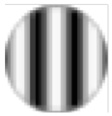
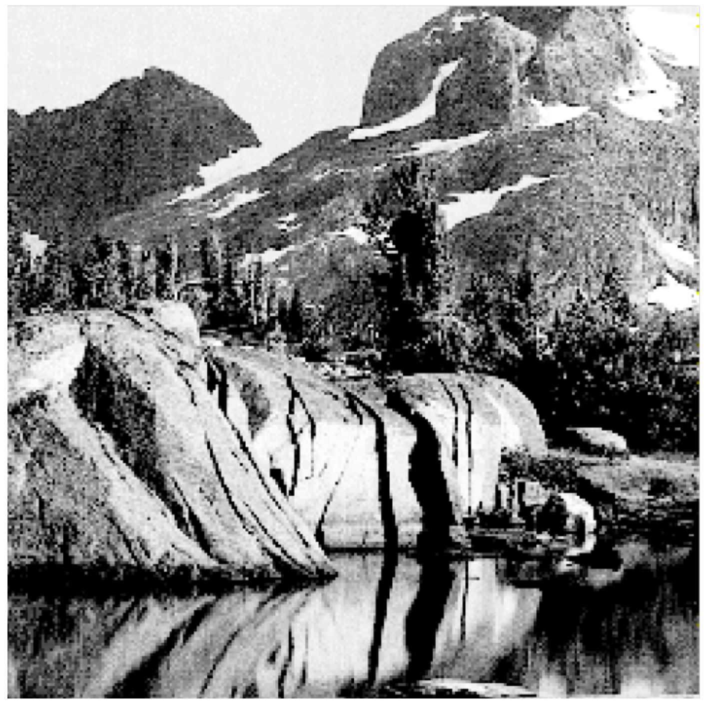
Spatial surround effects in visual processing

(and natural scenes)



Typical experimental stimulus
in vision experiment

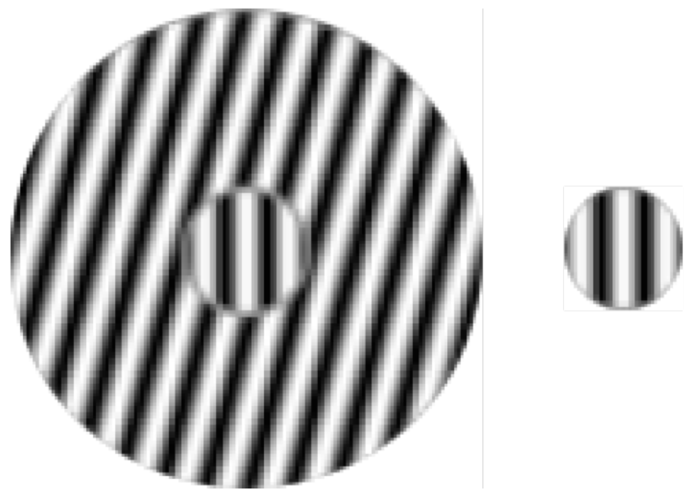


How are “natural” images different from the grating? Or bar?

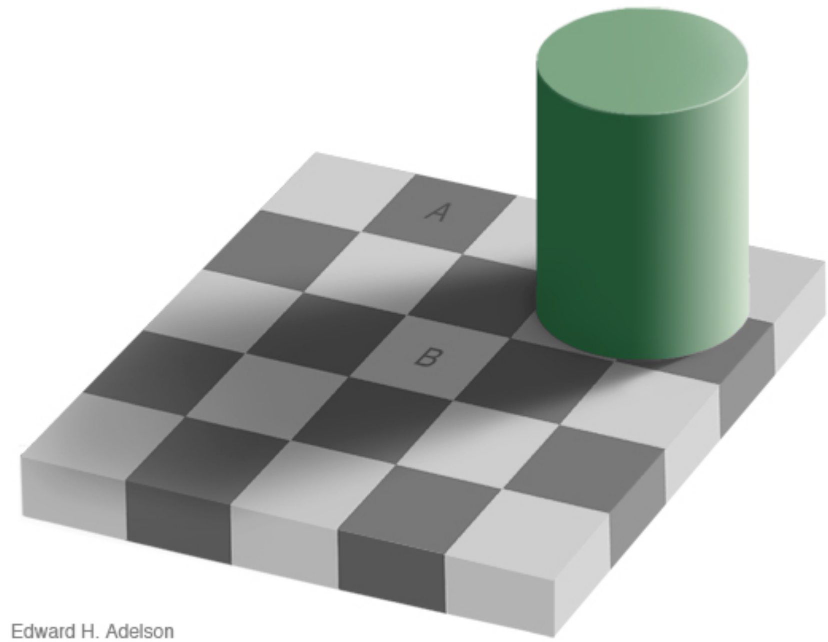
Spatial context

Spatial context

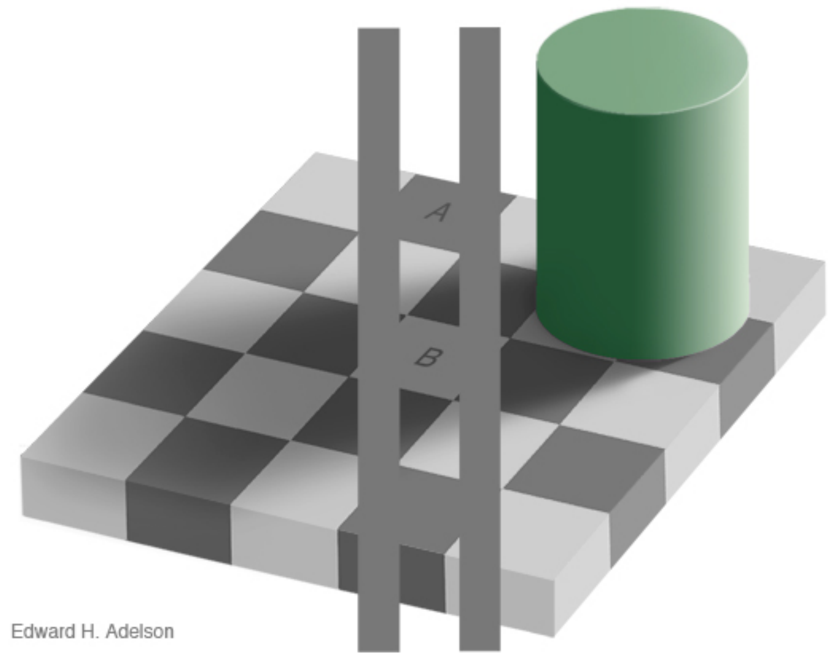
Images have spatial context information. What happens when we construct artificial stimuli with spatial context?



Contextual information influence perception (classical tilt illusion)



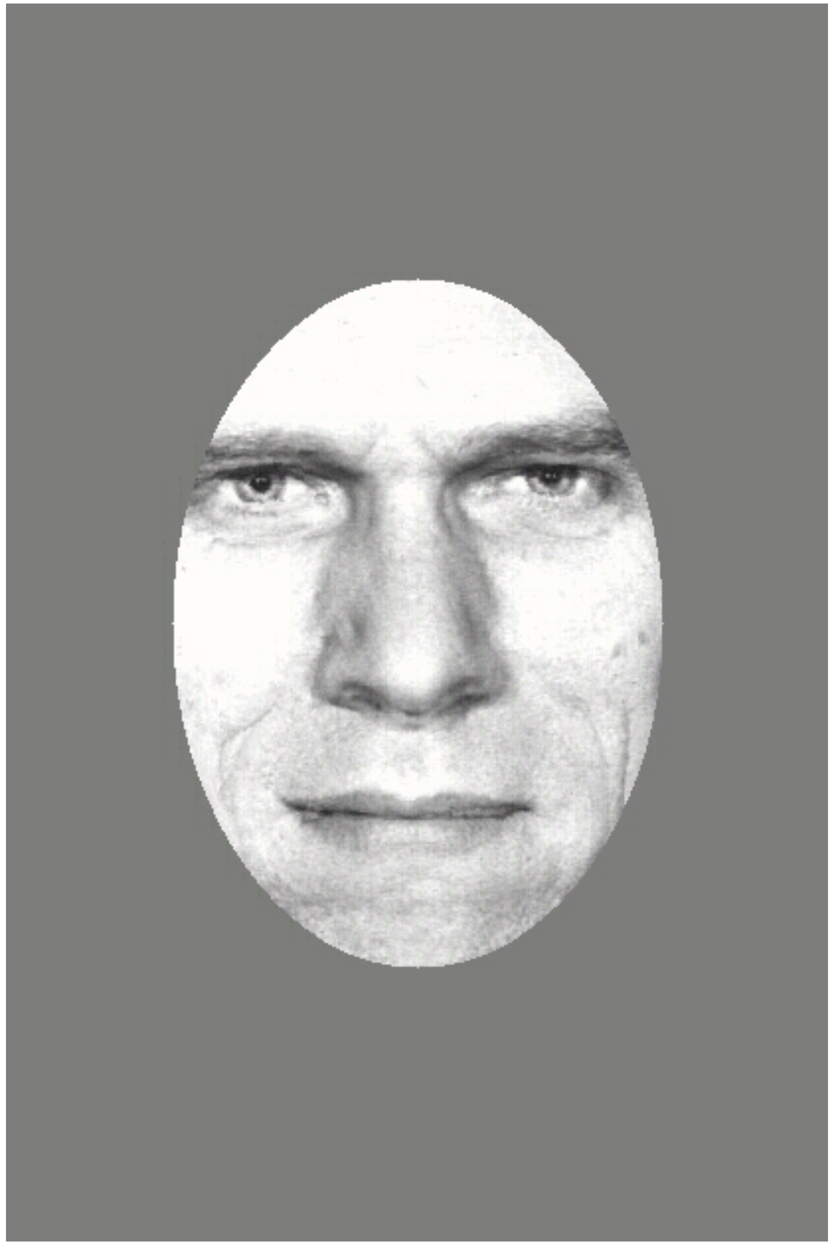
Contextual information influence perception



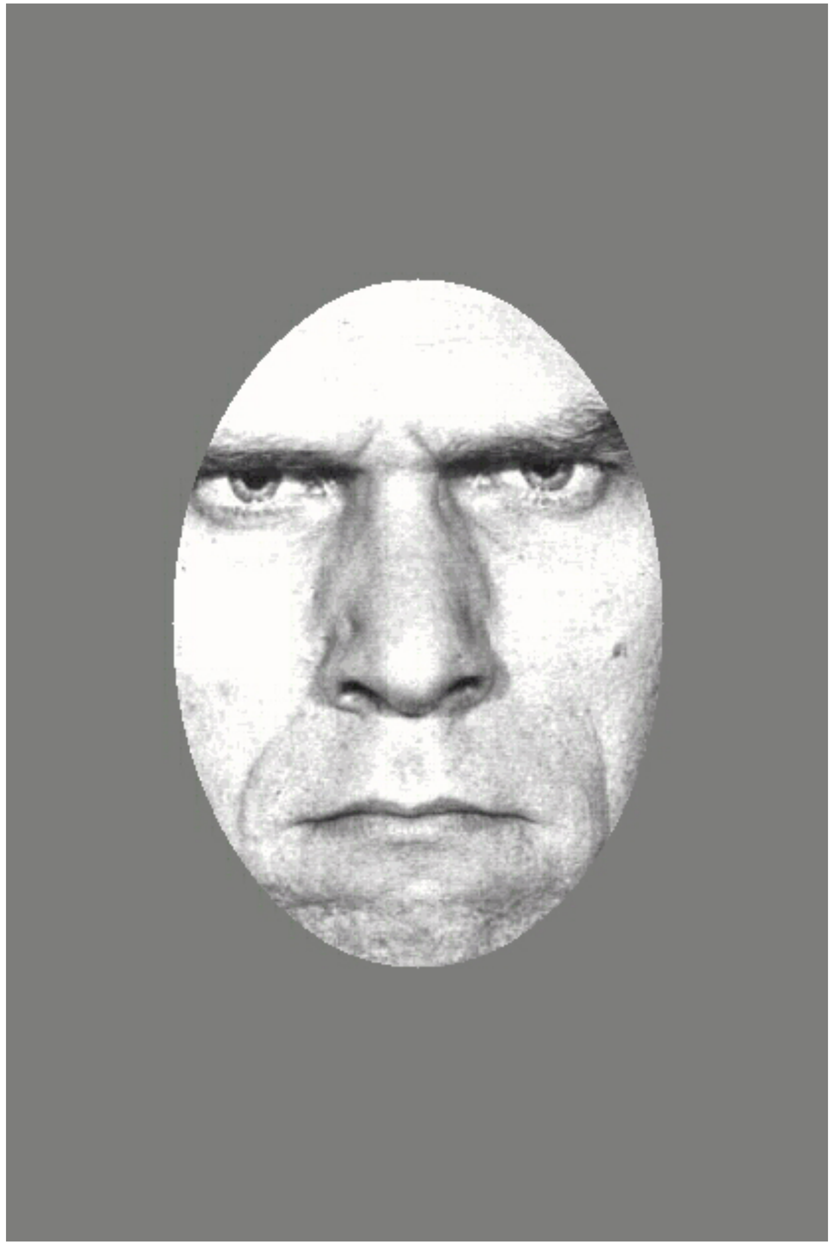
Contextual information influence perception

