Geometry of Neuroscience

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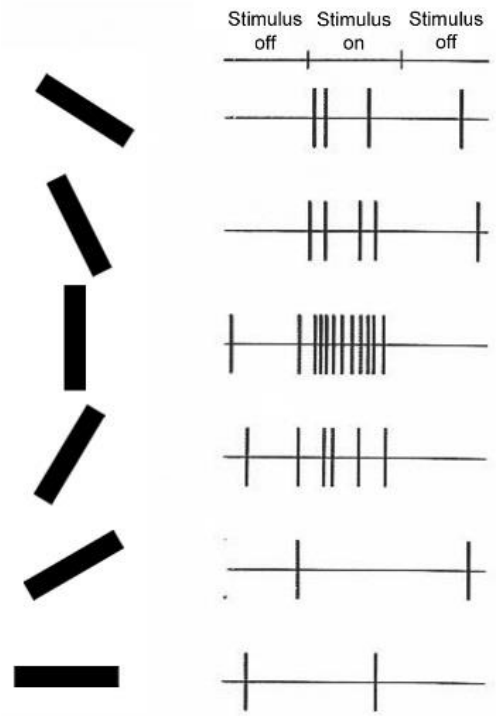
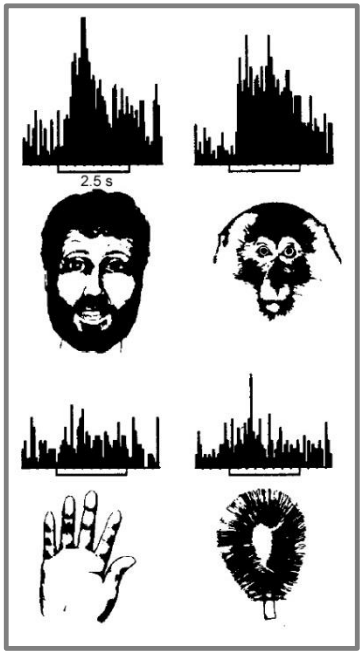
Feb 9: Neural Codes

