Spatial context, salience and eye movements

Computational neuroscience class
Odelia Schwartz, 2021

- Midterm assignments (graded)
- Final Projects / assignments
- Other questions

Final projects / assignments
Initial discussion

Choosing one of the following options:

1. You can work in a group on a project (if you are comfortable doing so remotely), or individually on a project. Projects can be done in any programming language. Ideally, group projects include multiple disciplines. Please discuss with me.

2. In liu of a project, you can hand in an individual assignment, in which you either extend one lab as a project (please discuss with me); or choose two of the upcoming labs, explain the labs and answer the questions at the end.

3. Students who do not have a CS or Engineering background can hand in a discussion about a computational neuroscience paper. You can choose one of the papers that we discuss in class (I will make this more explicit, providing a choice of papers). Please discuss with me.

Spatial context

Spatial context

Contextual influences

- Perceptual illusions: “no man is an island..”

Review paper on context:
Schwartz, Hsu, Dayan, Nature Reviews Neuroscience 2007

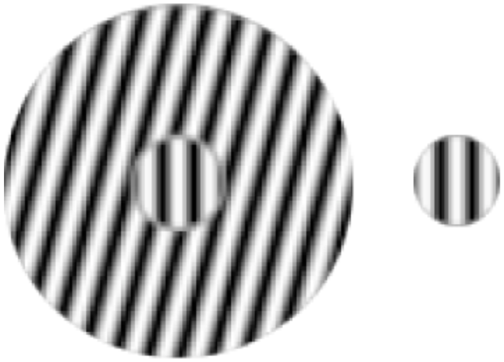
Contextual influences

- Perceptual illusions: “no man is an island..”

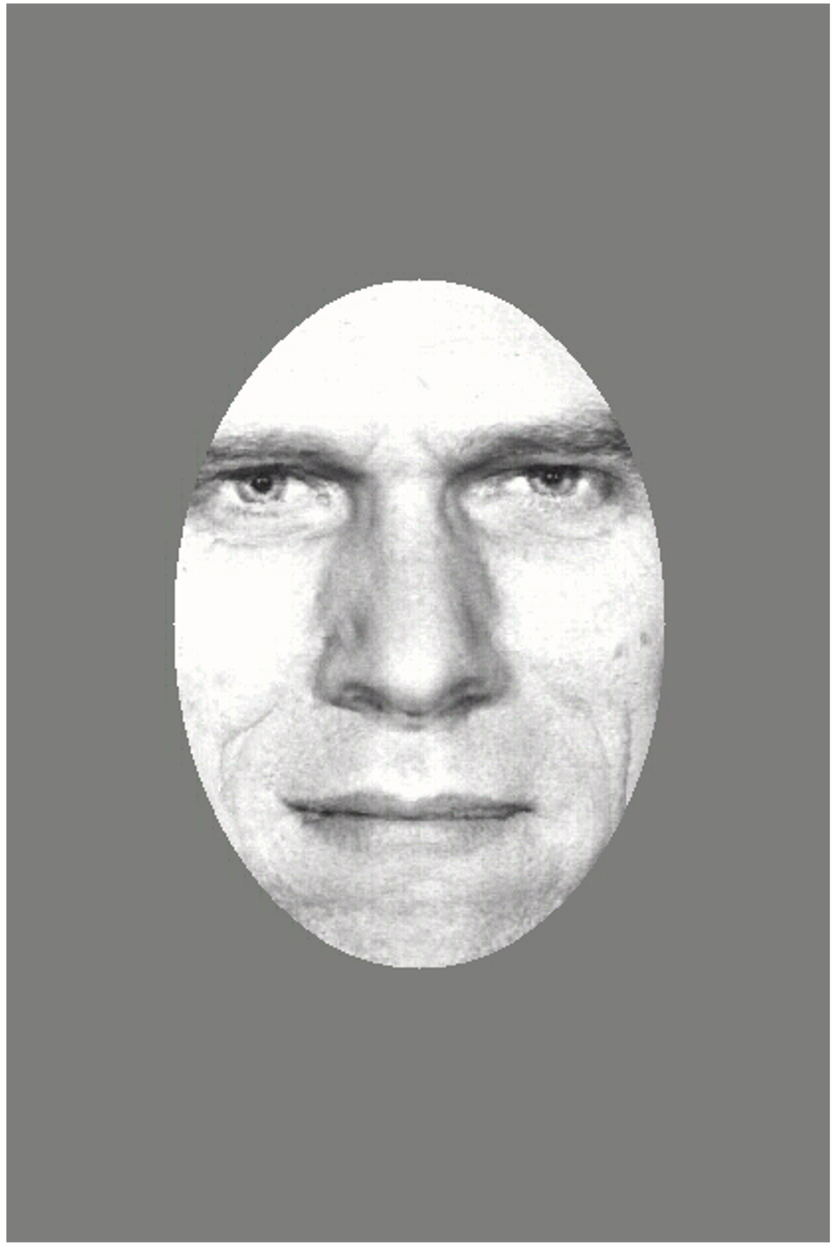
Review paper on context:
Schwartz, Hsu, Dayan, Nature Reviews Neuroscience 2007

Contextual influences

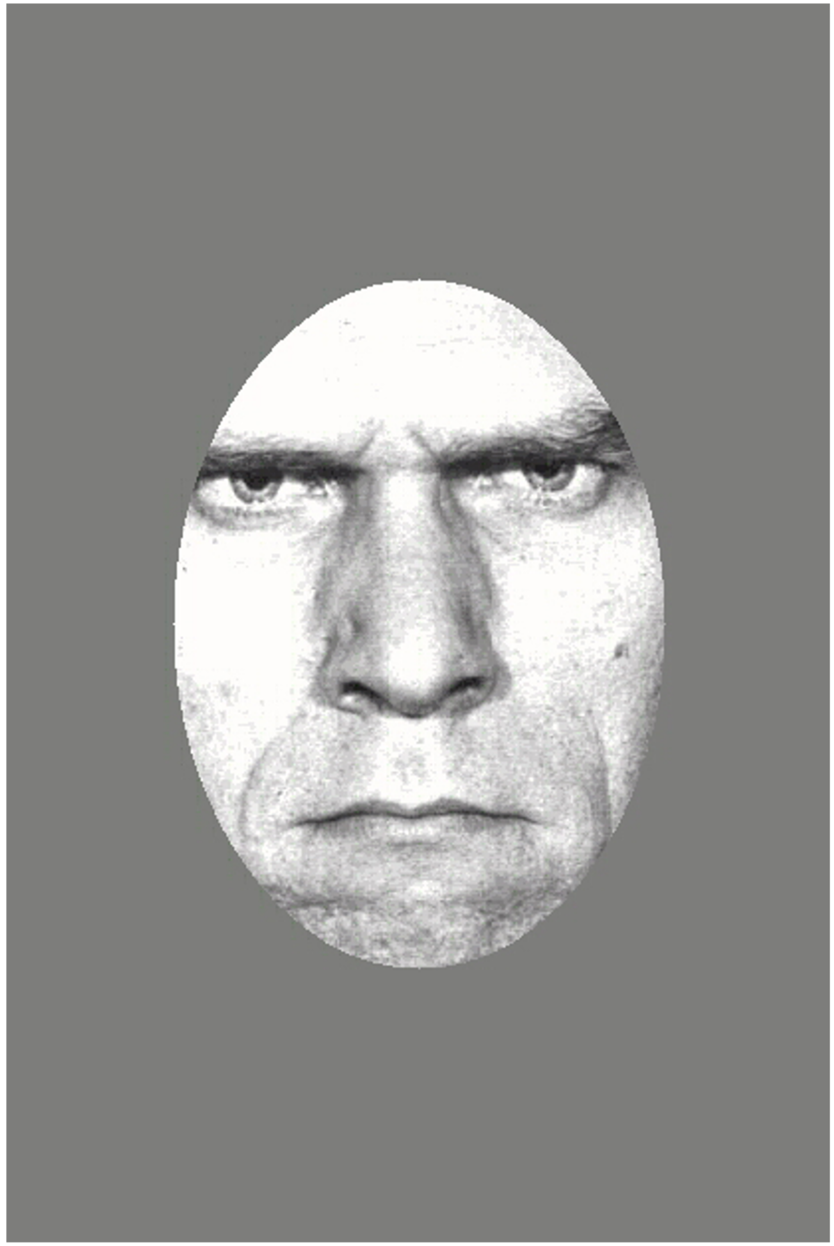
- Perceptual illusions



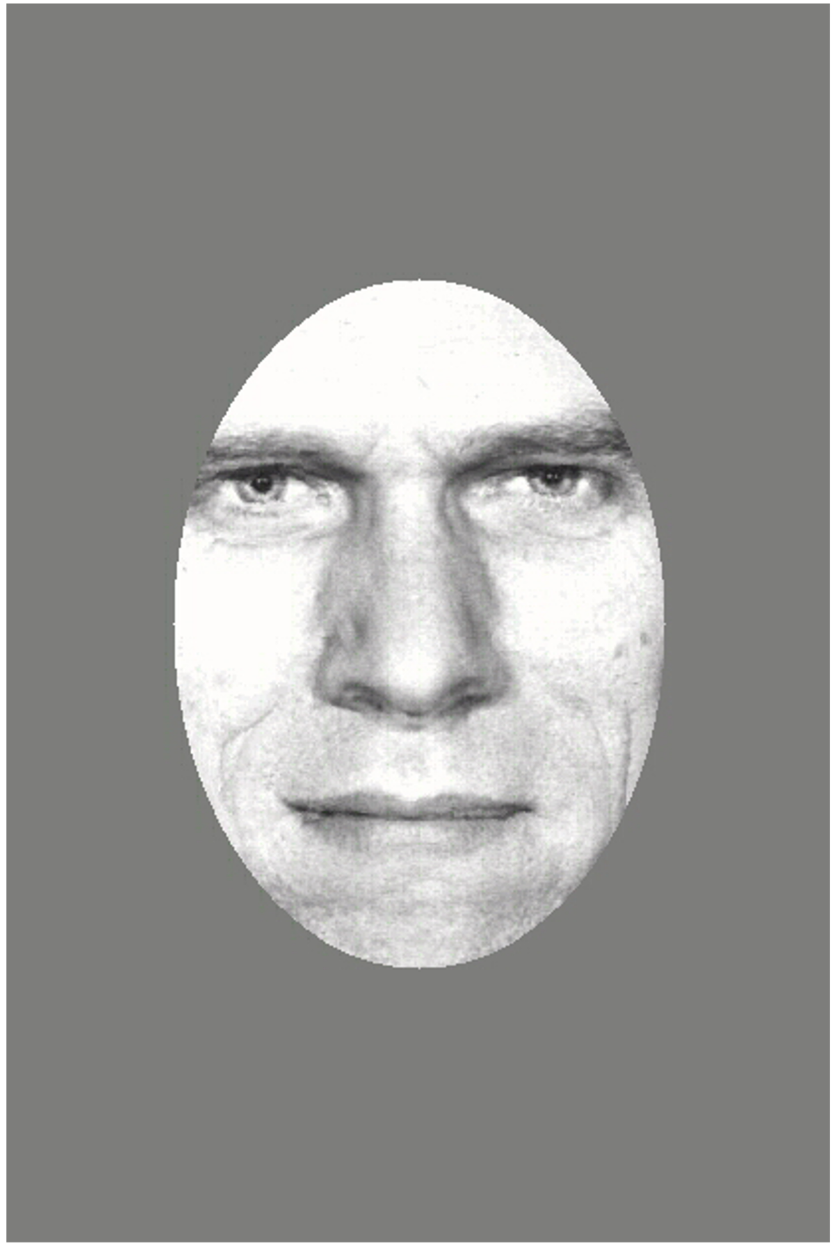
Contextual effects in time...



Adaptation to expression: pre-adapt (from Michael Webster)



