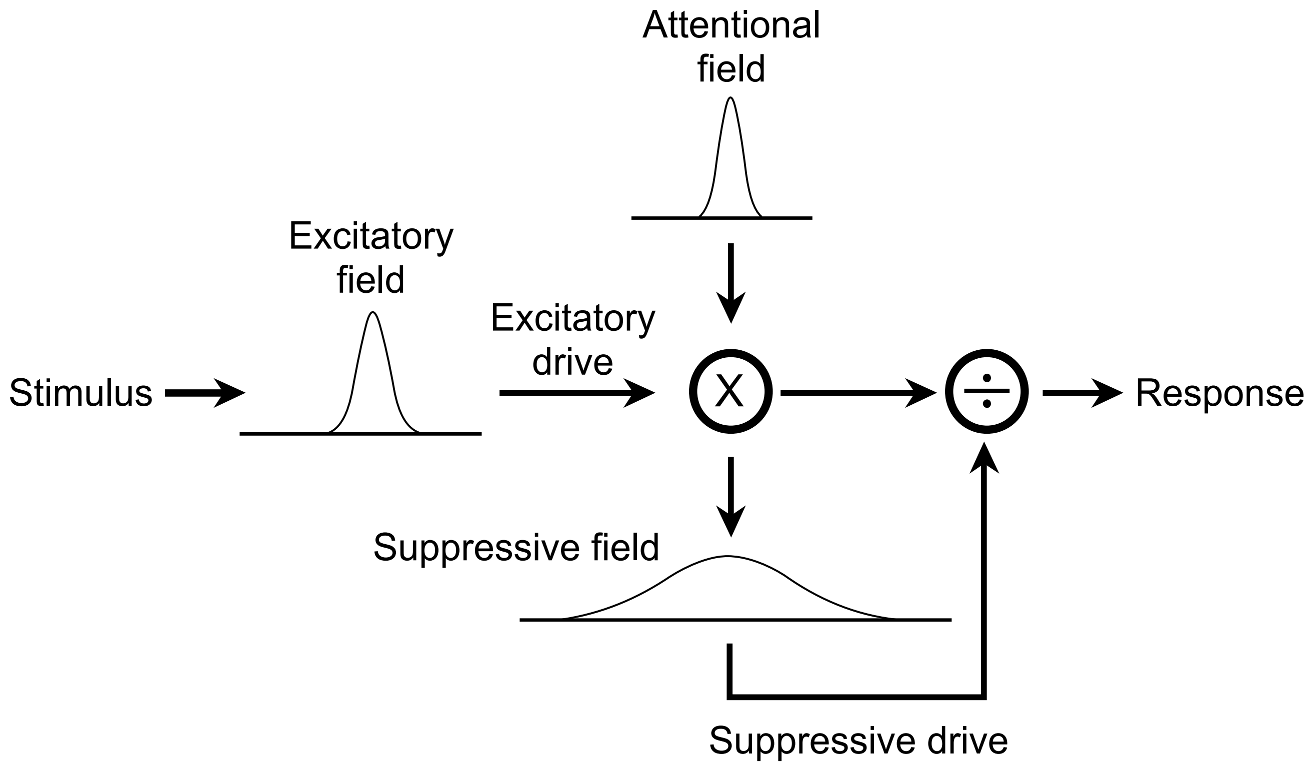
The Normalization Model of Attention



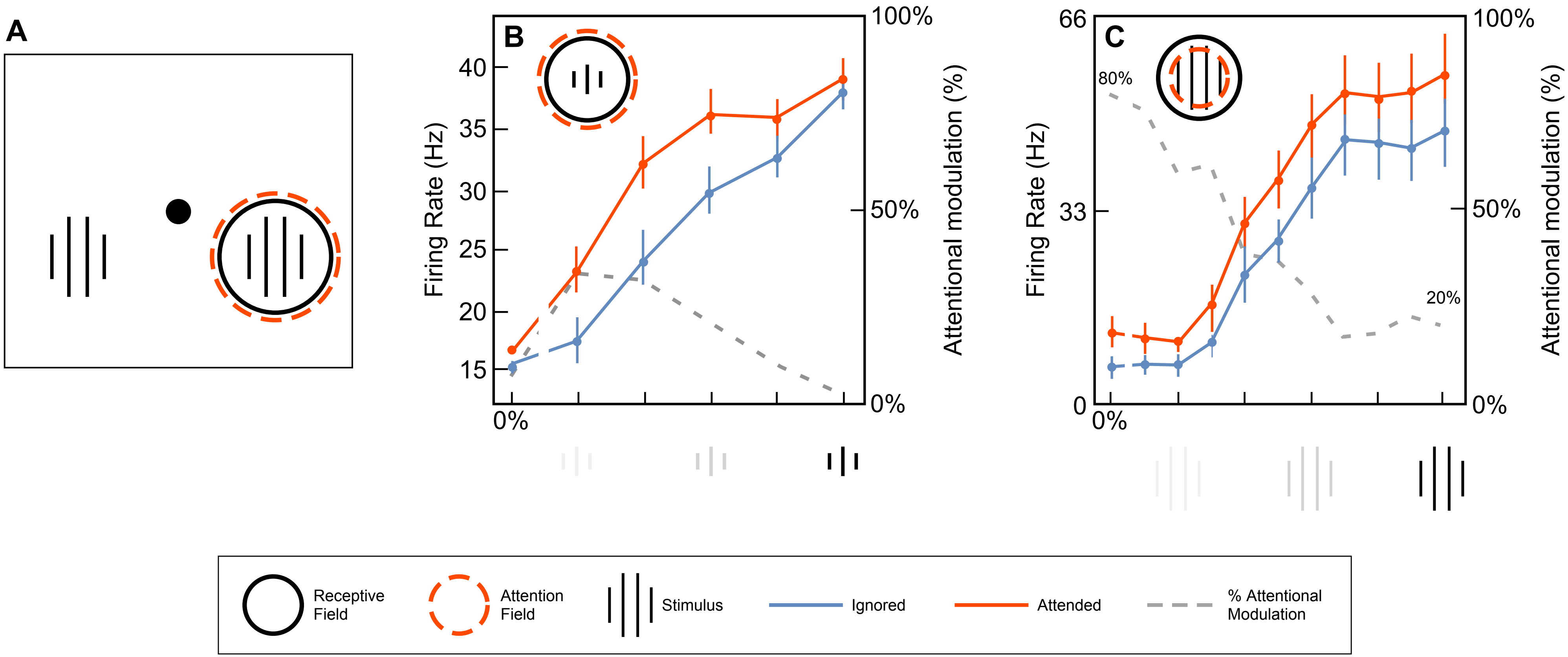
David J. Heeger
NYU

John H. Reynolds
Salk

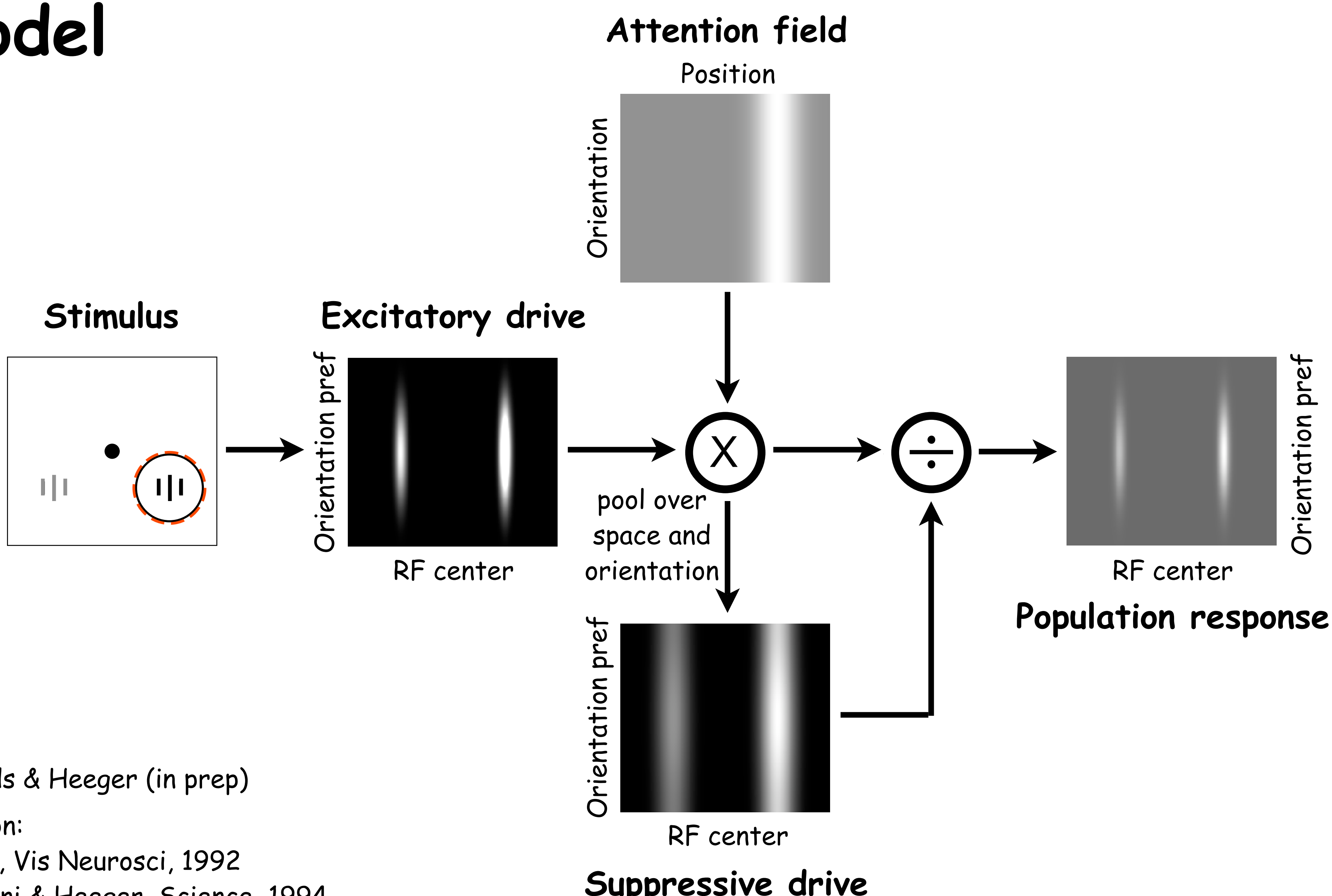
Contrast gain & response gain

Reynolds, Pasternak, & Desimone, Neuron, 2000

Williford & Maunsell, J Neurophysiol, 2006



