Sampling in a hierarchical model of images reproduces top-down effects in visual perception

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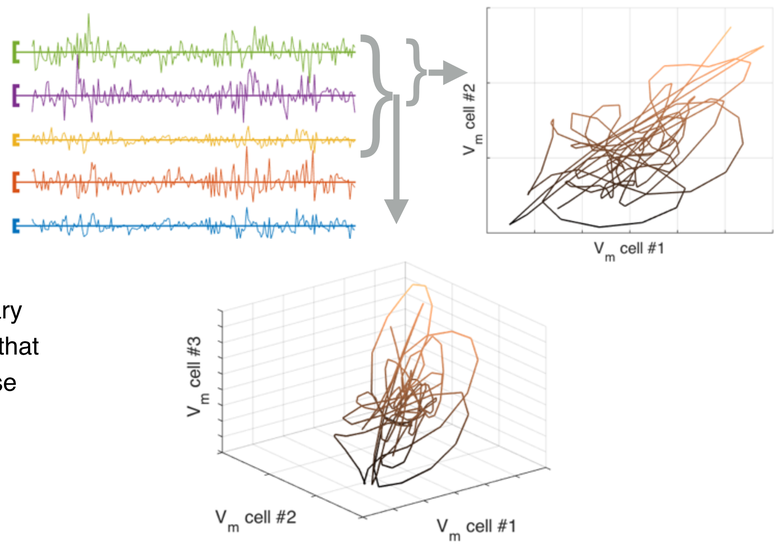
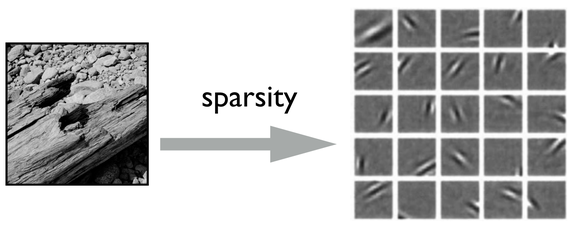
Prediction of neural population activity

- The target of prediction is the statistics of population responses to stimuli
  - mean
  - signal correlation and variance
  - noise correlation and variance
- higher-order statistics - n-ary interactions between cells that are not reducible to pairwise correlations
- spontaneous activity correlations



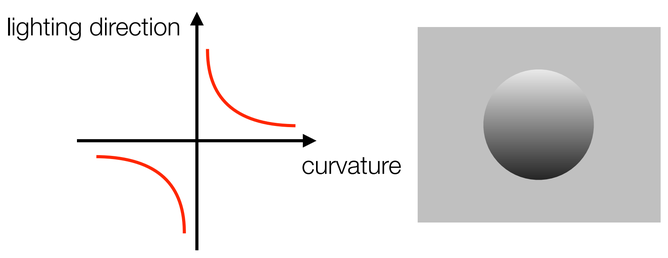
Normative approach to neural response distributions

- response properties are determined by stimulus statistics
- stimulus induced responses are affected by expectations
- mean responses correspond to (independent) features of (natural) stimuli
  - selectivity for orientation, frequency and phase
  - cross-orientation suppression
- mean responses of V1 simple cells are predicted by activations in an image model effective in compression and denoising



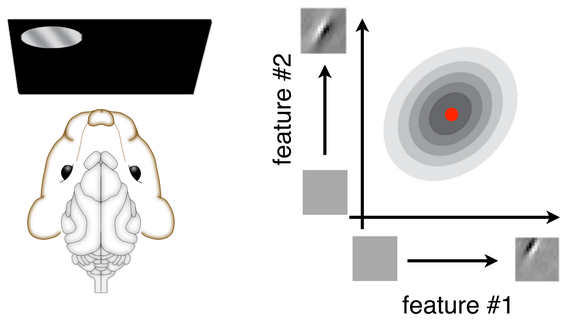
Uncertainty and variability/covariability

- ambiguity is an inherent property of observations, not only sensory noise, implying uncertainty