Single neuron firing rate



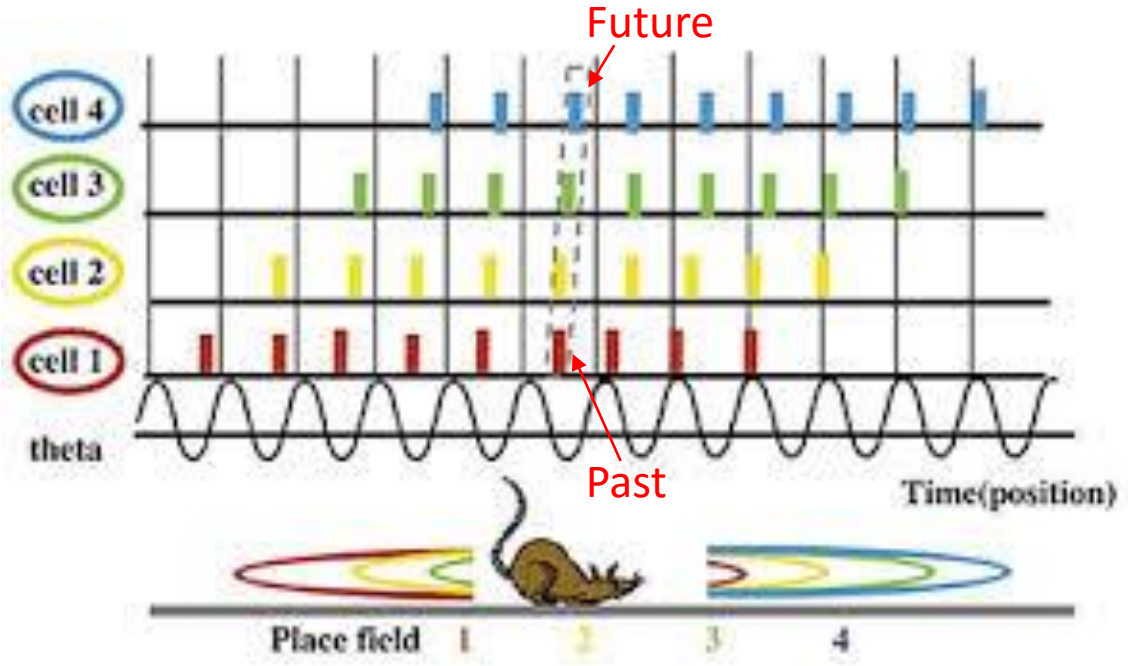
Hubel and Wiesel, J. Physiol., 1959



Desimone et al., J Neurosci., 1984

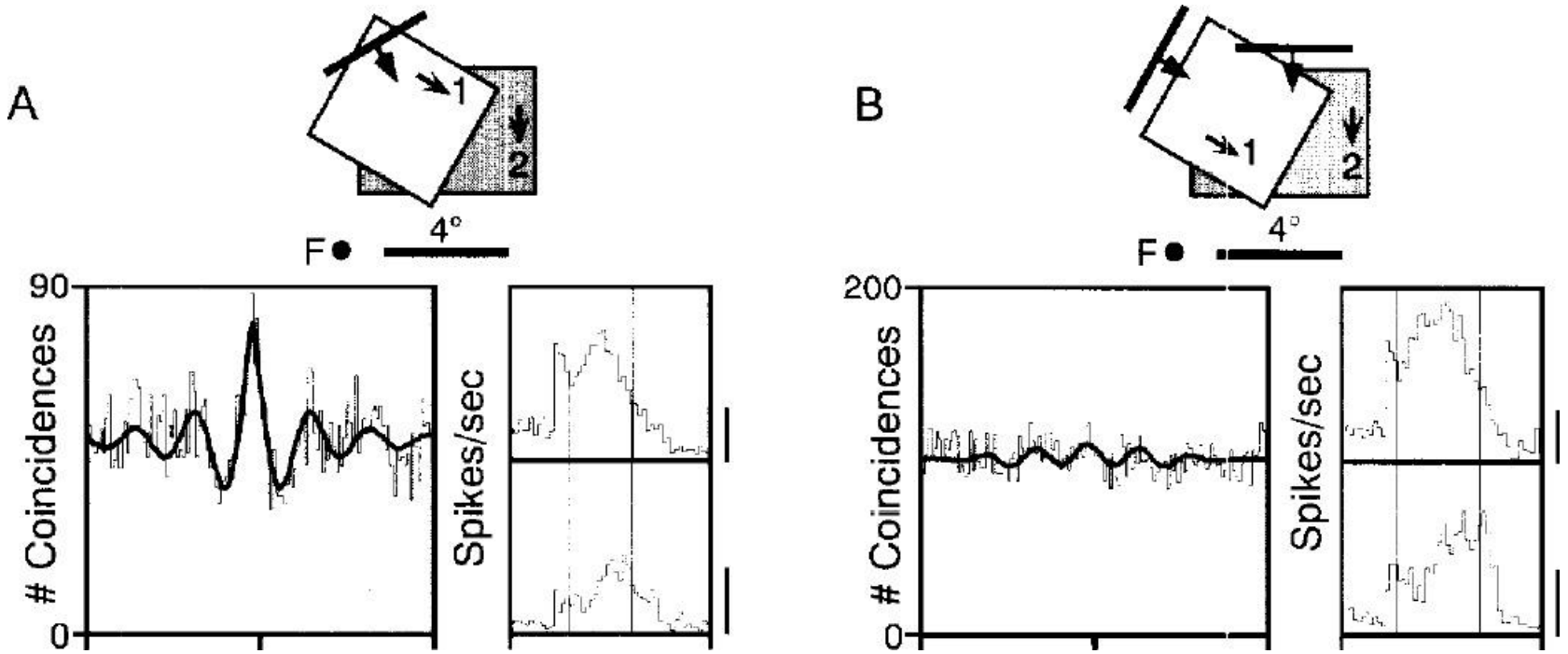
Single neuron spike phase

A place cell fires in one place in a square box



Phase precession

Ensemble synchrony/coherence



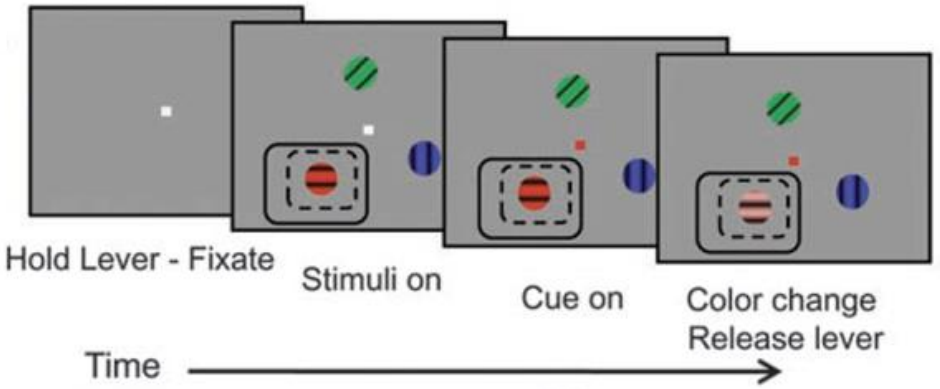
Kreiter

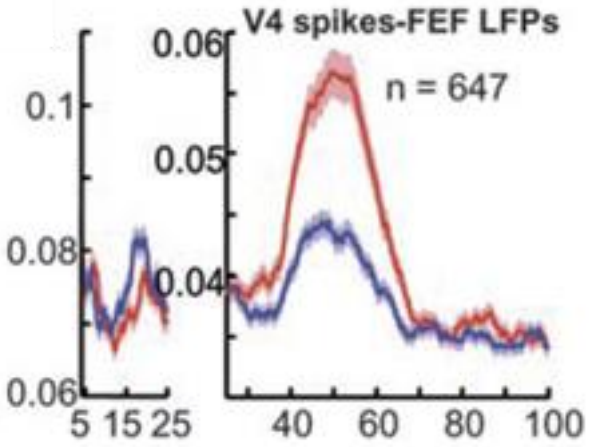
$$C_{jk}(tau) = 1/M \sum_{i=1}^{M} \sum_{t=1}^{T} x_j^i(t)\, x_k^i(t + tau)$$

$$CCG(tau) = \frac{C_{jk}(tau)}{SQRT(L_j\, L_k)}$$

- Control: Shuffled cross correlogram

Ensemble synchrony/coherence





Gregoriou and Desimon 2009