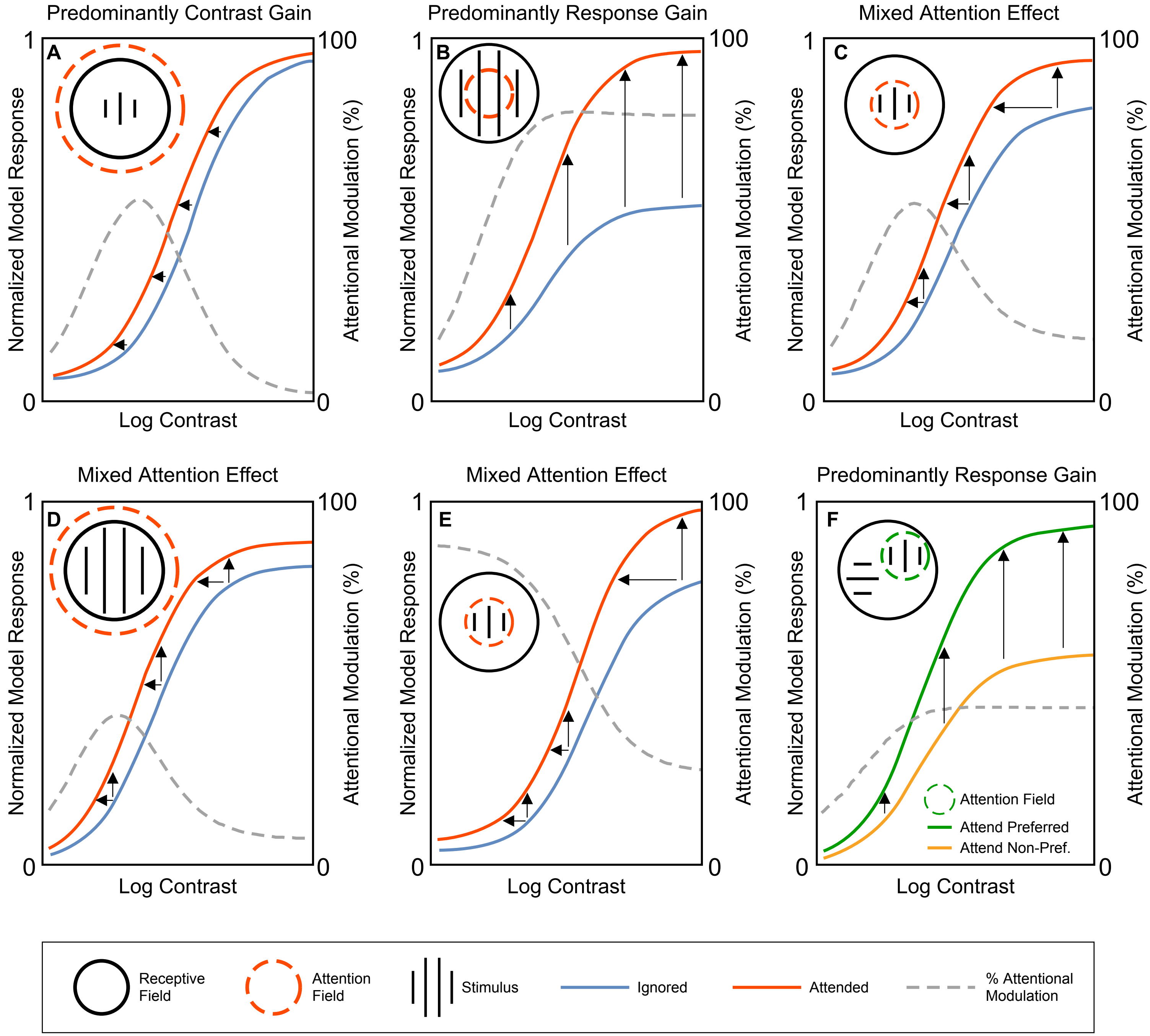
Model



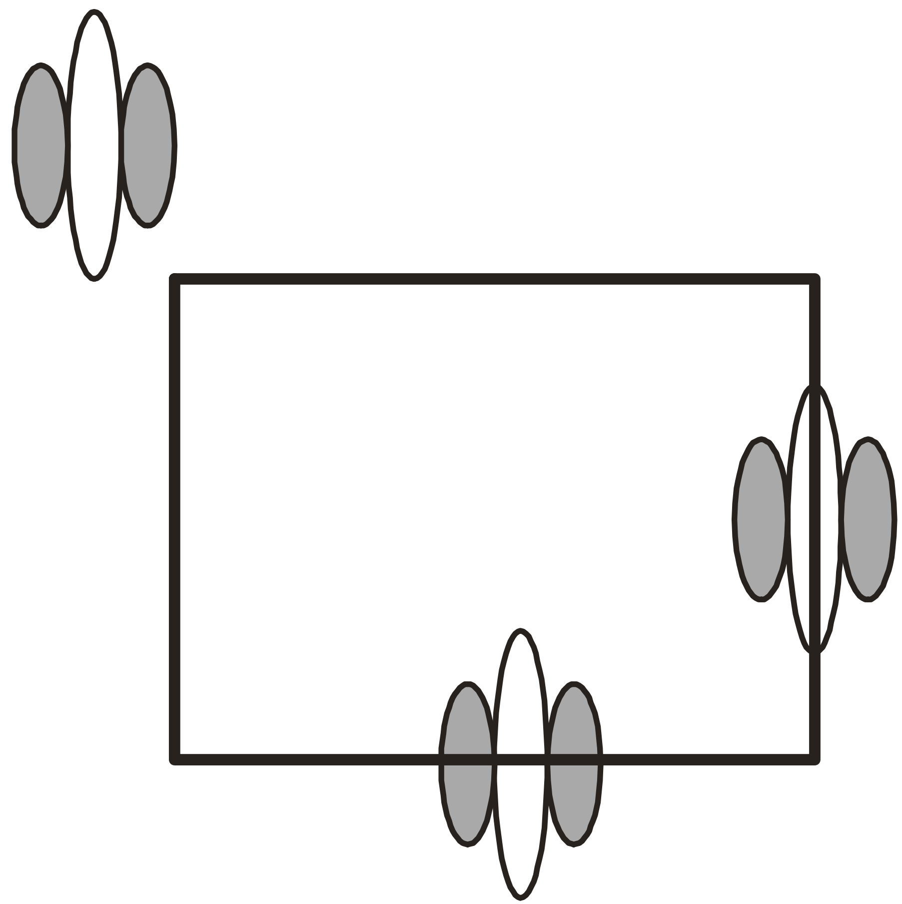
Reynolds & Heeger (in prep)

Based on:
Heeger, Vis Neurosci, 1992
Carandini & Heeger, Science, 1994
Carandini, Heeger & Movshon, J Neurophysiol, 1997
Cavanaugh, Bair, & Movshon, J Neurophysiol, 2002
Reynolds & Chelazzi, Ann Rev Neurosci, 2004