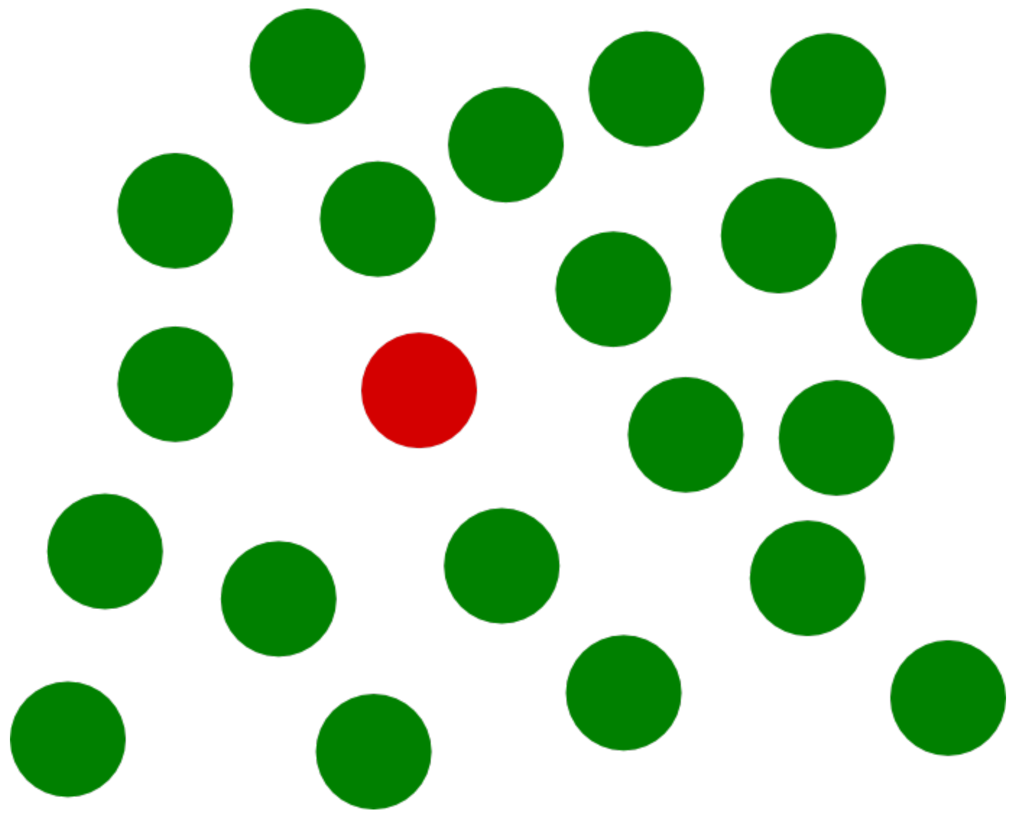
adapt



post-adapt

Contextual influences

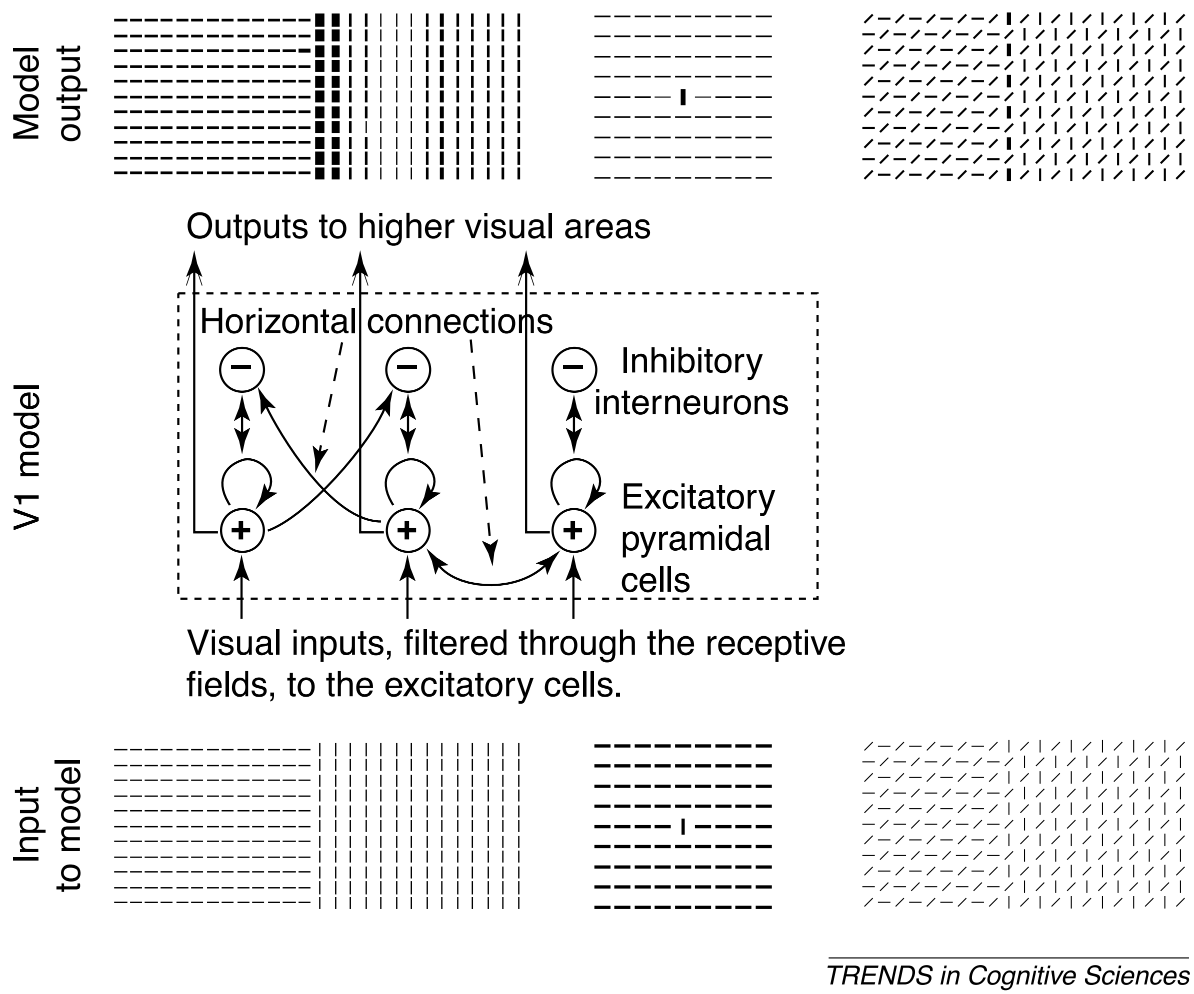
- Visual salience



Contextual influences

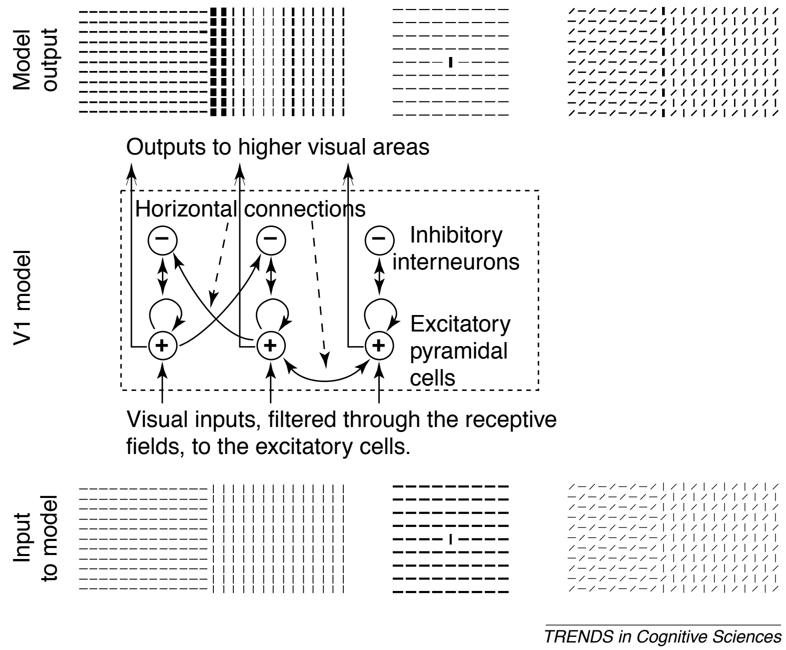
- Visual salience

Salience model of V1 (Zhaoping)



Li Zhaoping, Trends in Cognitive Sciences, 2002.

Salience model of V1 (Zhaoping)



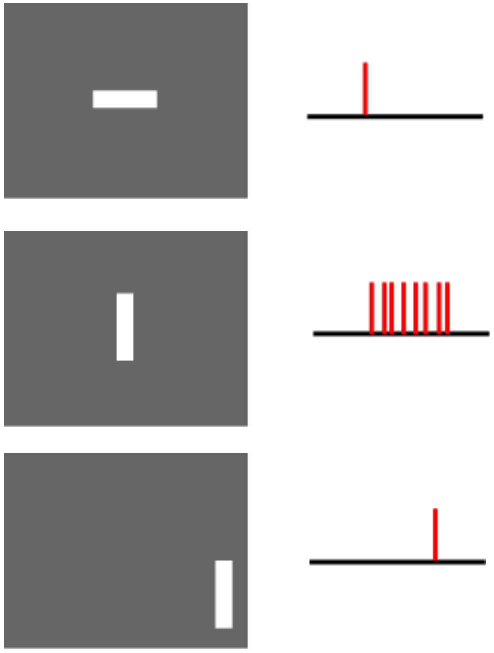
- Dynamical circuit model
- V1 salience map
- Salience as breakdown of statistical homogeneity

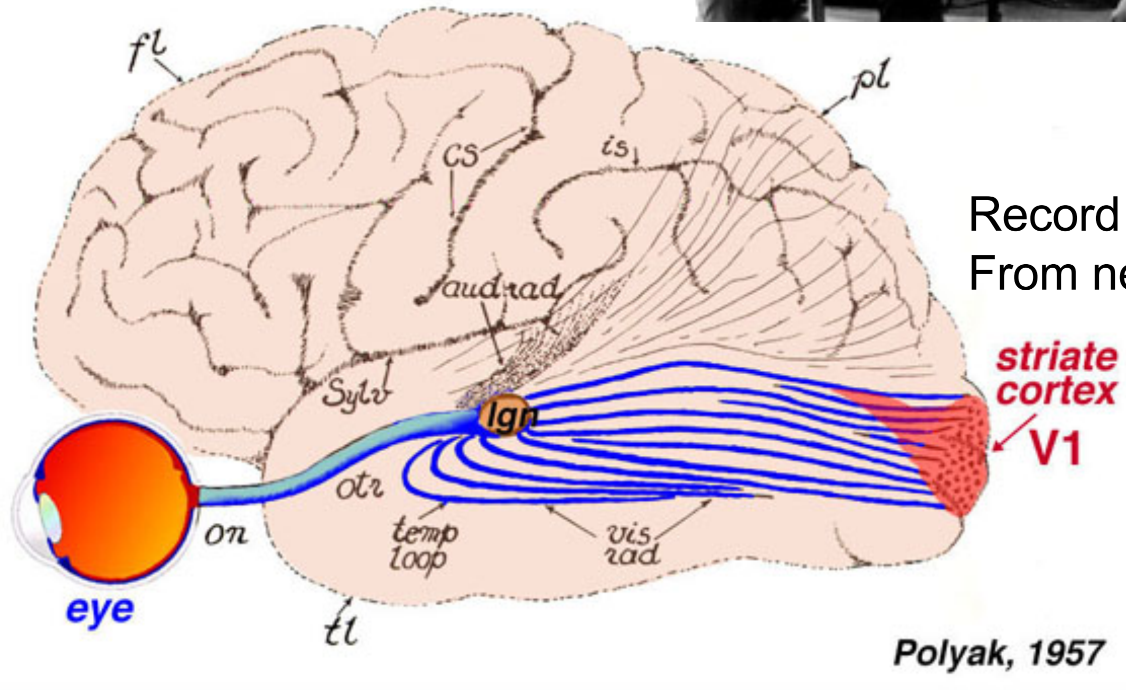
Li Zhaoping, Trends in Cognitive Sciences, 2002.

Surround context (non classical receptive field) effects in visual neurons

What about neurons?

- Cortical neural processing

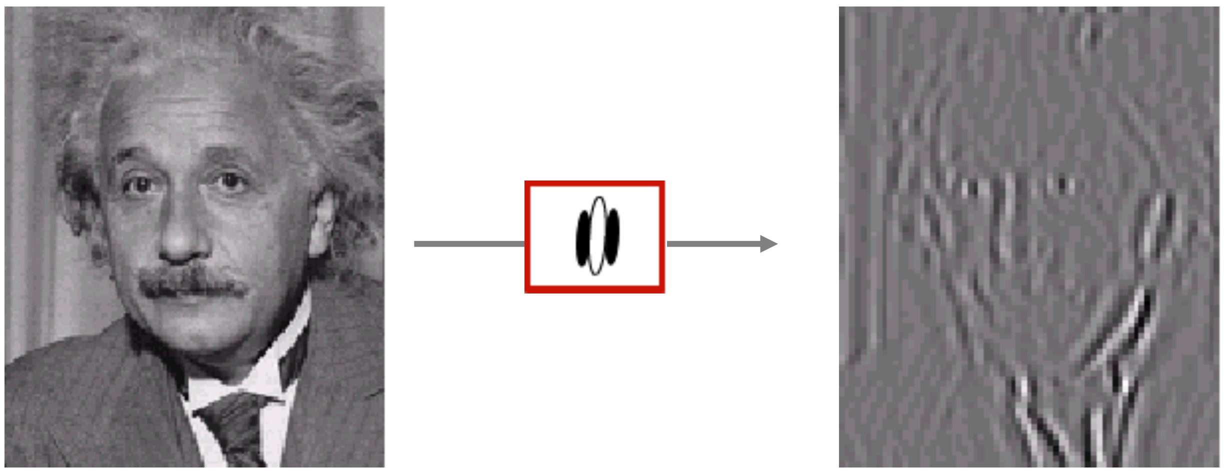




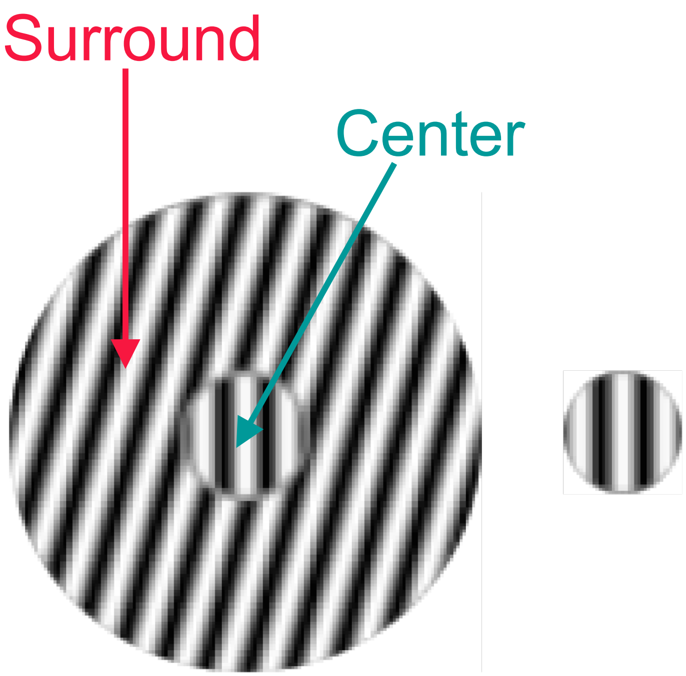
Record
From neuron

What about neurons?

- Computer science / Engineering: visual receptive field or filter

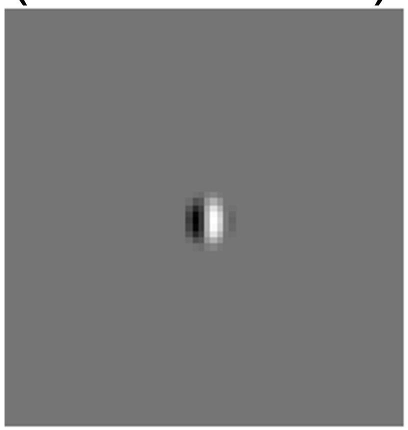


Focus: spatial surround context



Visual cortex: non classical RF

Center (classical RF)



Large response

Surround (non classical RF)

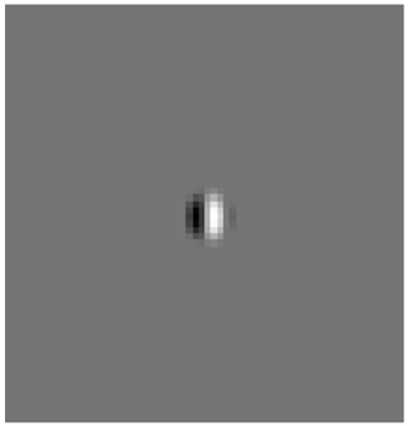
No response

Surround stimulus defined such that by itself there is no response in the neuron

Visual cortex: spatial surround

Stimulus

Center (classical RF)

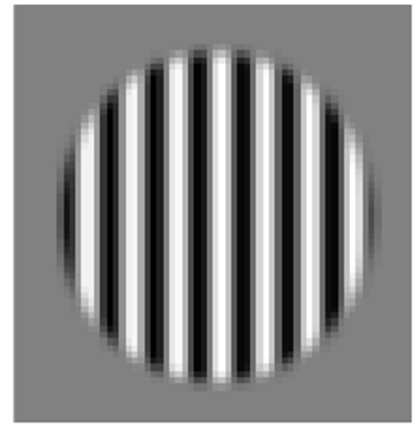


Large response

Surround (non classical RF)