Ensemble synchrony/coherence

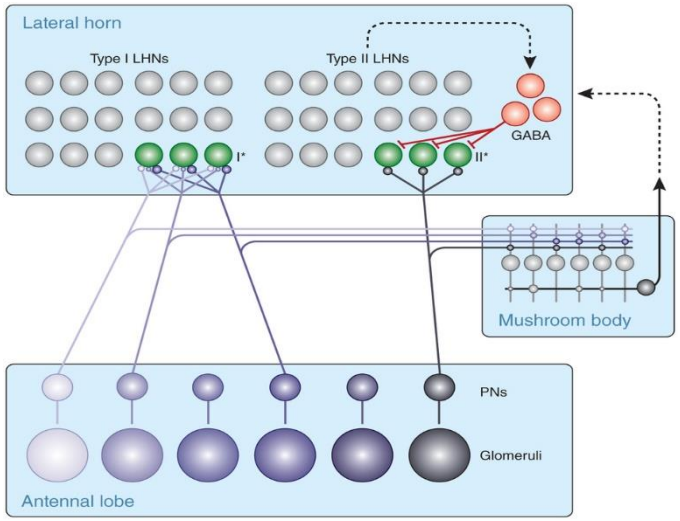
Coherence Analysis. We calculated spike-LFP, spike-spike and LFP-LFP coherency, which is a measure of phase locking between two signals as a function of frequency. To achieve optimal spectral concentration we used multi-taper methods for spectral estimation providing a smoothing of ±10Hz in frequencies above 25Hz and ±3Hz for lower frequencies. An optimal family of orthogonal tapers given by the discrete prolate spheroid sequences (Slepian functions) was used as described before *(S2-S4)*. Coherency for two signals x and y is calculated as