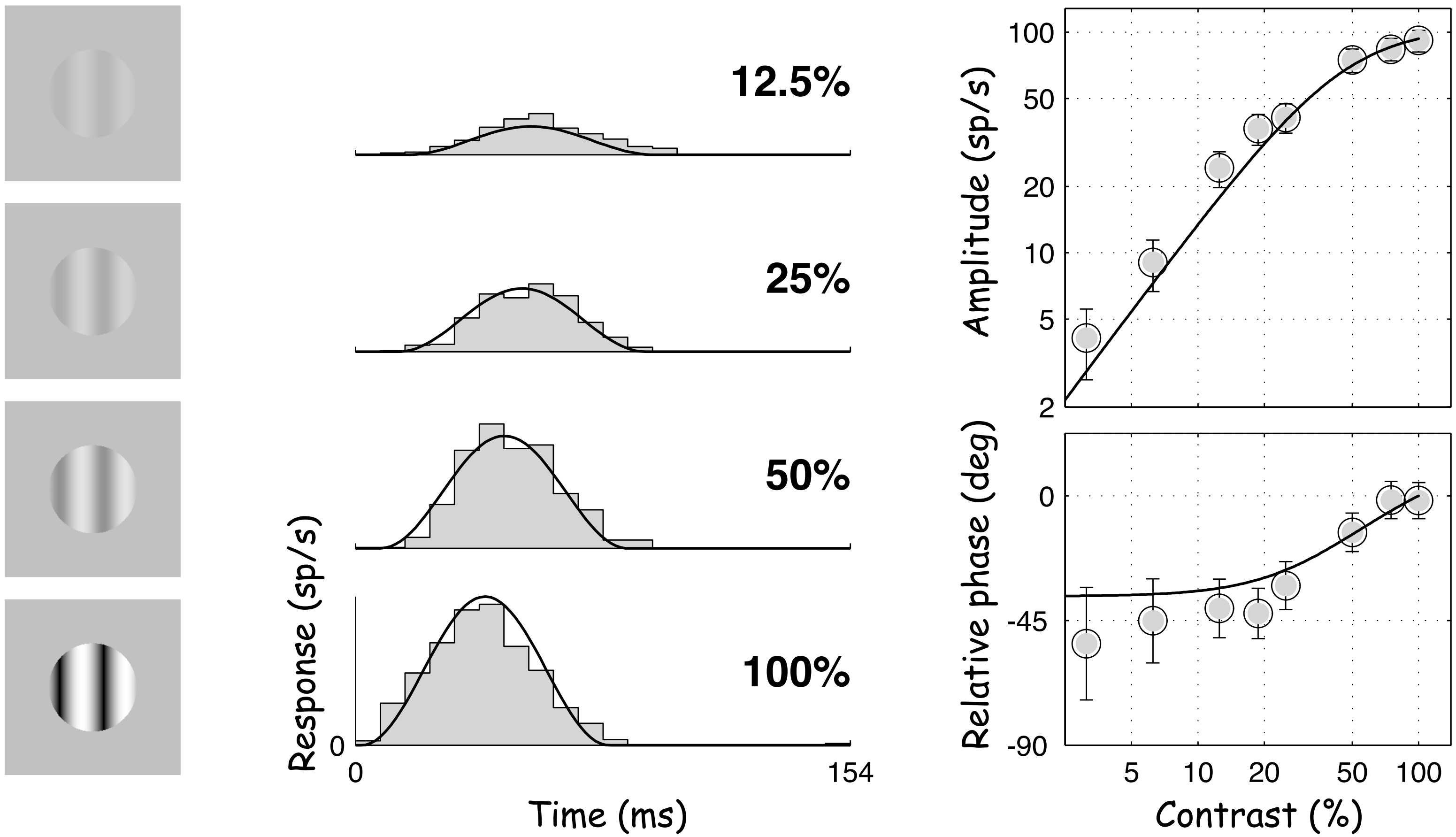
Simulated responses



Orientation selectivity model

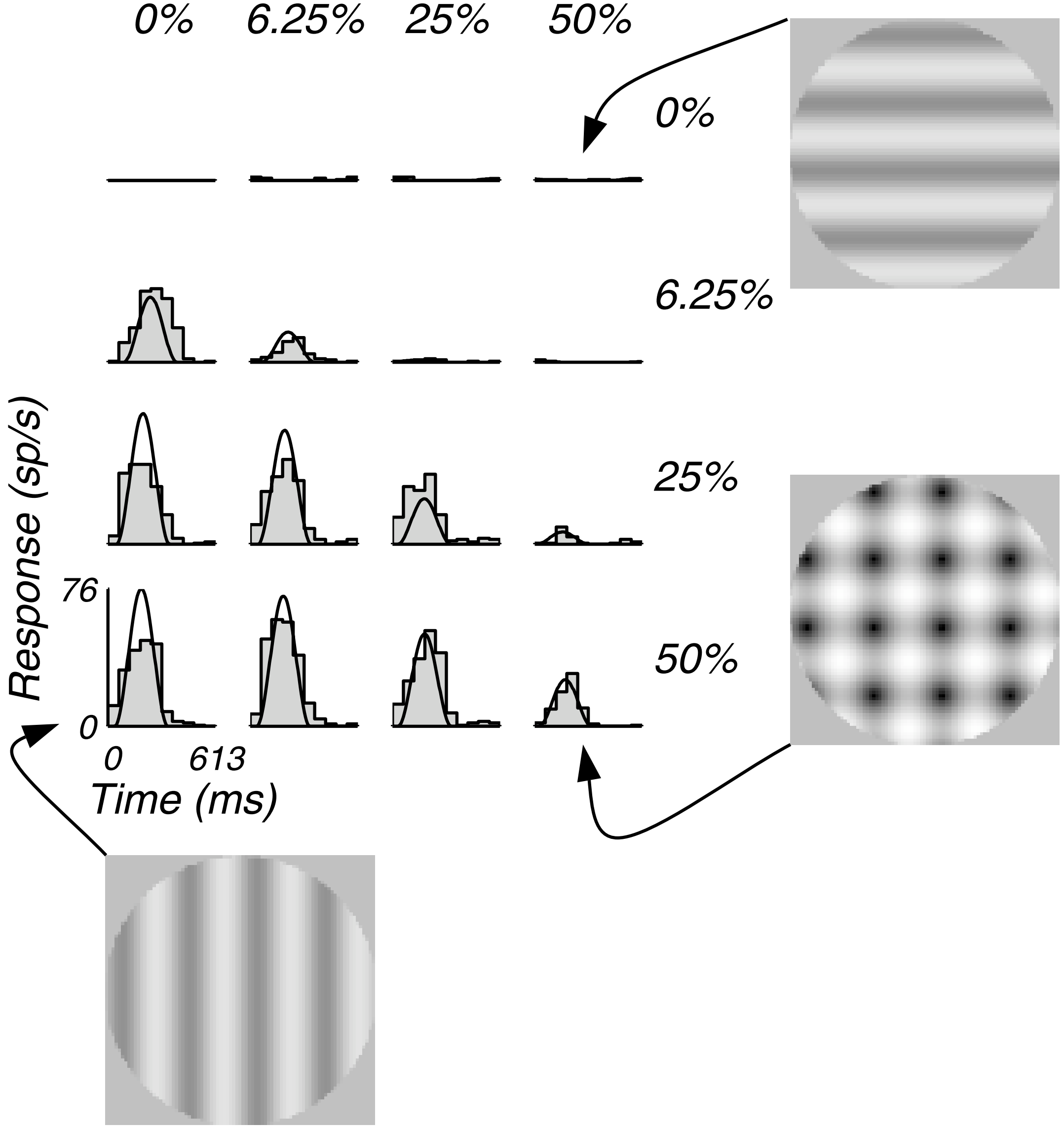


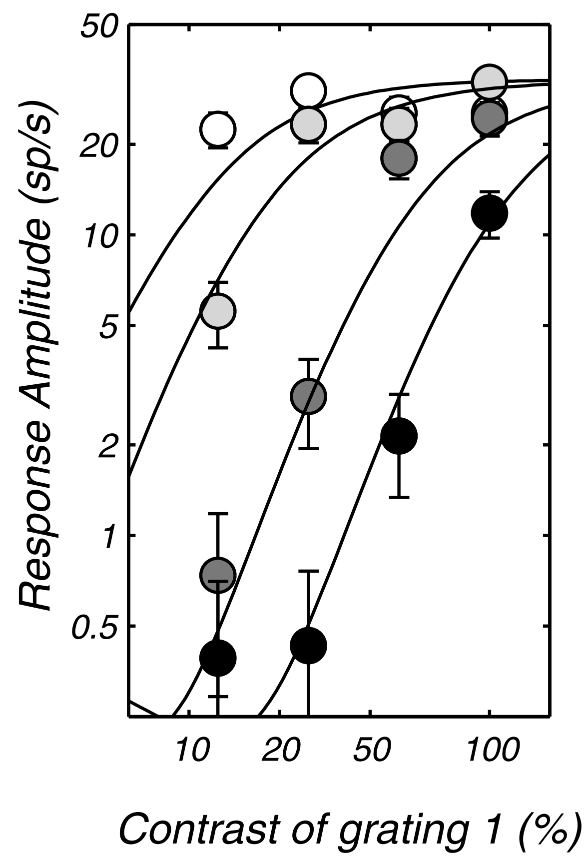
Response saturation and phase advance



Carandini, Heeger & Movshon, J Neurosci, 1997