No response

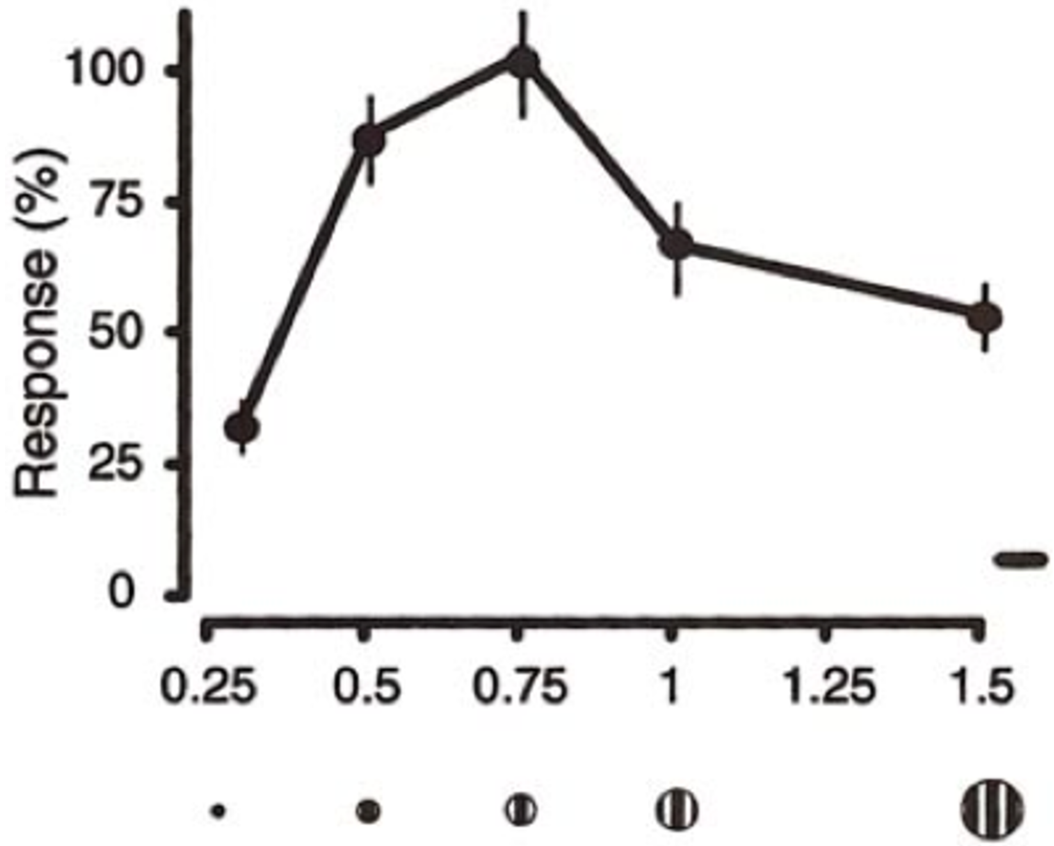
Center & surround



Suppressed response

But surround stimulus can modulate response to center. Cortical neurons are affected by spatial context (often reduced response, as illustrated by spiking cartoon).

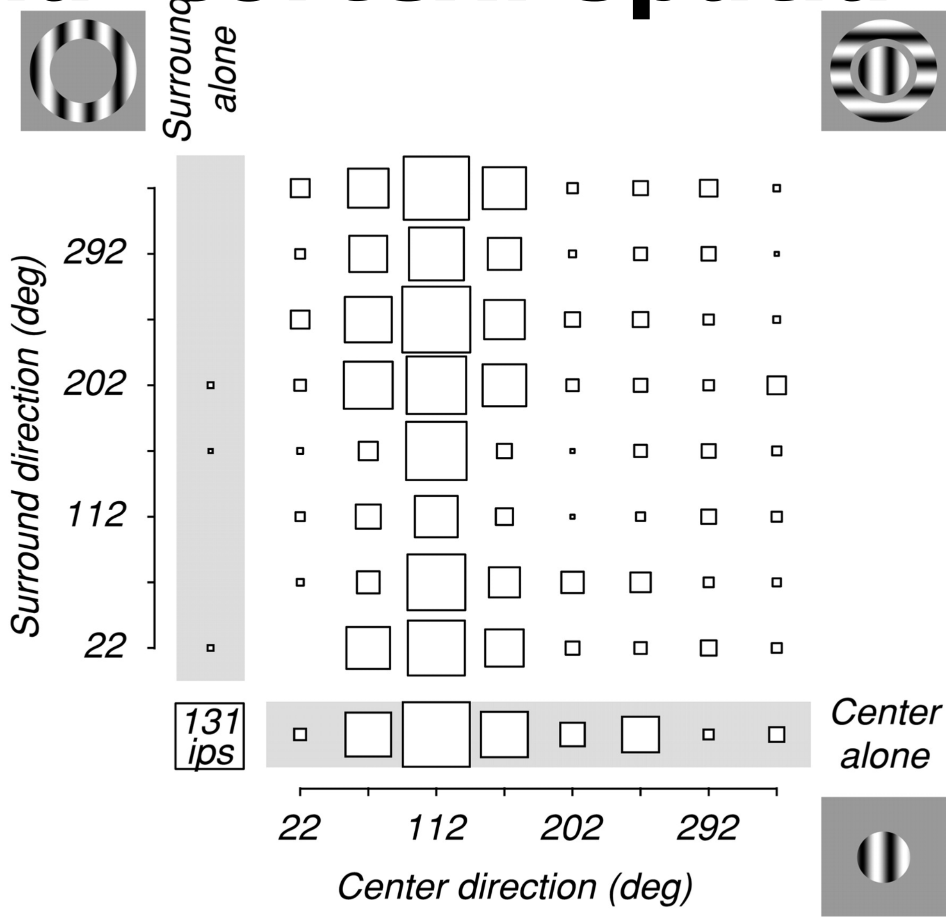
Visual cortex: spatial surround



Jones and Silito, 2001

Response reduced as stimulus size (spatial context) made larger

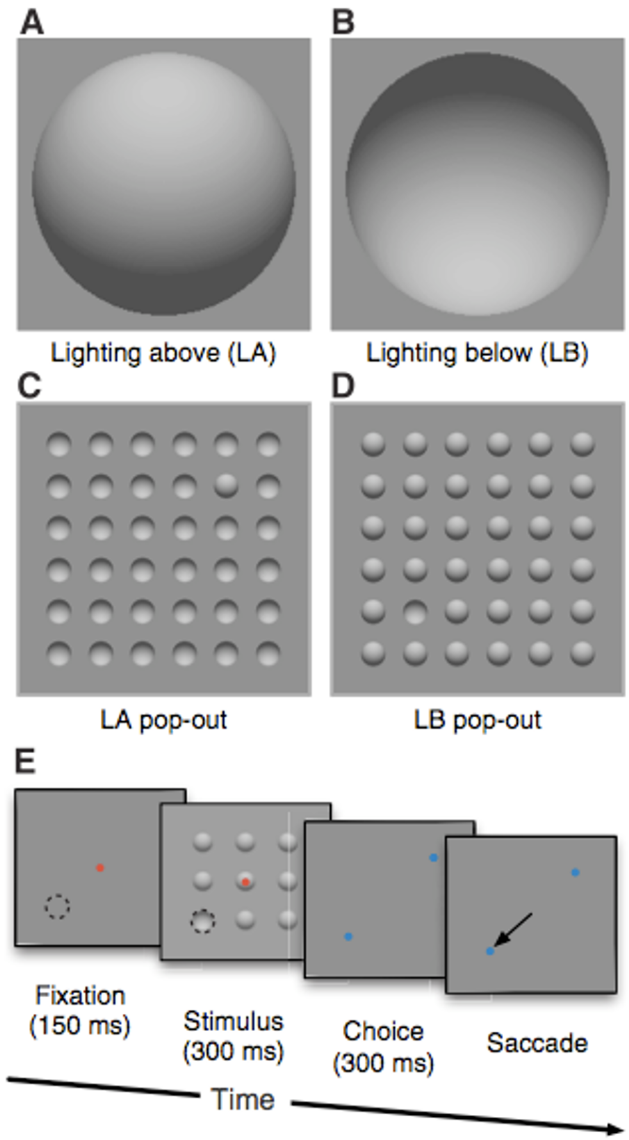
Visual cortex: spatial surround



Response reduced most when the center and surround stimuli have the same orientation

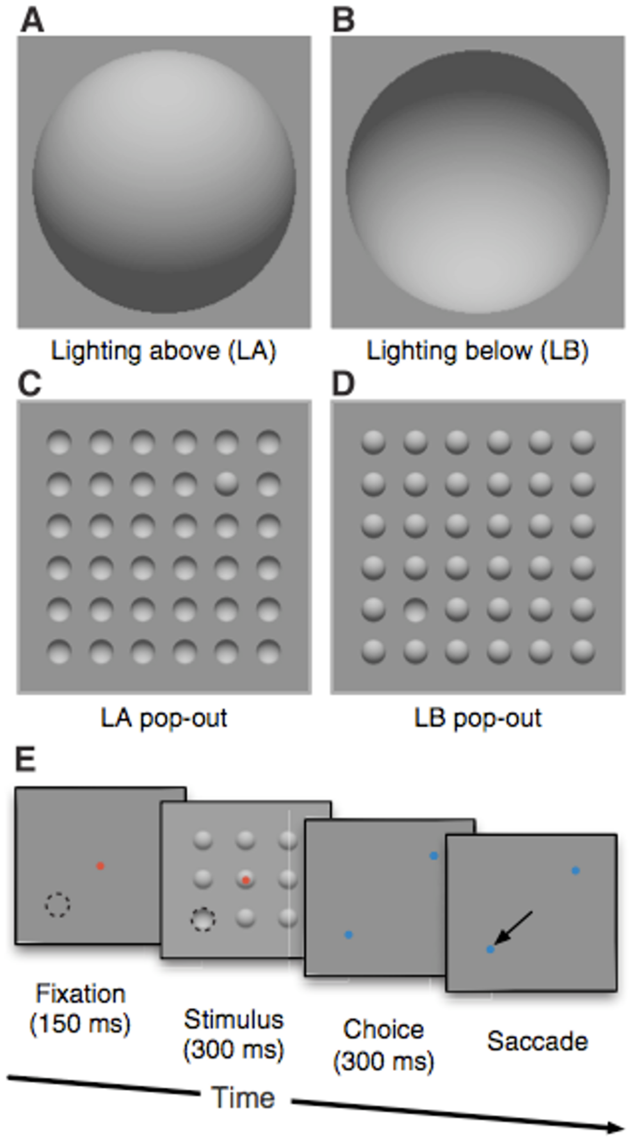
Cavanaugh et al. 2002

Context by other visual cues?



Smith et al. 2007

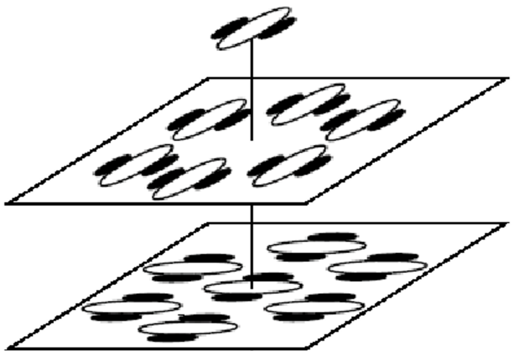
Context by other visual cues?



Which one pops out more?

Smith et al. 2007

Simple descriptive model of cortical surround effects



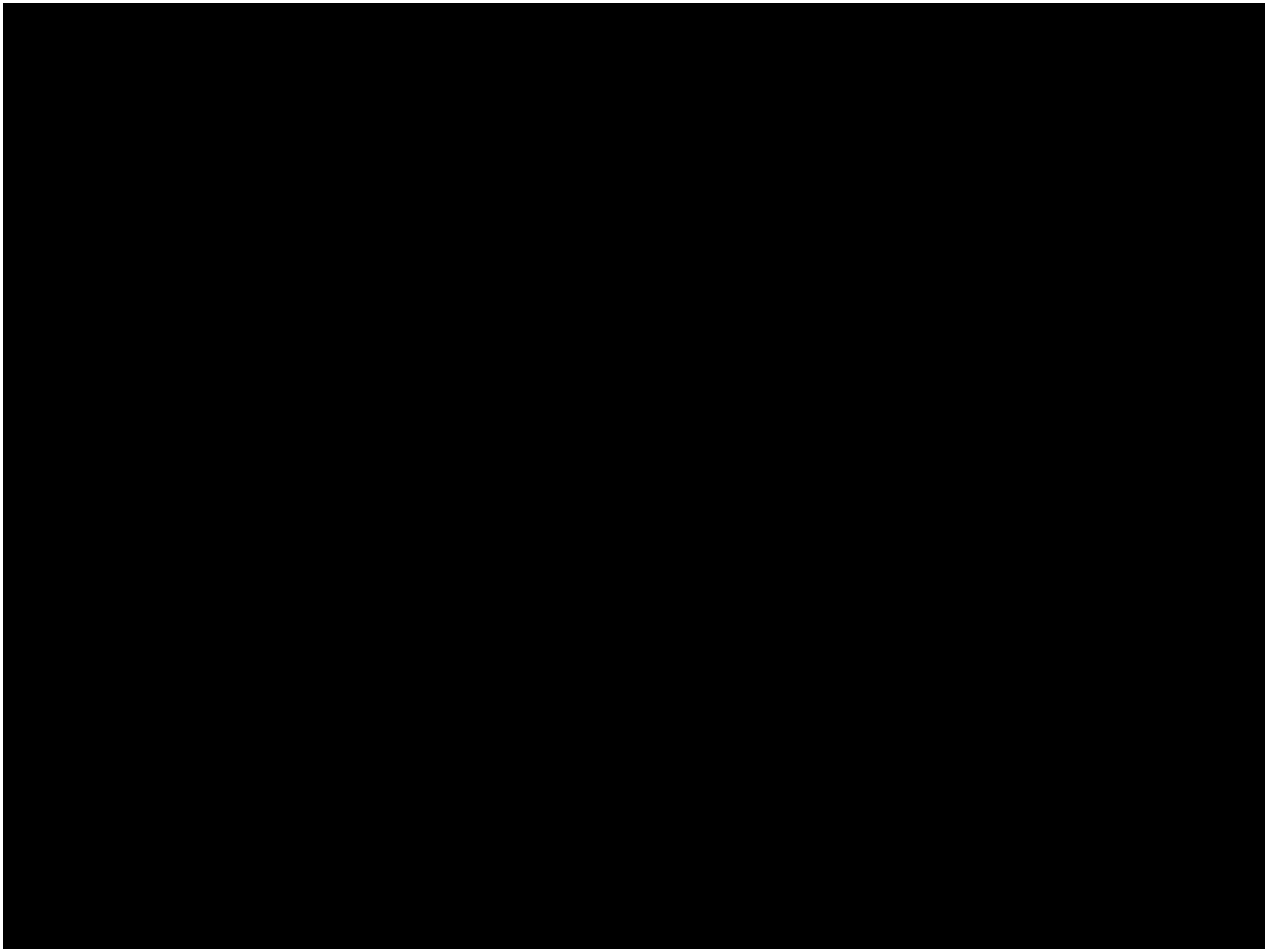
$$R_i = \frac{L_i^2}{\sum_j w_{ji} L_j^2 + \sigma^2}$$