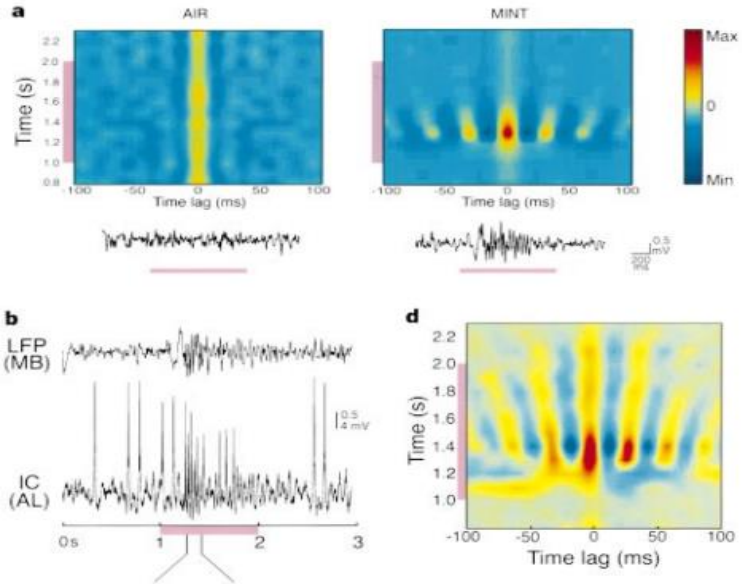
$$Cxy(f) = \frac{Sxy(f)}{\sqrt{(Sx(f)Sy(f))}}$$

where Sx(*f*), and Sy(*f*) represent the auto-spectra and Sxy(*f*) the cross-spectrum of the two signals x and y. Auto-spectra and cross-spectra are averaged across trials before the coherency calculation. Coherency is a complex quantity with its absolute value, called coherence, ranging from 0 (when there is no consistent phase relationship between the two signals) to 1 (when the two signals have a constant phase relationship).

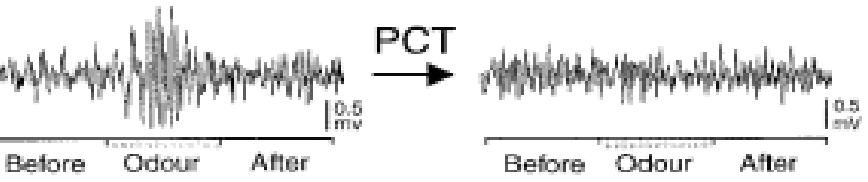
Cross-spectrum = Fourier transform of cross covariance

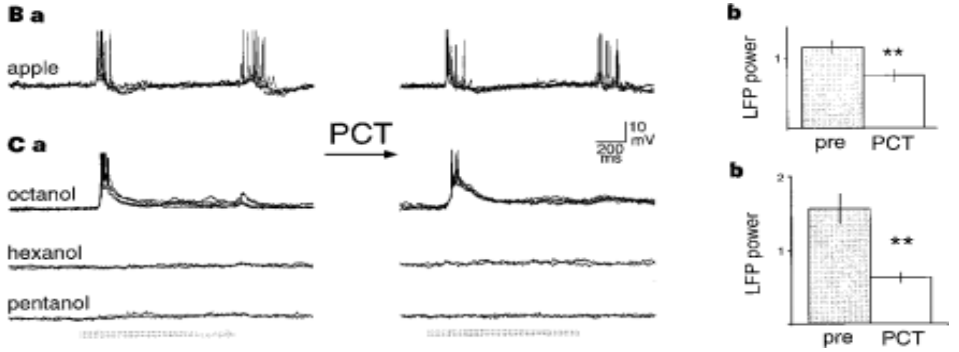
Ensemble synchrony/coherence





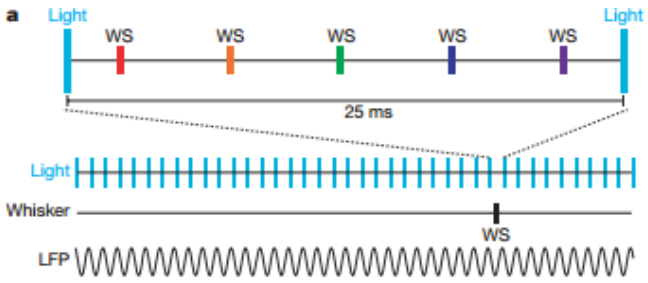
Stopfer and Laurent 1997

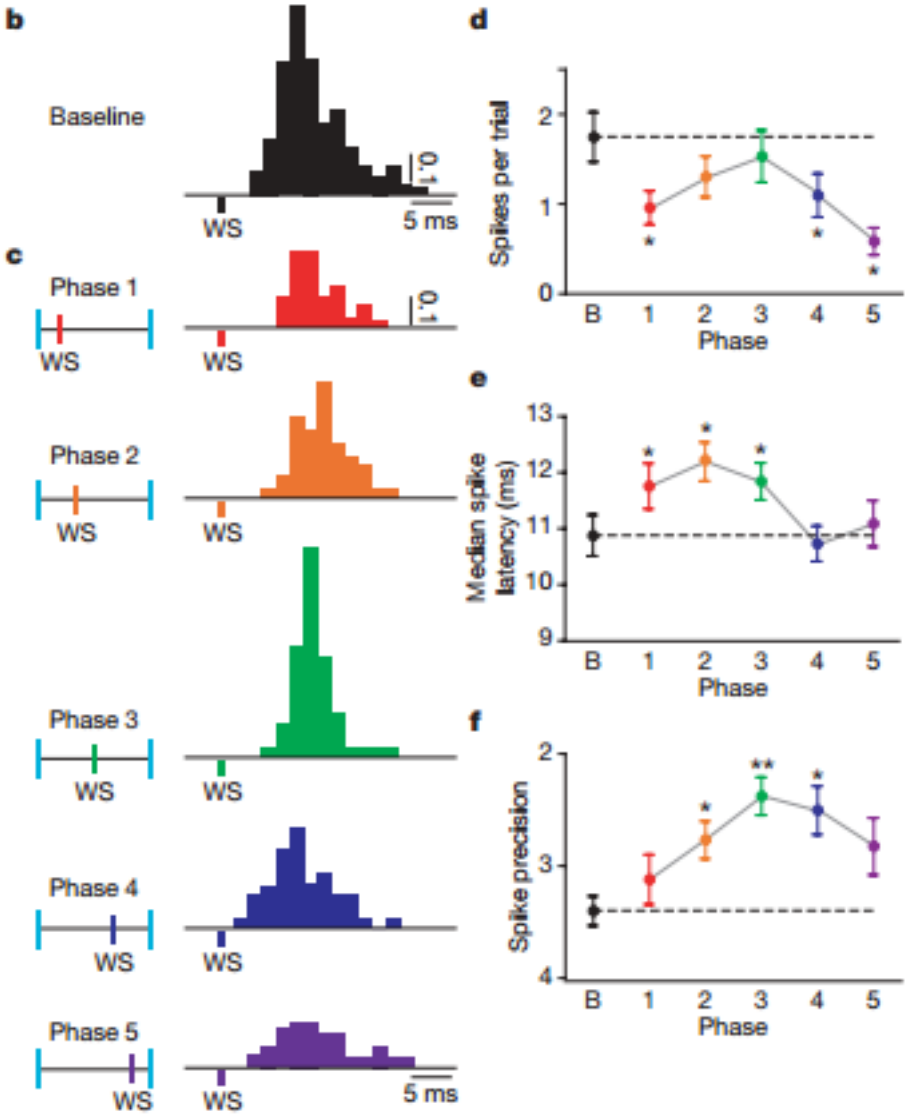




Synchrony plays a role in fine sensory discrimination.
Desychronization impairs discrimination of similar odors.