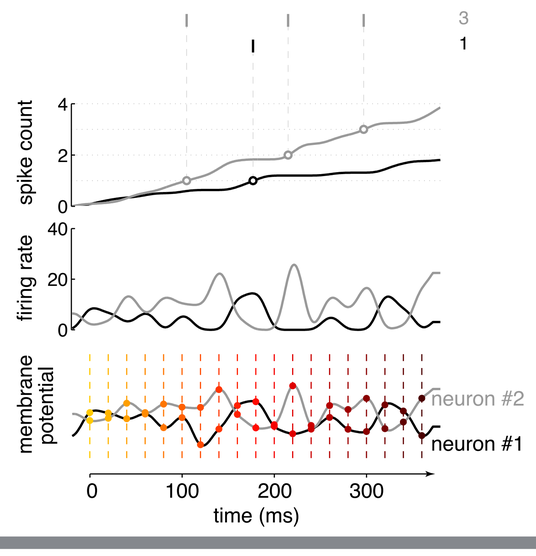
- Gestalt rules describe perceptual computation with ambiguous input
- a point estimate is not enough, not even together with a confidence estimate - optimal behaviour requires computation with values other than the most probable as well
- probability distributions encode all information that the animal possesses about a quantity

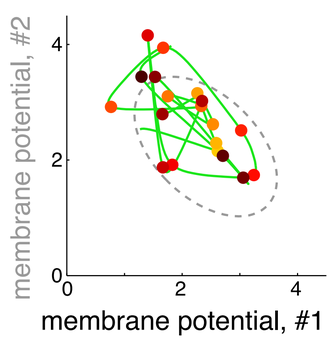
$$\max\left(\mathrm{P}(a_1, a_2 \mid \mathrm{image}, c)\right)$$



Sampling theory

- every source of perceptual uncertainty implies variability in the responses
- variability can be predicted if we regard the time course of membrane potentials as a stochastic process producing samples from the probability distribution of latent features implied by the observation at hand
- changes in response variability in relation to stimulus contrast may be predicted via sampling



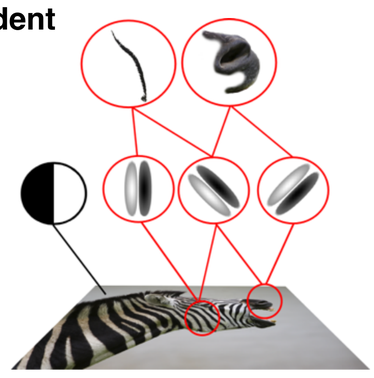


Acknowledgement
This work was supported by an MTA Lendület Fellowship (G.O. and M.B.)

A model of context-dependent covariance

$$p(v \mid g) = \mathcal{N}(v; 0, \sum_{j=1}^{K} g_j C_j)$$

$$p(x \mid v, z) = \mathcal{N}(x; zAv, \sigma_x I)$$

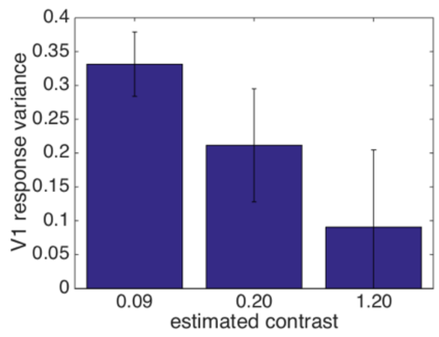


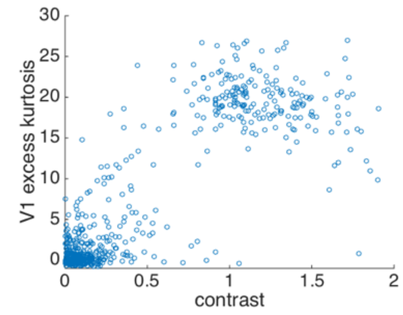
stimulus	x
linear receptive fields	A
STD of observation noise	σ_x
contrast	z
V1 simple cell activations	v
number of Gestalt components	K
Gestalt components	$C_{1..K}$
Gestalt intensities	g

- V1 neuron responses are primarily related to the stimulus through their receptive field properties
- We wish to capture higher-order statistics of V1 responses, and correlations of the responses depend heavily on context, thus a single covariance matrix is not enough
- Gestalt principles are encoded as a set of covariance matrices, and their weighted sum constitutes the noise covariance of V1 cells
- A feature of natural images is the presence of an independent contrast variable
- Stochastic evolution of the membrane potential is derived from sampling the probability distribution of latent variables implied by the stimulus