Linear filters followed by nonlinearity (divide by surround responses)

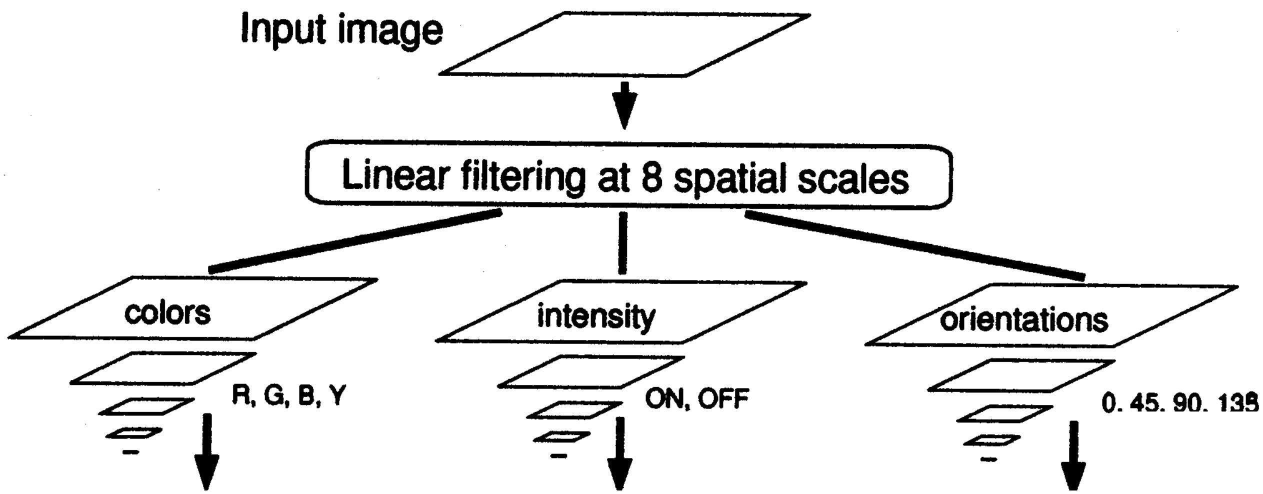
After Heeger 1992

Eye movements and salience

Example 1: Eye movements and salience (Laurent Itti, University of Southern California)

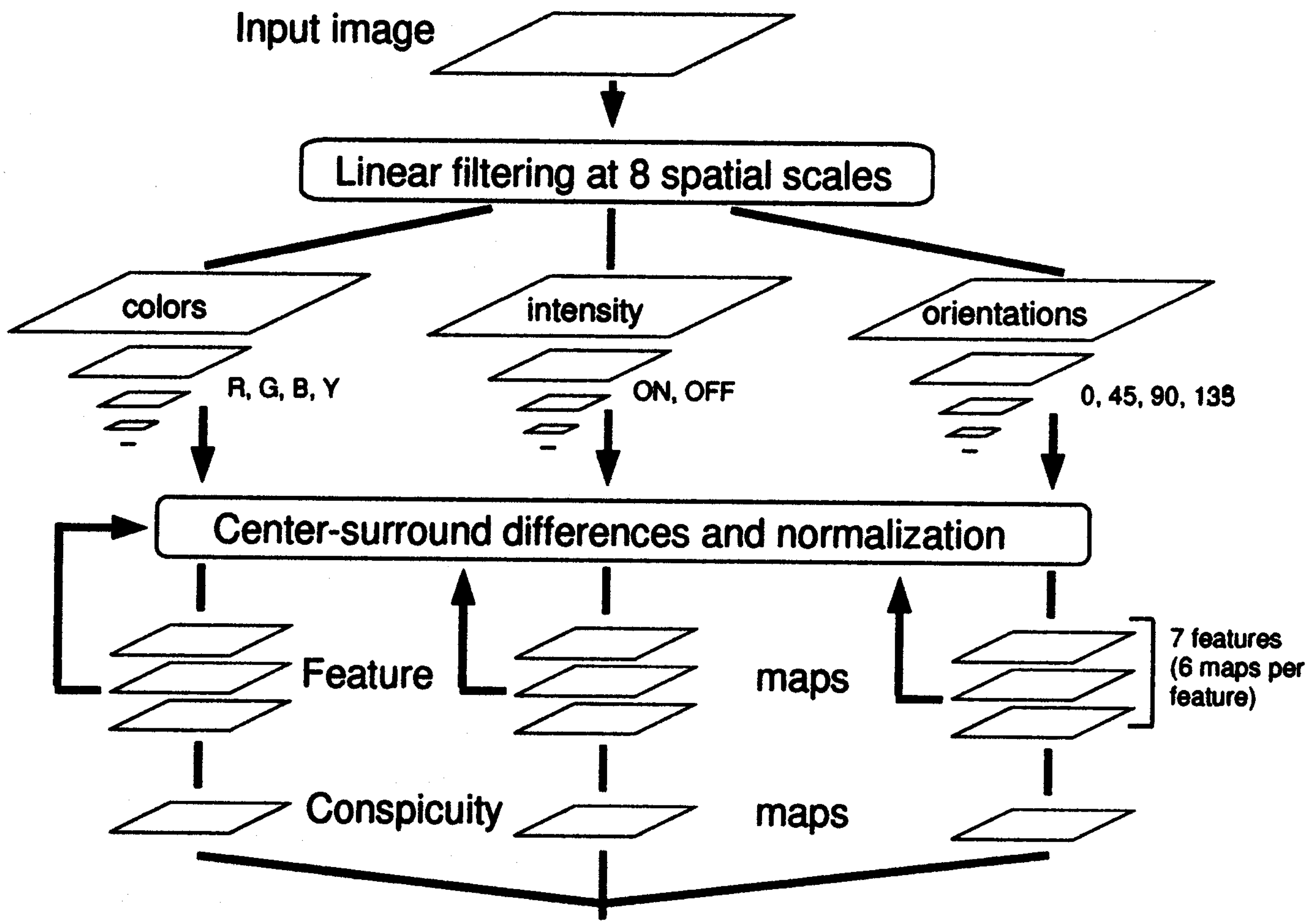


Eye movements and salience (Itti and Koch, 2000)



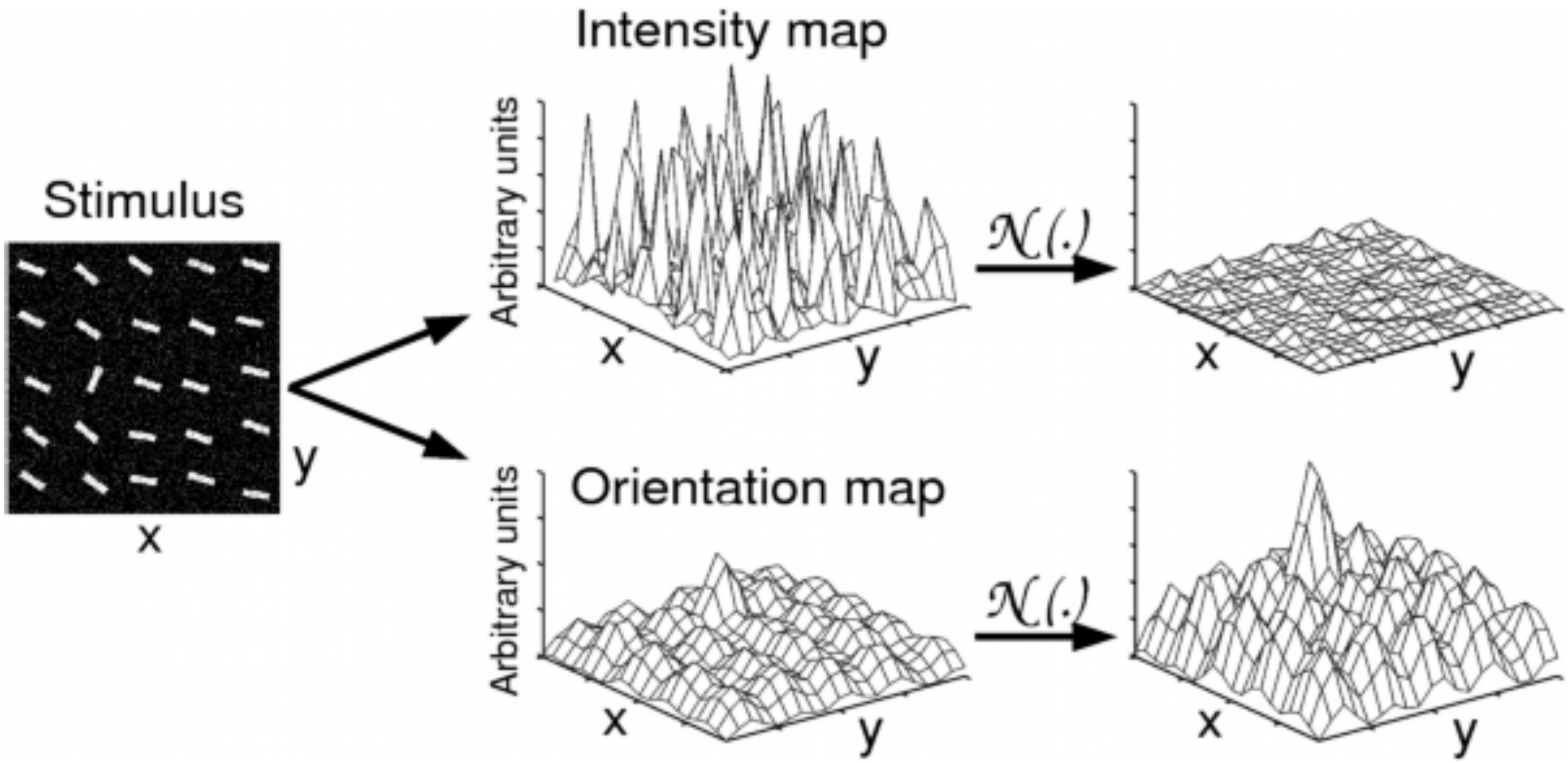
Analyze salience for different features:
Colors, intensity, orientations ….

Eye movements and salience (Itti and Koch, 2000)



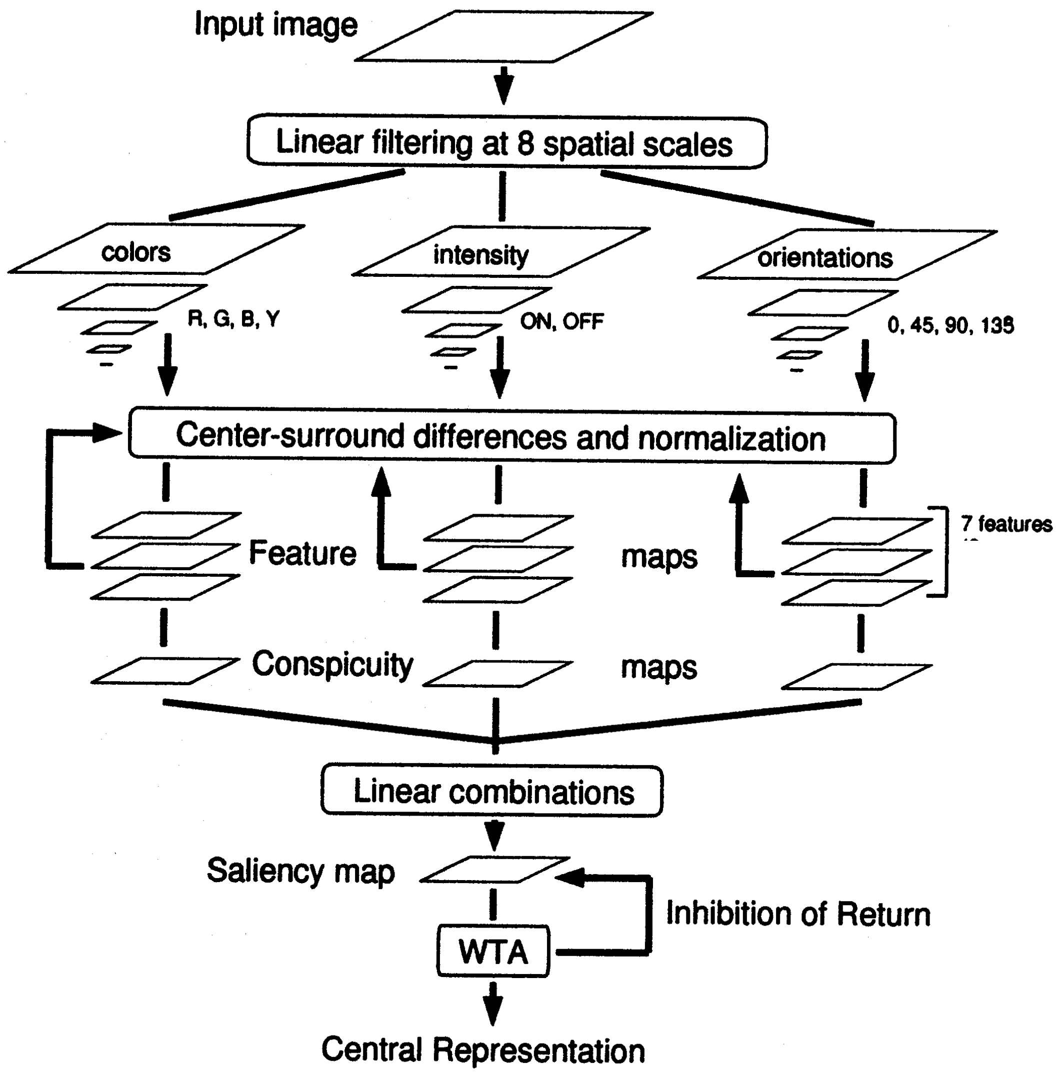
Analyze salience for different feature maps:
Colors, intensity, orientations ….

