A Model of Contingent Adaptation in Cortex

Michael S. Landy, Zachary M. Westrick & David J. Heeger

New York University
Dept. of Psychology and
Center for Neural Science

Outline

- Introduction: A variety of effects of pattern adaptation in cortex
- A model for contingent adaptation
- Simulation results
- Implications for behavior

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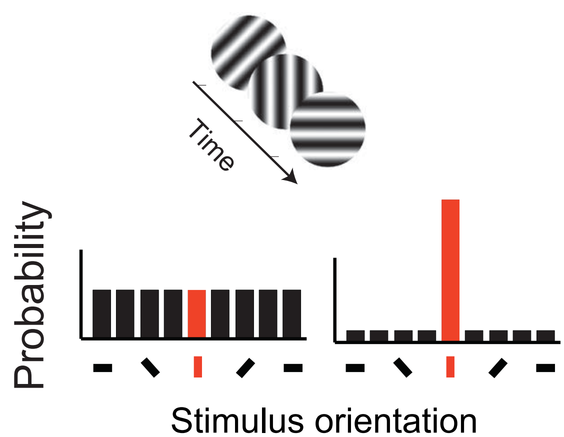
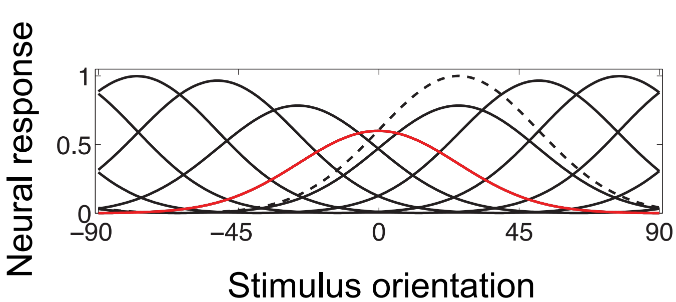
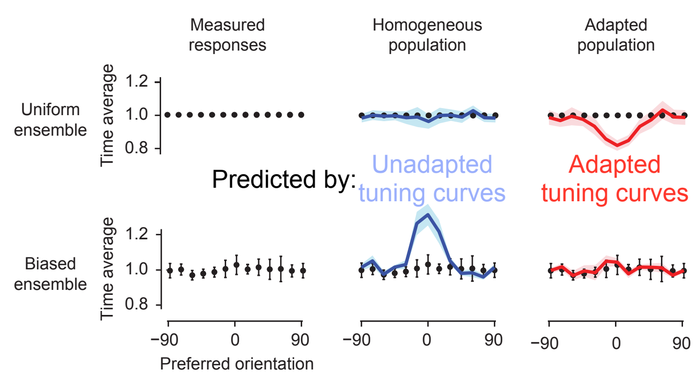
Adaptation to orientation



Standard model: Gain adaptation

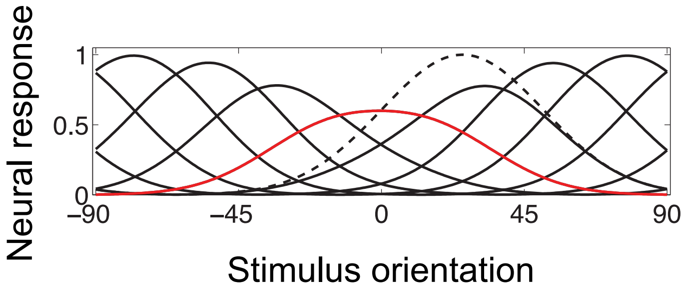


The effect: Homeostasis of firing rate



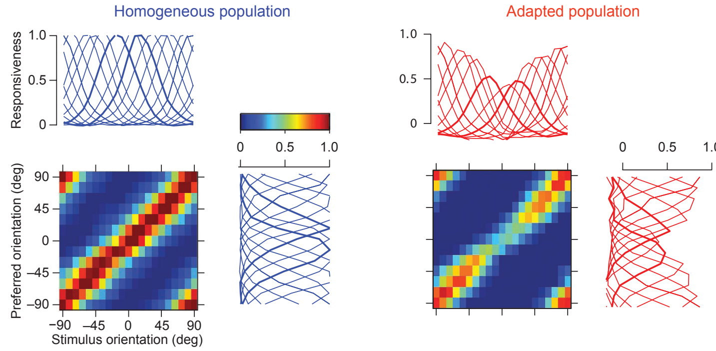
From: Benucci et al., 2013

But: Tuning-curve repulsion is also evident



Cat: Benucci et al., 2013; Dragoi et al., 2000, 2001; Felsen et al., 2002
Macaque: Muller et al., 1999; Patterson et al., 2013; Wissig et al., 2013