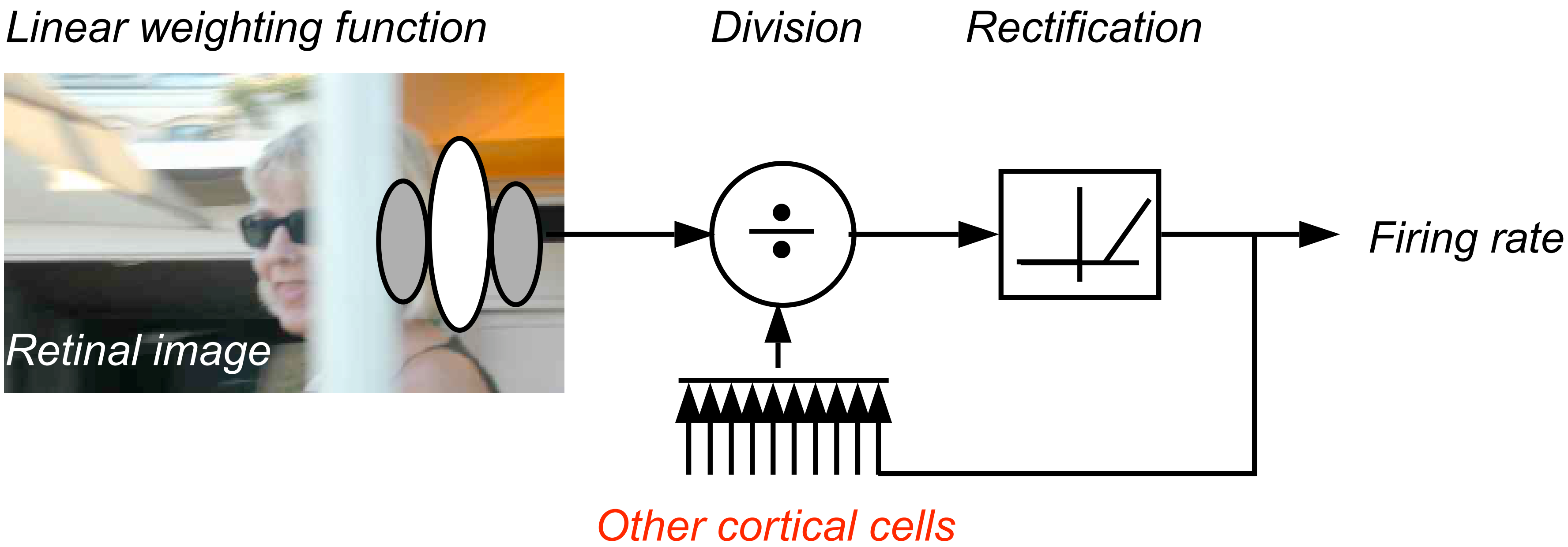
Masking





Carandini, Heeger & Movshon, J Neurosci, 1997

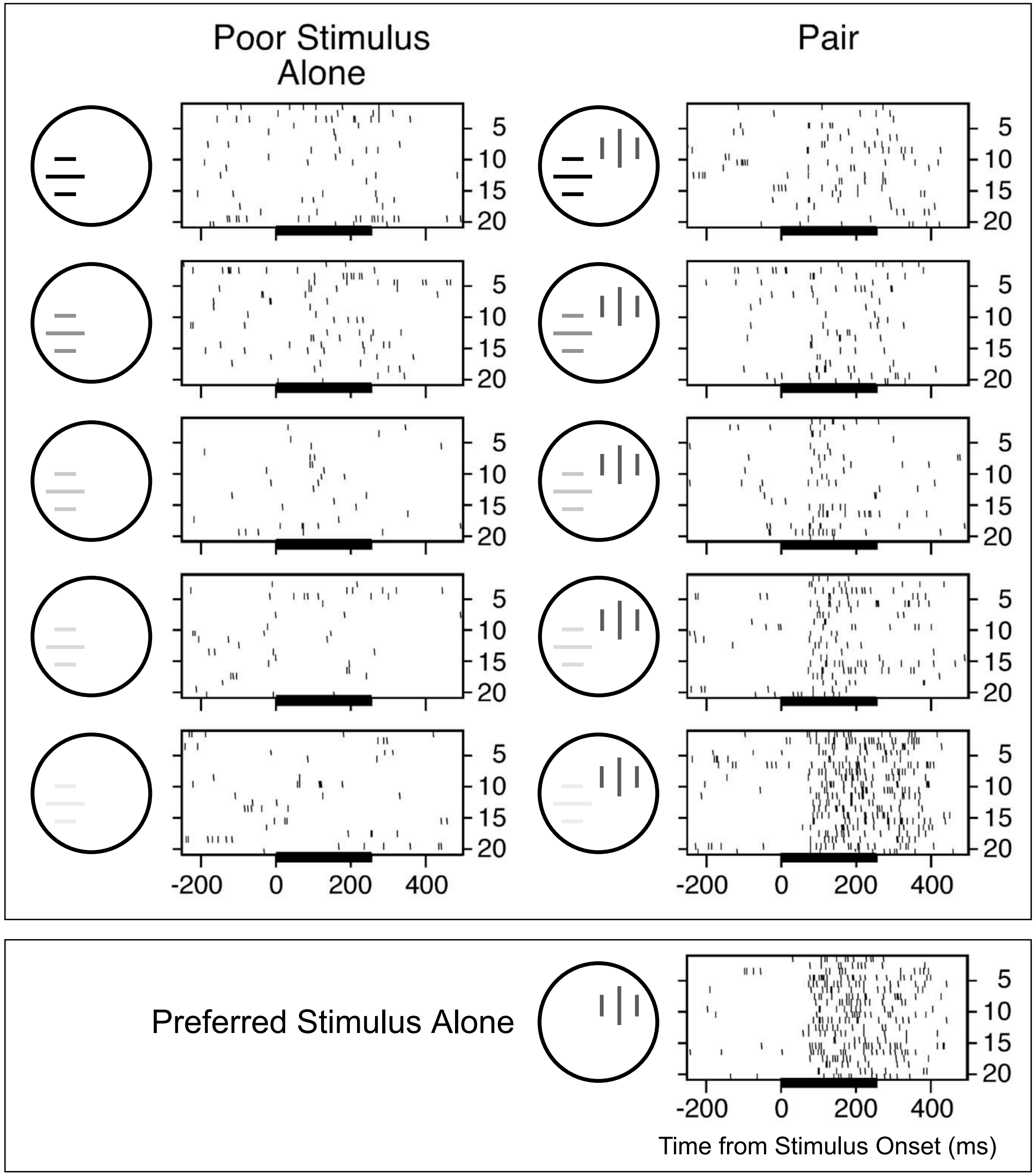
Normalization model



$$\text{normalized response} = \frac{\text{unnormalized response}}{\sum \text{unnormalized responses} + \sigma}$$