Eye movements and salience (Itti and Koch, 2000)



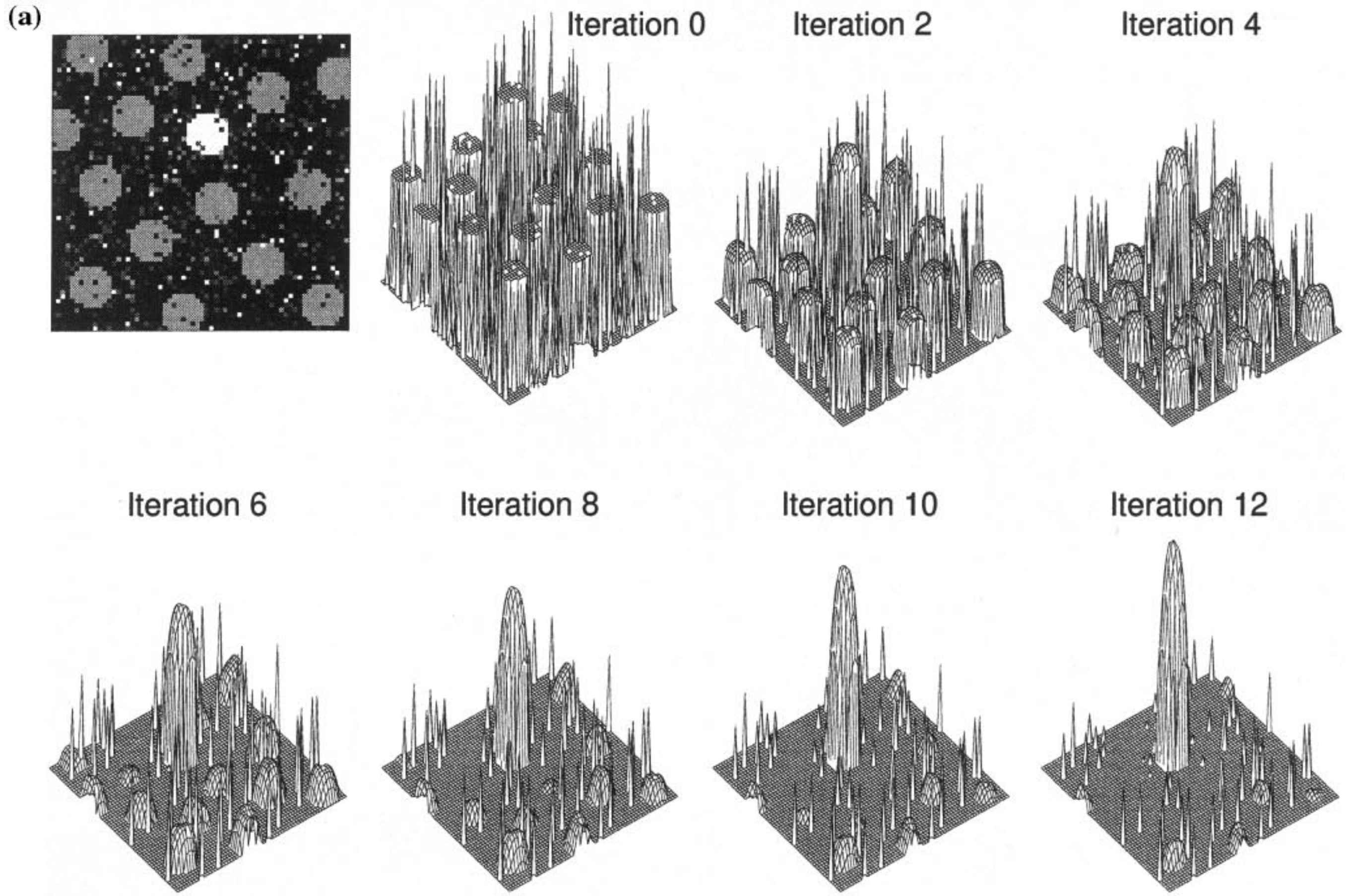
From Wikipedia page

Eye movements and salience (Itti and Koch, 2000)

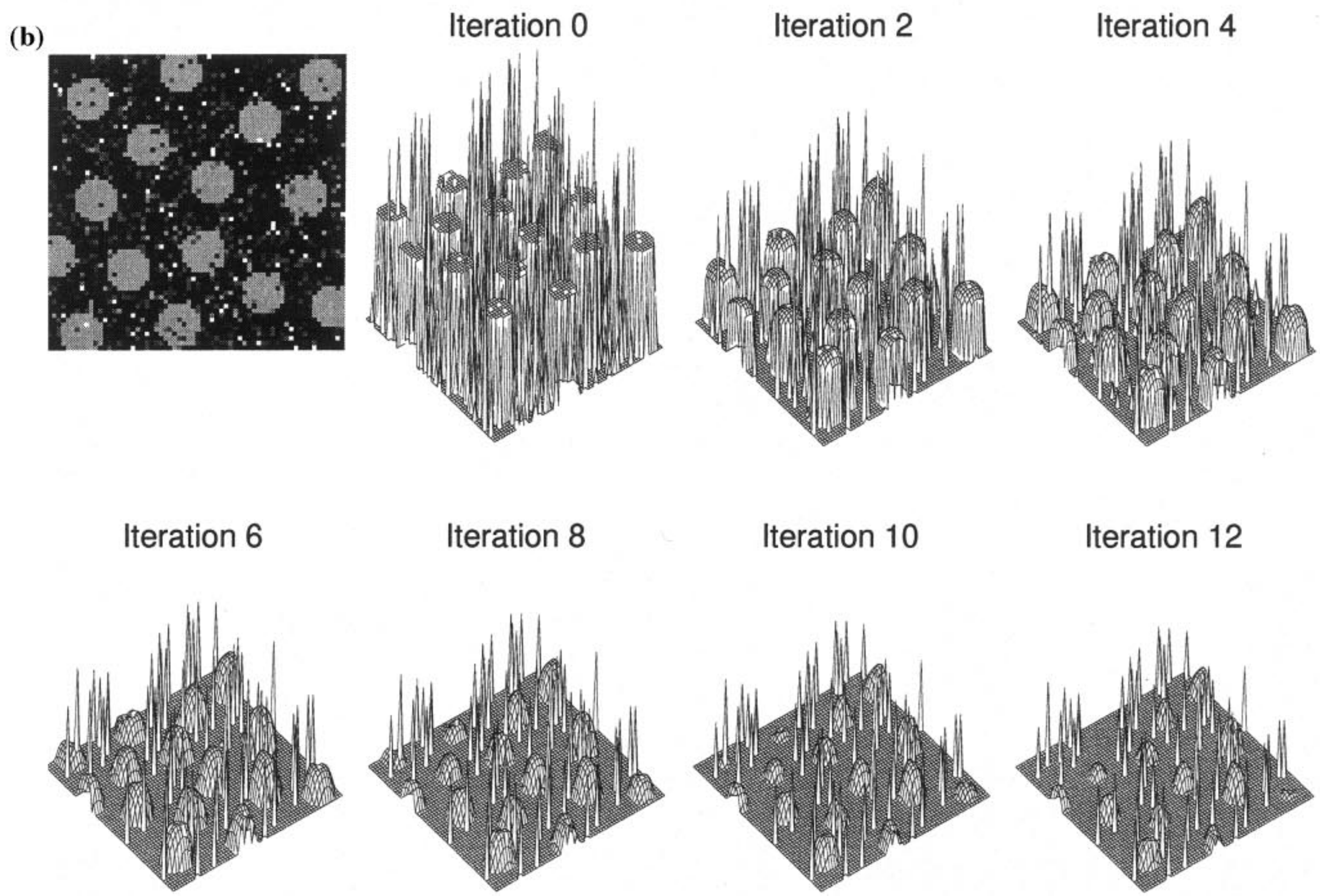


Linearly combine the salience maps of different features

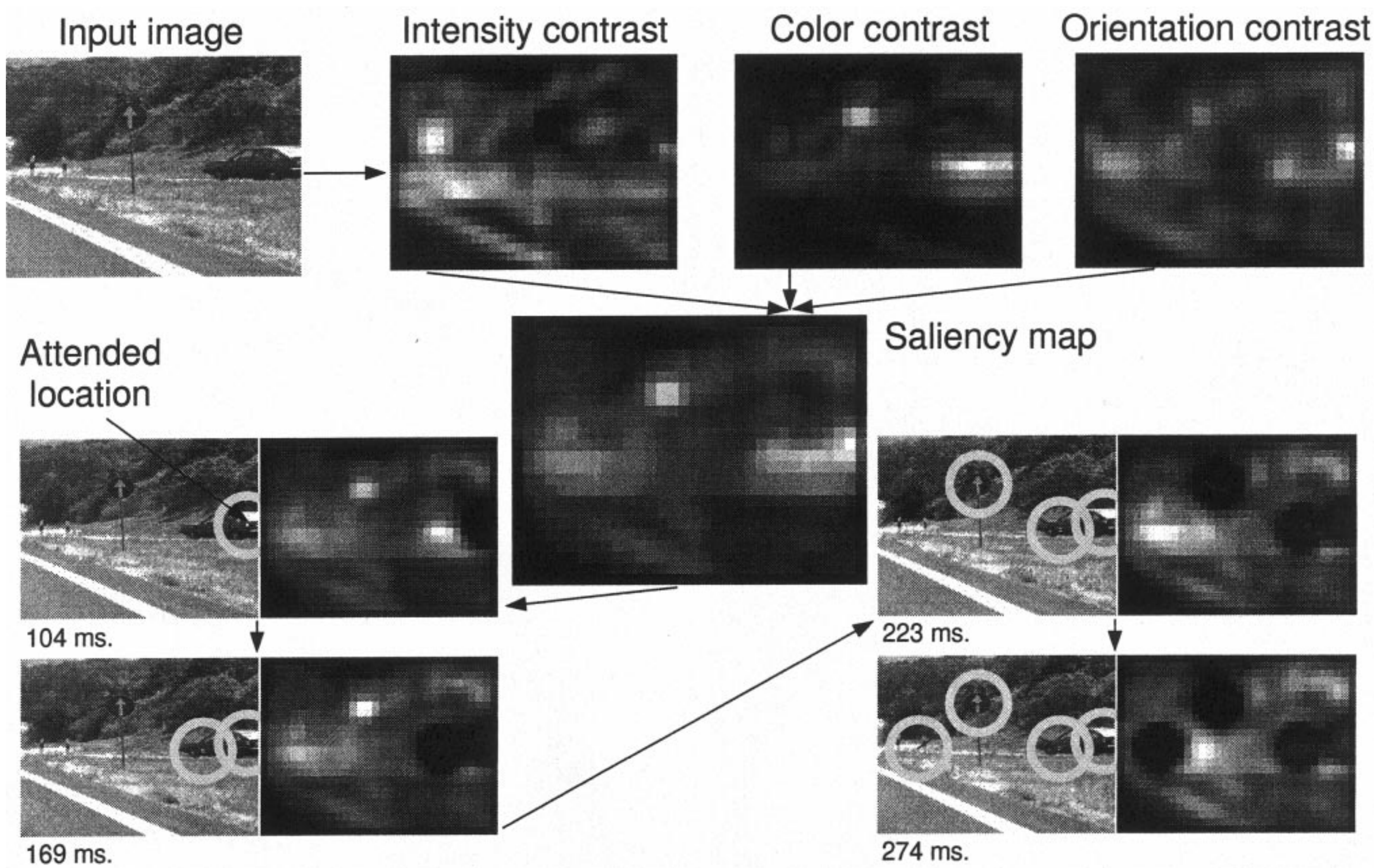
Eye movements and salience (Itti and Koch, 2000)



Eye movements and salience (Itti and Koch, 2000)



Eye movements and salience (Itti and Koch, 2000)



Eye movements: not only salience (Yarbus 1967)

Eye movements: not only salience (Yarbus 1967)

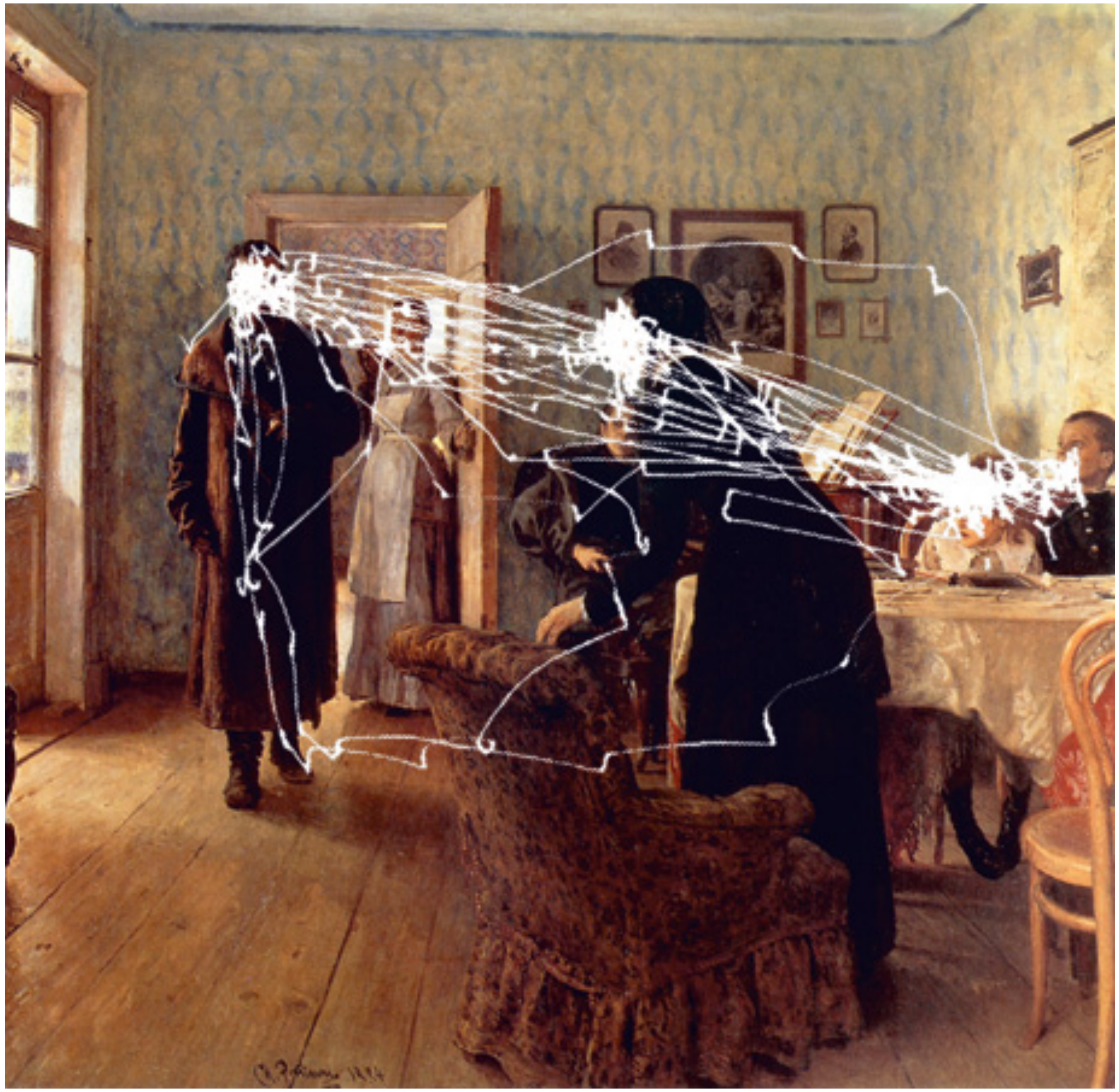
Free examination

Eye movements: not only salience (Yarbus 1967)