Contextual information influence perception

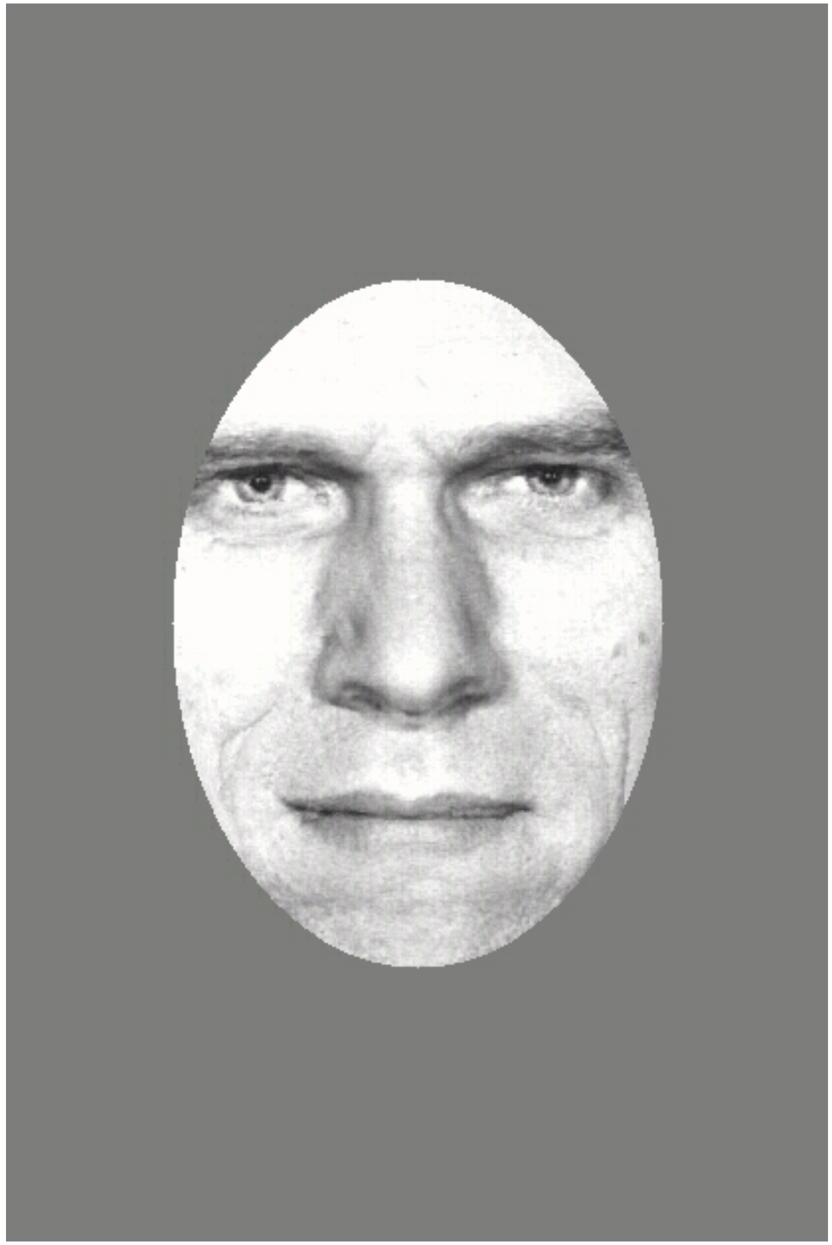
Contextual effects in time...



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

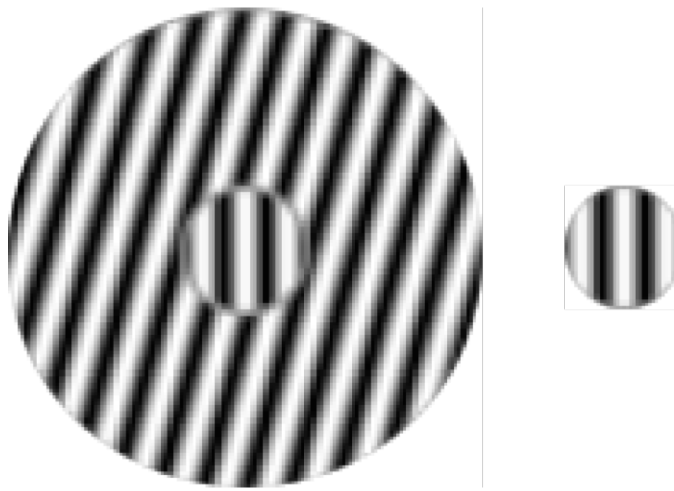


adapt

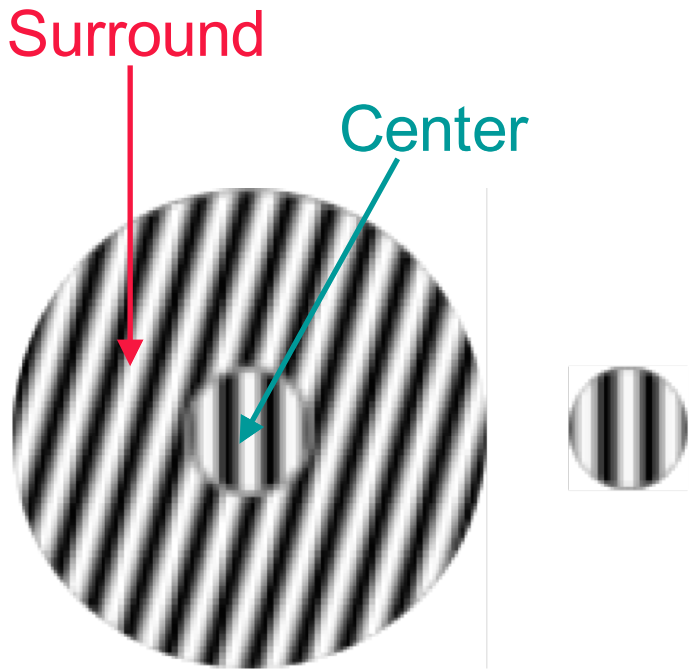


post-adapt

Focus: spatial surround context



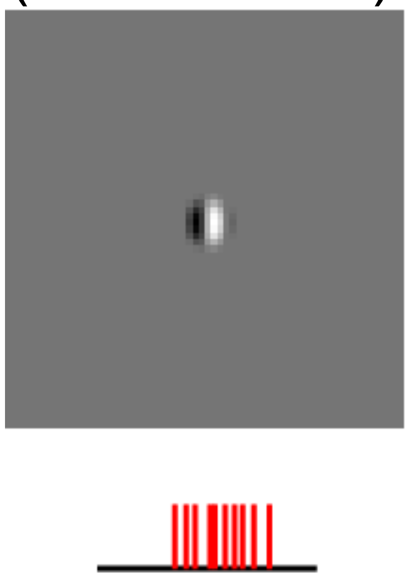
Focus: spatial surround context



Surround (non classical receptive field) effects in visual physiology

Visual cortex: non classical RF

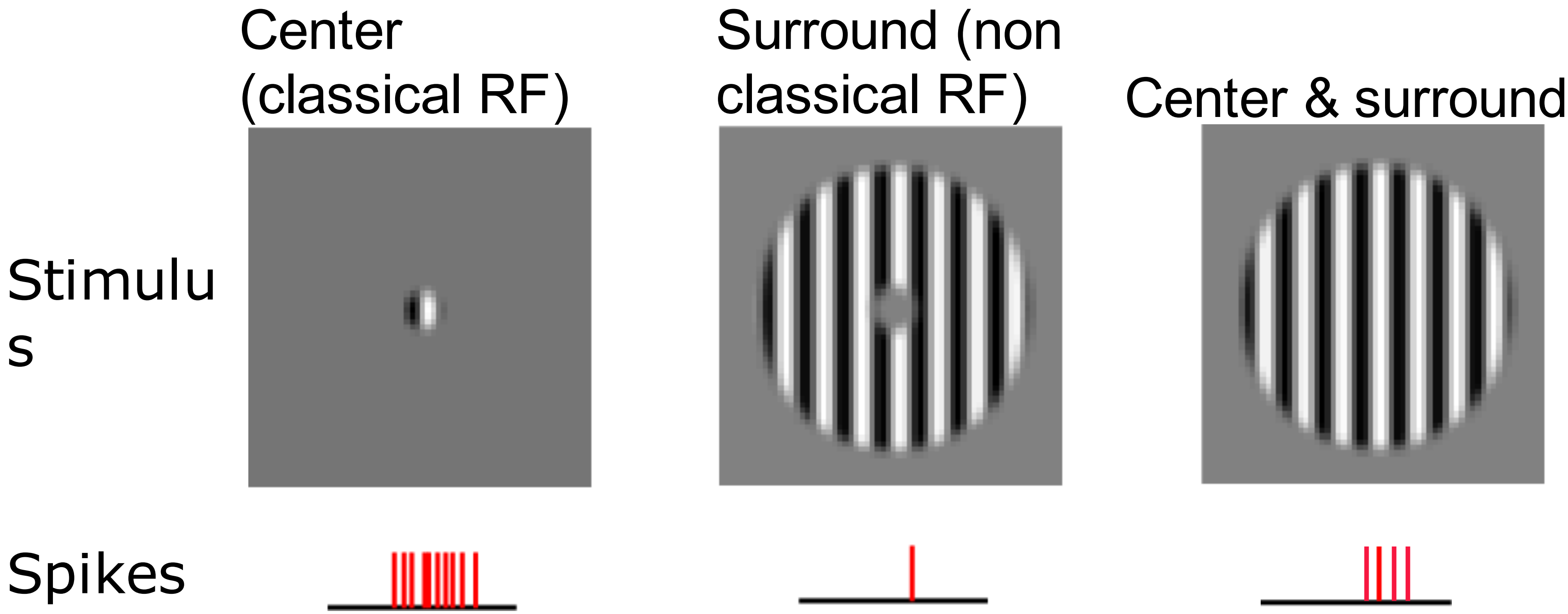
Center
(classical RF)



Surround (non
classical RF)

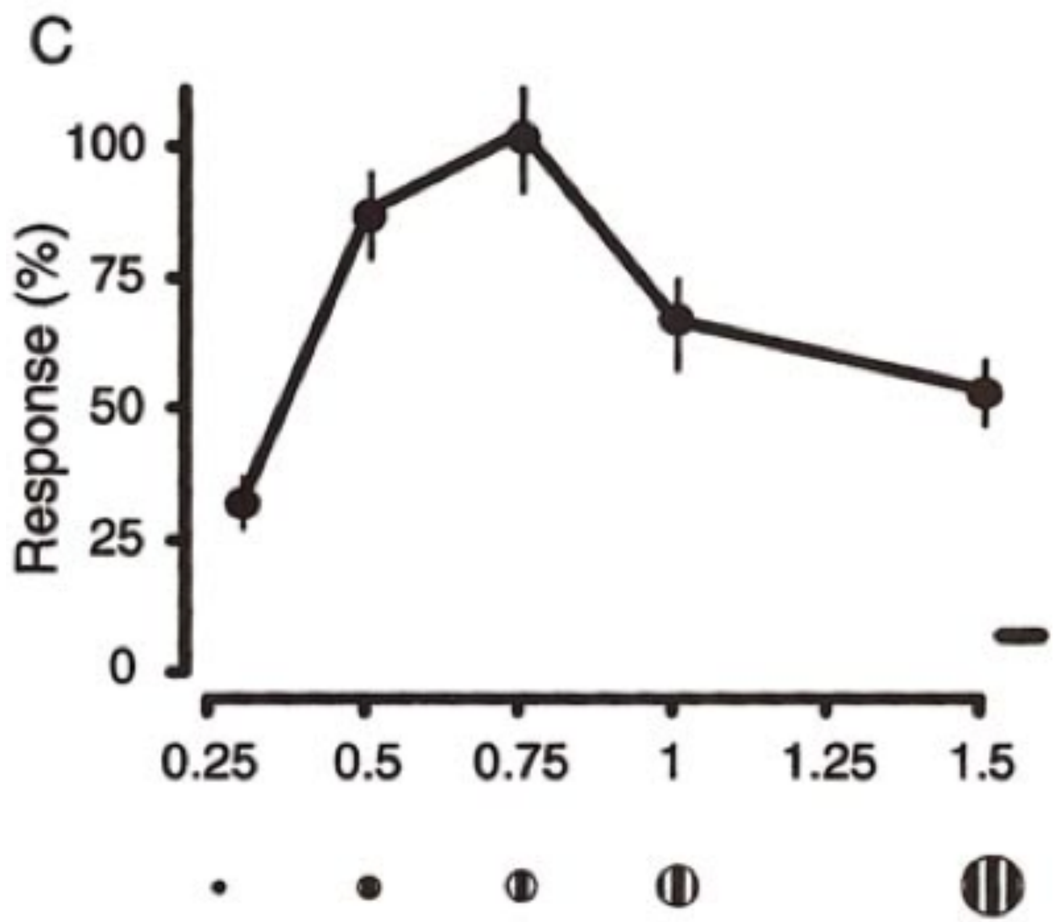
Surround stimulus is defined such that by itself elicits no response

