A Dynamic Model for Decoding Direction and Orientation in Macaque Primary Visual Cortex

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1. Motivation

1. When an oriented moving bar reaches the classical receptive field (cRF) of V1 neurons, how are directional and orientational (tuning) information dynamically encoded in their activity?
2. How could this information be decoded from a V1 population, within and outside the cRF (while approaching or passing the RF)?

2. Stimulation Paradigm

- Awake macaque monkeys.
- Stimulus: oriented moving bar, 12 directions.
- Extracellular recordings in area V1 (67 cells).

3. Decoding Approach [1]

1. Definition of a model for the inter-trial variability of spike counts. We use the Poisson model, which needs only one parameter, its mean μ:
   \[ P(k) = \frac{e^{-\mu} \mu^k}{k!} \]  
(1)
2. Estimation of the tuning function on the stimulus’ parameters (orientation, direction, ...) : f(θ̂|θ) = mean(k | i) such that :
   \[ P(k) = \frac{f(\theta)^k}{k!} \]  
(2)
3. Pooling of the population information assumes conditional independence:
   \[ P(Y|\theta) = \prod_{i=1}^{N} P(k_i|\theta), Y = [k_1, k_2, k_N] \]  
(3)
4. Bayes’ rule: P(\theta|Y) = \frac{P(Y|\theta) P(\theta)}{\sum_{\theta} P(Y|\theta) P(\theta)}
5. Maximum likelihood paradigm:
- The evidence term P(Y) is a normalization term independent of θ → P(Y) = const
- There is no prior knowledge on θ → ∀(θ1, θ2), P(θ1|θ2) = P(θ2) 
- Maximizing the posterior P(θ|Y) is equivalent to maximizing:
  \[ L(\theta) = P(Y|\theta) = \prod_{i=1}^{N} L(\theta)^k, \frac{e^{\mu \cdot L(\theta)}}{k!} \]

4. Generative Tuning Model

\[ f(\phi, \theta, t) = R_0 + (R_m - R_0) \cdot e^{b \cdot (cos(2(\theta - \phi)) - 1)} \cdot e^{pt \cdot (cos(\phi - \phi) - 1)} \]
\[ D \perp O \rightarrow \theta \]

5. Generalized Dynamic Tuning Model

\[ f(\phi, \theta, t) = R_0 + (R_m - R_0) \cdot A(t) \cdot (b + (1 - b) \cdot e^{pt \cdot (cos(2(\theta - \phi)) - 1)} \cdot e^{pt \cdot (cos(\phi - \phi) - 1)}) \]
with a Gaussian activation profile: \[ A(t) = \frac{1}{\sqrt{2 \pi \sigma^2}} e^{-\frac{(t-\mu)^2}{2\sigma^2}} \] and a constant offset-to-gain ratio : b

6. Dynamic Decoding of θ and φ

Decoding direction orthogonal to orientation:
-400ms -200ms 0ms
Decoding using separable direction and orientation:
-400ms -200ms 0ms

7. Prediction on Surrogate Data

Using the tuning curves, we generated surrogate spike rasters for φ = 0 and θ ∈ {π/6, π/3, 0}:

Orientation Tuning
Direction Tuning
Joint O-D Tuning
Orientation
Direction

References


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