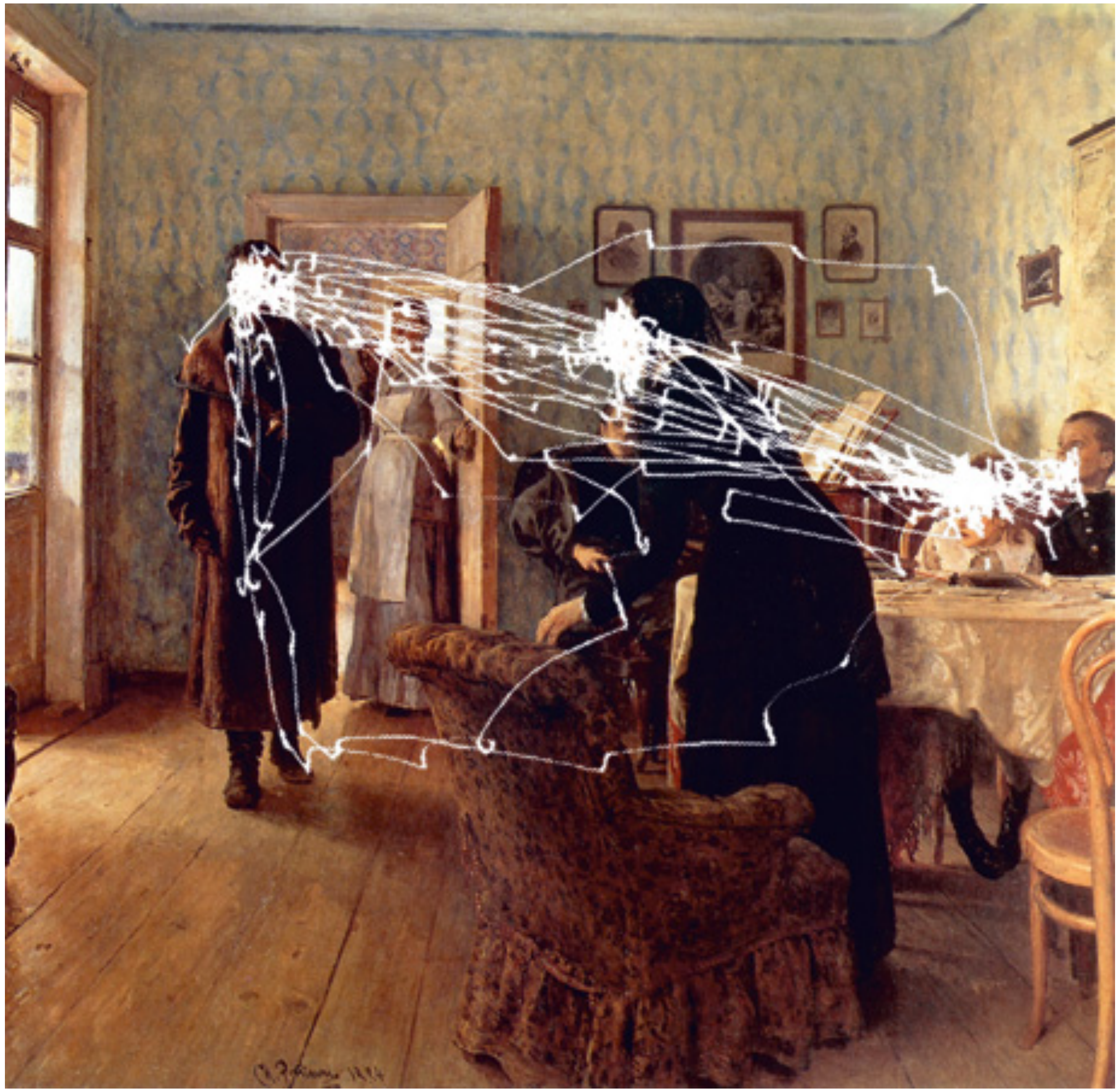
Eye movements: not only salience (Yarbus 1967)

Remember the clothes worn by people

Eye movements: not only salience (Yarbus 1967)

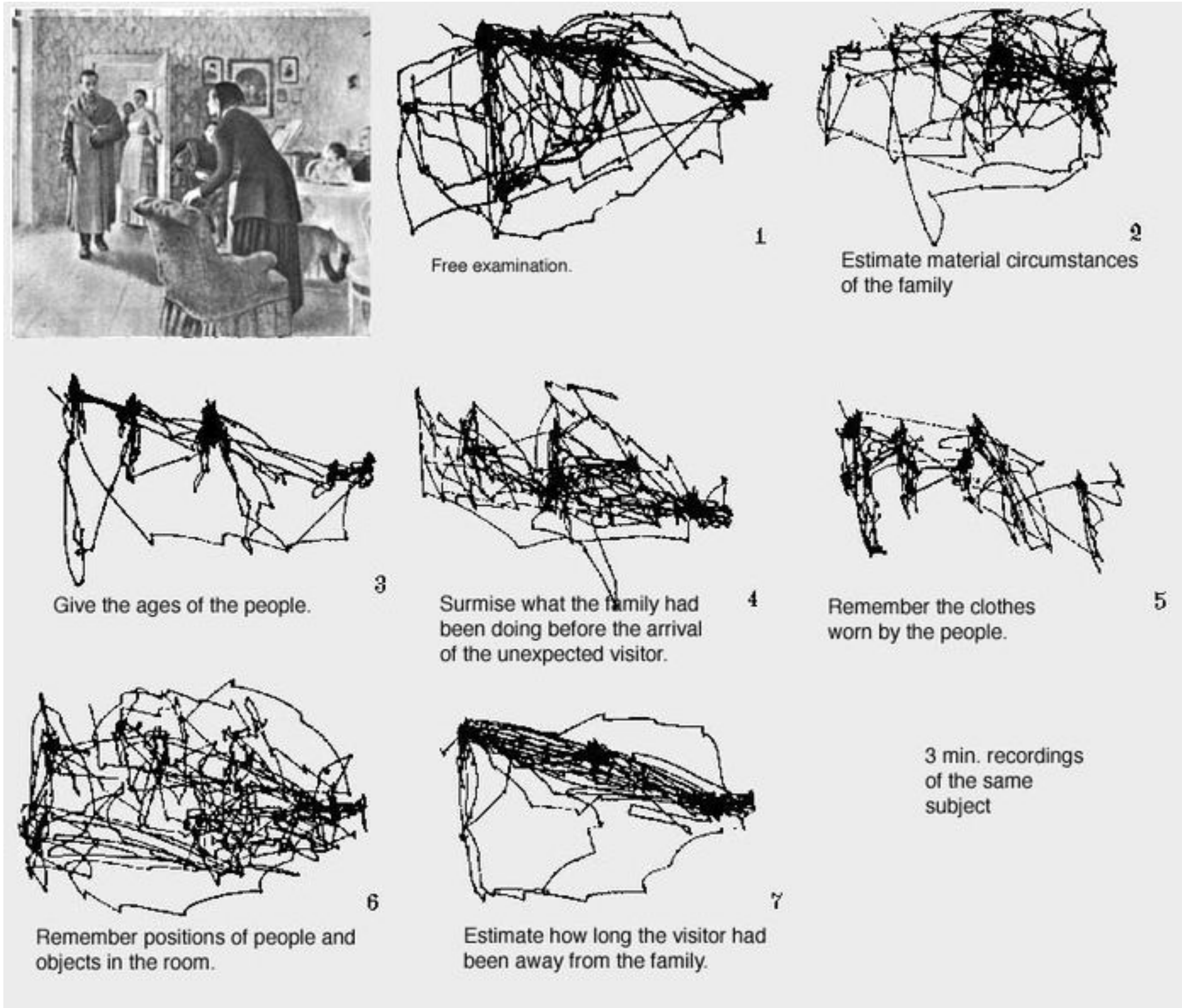


Eye movements: not only salience (Yarbus 1967)



Give the ages of the people

Eye movements: not only salience



Surround spatial context and cortical neural processing of visual scenes

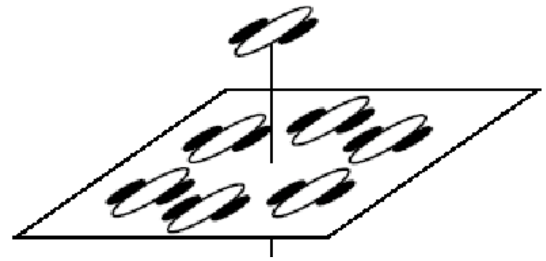
Motivation

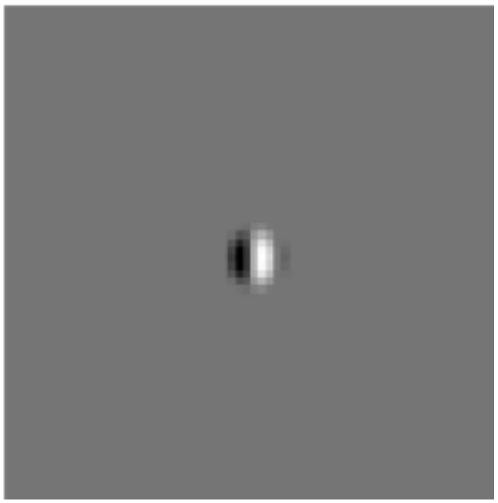
- Spatial context plays critical role in object *grouping* and recognition, and in *segmentation*. It is key to everyday behavior; deficits have been implicated in neurological and developmental disorders and aging

- Poor understanding for how we (and our cortical neurons) process complex, natural images

Contextual influences

- Cortical visual neurons (V1)





Large response

Suppressed response

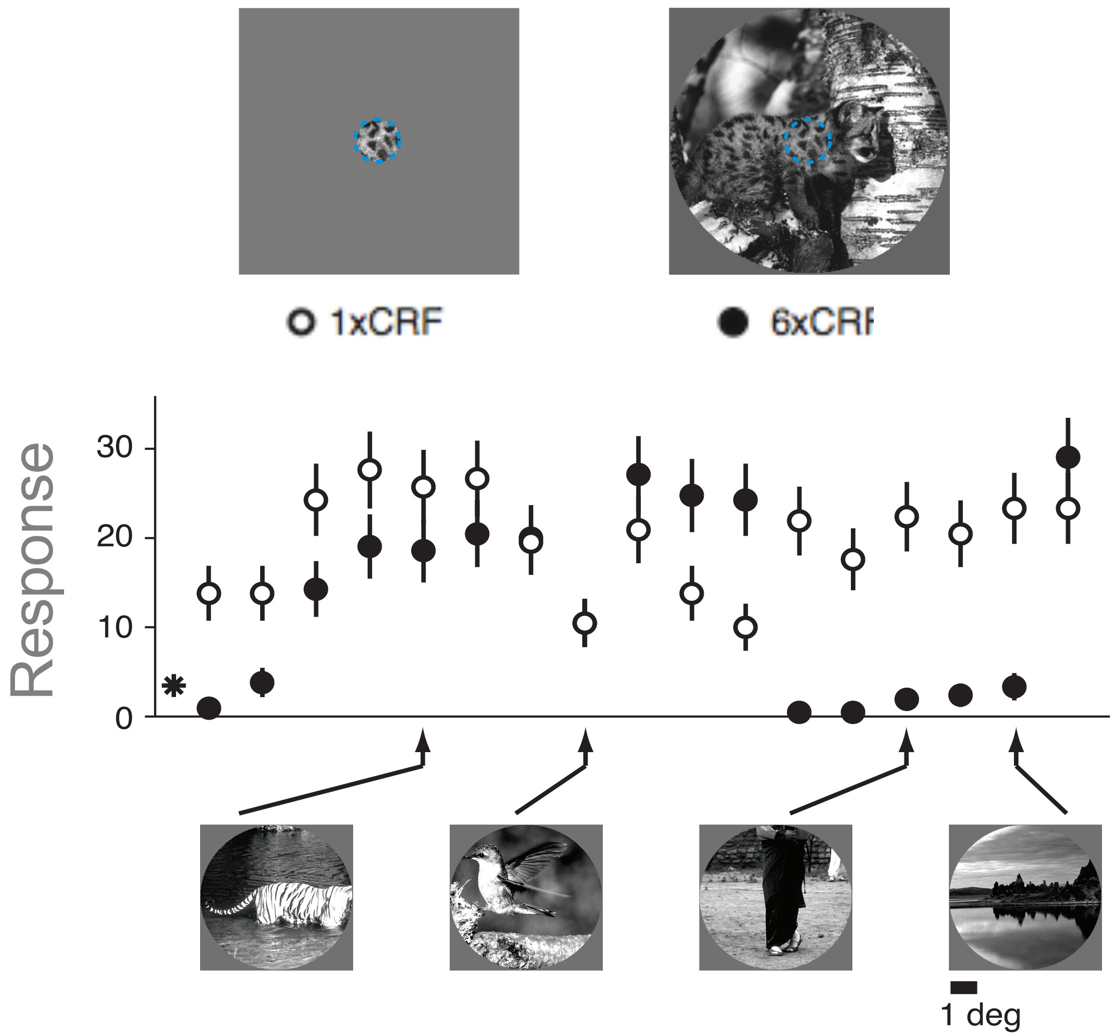
??