Visual cortex: spatial surround



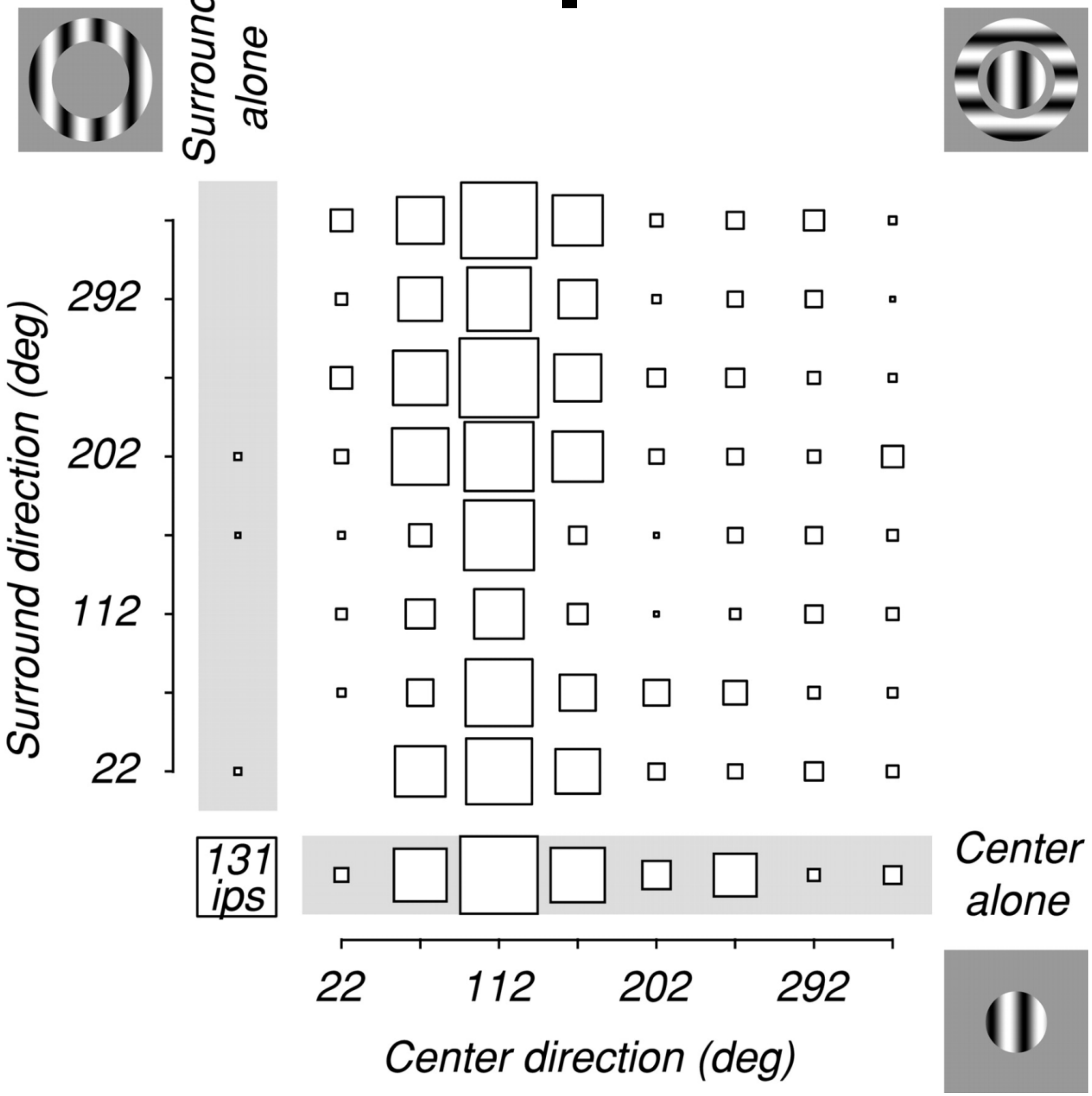
But surround stimulus can modulate response to center. Cortical neurons are affected by spatial context.

Visual cortex: spatial surround



Jones and Silito, 2001

Visual cortex: spatial surround



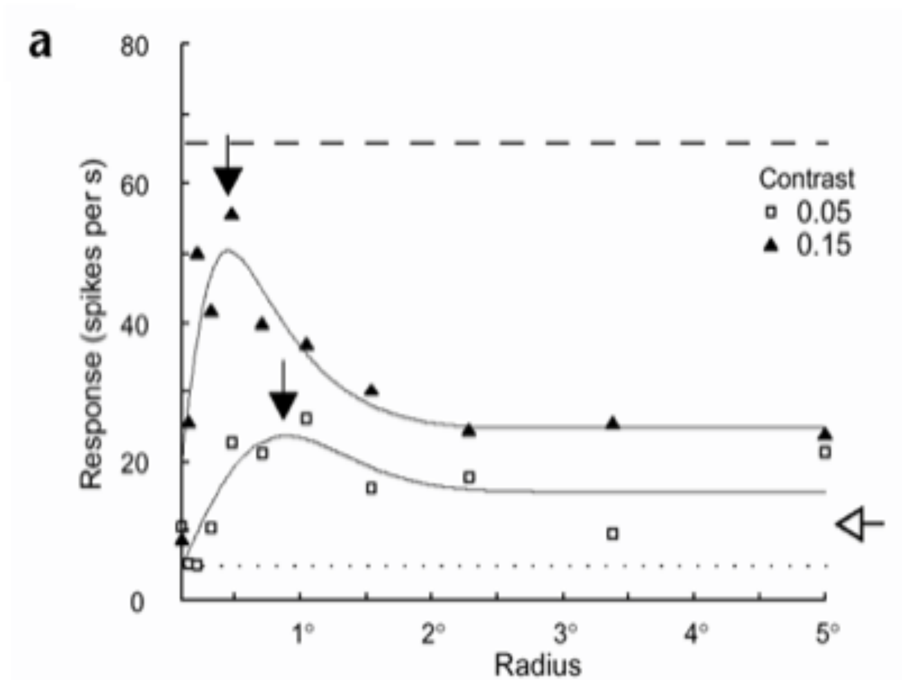
Cavanaugh et al. 2002

Summary so far for physiology:

Many studies find most suppression when surround matches center (in direction, orientation, etc.). Some studies report less suppression or enhancement when surround is very different from center.

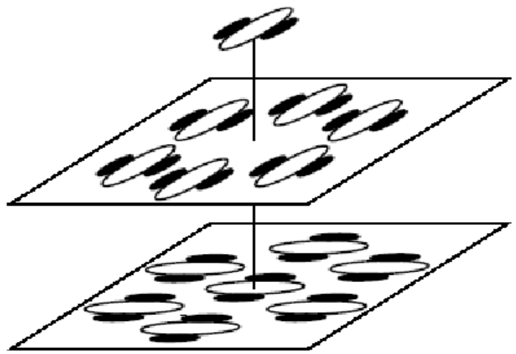
Other effects…

Surround responses can be complex...



Sceniak et al. 1999

Simple descriptive model of cortical surround nonlinearity



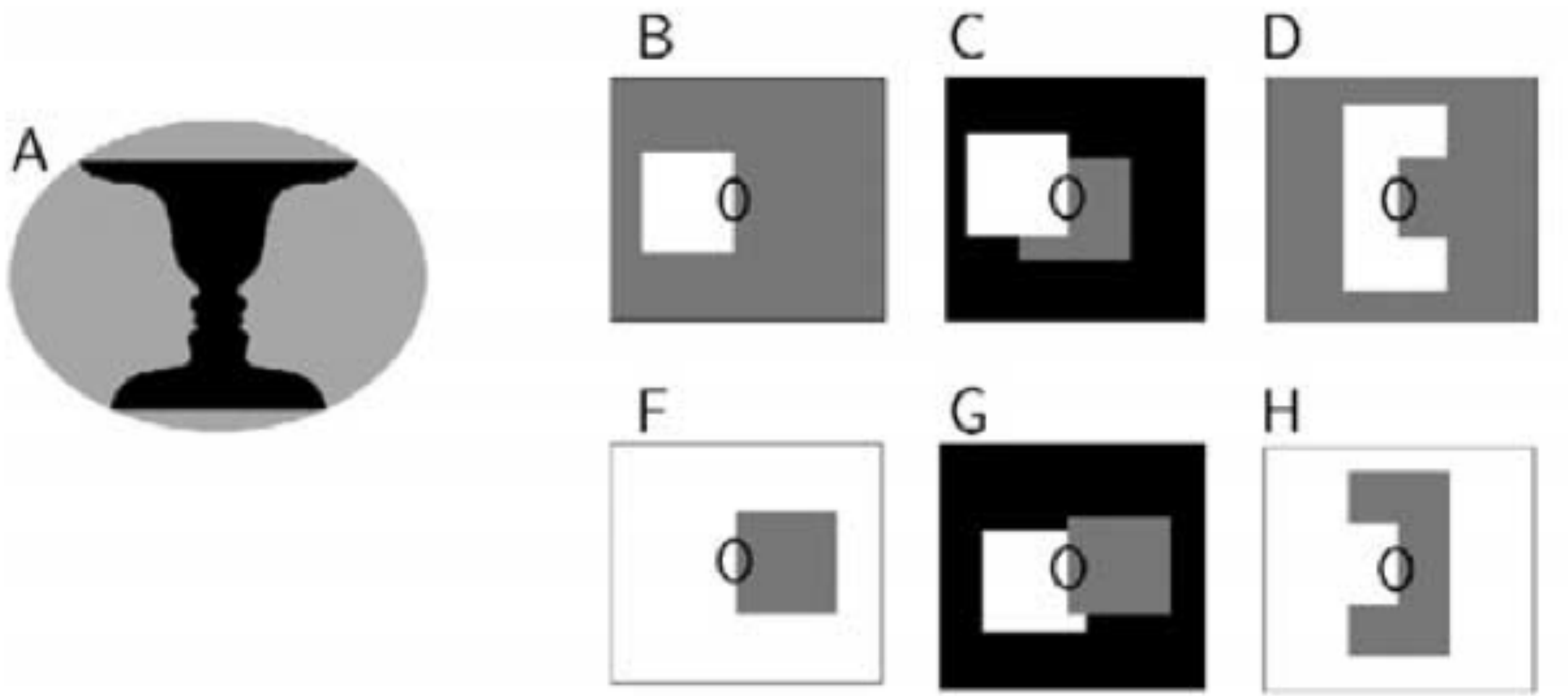
$$R_i = \frac{L_i^2}{\sum_j w_{ji} L_j^2 + \sigma^2}$$

- Linear filters followed by nonlinearity

After Heeger 1992

Context by other visual cues? Figure ground?

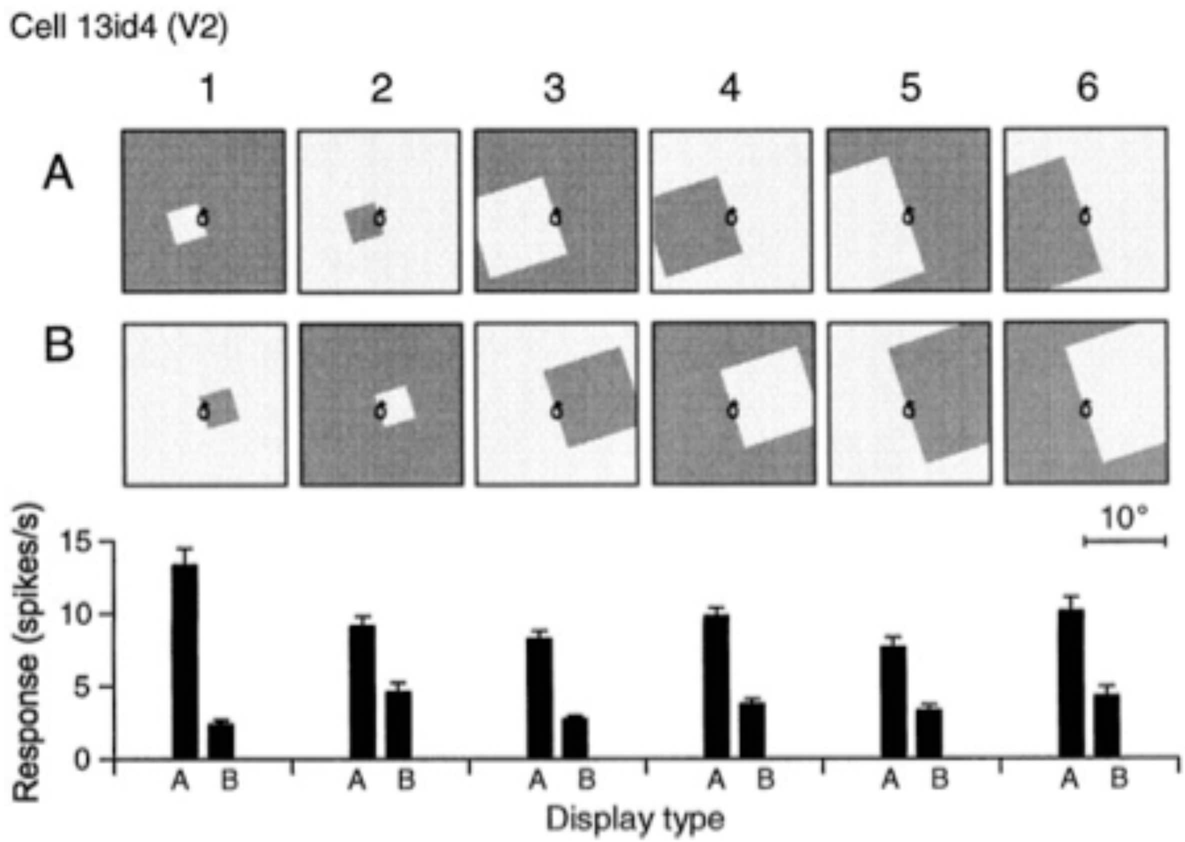
…



From Zhaoping 2005; stimuli used in cortical physiology by Von der Heydt et al.