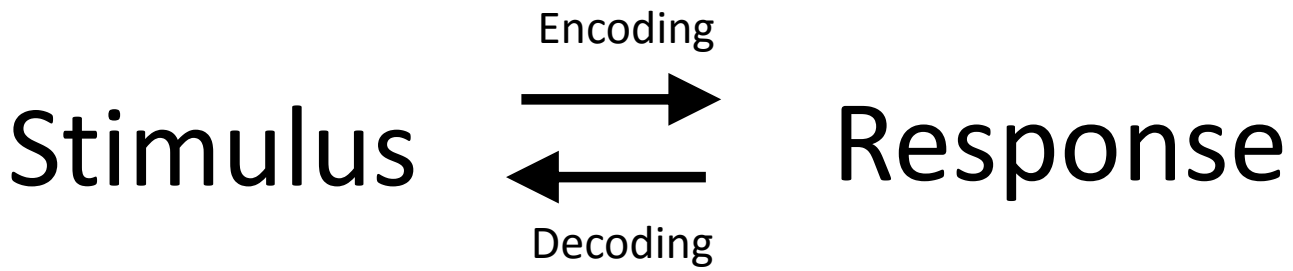
Ensemble synchrony/coherence





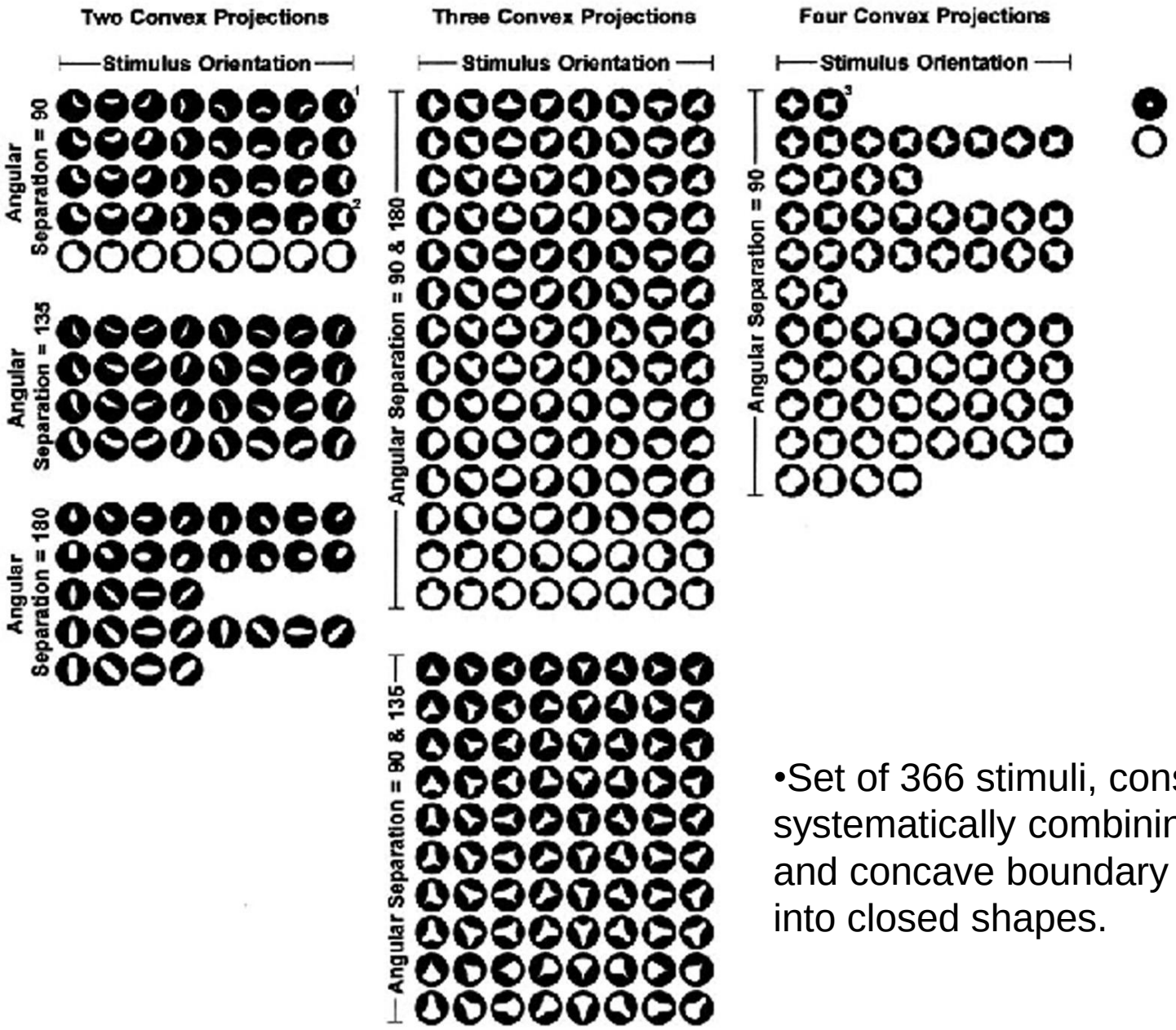
Cardin and Moore 2009

Neural Codes: Decoding/Encoding



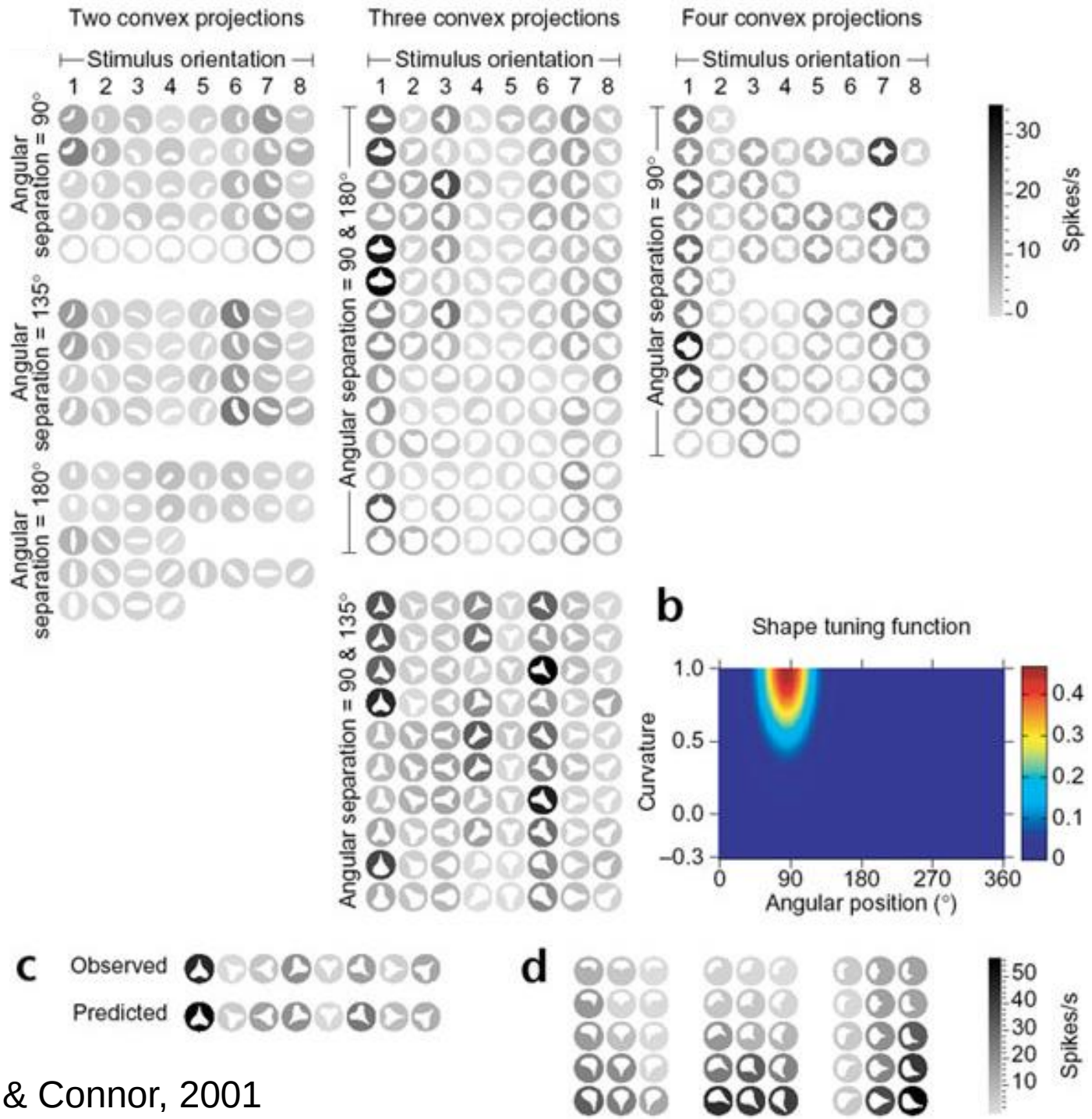
- Encoding: model, fit parameters based on responses to a training set
- Decoding: invert the model, or use Bayesian inference to relate P(s|r) to P(r|s)