Predictions of the model about V1 variability

- Increasing stimulus contrast decreases response variance: **Churchland et al, Nat neurosci, 2010.**
- V1 activations should be sparsely distributed: **Vinje & Gallant, Science, 2000.**

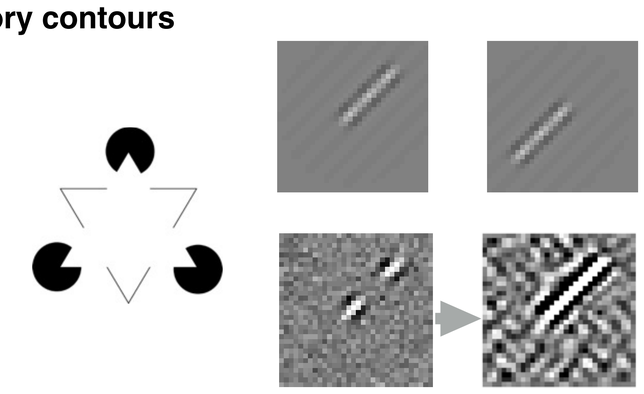




Predicting the response to illusory contours

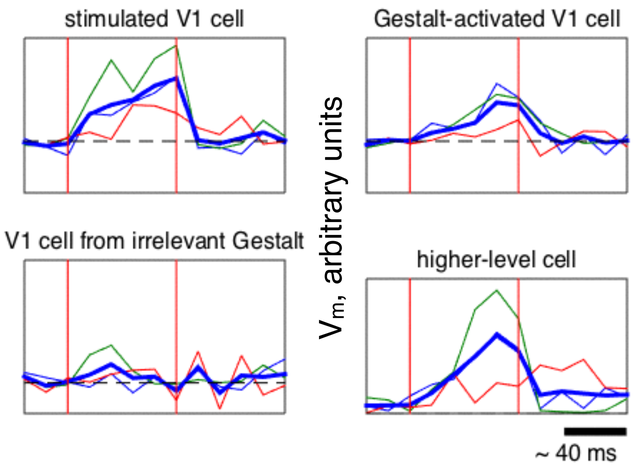
Stimulus

- To compare model responses to experimental results with IC a test stimulus is constructed
- Bottom left: stimulus
- Bottom right: percept defined by V1 simple cell activations, projected back in the stimulus space



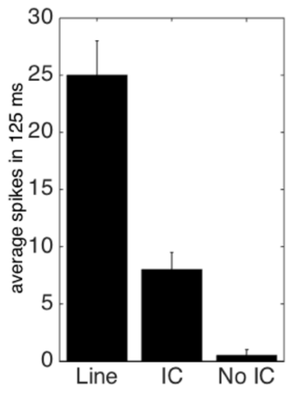
Firing rates

- Simulated membrane potential responses to the stimuli are obtained from the model
- Non-stimulus-evoked activity in V1 follows the activation of higher-level areas
- The model reproduces the magnitude ratio of response rates to real contours, ICs and background
- Mean spike count in V1 as a response to different stimuli in receptive field from **Lee & Nguyen, PNAS, 2001.**



Latencies in activation

- Lee & Nguyen: response to ICs arrives with an additional latency of 55 ms compared to real contours
- In the model, responses in cells that are not activated by the stimulus, but a top-down signal, lag behind by about 40 ms
- The temporal order of evoked responses in V1 and V2 is reversed with ICs compared to lines. The model predicts evoked response in higher-level cells that precede activation in V1 cells with RFs at the IC



Predicting correlations and variances

- Specific values may be predicted by learning the component parameters from a set of stimuli that is statistically typical to the animal (normally natural images)
- Learning performance of an iterative parameter fitting scheme is demonstrated with synthetic data

Proposed experimental paradigms

- Top-down effects on response variances become comparable to predictions if all stimuli are contrast-controlled
- Top-down effects on noise correlations may be predicted by the model using stimuli in which IC strength is controlled