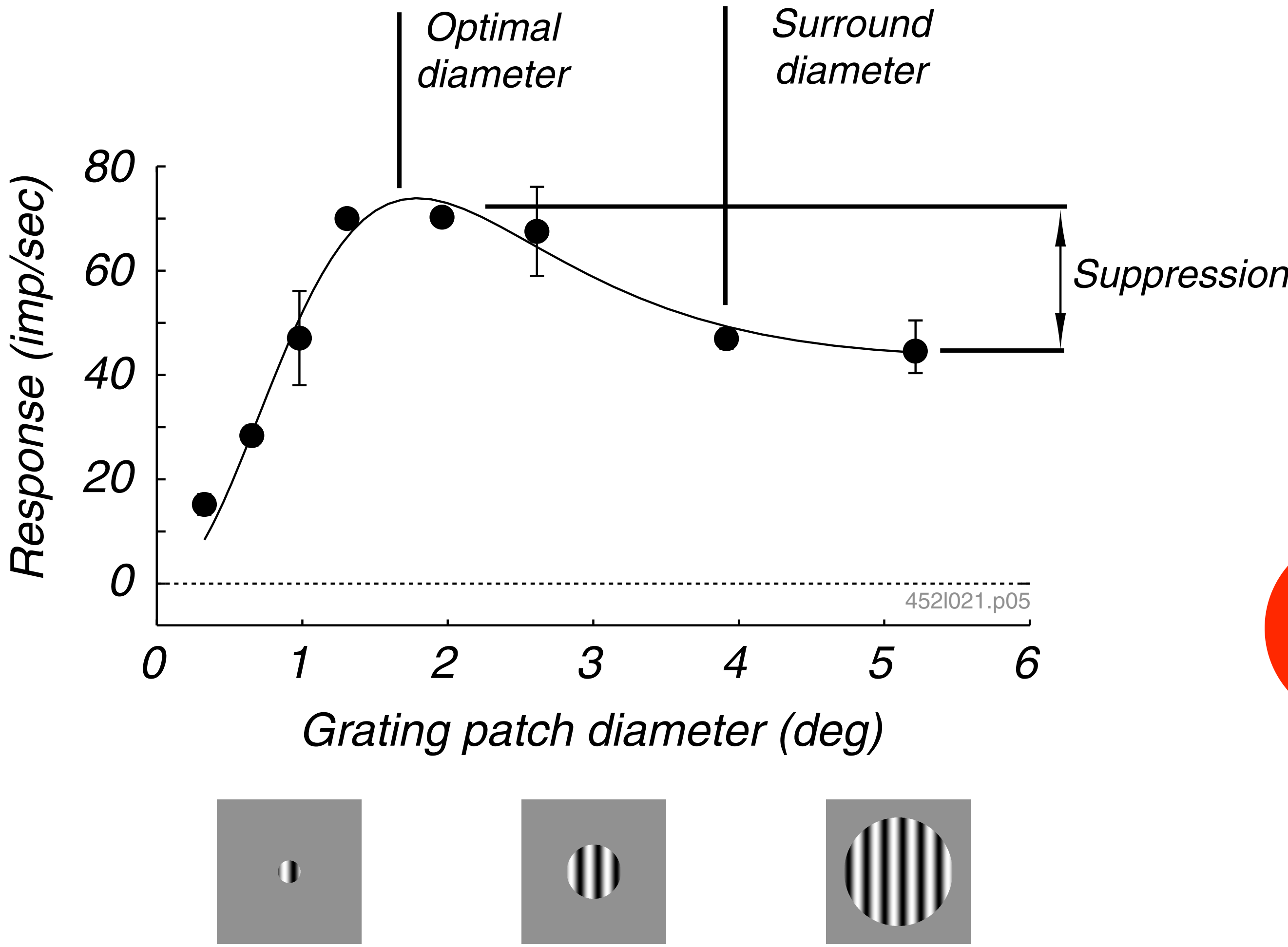
Heeger, Vis Neurosci, 1992

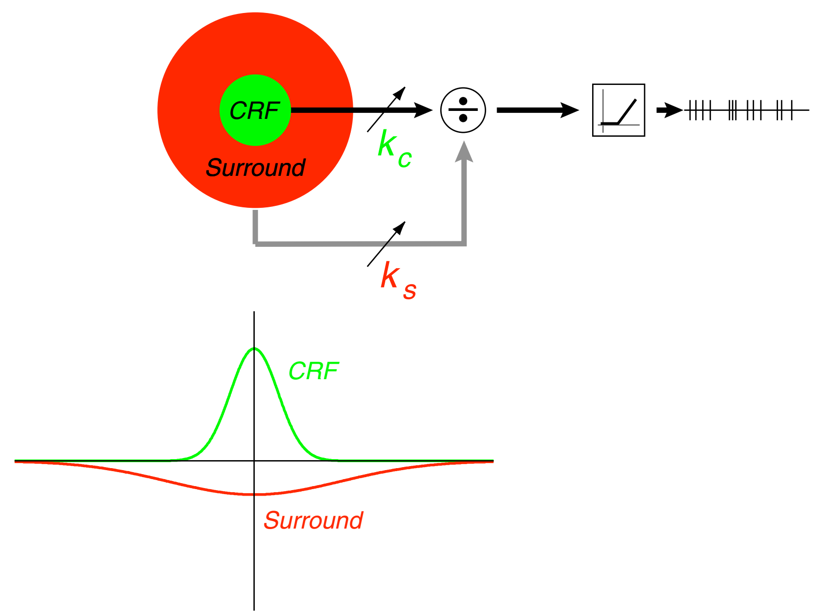
Normalization in V4



Reynolds & Desimone, Neuron, 2003

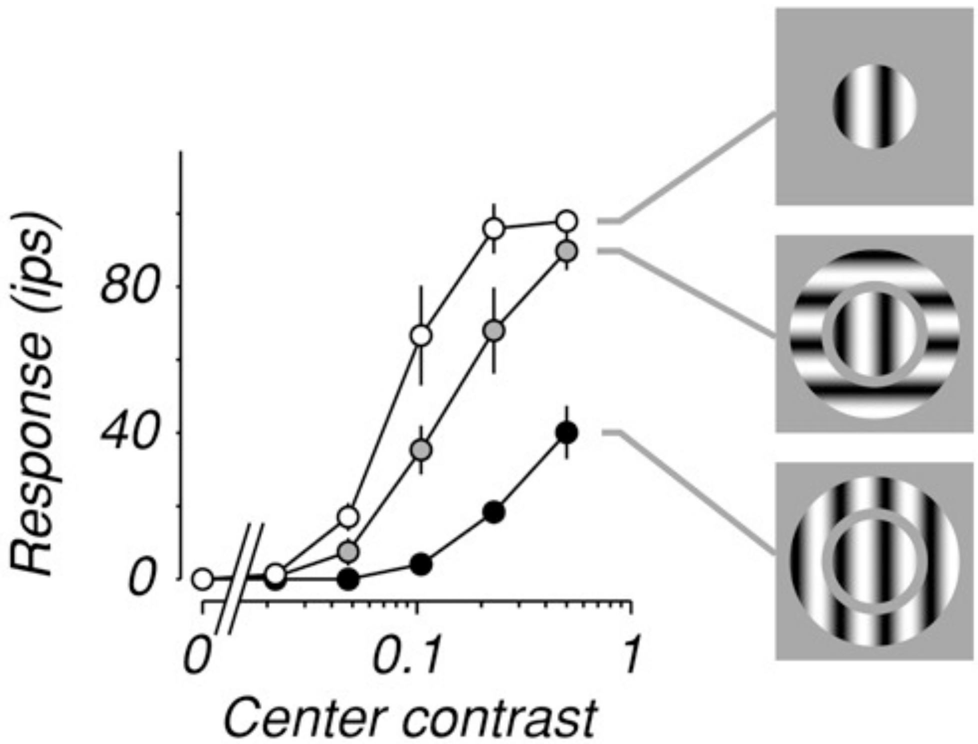
Surround suppression & normalization

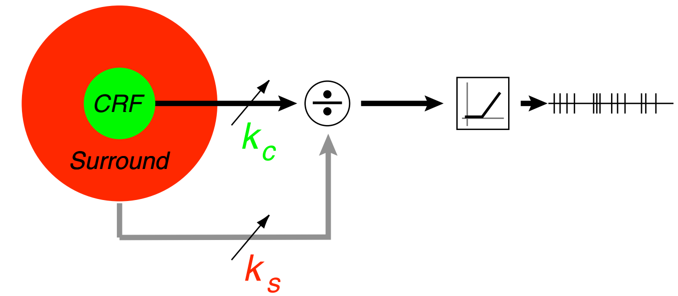


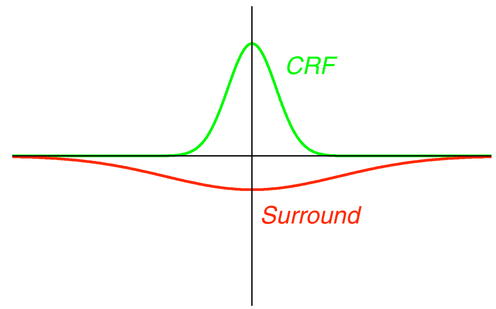


Cavanaugh, Bair & Movshon, J Neurophysiol, 2002

Surround suppression & normalization





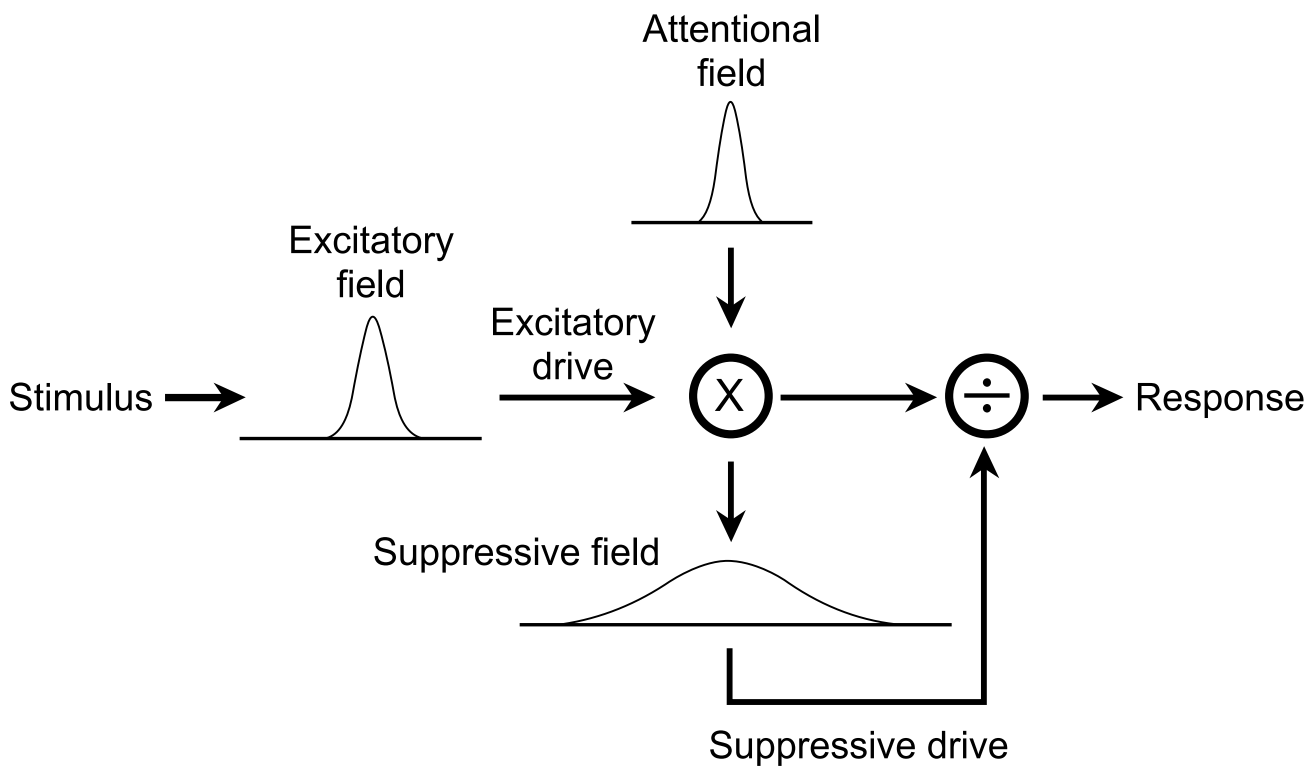


$$R = \alpha \frac{c}{c + \beta c_s + \sigma}$$

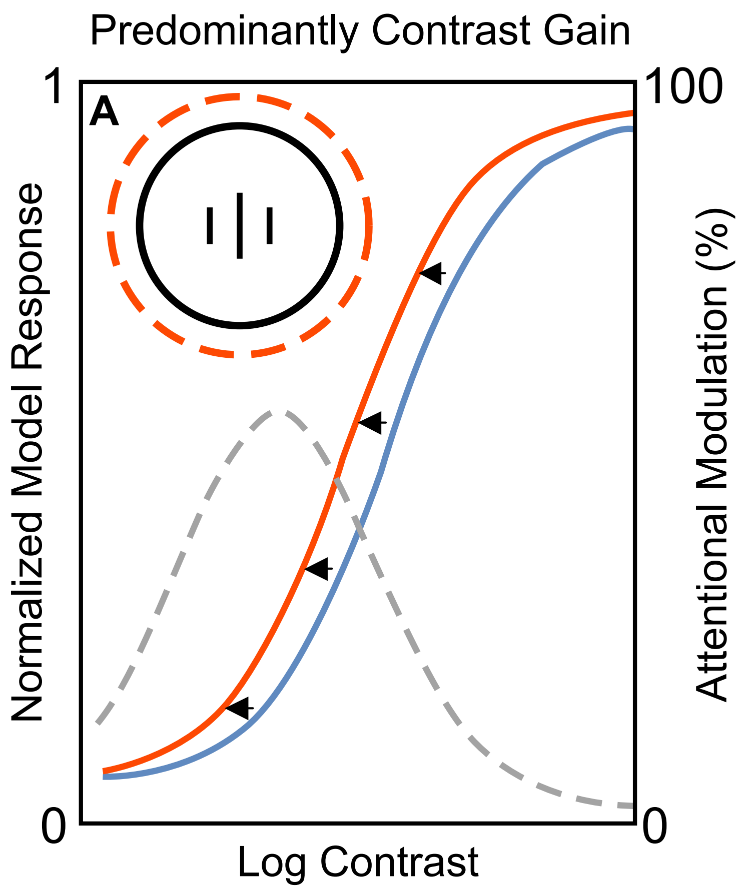
$0 < \beta < 1$ surround suppression

Cavanaugh, Bair & Movshon, J Neurophysiol, 2002

Normalization model of attention



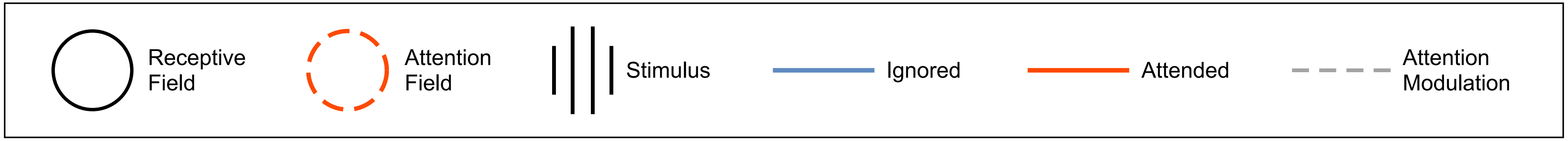
Small stimulus, large attention field



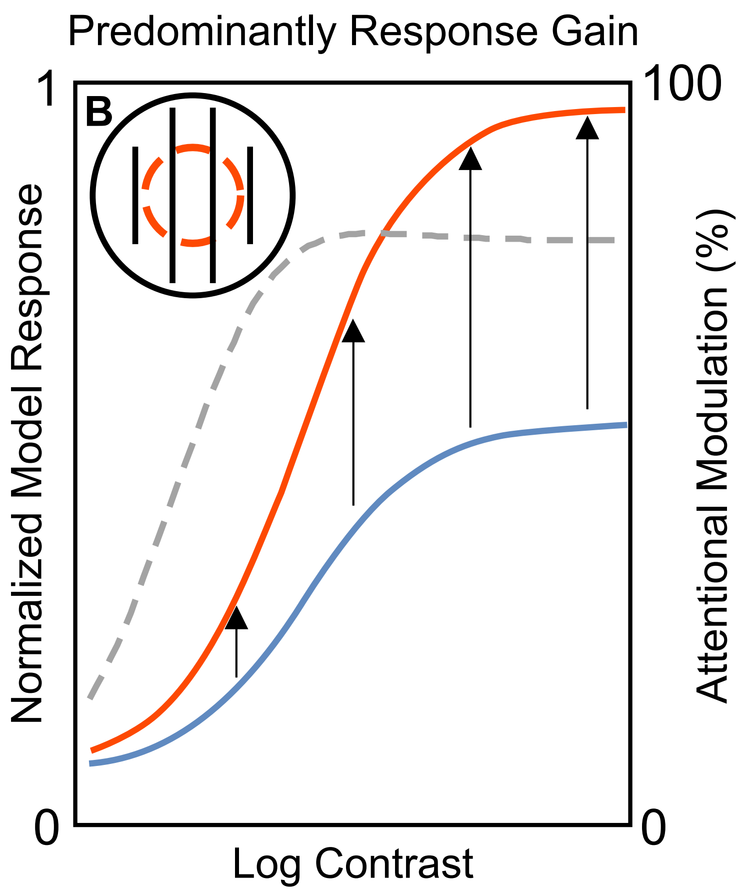
$$R = \alpha \frac{c}{c + \sigma}$$