Reconstructing shapes from V4 activity

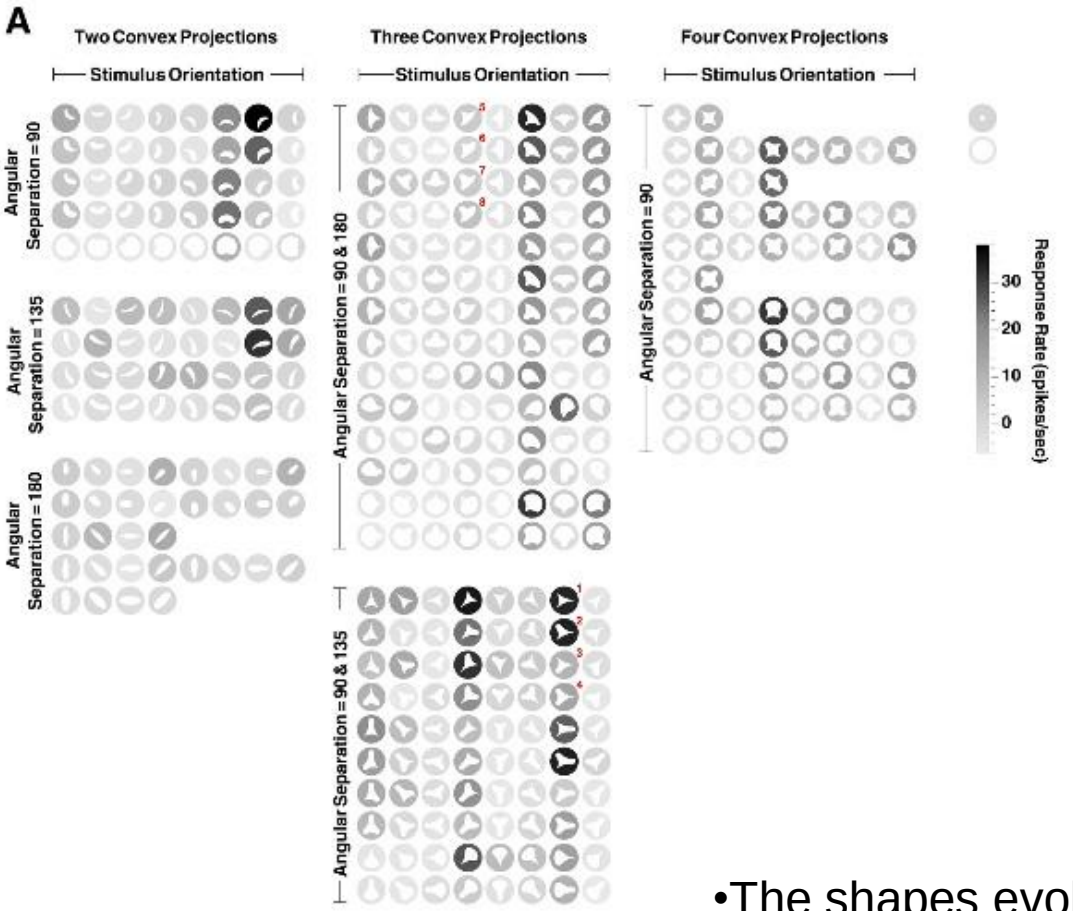


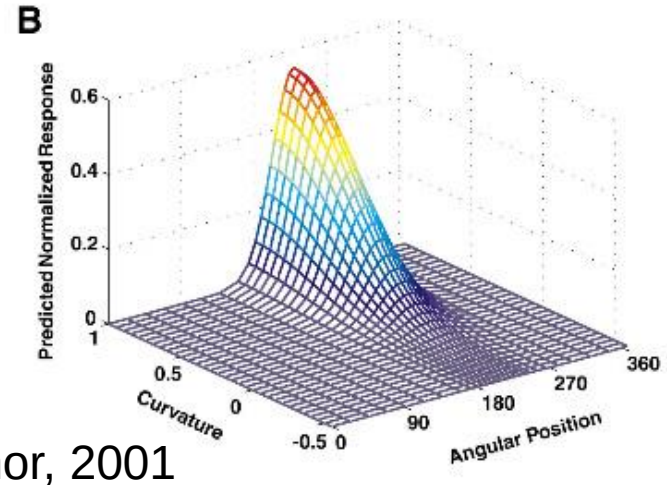
•Set of 366 stimuli, constructed by systematically combining convex and concave boundary elements into closed shapes.

Pasupathy & Connor, 2001



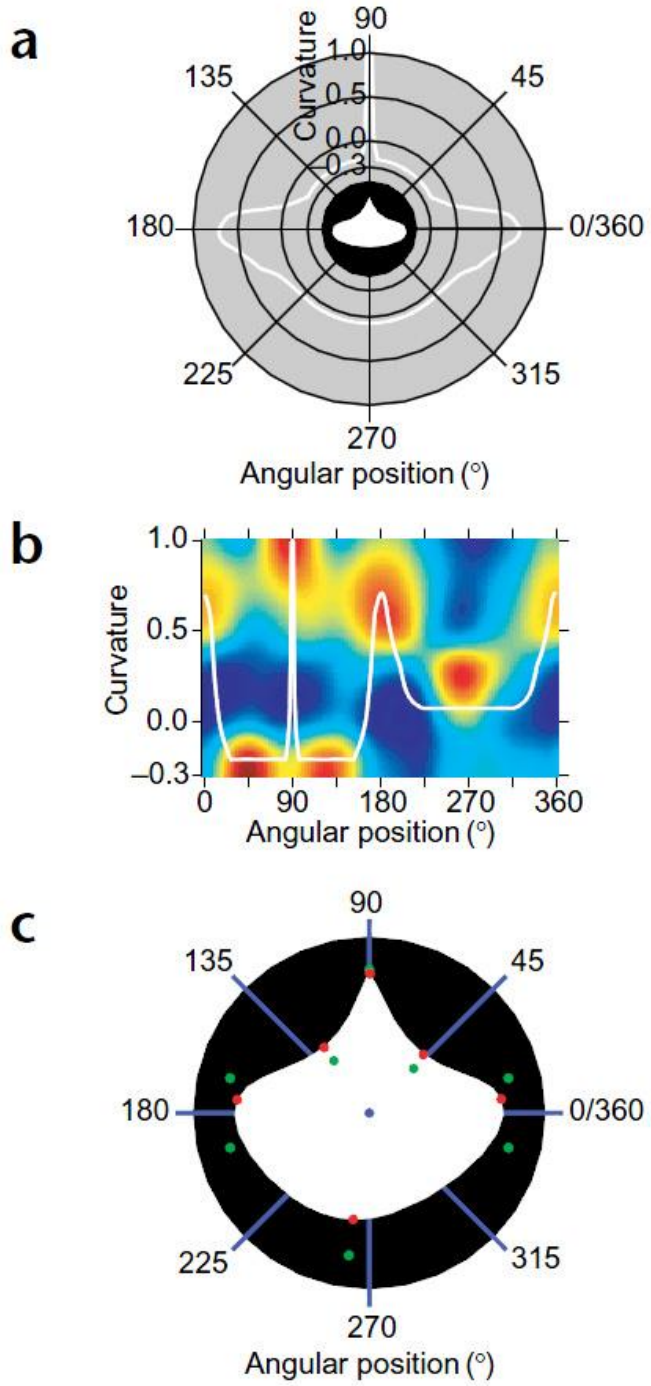
Pasupathy & Connor, 2001





•The shapes evoking strongest responses were characterized by a consistent type of boundary conformation at a specific position within the stimulus.

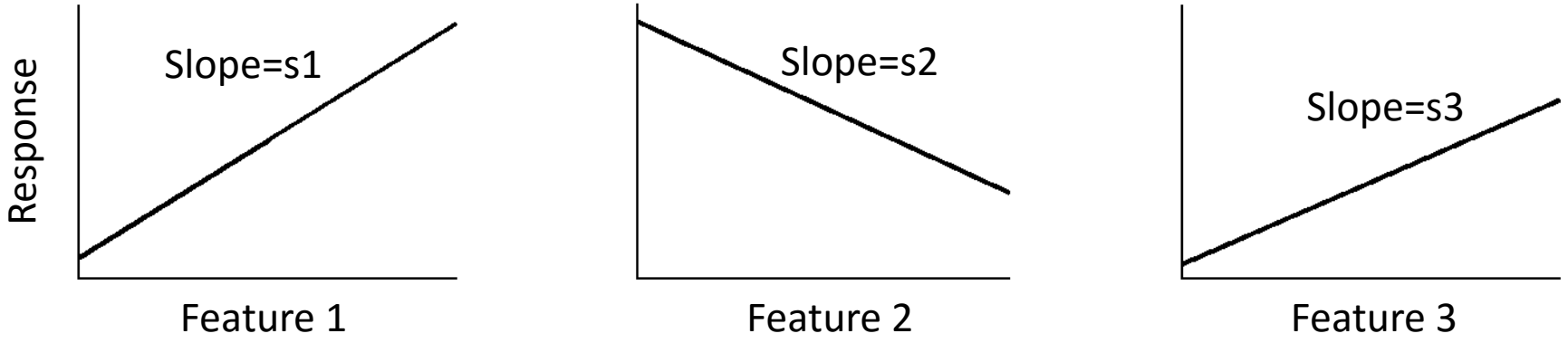
Pasupathy & Connor, 2001



Pasupathy & Connor, 2001

Reconstructing a face from face patch activity

Ramp-shaped tuning implies linear relationship between features and responses



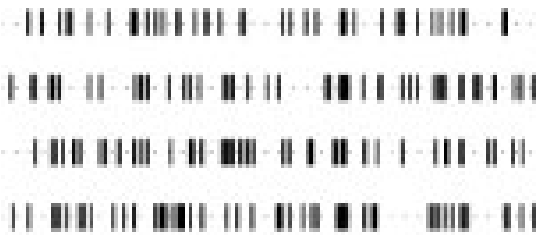
$$Response = s1 \cdot feature1 + s2 \cdot feature2 + \cdots s50 \cdot feature50 + c$$