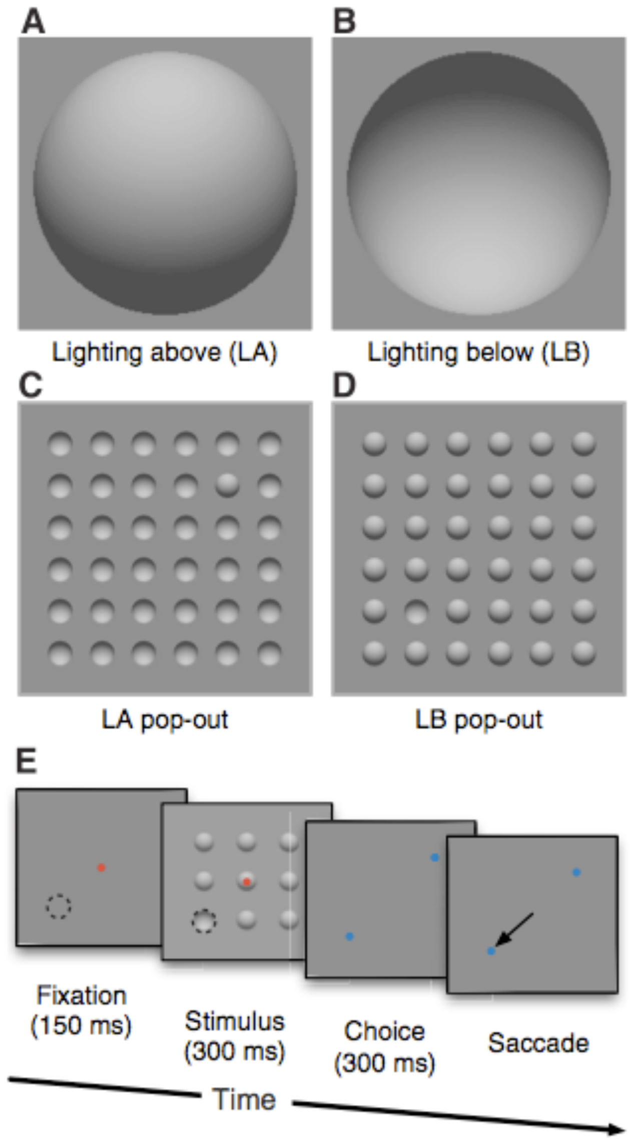
Context by other visual cues? Figure ground?

…



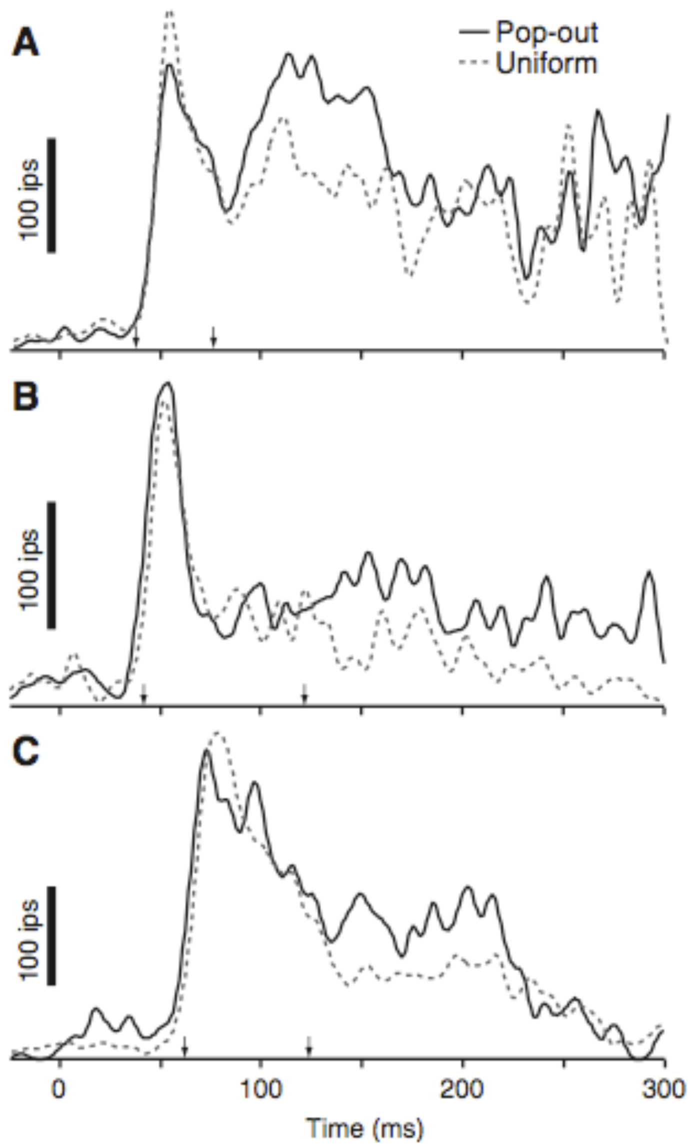
Zhou et al. 2000

Context by other visual cues?



Smith et al. 2007

Context by other visual cues?

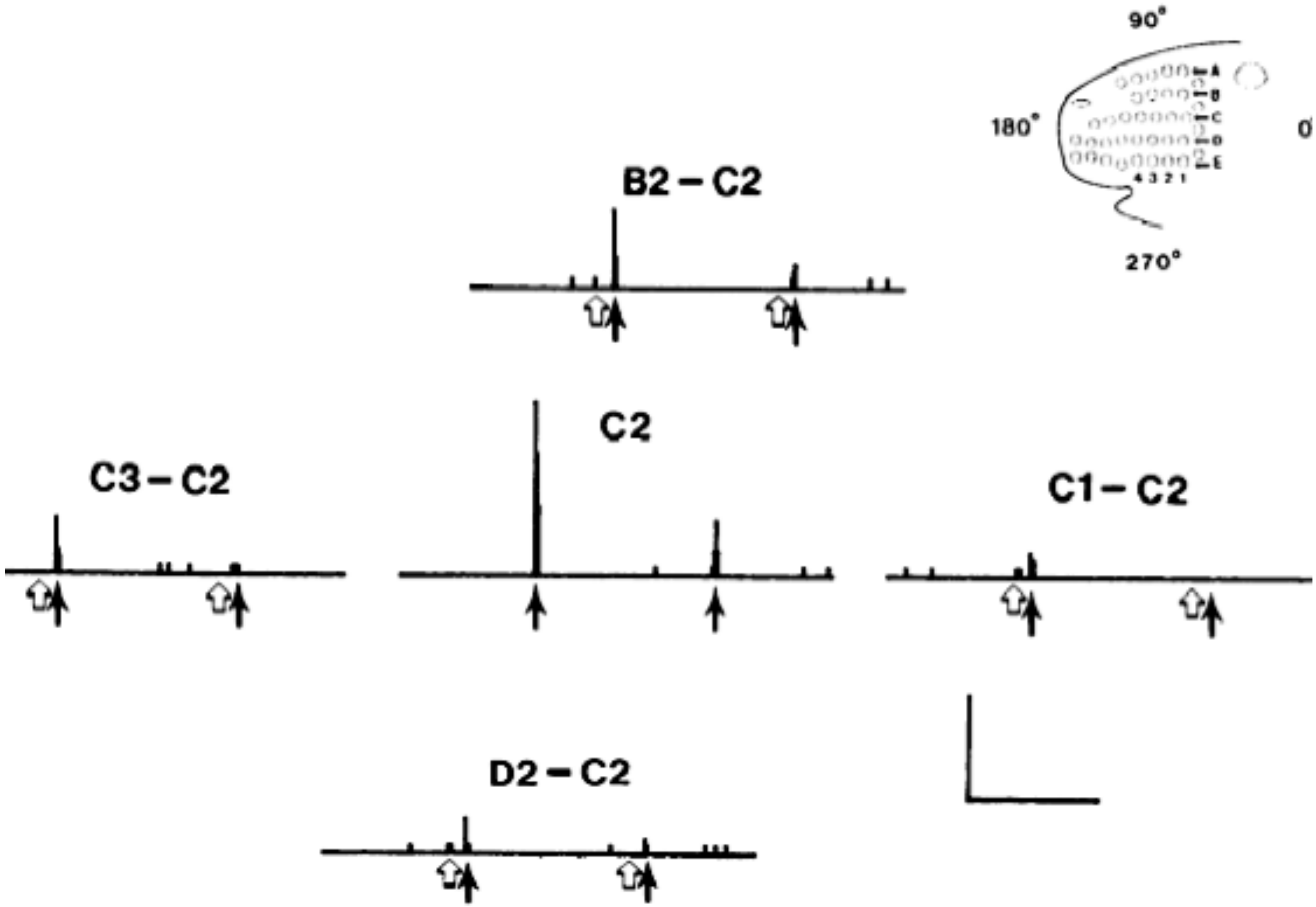


Note long latency

Smith et al. 2007

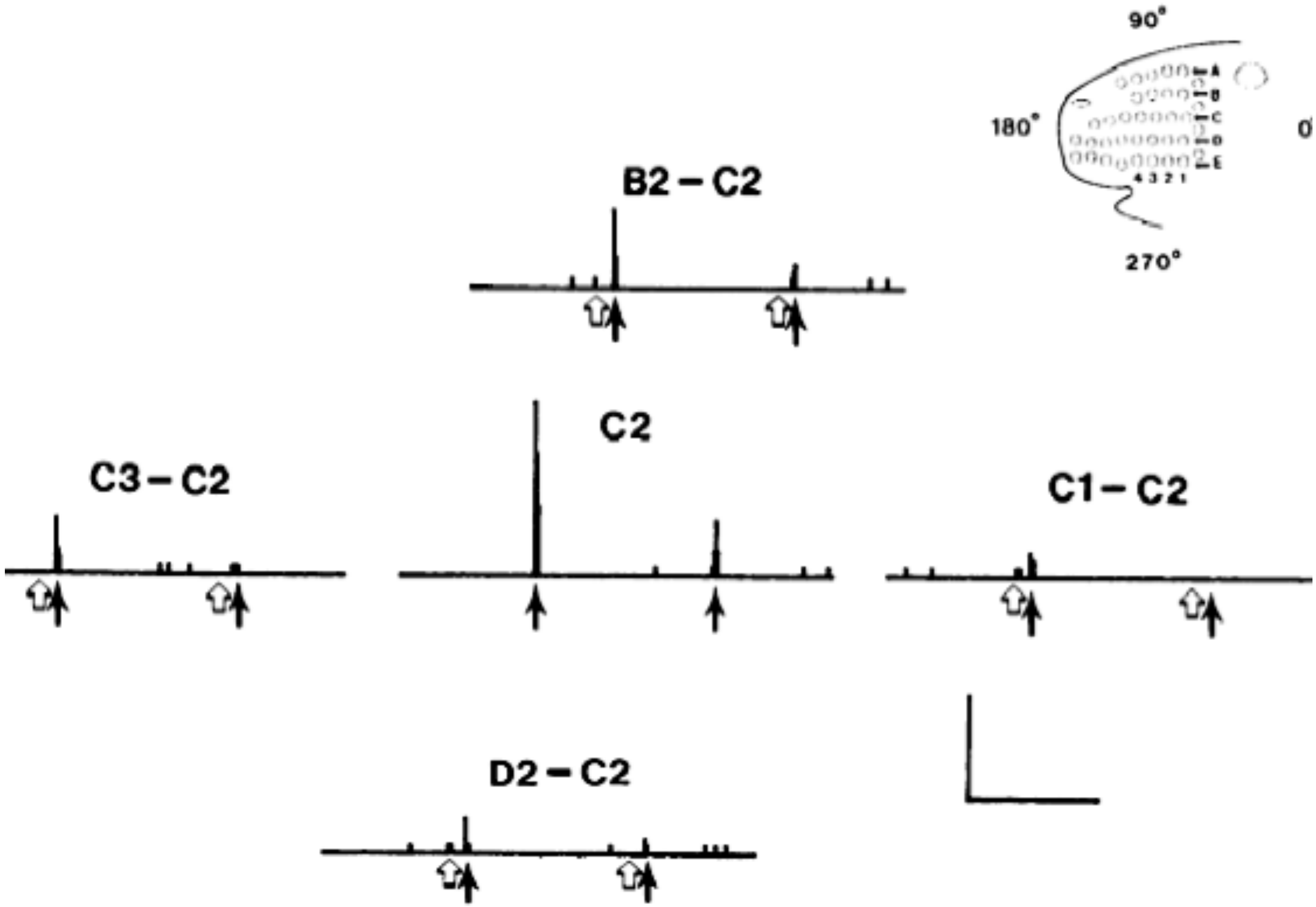
In what other sensory systems
might we expect contextual effects?

Context not unique to vision…



Simons and Carvell, 1989

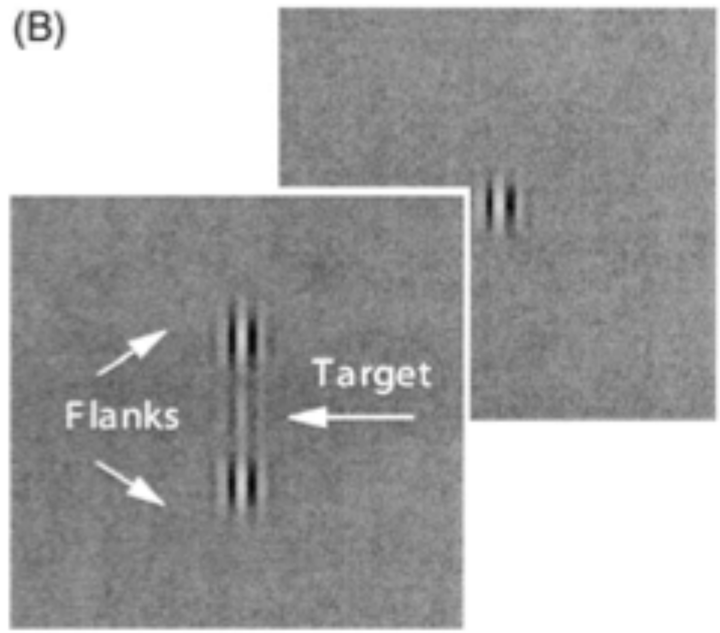
Context not unique to vision…



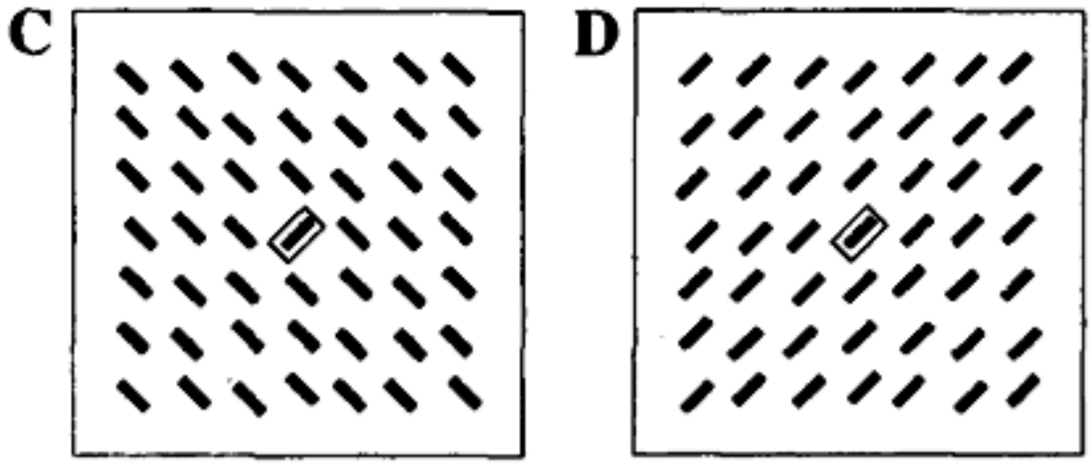
Simons and Carvell, 1989

Surround effects can lead to perceptual illusions.
What are surround effects good for?