Simple oriented stimuli

Image

Cortical Neurons

- Spatial context and natural scenes



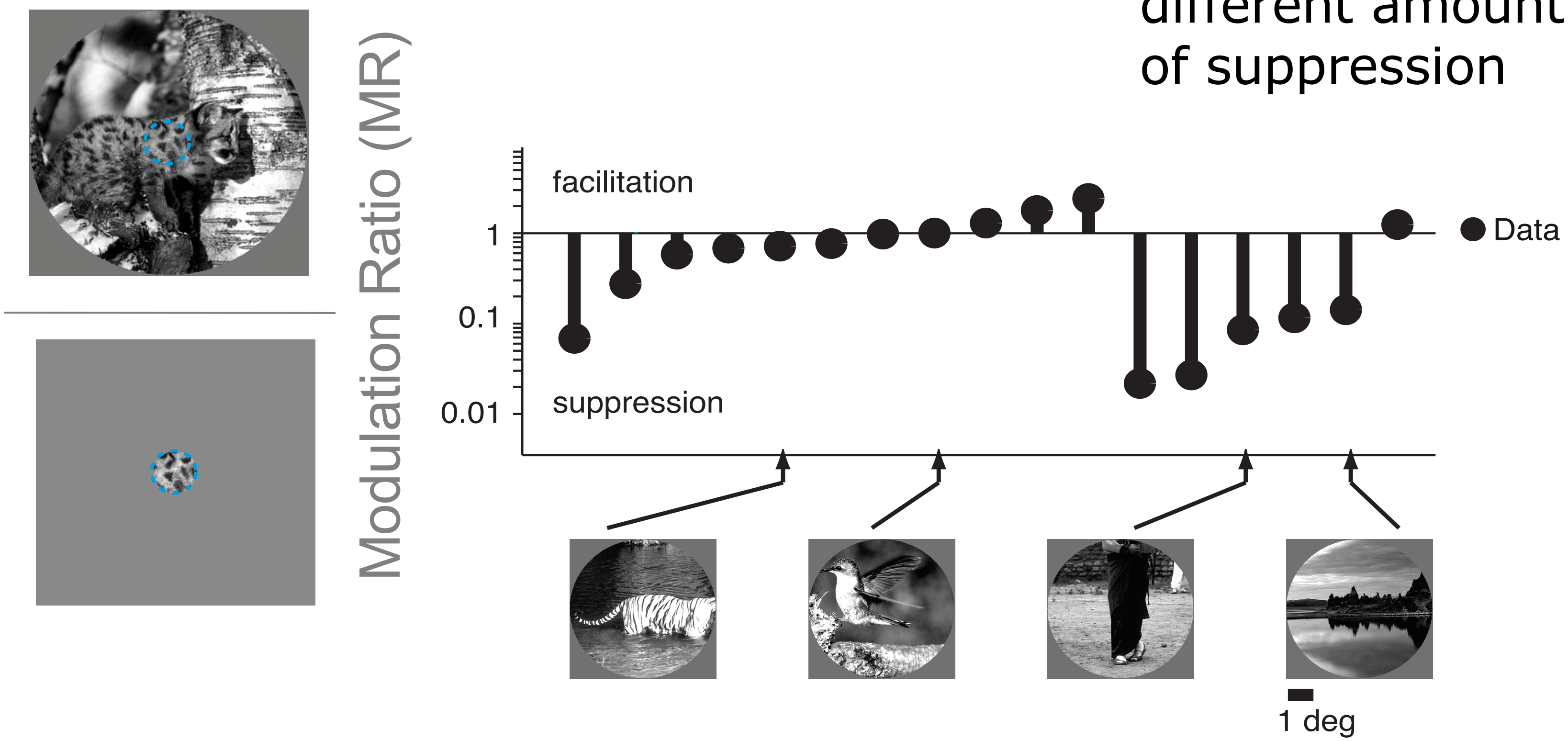
One neuron, different images, different amount of suppression by large stimuli

Data: Adam Kohn lab (Coen-Cagli, Kohn, Schwartz, 2015)

Cortical Neurons

- Spatial context and natural scenes

One neuron, different images, different amount of suppression



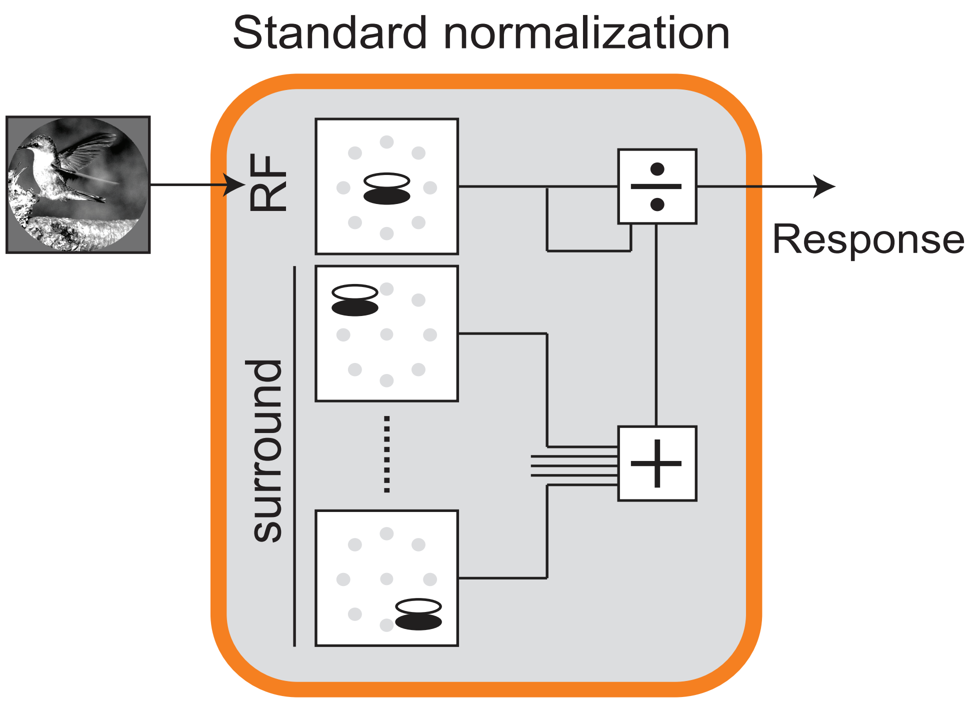
Data: Adam Kohn lab (Coen-Cagli, Kohn, Schwartz, 2015)

Cortical Neurons

- Spatial context and natural scenes

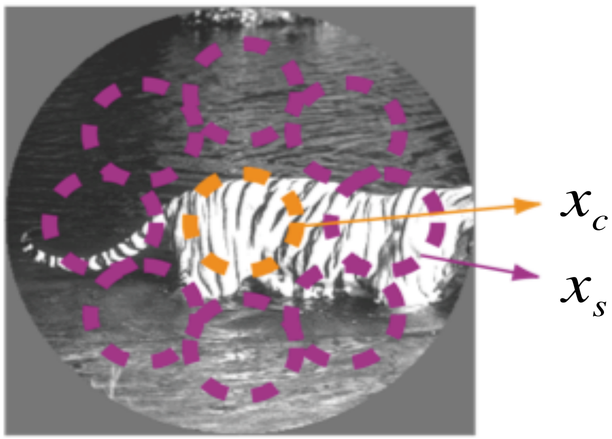
Can we capture data with canonical divisive normalization? (descriptive model)

Divisive normalization



- Descriptive model
- Canonical computation (Carandini, Heeger, Nature Reviews Neuro, 2012)
- Has been applied to visual cortex, as well as other systems and modalities, multimodal processing, value encoding, etc
- Here center responses divided by surround responses

Cortical Neurons

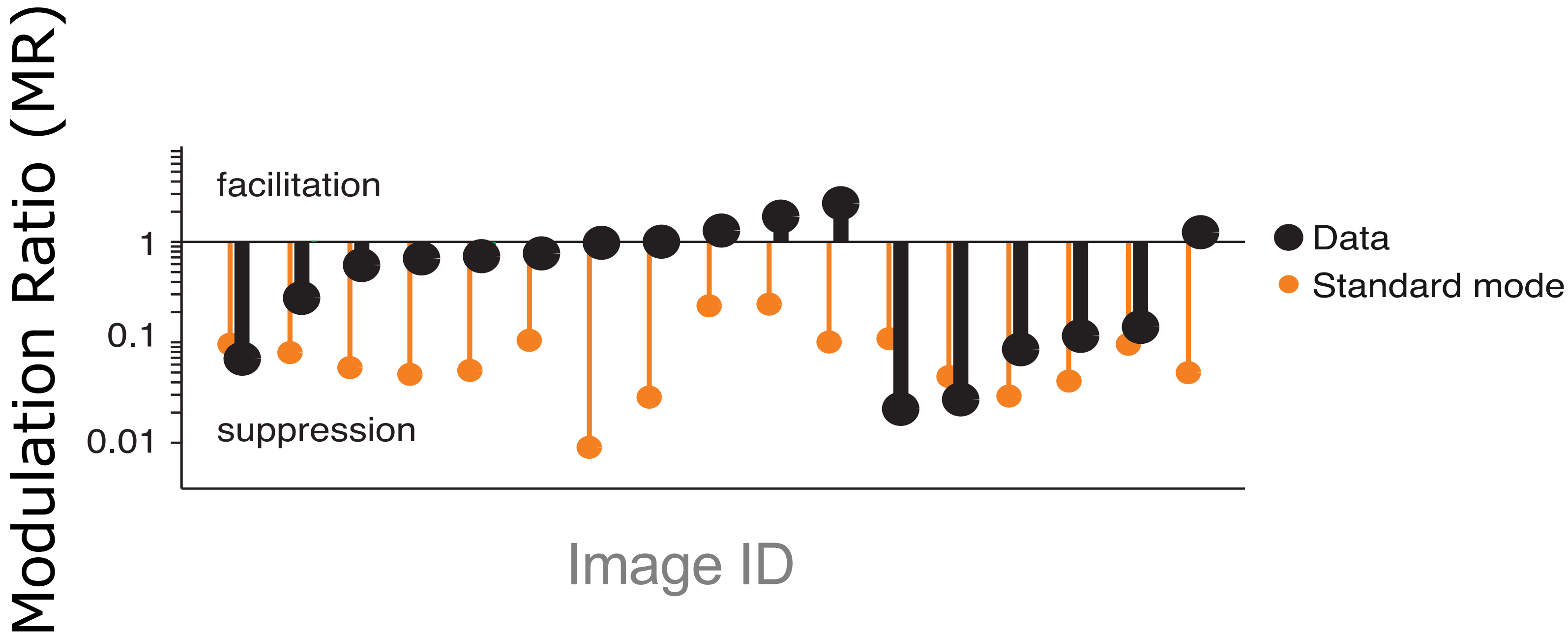


Canonical divisive normalization:

$$R_c \prec \frac{x_c}{\sqrt{x_c^2 + x_s^2}}$$

V1 Data: Adam Kohn lab

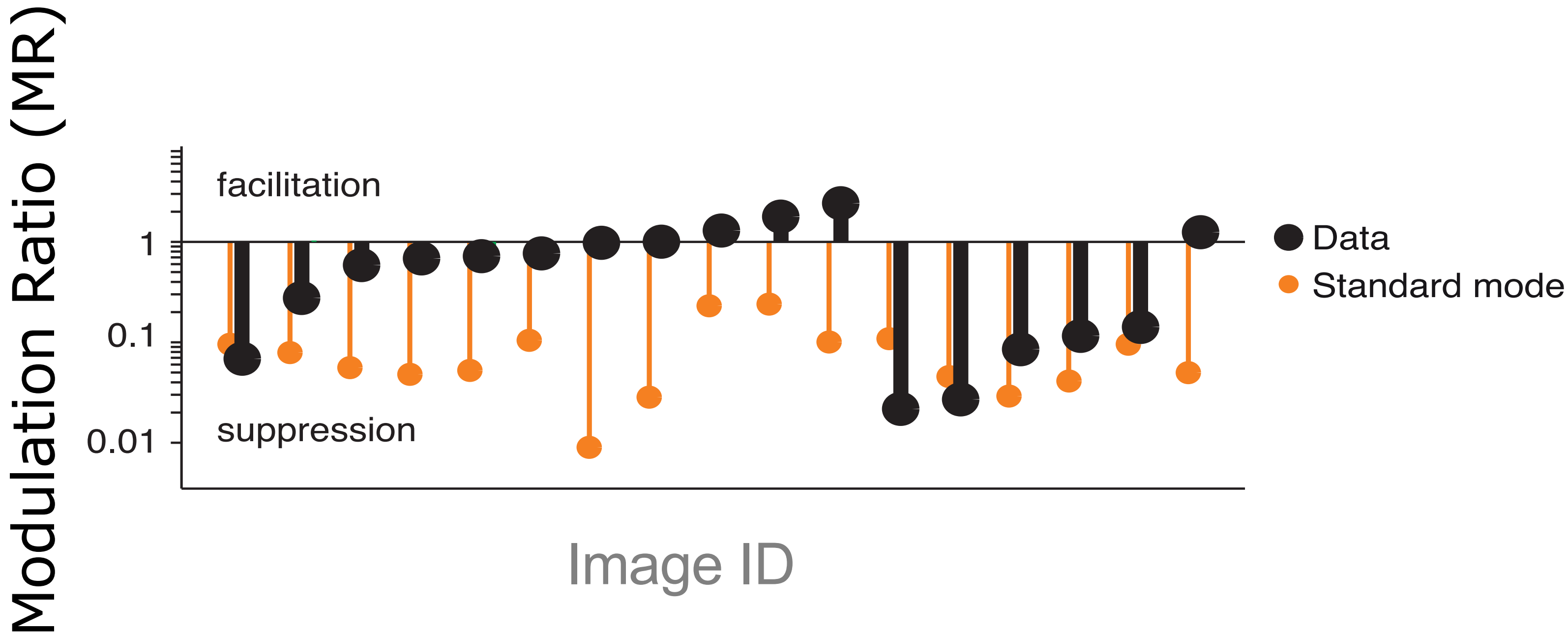
Cortical responses to natural images



- We fit the standard normalization model to neural data
- Often predicts suppression when there is none in the data
- Poor prediction quality

Data: Adam Kohn lab
Coen-Cagli, Kohn, Schwartz, Nature Neuroscience 2015

Cortical responses to natural images



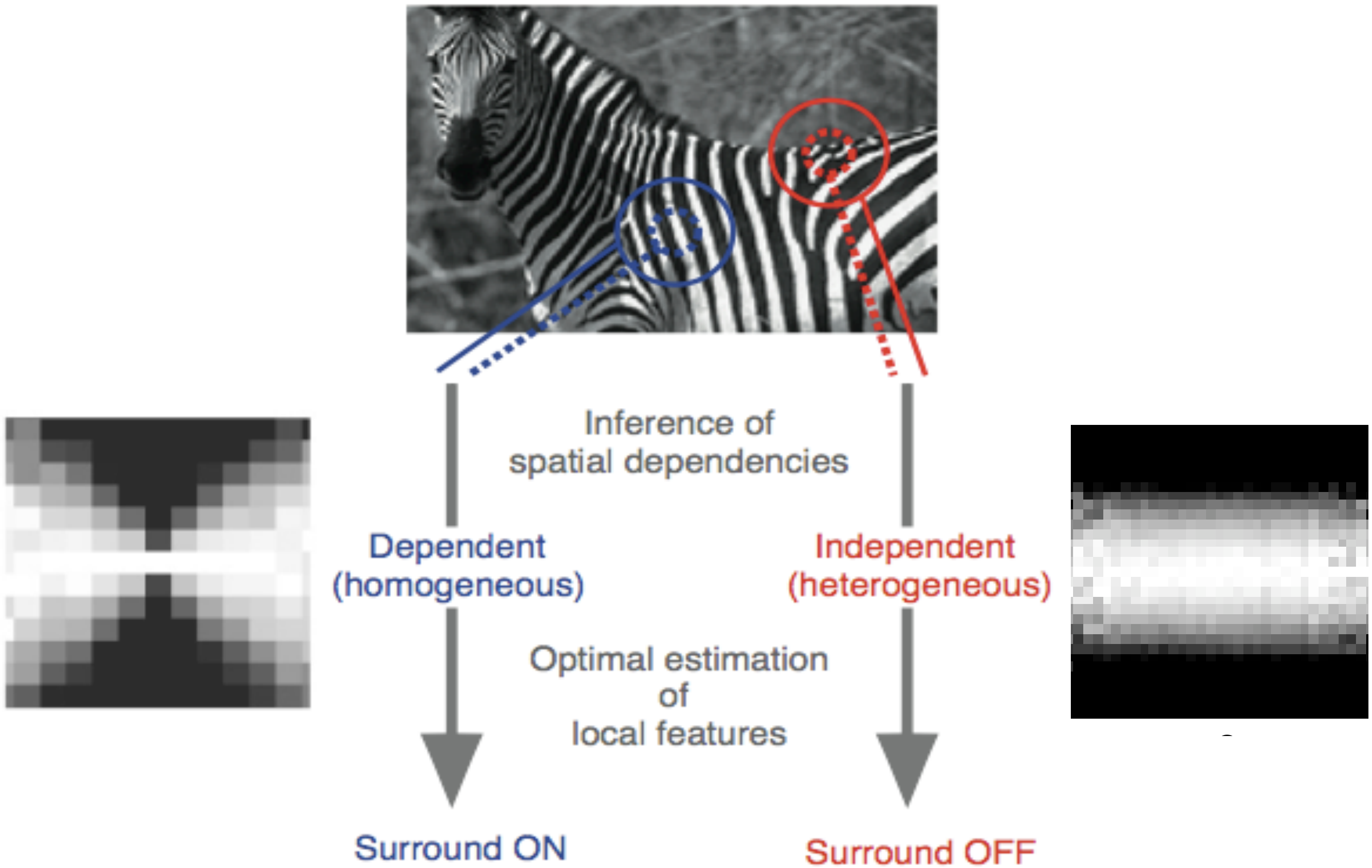
- Can we explain as strategy to encode natural images optimally based on expected spatial contextual regularities?