$$R = \alpha \frac{\gamma c}{\gamma c + \sigma} = \alpha \frac{c}{c + \sigma / \gamma}$$

$\gamma > 1$ attentional gain affects excitatory drive and suppressive drive equally



Large stimulus, small attention field



$$R = \alpha \frac{c}{c + \beta c + \sigma}$$

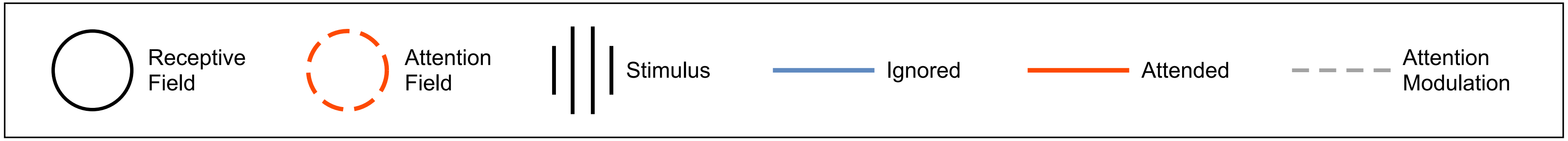
For $c >> \sigma$ $\quad R = \alpha \frac{1}{1 + \beta}$

$$R = \alpha \frac{\gamma c}{\gamma c + \beta c + \sigma}$$

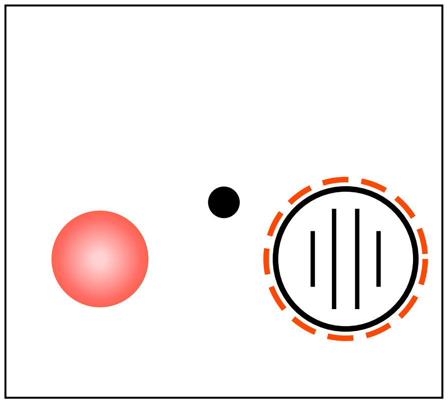
For $c >> \sigma$ $\quad R = \alpha \frac{\gamma}{\gamma + \beta}$

$\gamma > 1$ attentional gain

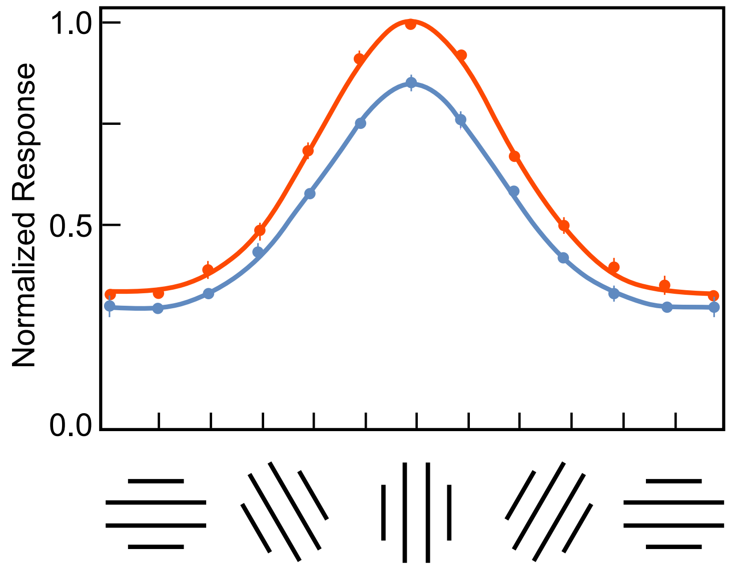
$0 < \beta < 1$ surround suppression



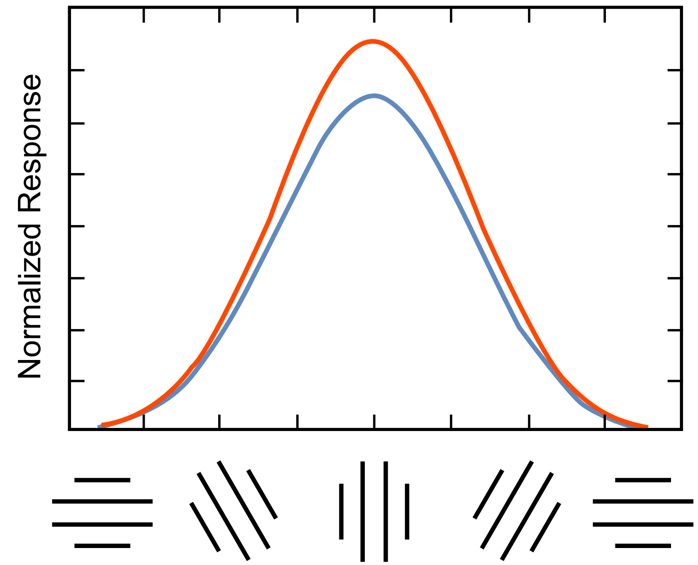
Spatial attention scales tuning curve



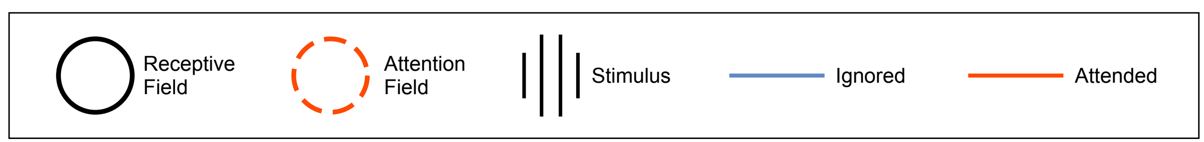
McAdams & Maunsell,
J Neurosci, 1999



Model



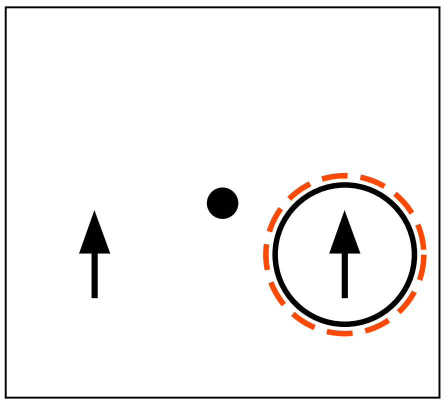
One stimulus within receptive field and the other contralateral.