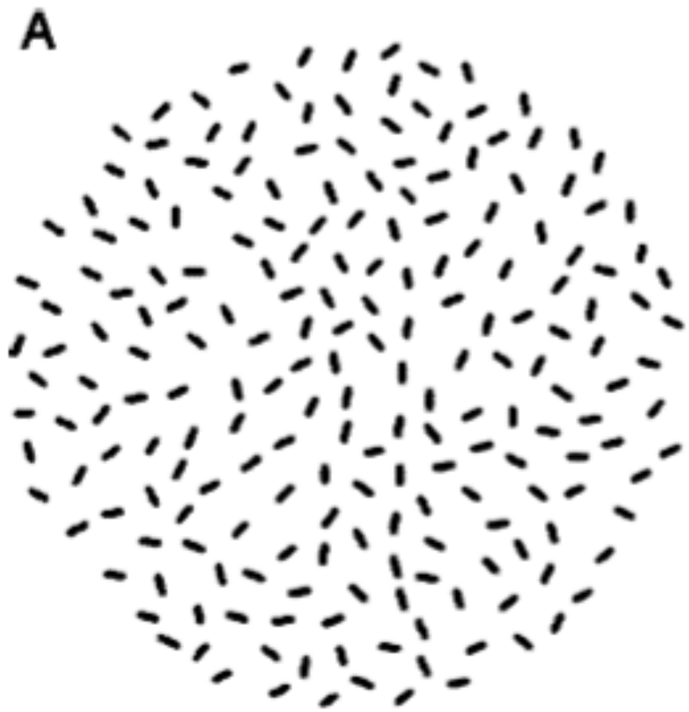
Enhancing a low contrast center target?



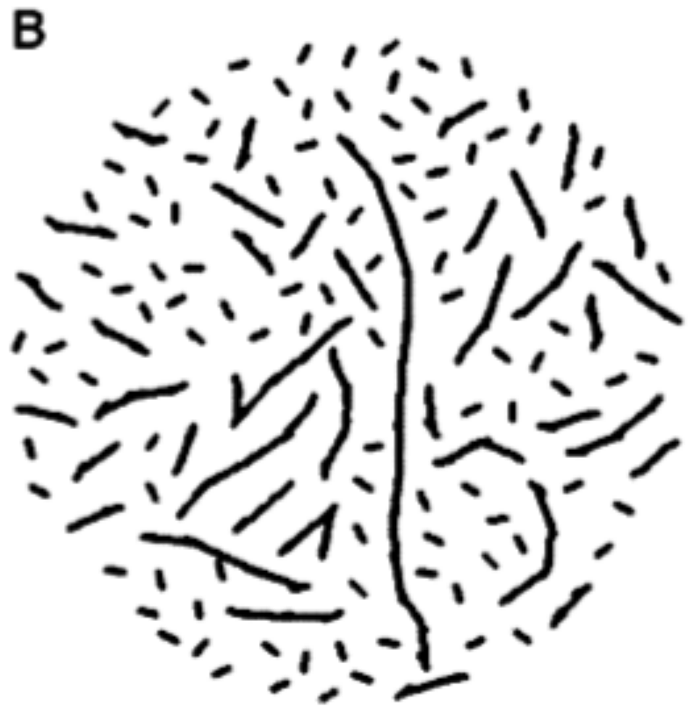
Perceptual
popout?



Contours in the presence of distractors?



Contours in the presence of distractors?



Discussion

Type of stimuli in visual experiments: artificial experimental such as bars or gratings; natural images

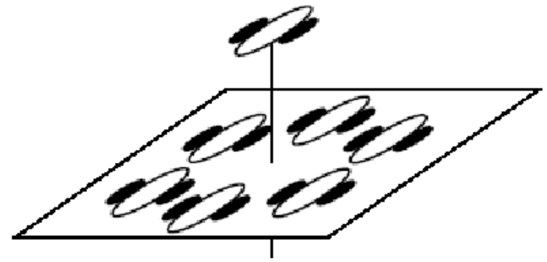
Contextual effects abound in vision and other sensory systems (we focused on visual surround effects physiology and perception)

Images contain contextual structure (such as spatial surround); understanding these regularities can be used to design experiments and build models

Scene statistics and Divisive Normalization

Contextual influences

- Cortical visual neurons (V1)



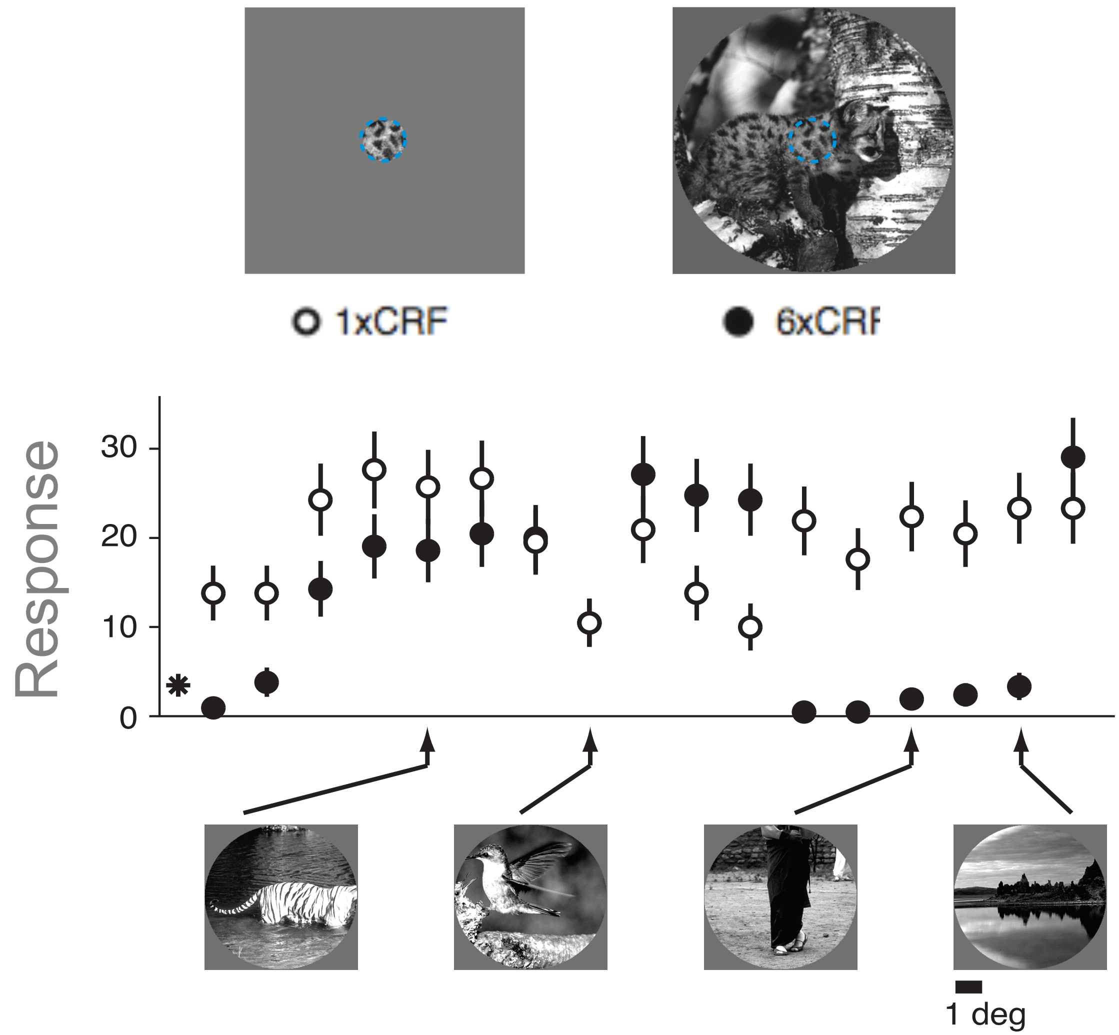
Motivation

- 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

Cortical Neurons

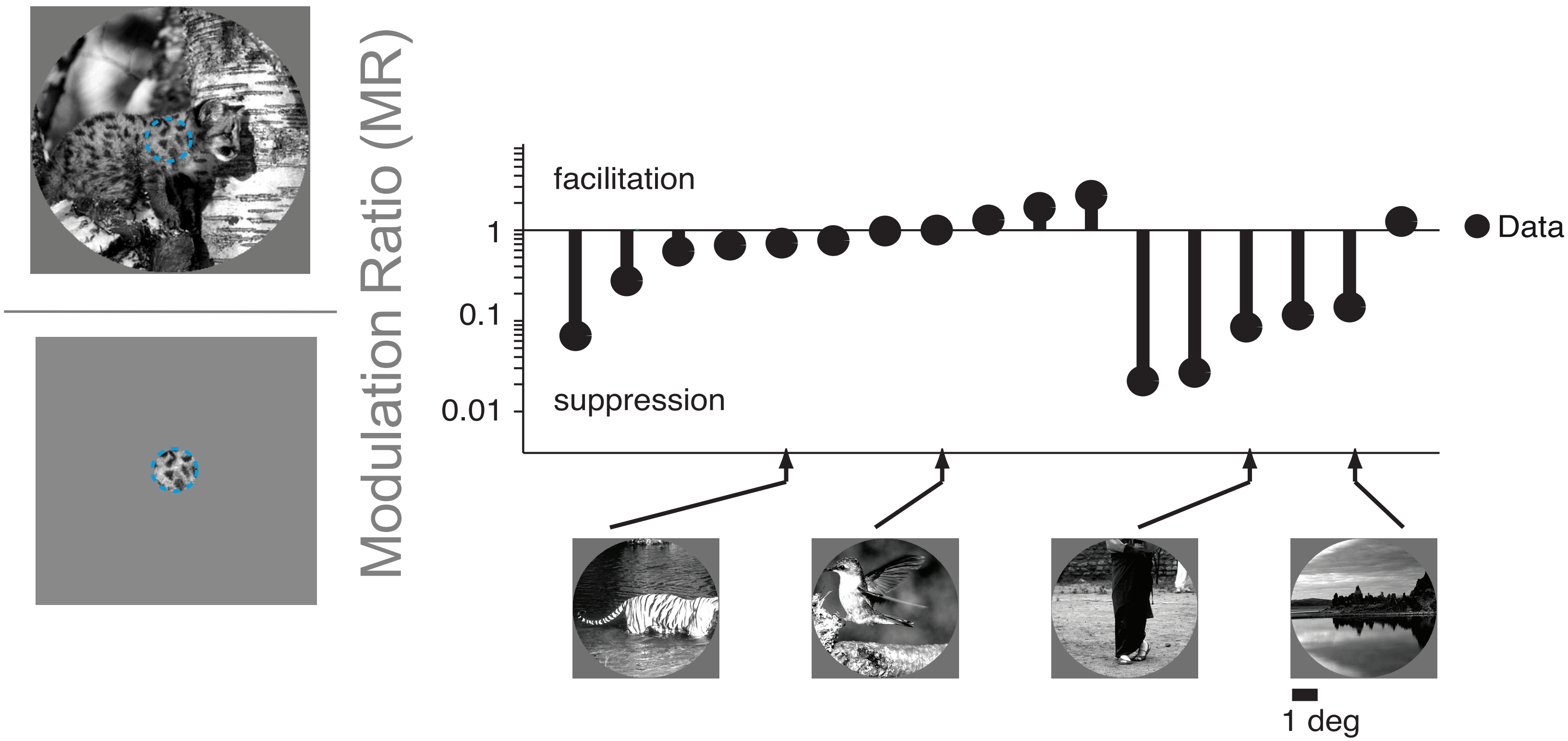
- Spatial context and natural scenes



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

Cortical Neurons

- Spatial context and natural scenes



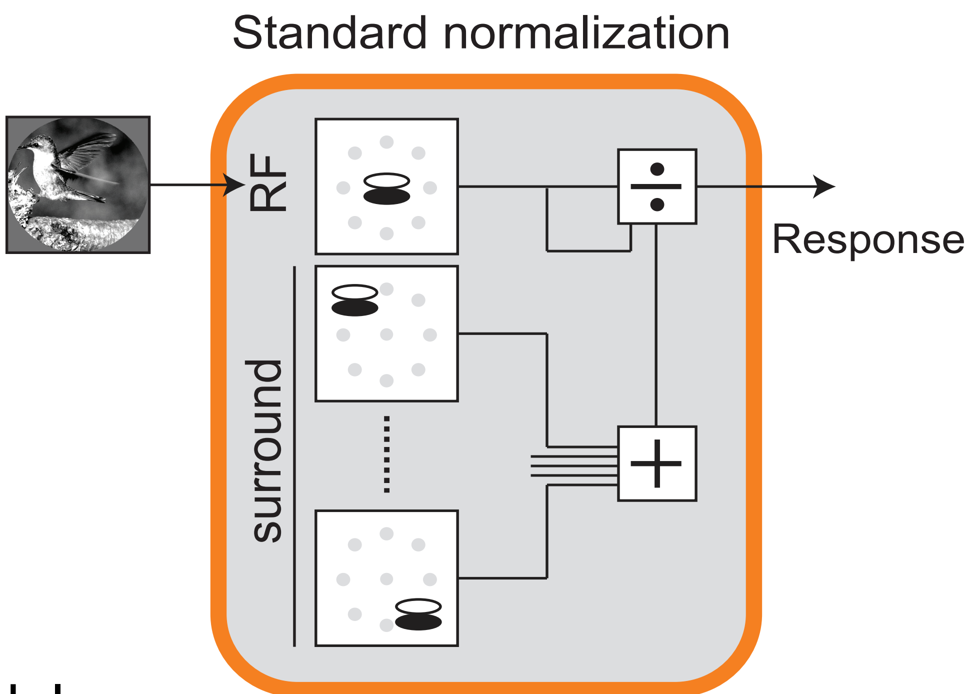
Data: Adam Kohn lab (Coen-Cagli, Kohn, Schwartz, 2015)

