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

- Control: Shuffled cross correlogram
Ensemble synchrony/coherence

Gregoriou and Desimone 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

\[ C_{xy}(f) = \frac{S_{xy}(f)}{\sqrt{(S_x(f)S_y(f))}} \]

where \(S_x(f)\), and \(S_y(f)\) represent the auto-spectra and \(S_{xy}(f)\) 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

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

Stopfer and Laurent 1997
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
A set of 366 stimuli, constructed by systematically combining convex and concave boundary elements into closed shapes.

Pasupathy & Connor, 2001
The shapes evoking strongest responses were characterized by a consistent type of boundary conformation at a specific position within the stimulus.
Reconstructing a face from face patch activity
Ramp-shaped tuning implies linear relationship between features and responses

\[ \text{Response} = s_1 \cdot \text{feature}_1 + s_2 \cdot \text{feature}_2 + \cdots + s_{50} \cdot \text{feature}_{50} + c \]

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

Invert transformation

\[ \vec{F} = W \cdot \vec{R} + \vec{C}' \]
Decoding face identity

\[ \vec{F} = W \cdot \vec{R} + \vec{C} \]

50-d Face feature vector

Cell responses

decoder

\[ \{ \vec{F} = W \cdot \vec{R} + \vec{C} \} \]
Example reconstructed faces

Actual
Both (205 cells)
ML/MF (106 cells)
AM (99 cells)
Reconstructing natural scenes from fMRI activity

\[ p(s|r) \propto p(s) \prod p_i(r|s) \]

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

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”