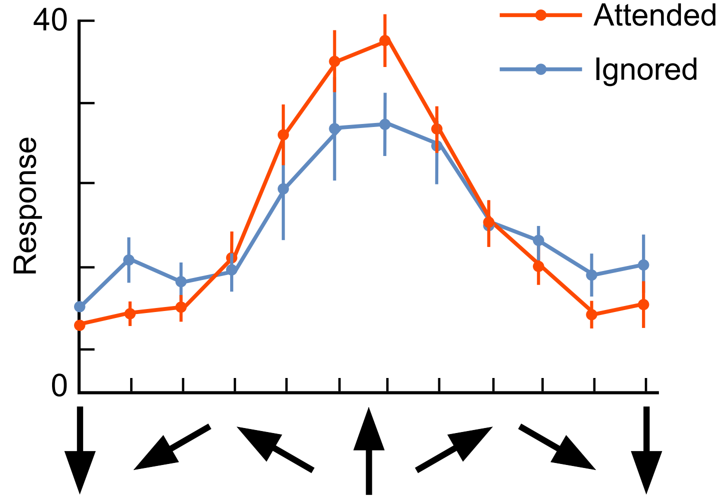
$$R(c,\theta) = \alpha R(c) R(\theta)$$

Separable function of contrast and orientation; change in response gain or contrast gain affects only R(c).

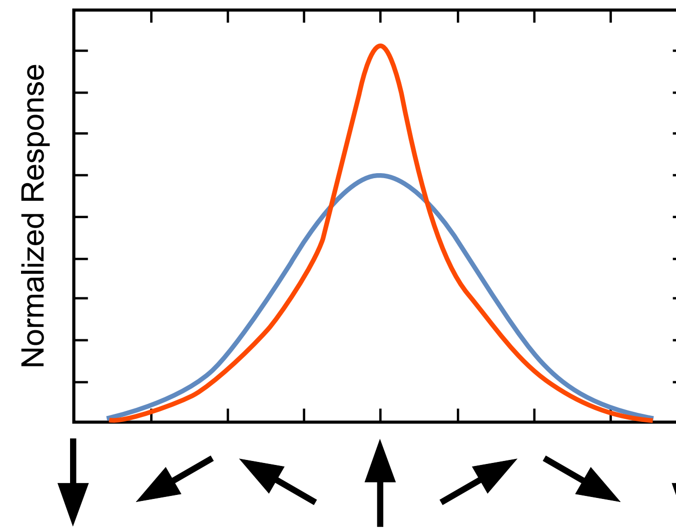
Featural attention can sharpen tuning curves



Treue & Martinez-Trujillo, Nature, 1999



Model



Two stimuli moved same direction on each trial, one within receptive field, and other in opposite hemifield. Attend fixation or attend same motion in opposite hemifield.

$$R(\theta) = \alpha A(\theta) E(\theta)$$

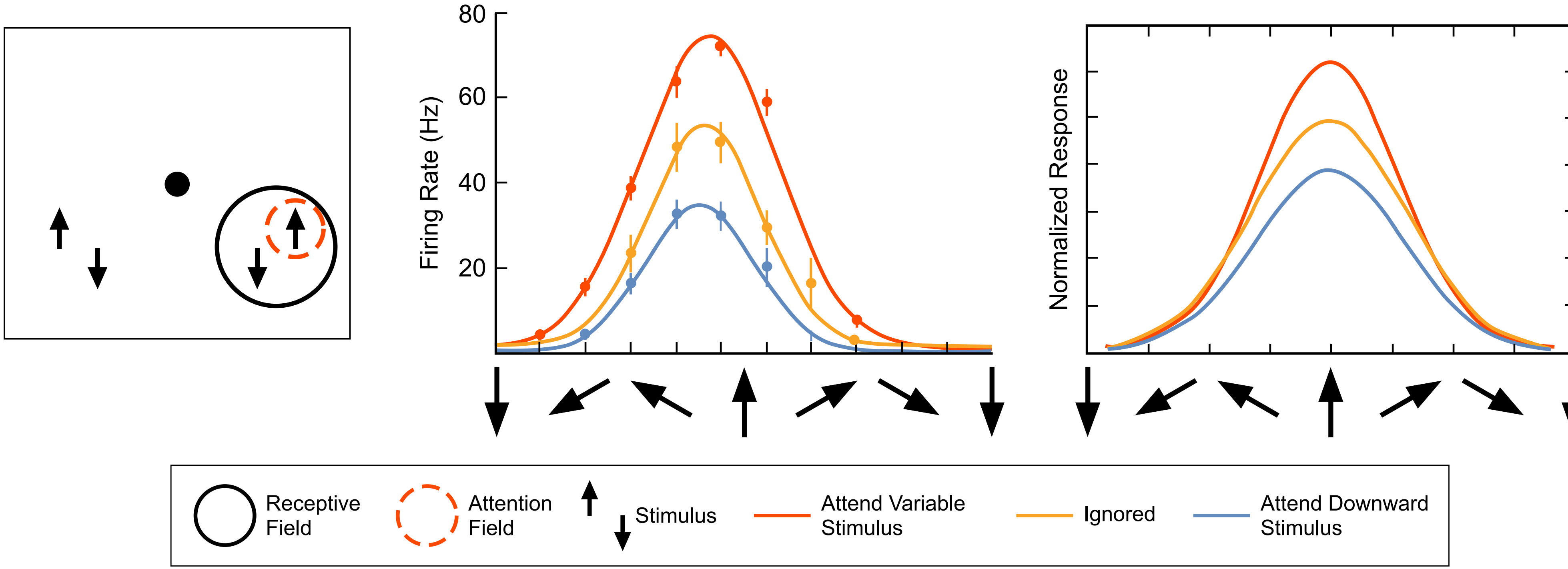
Attention field

Excitatory drive

Attention can increase or decrease gain (selection)

Martinez-Trujillo & Treue, Curr Biol, 2004

Model



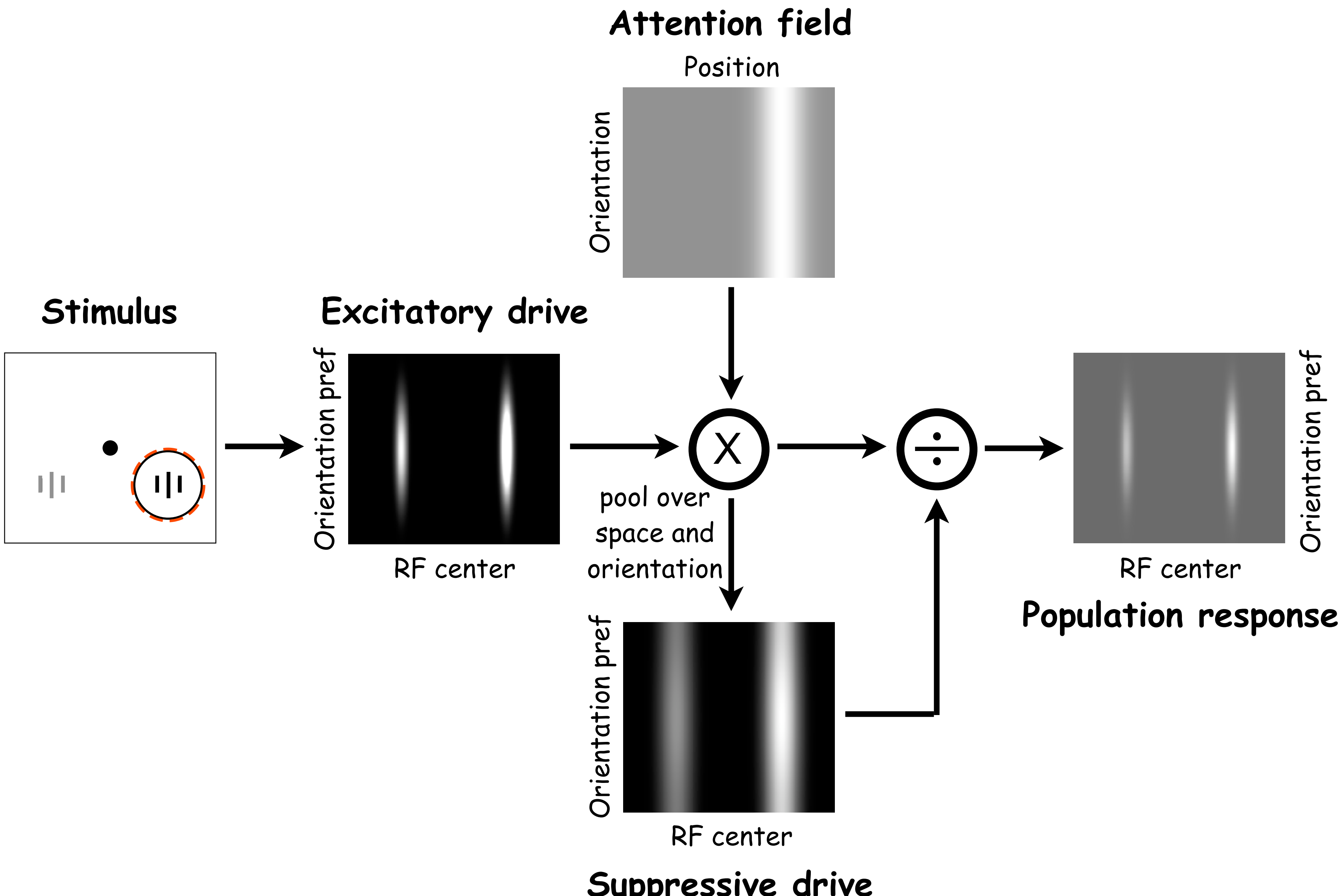
Two stimuli within receptive field. One moved in non-preferred direction. Other direction varied.