Cortical Neurons

- Spatial context and natural scenes

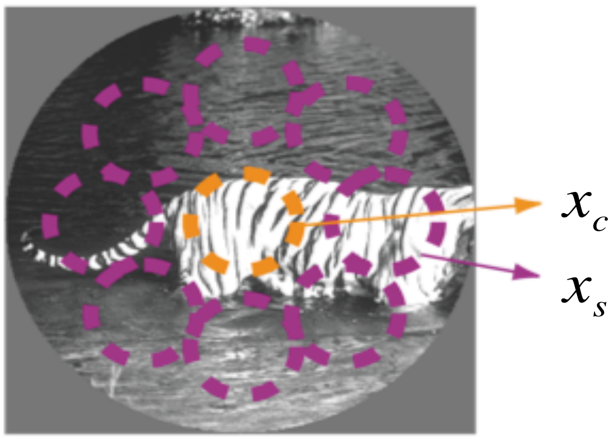
Can we capture data with canonical divisive normalization? (descriptive model)

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

Cortical Neurons

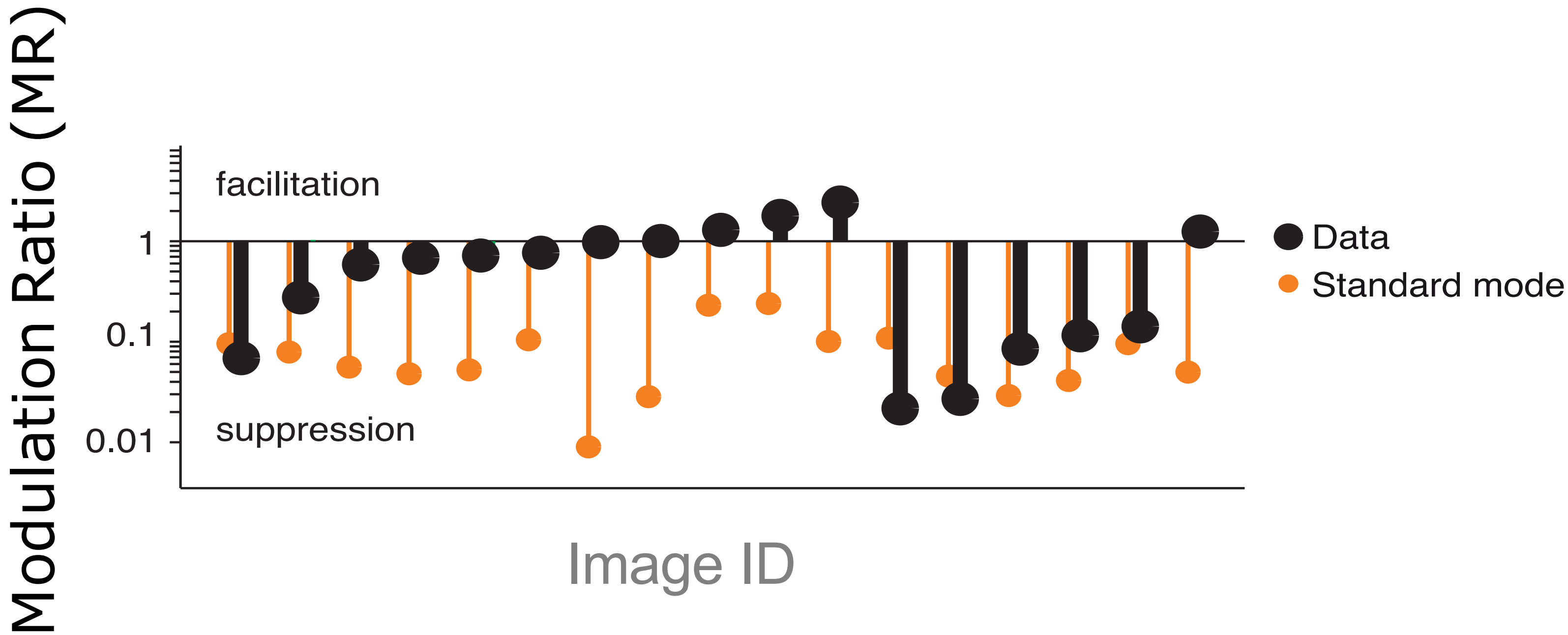


Canonical divisive normalization:

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

V1 Data: Kohn lab

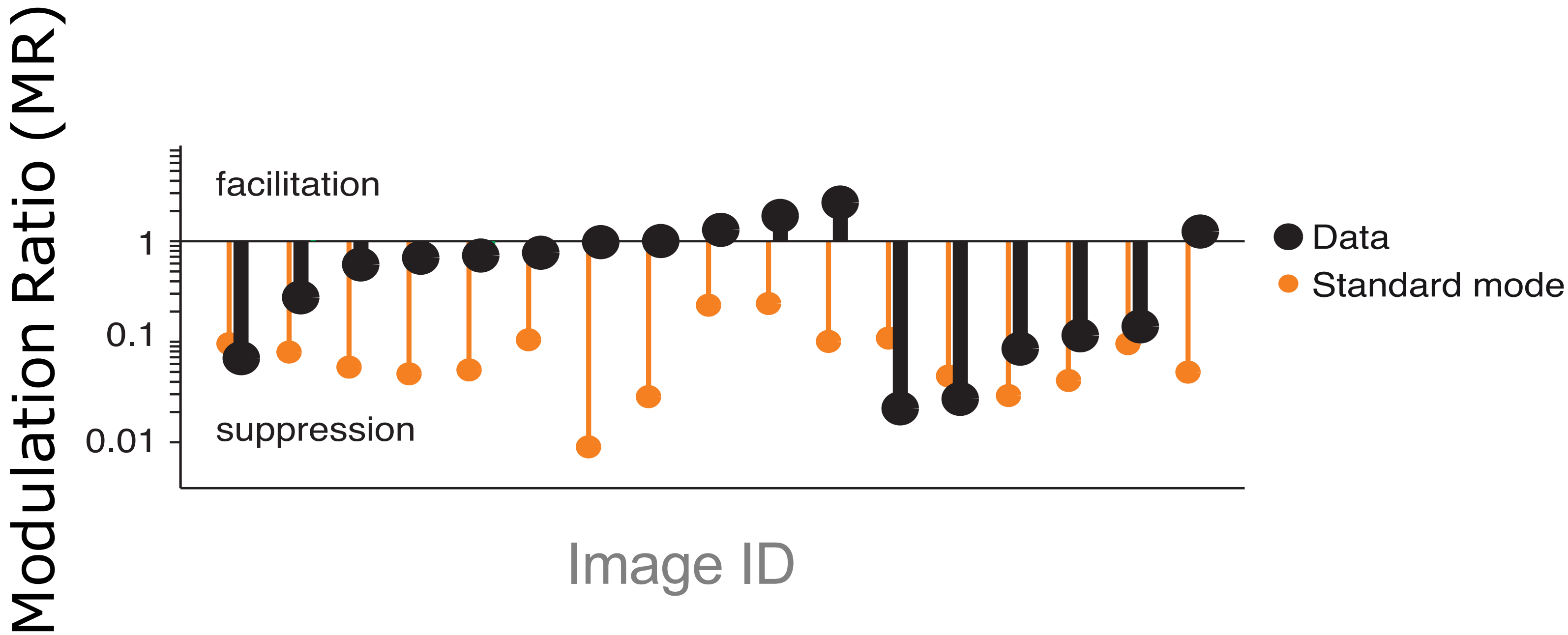
Cortical responses to natural images



- We fit the standard normalization model to neural data
- Poor prediction quality

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

Cortical responses to natural images



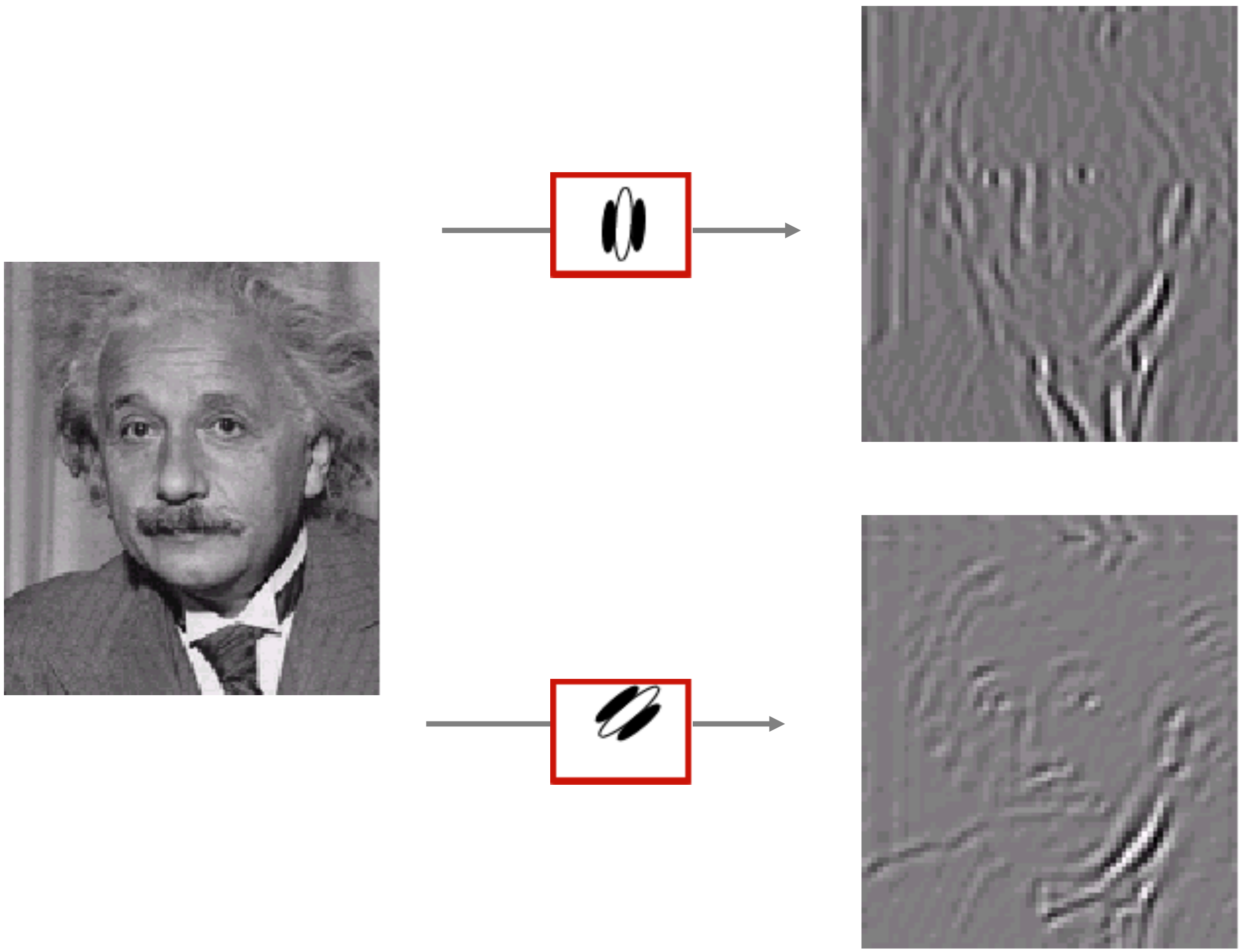
- Can we explain as strategy to encode natural images optimally based on expected contextual regularities?