The net effect: Both neuron- and *stimulus*-specific adaptation



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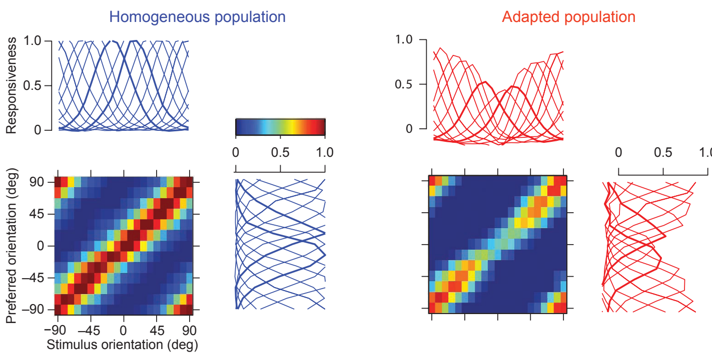
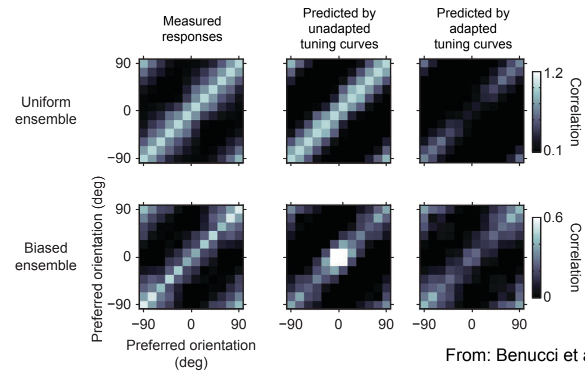
The net effect: Both neuron- and *stimulus*-specific adaptation



Adapted responses = Unadapted X neuron-specific gain X stimulus-specific gain factor

Another interesting outcome: Approximate maintenance of correlation structure



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Can these effects be predicted by a single model?

- Neuron-specific adaptation
- Stimulus-specific adaptation
- Approximate correlation homeostasis

We suggest that a simple learning rule paired with normalization can account for these results.

Normalization (Heeger, 1993)

$$R_i(\theta) = \frac{F_i(\theta)^2}{s + \sum_{j=1}^{N} F_j(\theta)^2}$$

where F_i is the feed-forward drive to neuron i and R_i is its response to a stimulus with orientation θ.

Normalization with weights

$$R_i(\theta) = \frac{F_i(\theta)^2}{s + \sum_{j=1}^{N} W_{j,i} F_j(\theta)^2}$$

where $W_{j,i}$ is the weight by which neuron j contributes to the inhibitory normalization pool for neuron i.

Our model: Contingent adaptation

$$R_i(\theta) = \frac{F_i(\theta)^2}{s + \sum_{j=1}^{N} W_{j,i} F_j(\theta)^2}$$

$$W_{j,i}^{t+1} = W_{j,i}^{t} + \alpha \times \left(R_j^t R_i^t - C_{j,i}\right)$$

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$$C_{j,i} = E_{\text{unbiased}}(R_j R_i)$$