Data: Adam Kohn lab
Coen-Cagli, Kohn, Schwartz, Nature Neuroscience 2015

Divisive normalization: richer model

Divisive normalization *descriptive* models have been applied in many neural systems. We sought to develop a richer model based on image statistics

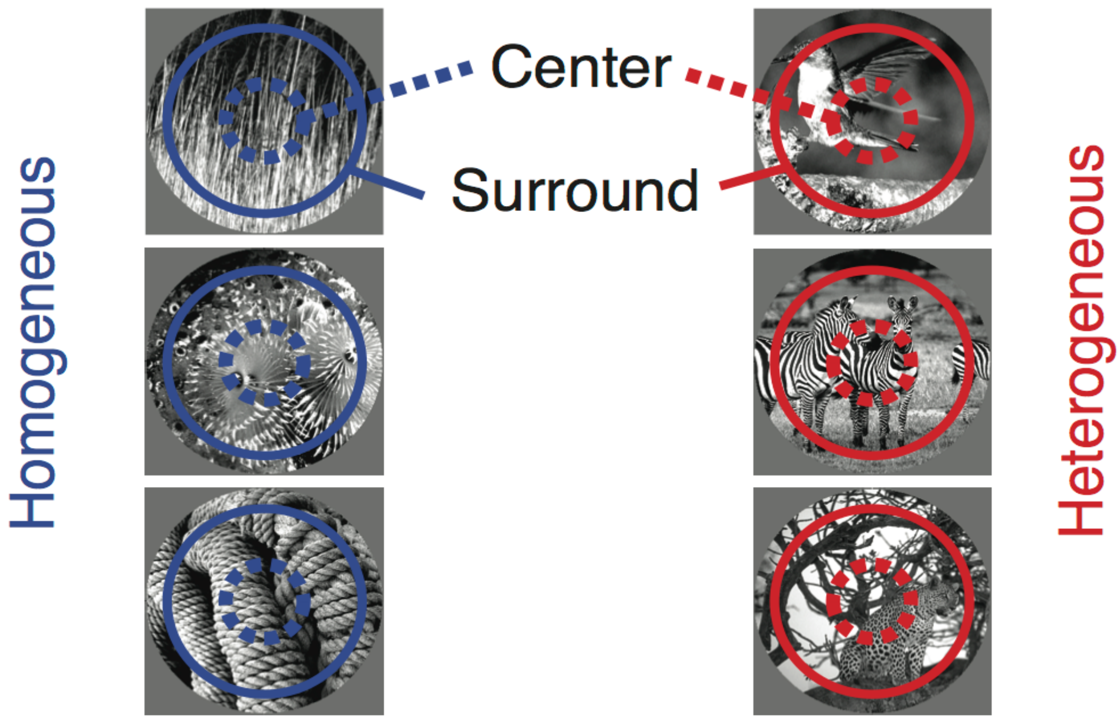
Flexible Divisive Normalization



Divide Don’t divide

Model and experimental tests: Cagli, Kohn, Schwartz 2015

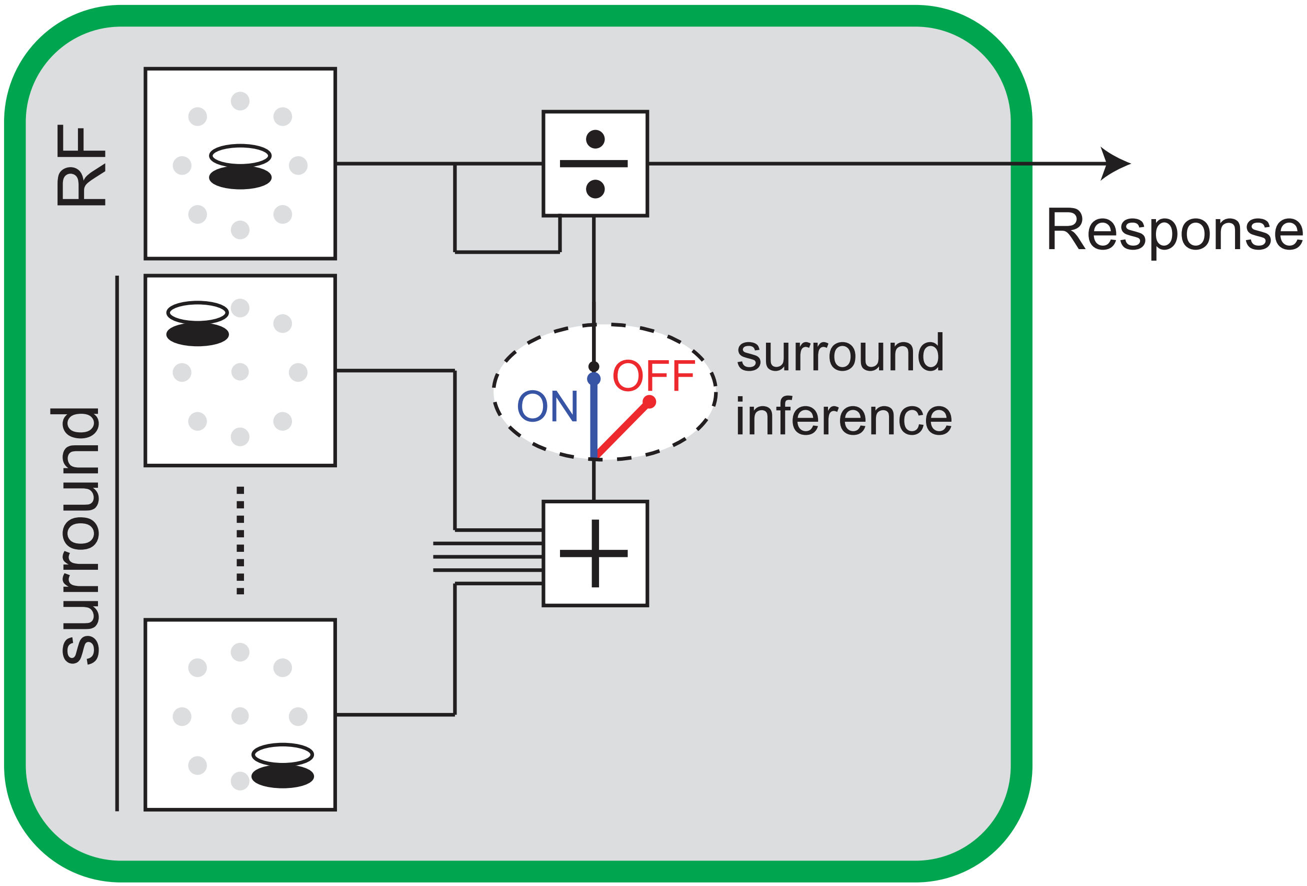
Model predictions for natural images



- **Homogeneous and heterogeneous determined by model!**
- Expect more suppression in neurons for homogeneous
- Related to salience (eg, Zhaoping Li)

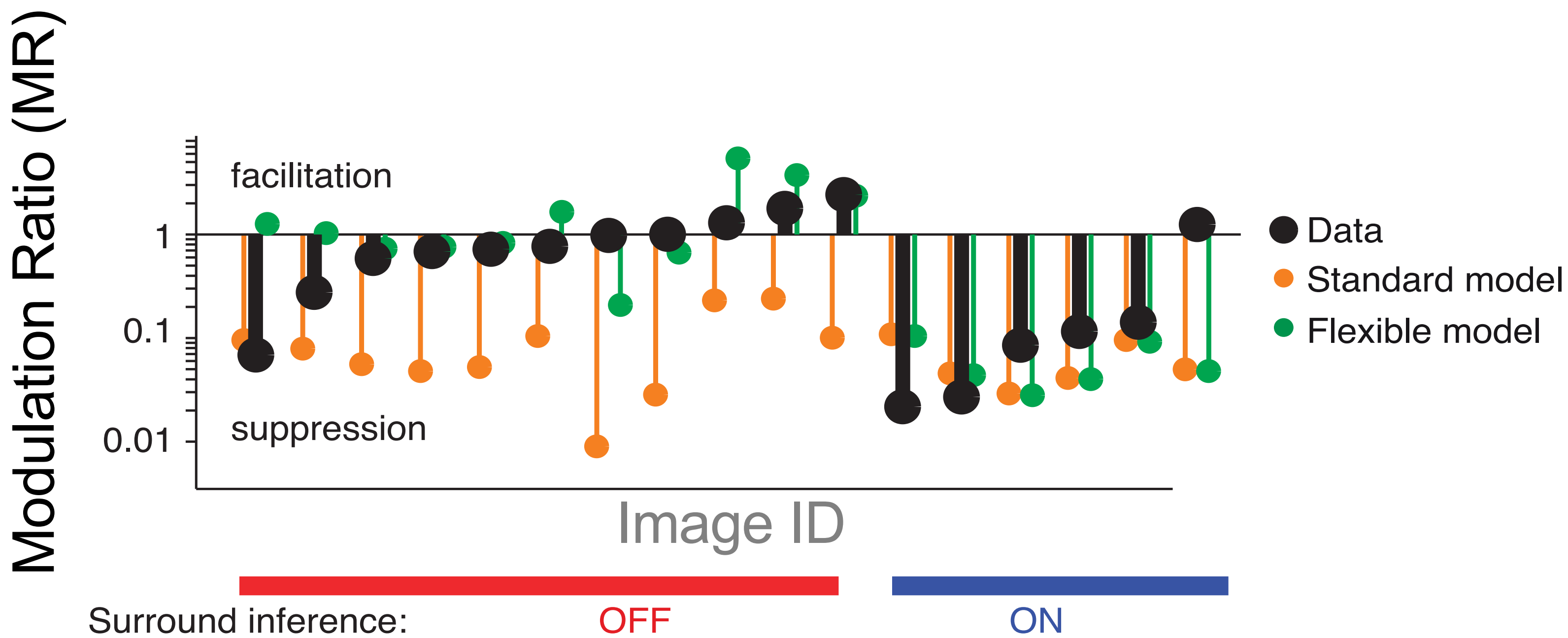
Coen-Cagli, Kohn, Schwartz, Nature Neuroscience 2015

Model summary



Inference determined by model

Natural scenes data



- Taking account of image statistics across space, we obtain better fit to neural data with the model

Coen-Cagli, Kohn, Schwartz, Nature Neuroscience, 2015

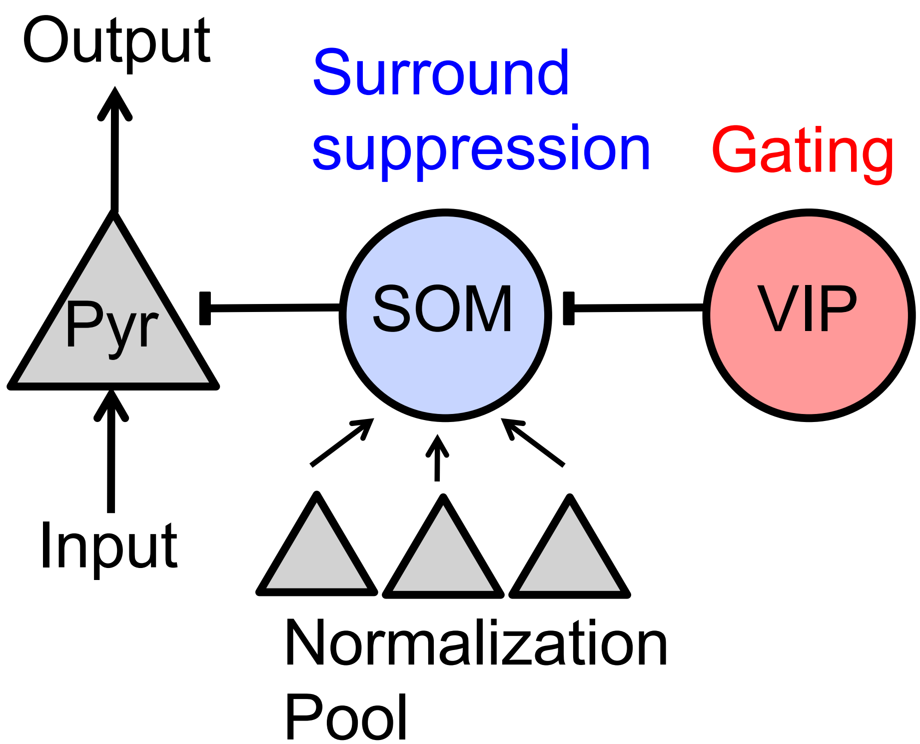
Model Mechanisms

Divisive normalization:

- Feedback inhibition
- Distal dendrite inhibition
- Depressing synapses
- Internal biochemical adjustments
- Non-Poisson spike generation

Flexible Normalization Mechanism?

- Adjusting gain by circuit mechanisms?
- Distinct classes of inhibitory interneurons? (eg, Adesnik, Scanziani et al. 2012; Pfeffer, Scanziani et al. 2013; Pi, Kepecs et al. 2013; Lee, Rudy et al. 2013)



Key take-home points

- New approach to understanding cortical processing of natural images. Rather than fitting more complicated models, use insights from scene statistics

- Connects to neural computations that are ubiquitous, but enriches the “standard” model

- Our results suggest flexibility of contextual influences in natural vision, depending on whether center and surround are deemed statistically homogeneous

Deep learning: normalization

Normalization has been shown to sometimes improve object recognition in deep neural networks

- Local normalization in Alexnet, 2012
- Other recent normalizations include: batch normalization in Ioffe and Szegedy, 2015; layer normalization in Ba et al., 2016
- More restricted than some of the normalizations used in cortical modeling
- But face some similar questions: How to choose what neural activations to normalize by