In short, $\vec{R} = S \cdot \vec{F} + \vec{C}$

Invert transformation

$$\vec{F} = W \cdot \vec{R} + \vec{C'}$$

Decoding face identity



$$\underbrace{\vec{F}}_{\text{50-d Face feature vector}} = W \cdot \underbrace{\vec{R}}_{\text{Cell responses}} + \vec{C}$$

decoder

Example reconstructed faces

Actual

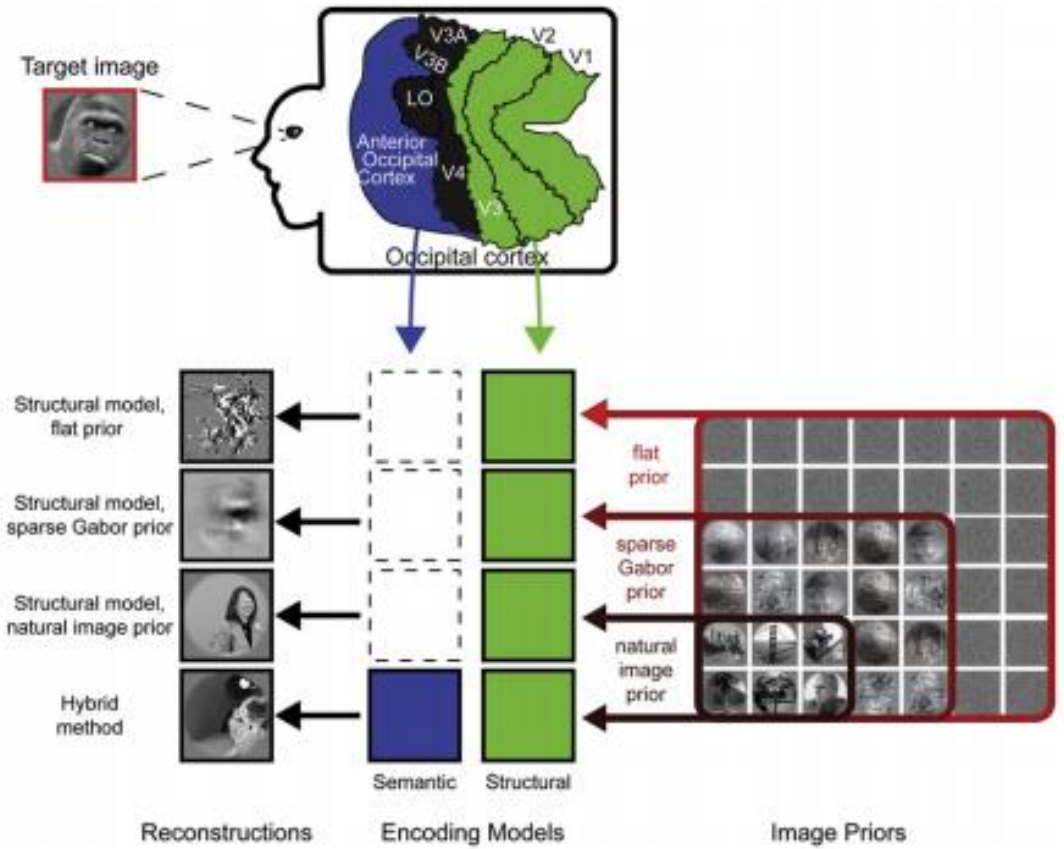
Both
(205 cells)

ML/MF
(106 cells)

AM
(99 cells)

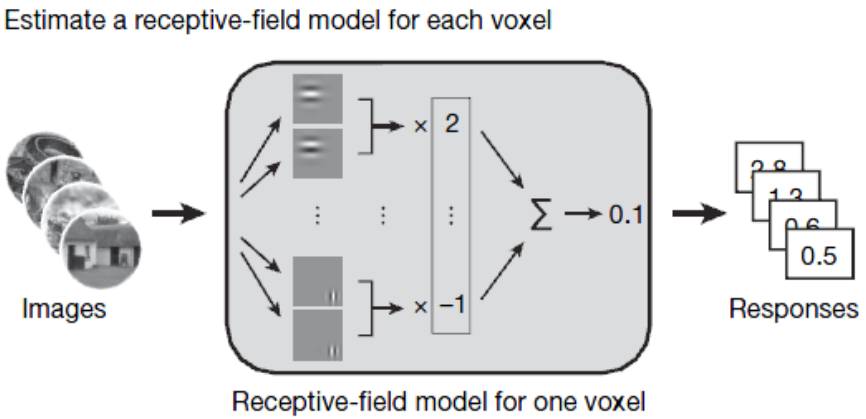
Reconstructing natural scenes from fMRI activity

$$p(\mathbf{s}|\mathbf{r}) \propto p(\mathbf{s}) \prod_i p_i(\mathbf{r}_i|\mathbf{s})$$