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

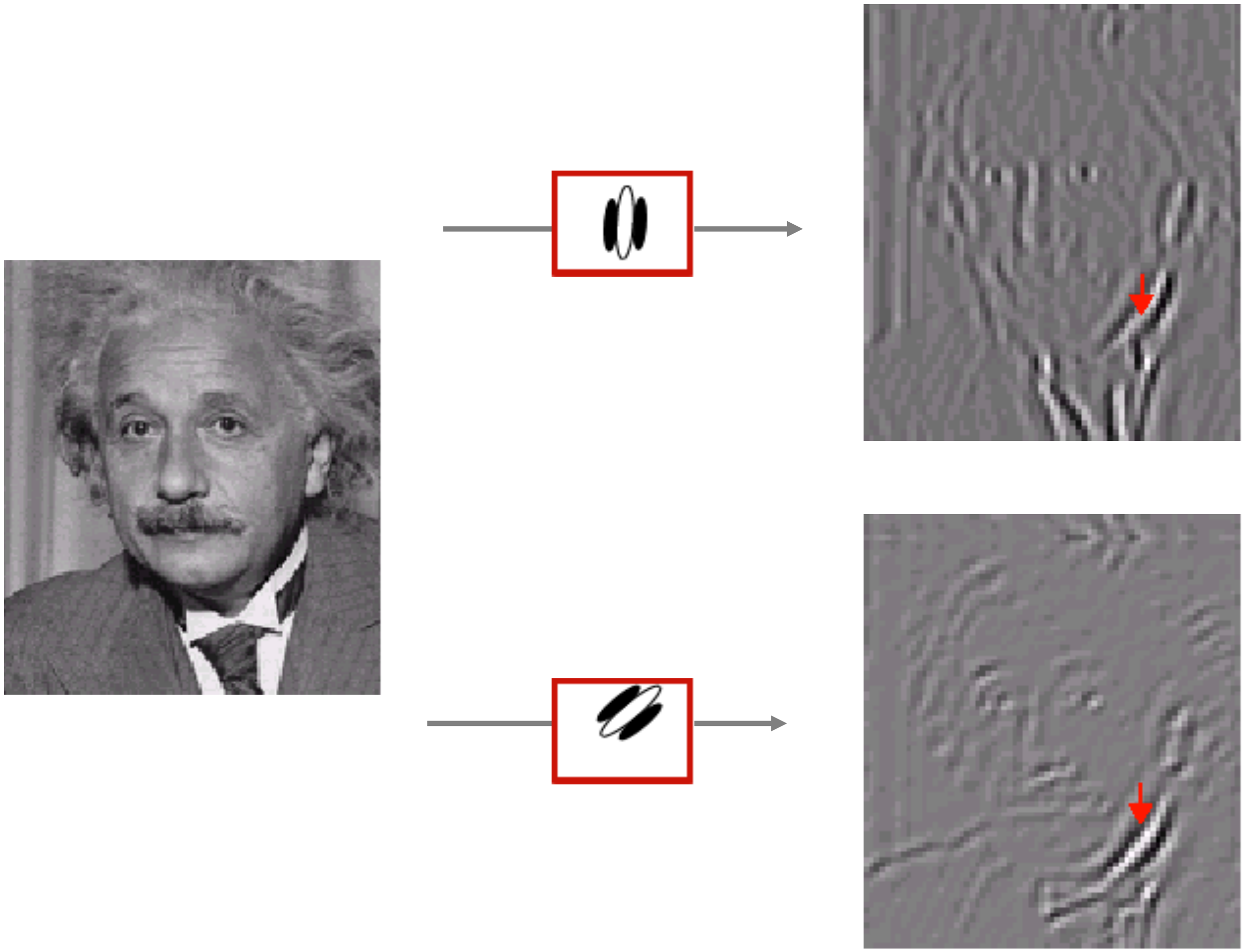
Outline

- Experimental data on cortical responses to natural images (standard descriptive model can't explain)
- Computational neural model that captures contextual regularities in natural images
- A Interplay of modeling with biological neural and psychology data (focus on natural images data)

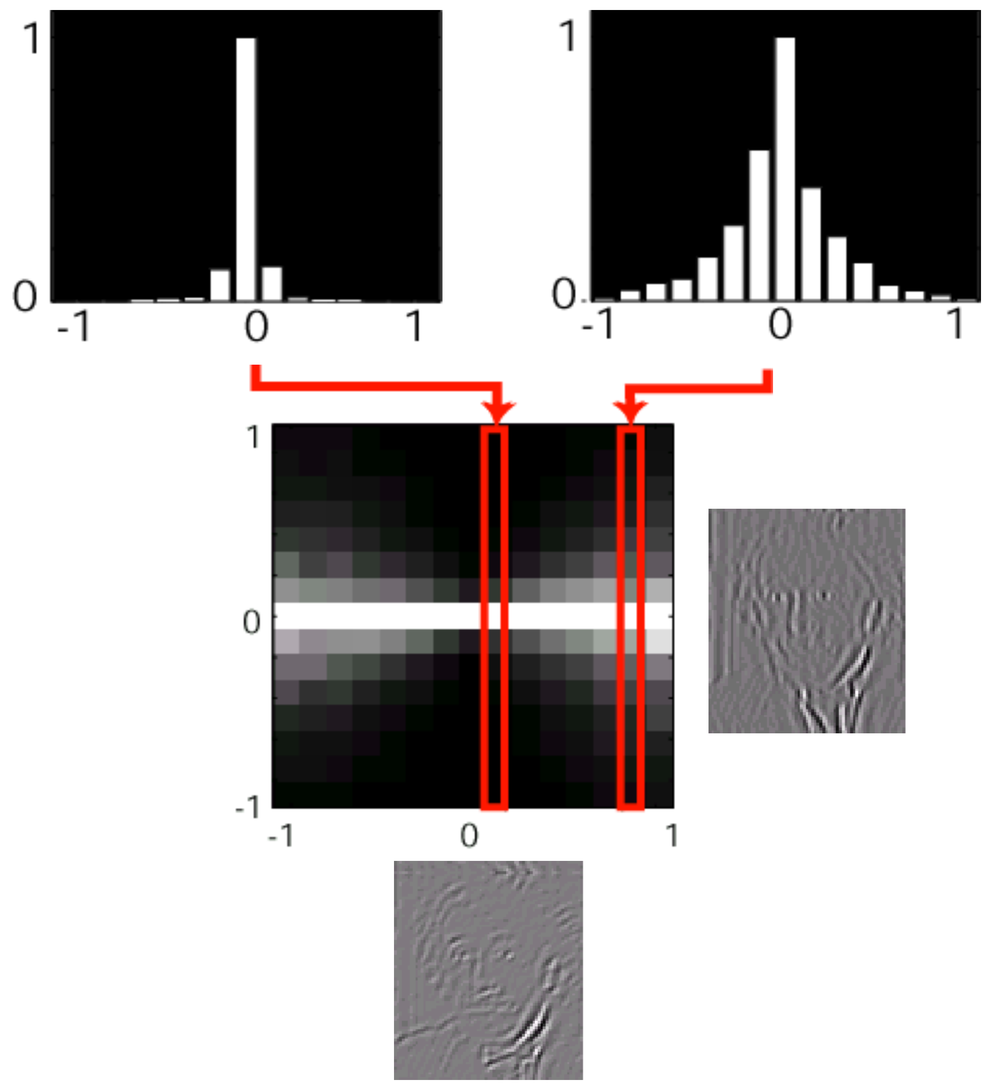
Contextual dependencies across space



Contextual dependencies across space

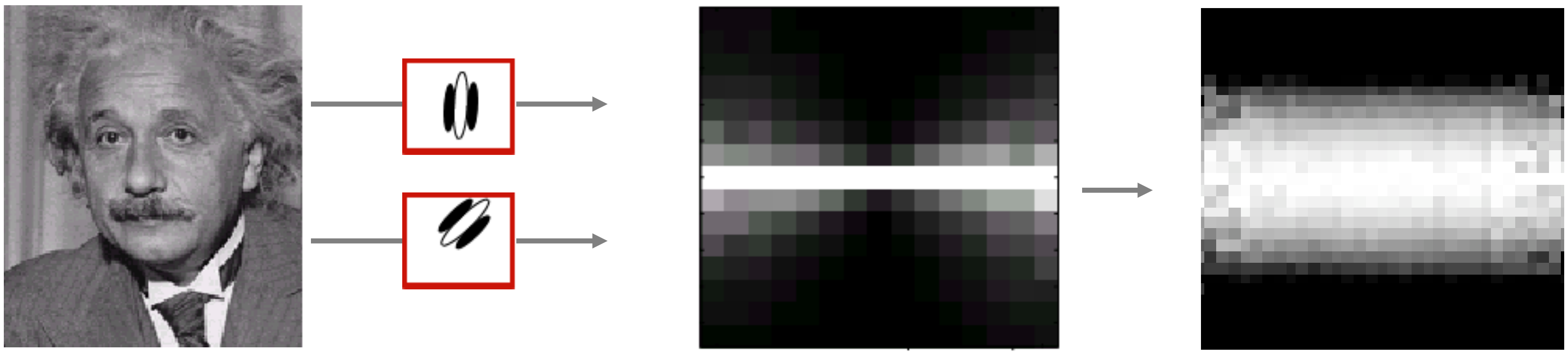


Contextual dependencies across space



Schwartz, Simoncelli, Nature Neuroscience 2001

Generative model framework

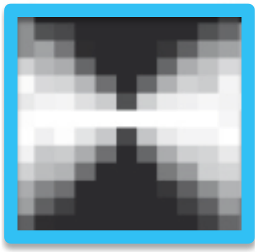


- Hypothesize that cortical neurons aim to reduce statistical dependencies (so as to highlight what is salient)
  Schwartz, Simoncelli 2001 (for salience: Zhaoping Li, 2002)

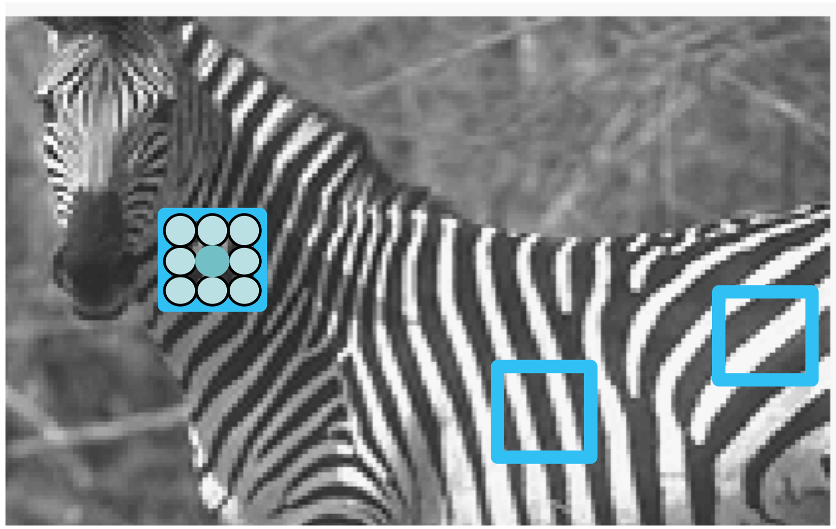
- Formally, we build a generative model of the dependencies and invert the model (Bayesian inference) – richer representation!
  Andrews, Mallows, 1974; Wainwright, Simoncelli, 2000; Schwartz, Sejnowski, Dayan 2006

- Generating the dependencies is a multiplicative process and to undo the dependencies we divide

Non-homogeneity of images



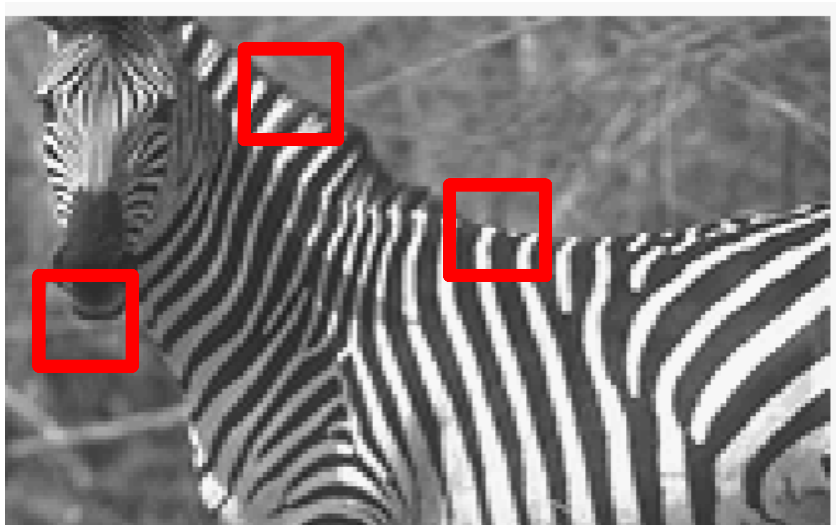
Center and surround dependent

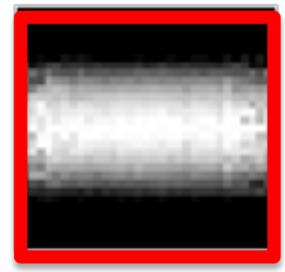


homogenous image patches

Schwartz, Sejnowski, Dayan, 2009; Coen-Cagli, Dayan, Schwartz, PLoS Comp Biology 2012

