Lecture 4: Cortical Architecture and Coding Schemes

Key Concepts:

- Multiple topographic maps, and multi-dimensional neuronal selectivity

- Types of neural codes: rate codes, place codes, temporal codes

- How to ‘read out’ place codes

- Effects of multiple stimulus dimensions on place codes
V1 (like most cortical areas) contains multiple topographic maps

Map of orientation selectivity

orientation selective V1 neurons are organized into a topographic map of orientation preference.

discovered by Hubel and Wiesel during microelectrode recordings in anesthetized cats
The structure of orientation maps has been revealed more completely by studies using optical imaging. Claims made about imaging orientation columns in V1 using fMRI, but remain controversial. Orientation map has been recently visualized with single-cell resolution using two-photon calcium imaging.
Map of spatial frequency selectivity

- V1 also contains a systematic map of spatial frequency

- Within the bands of V1 that respond to a particular orientation, there are subregions that respond best to different spatial frequencies

- Each location in V1 contains neurons that are selective for both orientation and spatial frequency
Multiple maps imply that individual neurons are tuned for multiple stimulus dimensions. How does this work?

- Response as a function of orientation shows a characteristic bell-shaped (Gaussian) curve.

- When the spatial frequency of the stimulus changes, the whole orientation tuning curve scales up or down.

- Peak of curve does not shift with spatial frequency change.

- This is typical of neurons tuned to multiple dimensions in sensory systems and is very beneficial to neural coding.

To see why this is important, we first need to understand how to decode responses of a population of neurons with bell-shaped curves.
Basic Types of Neural Codes

1) Rate Code: The absolute level of neural activity tells you something about what (e.g., stimulus) activated the neuron

2) Place Code: The location of active neurons in a topographic map tells you something about what the stimulus was

3) Temporal Code: The timing of neuronal activity tells you something about what the stimulus was

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![Tuning curves](image1)

![Population response](image2)

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← Tuning curves: Average response of each neuron (across repeats) to many different stimuli

→ Population response: Response of each neuron to a single stimulus on a single trial (note x-axis difference)
How to Read-Out a Place Code?

a) Winner-Take-All:

Identify the most active neuron and take its orientation preference as an estimate of what the stimulus was. Only requires knowing most active neuron.

b) Vector Averaging (aka population vector)

Each neuron “votes” for its preferred orientation in proportion to its firing rate. The orientation of the “vector sum” is your estimate of what the stimulus was. Requires knowing all responses and preferences.

c) Many other possibilities, including optimal (Maximum Likelihood) decoding. Requires knowledge of the entire tuning curve of each cell.

\[
\log P(S|r) \propto \sum_i r_i \log(f_i(S))
\]

- \(P(S|r)\) = probability of observing stimulus \(S\) given population response \(r\)
- \(r_i\) = spike count from the \(i\)th neuron, assuming Poisson statistics
- \(f_i(S)\) = tuning curve of the \(i\)th neuron
How to deal with multiple tuning dimensions in place codes?

Consider a set of orientation-tuned neurons that is also tuned for spatial frequency. Let us consider a few examples of how OR and SF tuning may interact in the code.

1) If all neurons have the same SF preference, how will changing SF affect your estimate of orientation from the place code?

This works OK, precisely because each cell’s response has a multiplicative interaction between OR and SF. But… having no variation in SF preference limits the range of SF that can be represented accurately
1) If the SF preference increased from left to right across these 5 neurons, how would changing SF affect your estimates of orientation now?

This population represents a greater range of spatial frequencies, but having SF and OR preference linked will mean that the estimated stimulus orientation (e.g., by vector averaging) changes when the SF of the stimulus changes. Clearly bad.
3) So how can we code a broad range of OR and SF and still have our OR estimates be unaffected by SF?

This population of neurons varies has 3 different SF preferences for each of 5 different OR preferences. If you sum the responses down each column, the net response is similar for any of the 3 stimulus SF values (blue, magenta, orange lines). Hence, pooling across SF preferences (down columns) will give OR estimates that are invariant to SF. Similarly, pooling across OR preferences (across rows) could give SF estimates that are invariant to OR.
Selective pooling of neural responses is the answer!

How do topographic maps help this happen?
- They simplify the wiring needed to pool responses across one (irrelevant) stimulus dimension in order to extract a good estimate of a different (relevant) stimulus dimension.
- This generalizes well to more than two stimulus dimensions.

A good portion of what happens in perceptual learning probably has to do with learning how to selectively read-out sensory signals in the most optimal way.
-many V1 neurons have a 'nonclassical' (inhibitory) surround outside their classical receptive field

-stimuli in surround modulate response in orientation-specific manner -> coding of orientation contrast.

Why is this useful?

-likely mediated by long-range horizontal connections within V1 that connect orientation columns with similar preferences. Feedback may also play an important role (controversial).

-center-surround organization is found for many visual cues in many areas of the brain.