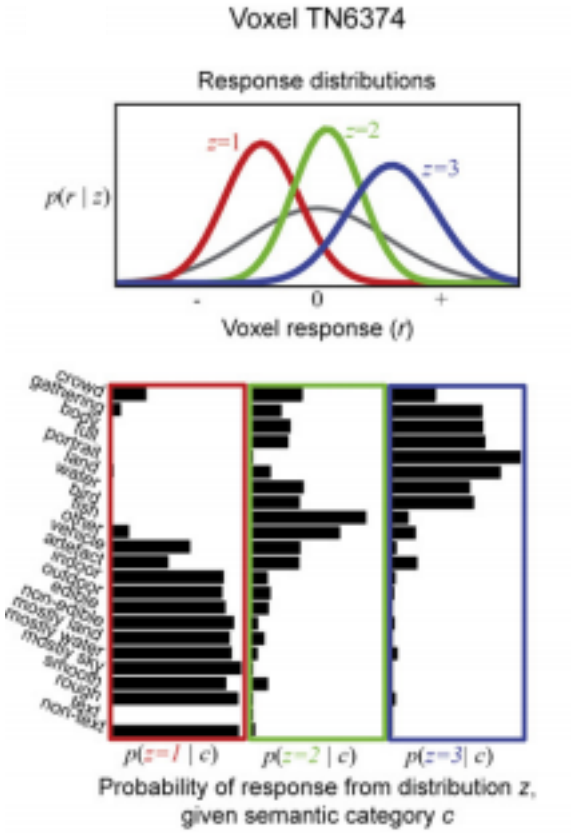


Naselaris & Gallant 2009

Reconstructing natural scenes from fMRI activity



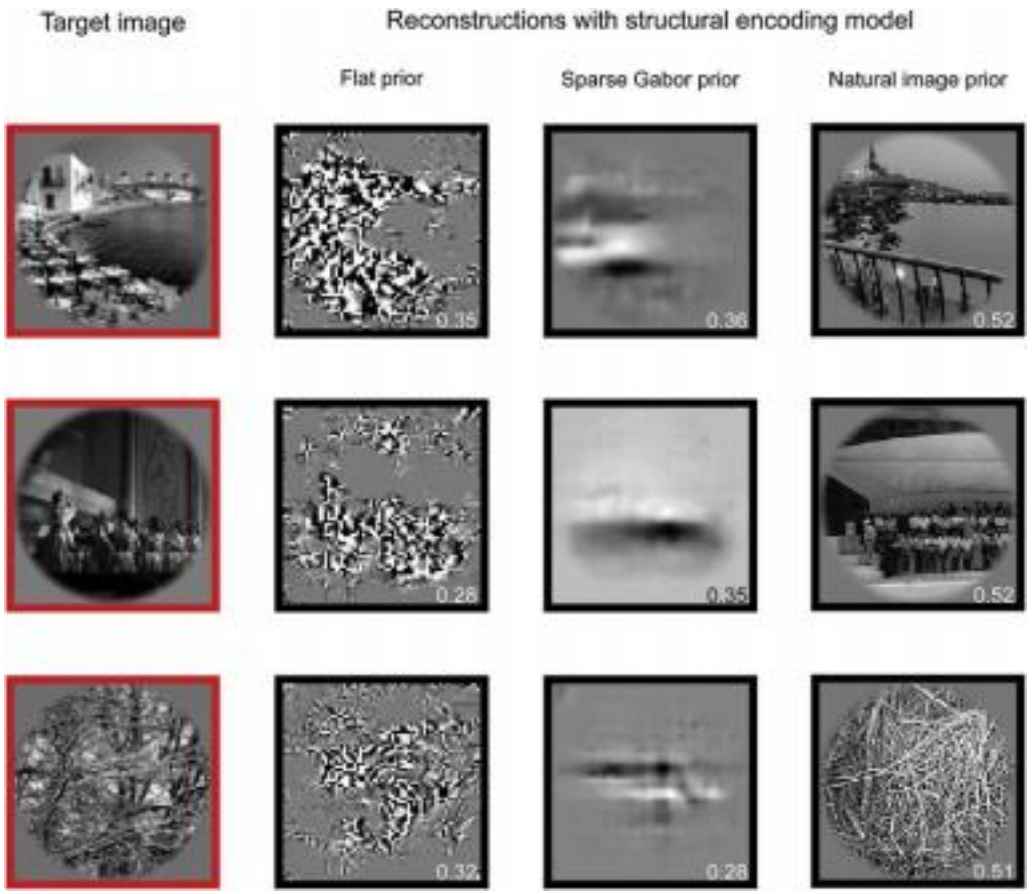
Structural encoding model



Semantic encoding model

Naselaris & Gallant 2009

Reconstructing natural scenes from fMRI activity



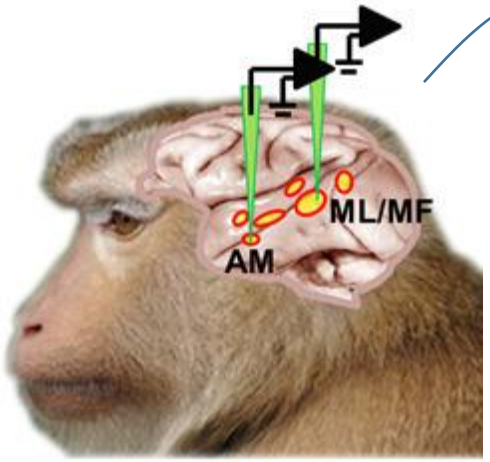
Naselaris & Gallant 2009

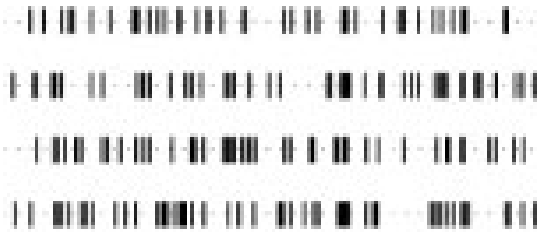
Philosophical problem

- “V1 neurons represent orientation”
- “V4 neurons represent curvature”
- “Face neurons represent facial shape and appearance”
- “Olfactory neurons represent smells”
- “Decision neurons represent decisions”

How does brain know what a particular neuron’s firing represents?

Philosophical problem





decoder

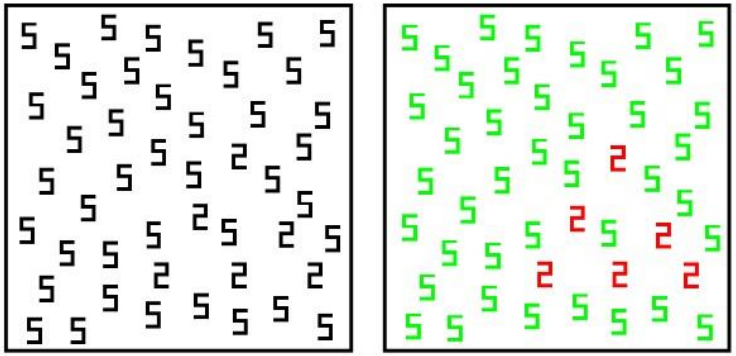
encoder

Ah, face patches are representing facial shape and appearance!

Philosophical problem

- There is no little electrophysiologist in the brain, yet we have rich conscious experience of sights and smells and feelings…we are not zombies.

Philosophical problem



Synesthesia

Sensory substitution

“Why is red red?” aka “The Qualia Problem” aka “The Hard Problem of Consciousness”