$$R_f(\theta) = \alpha E(\theta) / (k + \sigma)$$

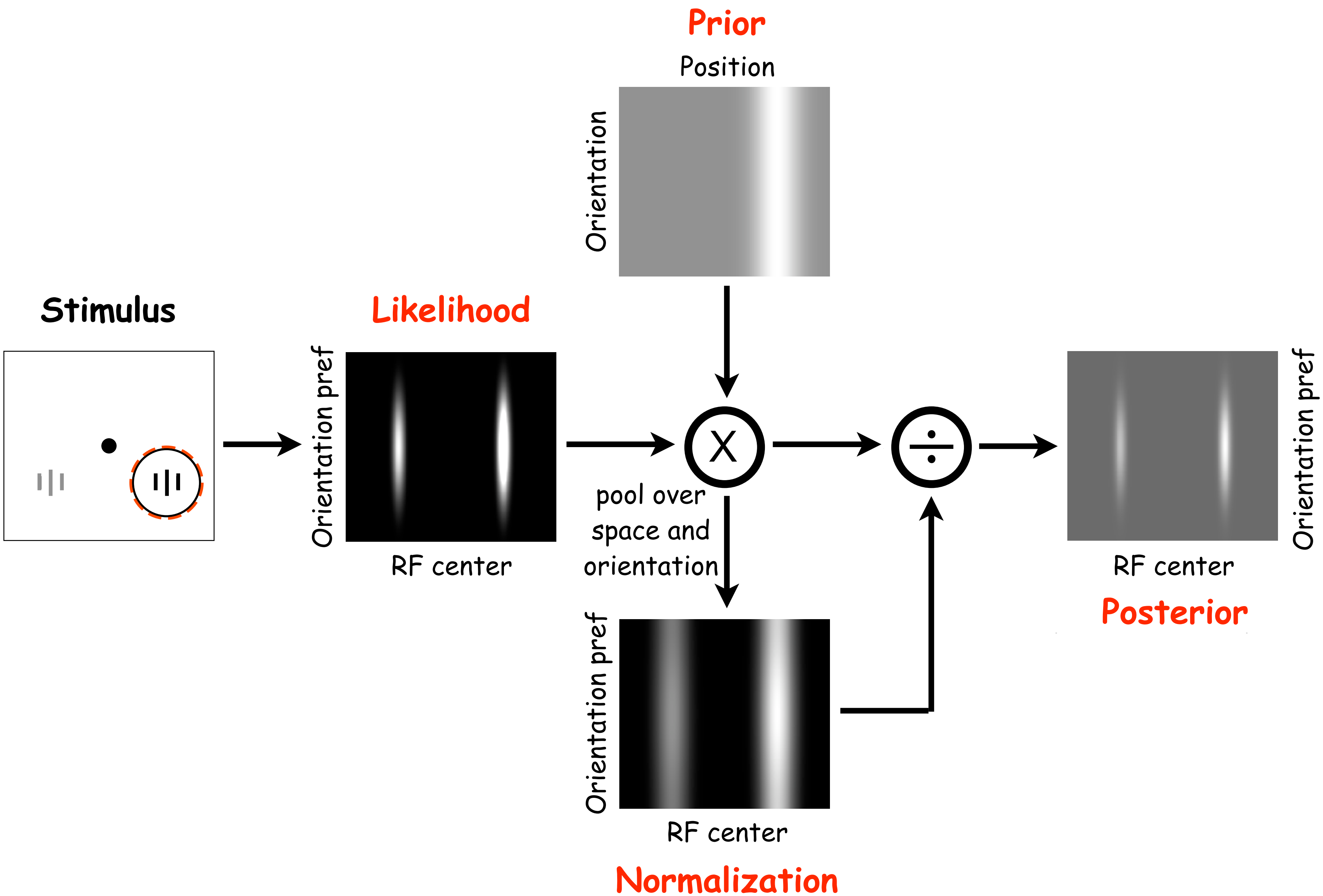
$$R_n(\theta) = \alpha E(\theta) / (\gamma k + \sigma)$$

$$R_v(\theta) = \alpha A(\theta) E(\theta) / (\gamma k + \sigma)$$

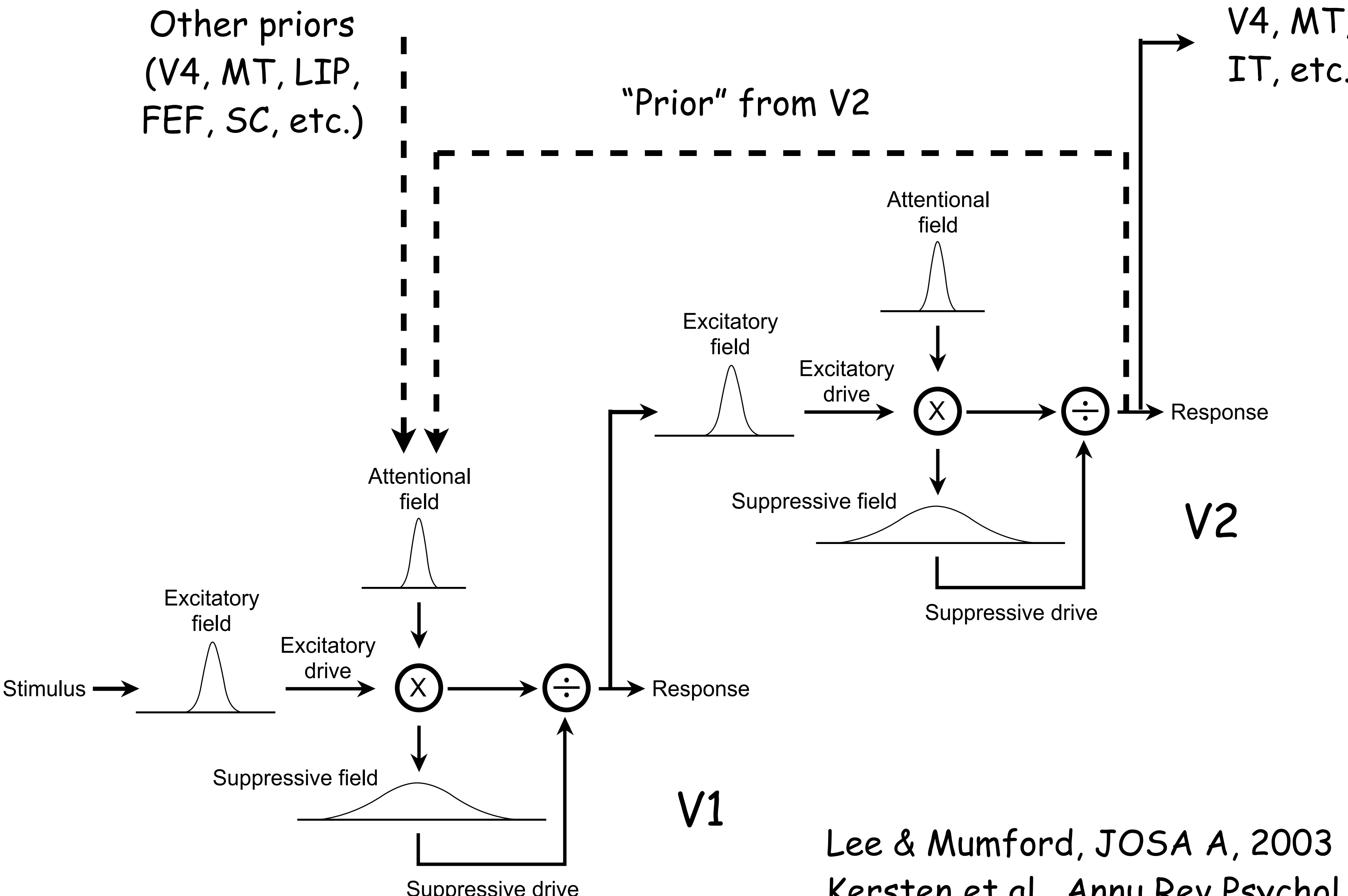
Bayesian inference



Bayesian inference



Hierarchical Bayesian Inference



Lee & Mumford, JOSA A, 2003

Kersten et al., Annu Rev Psychol, 2004