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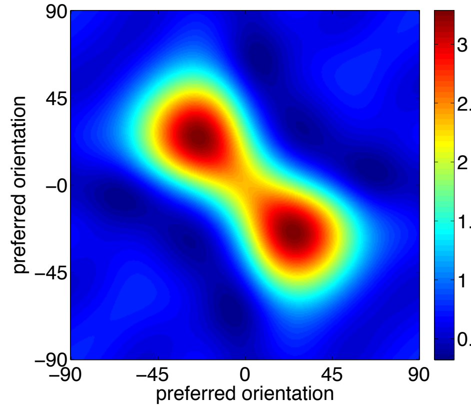
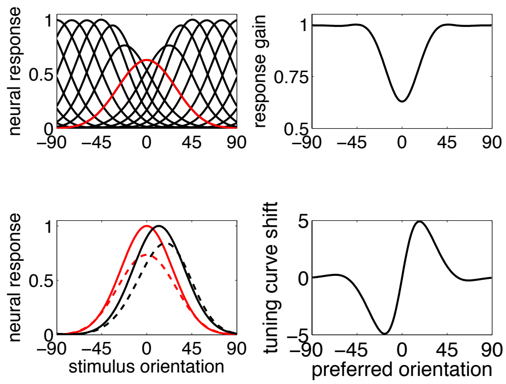
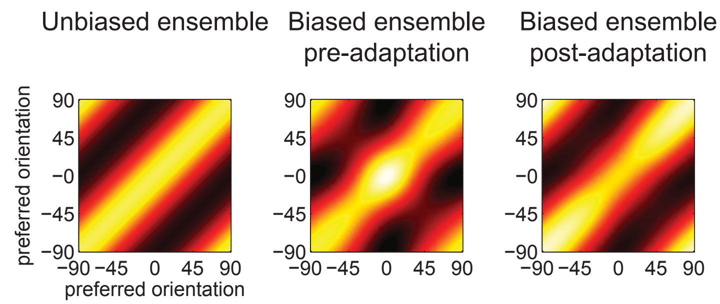
Normalization weights after adaptation to biased ensemble



Tuning curves after adaptation to biased ensemble



Approximate covariance homeostasis



Alternative models

That don't work:

- Maintenance of correlation rather than joint product
- Inherited adaptation and response gain control alone

That *do* work:

- Recurrent contingent adaptation

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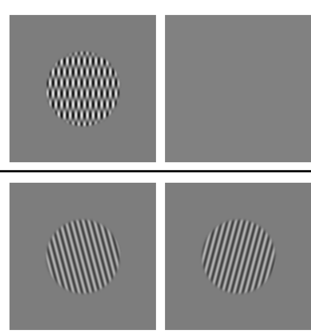
Contingent adaptation: Overlap masking

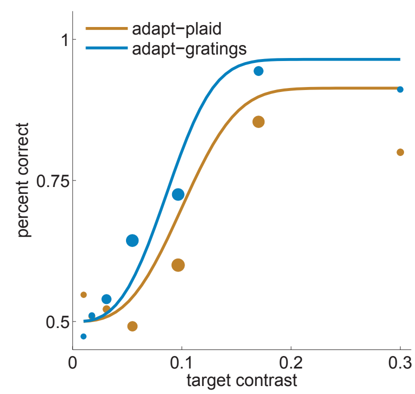
Plaid adapt: Adapt to ±15º plaid alternating with blank

Grating adapt: Adapt to +15º alternating with -15º grating



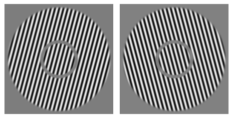
Task: Detect +15º grating masked by -15º grating

Contingent adaptation: Overlap masking

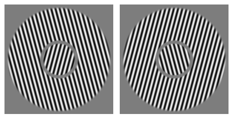


Contingent adaptation: Surround masking

Same-orientation adapt condition

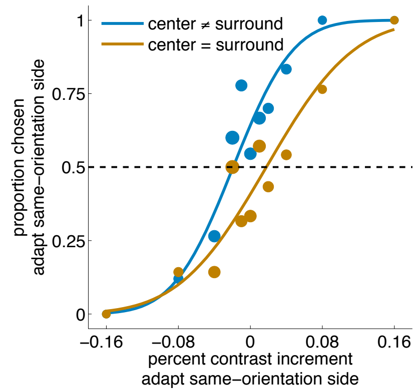


Different-orientation adapt condition



Adaptation is same-orientation on one side and different-orientation on the other. Test is same condition on both sides. Task is contrast discrimination.

Contingent adaptation: Surround masking



Conclusions

- Contingent-adaptation model accounts for several phenomena of cortical adaptation
- It has implications for psychophysical performance, and we have hints that its predictions will be borne out
- It bears resemblance to other forms of contingent adaptation (e.g., the McCollough effect), and may explain pattern-based effects (e.g., Nakashima & Sugita, *JOV*, 2014)