Non-homogeneity of images



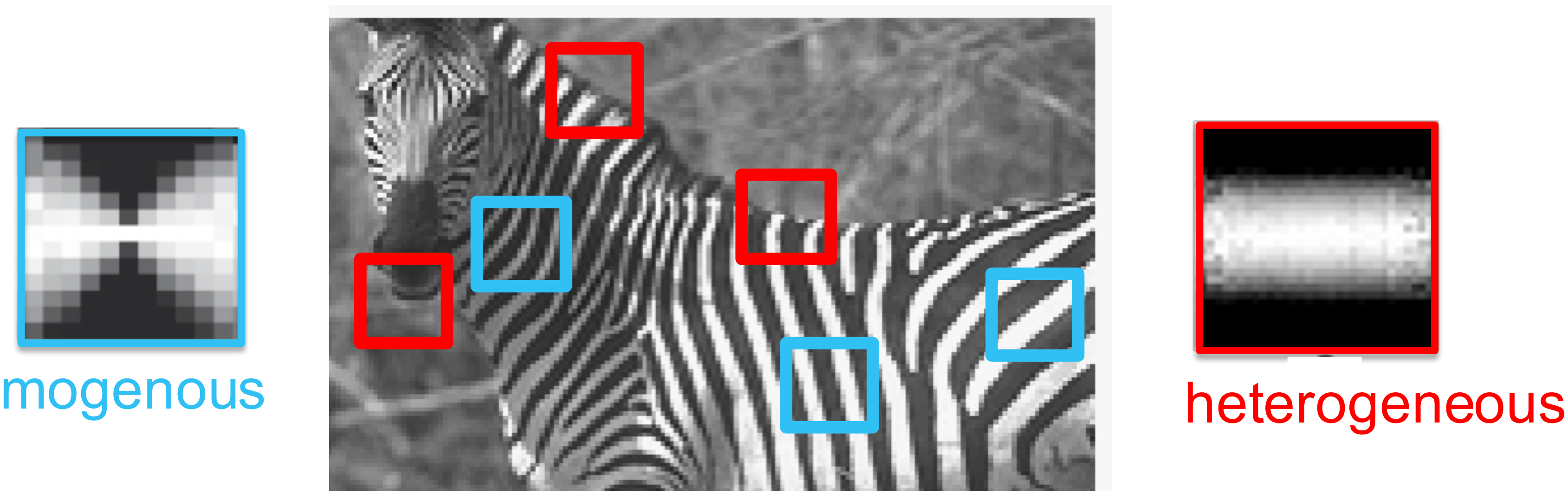


Center and surround independent

non-homogenous image patches

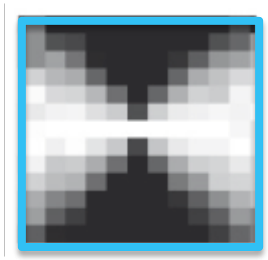
Schwartz, Sejnowski, Dayan, 2009; Coen-Cagli, Dayan, Schwartz, PLoS Comp Biology 2012

Non-homogeneity of images

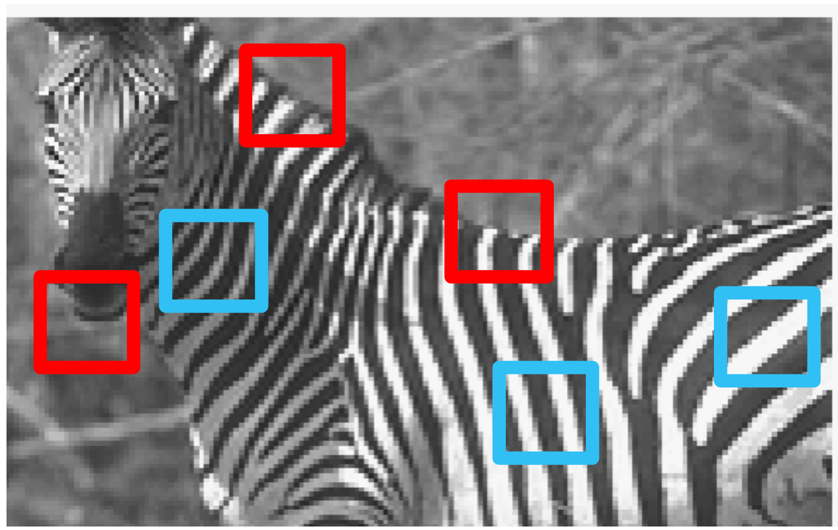


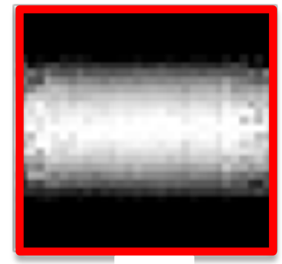
Schwartz, Sejnowski, Dayan, 2009; Coen-Cagli, Dayan, Schwartz, PLoS Comp Biology 2012

Non-homogeneity of images



divisive
normalization
ON

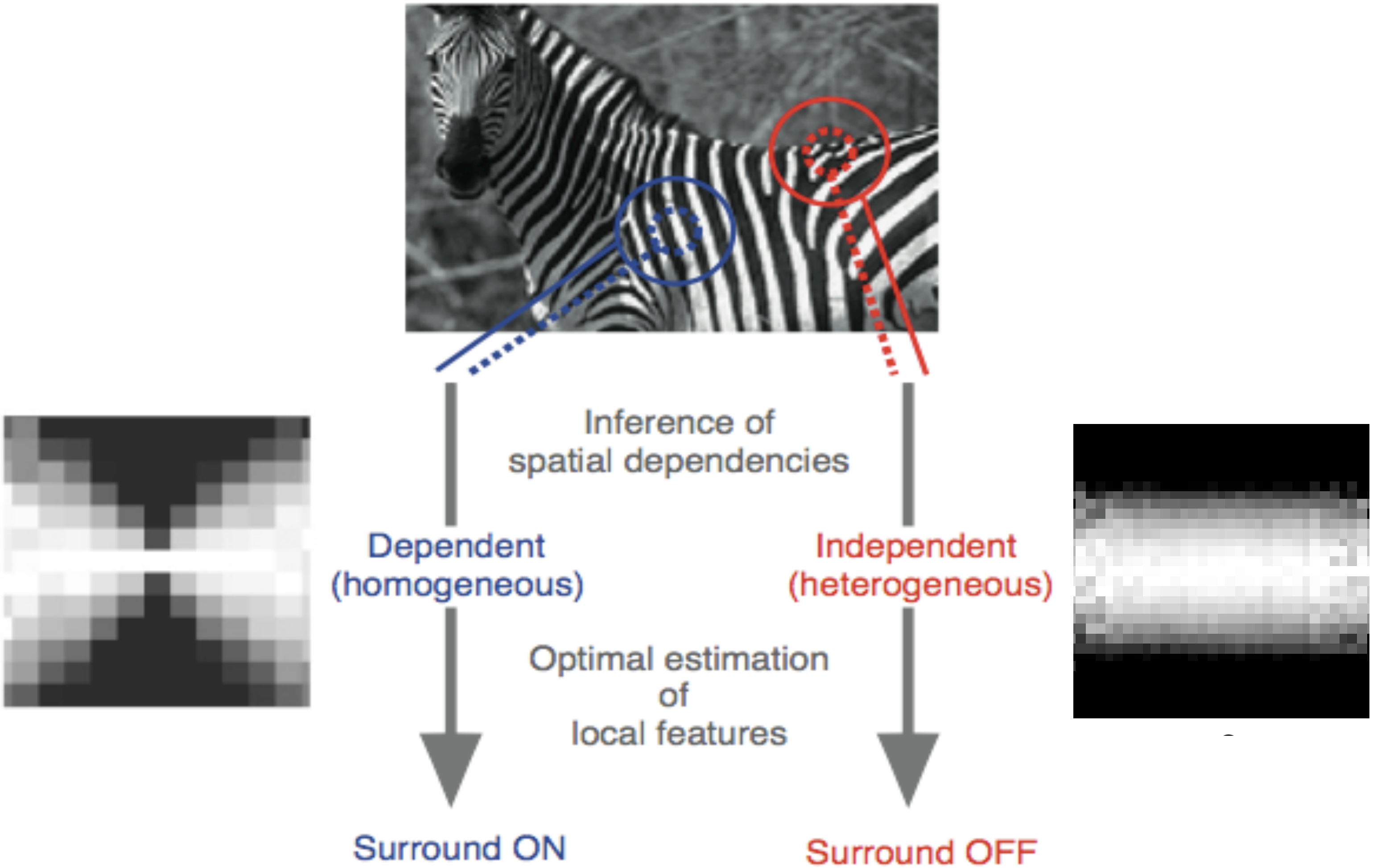




divisive
normalization
OFF

Schwartz, Sejnowski, Dayan, 2009; Coen-Cagli, Dayan, Schwartz, PLoS Comp Biology 2012

Flexible Divisive Normalization

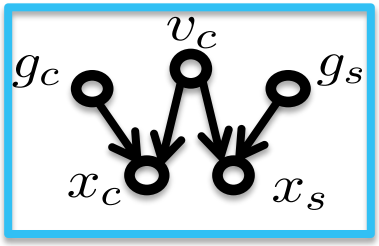


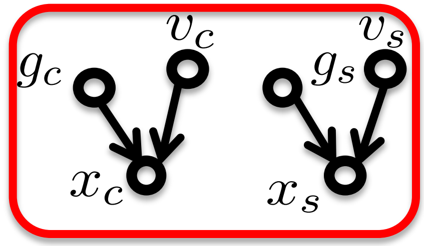
Divide

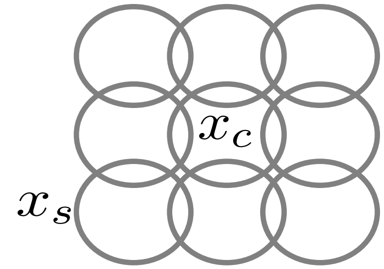
Don’t divide

Model and experimental tests: Cagli, Kohn, Schwartz 2015

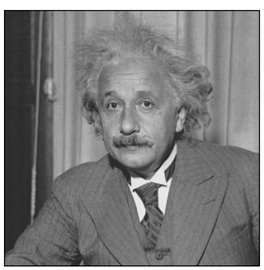
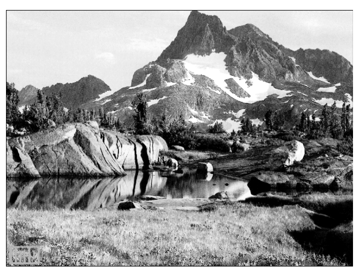
Model: Optimizing Image Ensemble





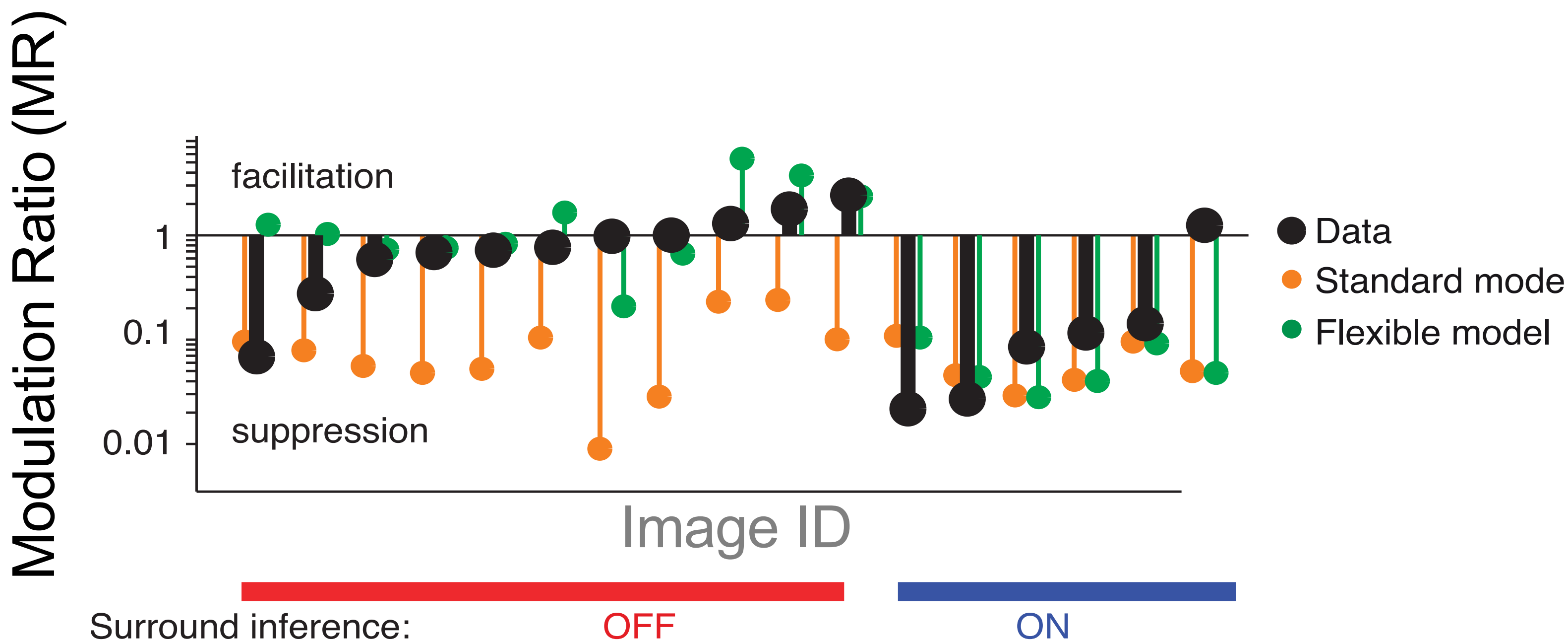


- 3x3 spatial positions, 6px separation
- 4 orientations in the center
- 4 orientations in the surround
- 2 phases (quadrature)
- model parameters (prior probability for dependent, independent and also linear covariance matrices) optimized to maximize the likelihood of a database of natural images using Expectation Maximization

Coen-Cagli, Dayan, Schwartz, PLoS Comp Biology 2012;
Schwartz, Sejnowski, Dayan, 2006

Natural scenes data



Coen-Cagli, Kohn, Schwartz, 2015

Model predictions for natural images

- Comparing model performance for cortical data

Standard divisive normalization

$$R_i = \alpha \left(\frac{E_{c,\phi_{pref}}}{\varepsilon + \beta E_c + \gamma E_s} \right)^n$$

Flexible divisive normalization:

$$R_i = \alpha \left(\frac{E_{c,\phi_{pref}}}{\varepsilon + \beta E_c + q(c,s) \gamma E_s} \right)^n$$

Determined by the model (not fit!)
1 if $p(\xi_1 \mid c,s) \geq 0.5$
0 otherwise

(similar results if non binary)