Dynamic Field Theory: Neural basis

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Activation fields... peaks as units of representation

- information, probability, certainty
- activation field
- metric contents
  - e.g., space, movement parameters, feature dimensions, viewing parameters, ...

- activation field
- dimension
- specified value
- no value specified

- activation field
- dimension
Formalizing the link between DFT and neurophysiology

What do neurons “represent”?

- notion of a tuning curve that links something outside the nervous system to the state of a neuron (e.g. through firing rate)
- based on the forward picture in which
  - the connectivity from the sensory surface
  - or the connectivity from the neuron to the motor surface
- determine the activity of the neuron
Example tuning curve in primary visual cortex (monkey)

(A) Example of tuning curves for different orientations.

(B) Graph showing the frequency response (f) as a function of orientation angle (s), with a bell-shaped curve indicating a peak at a specific orientation angle.

[Hubel, Wiesel, 1962]
Example: tuning curve in primary motor cortex (monkey)

[Georgopoulos, Schwartz, Kalaska, 1986]
What do populations of neurons represent?

The pattern of neural activity across multiple neurons represents a feature value much more precisely than individual neurons do.
Do all activated neurons contribute?

- Superior colliculus: topographic map of saccadic endpoint
- Deactivate portions of the population: observe predicted deviations of saccadic endpoint

similar work in MT


consensus, that localized populations of neurons best correlated with behavior

there are subtle issues of noise and correlation in populations

e.g., Cohen, Newsome J Neurosci 2009: about 1000 neurons needed to match behavioral performance

Neurophysiological grounding of DFT

Example 1: primary visual cortex A17 in the cat, population representation of retinal location

Jancke, Erlhagen, Dinse, Akhavan, Giese, Steinhage, Schöner JNsci 19:9016 (99)
- Determine RF profile for each cell
- Its center determines what that neuron codes for
- Compute a distribution of population activation by superposing RF profiles weighted with current neural firing rate
The **current** response refers to a stimulus experienced by **all** neurons.

Reference condition: localized points of light.
result: population distribution of activation defined over retinal space = representation of visual location
does a decent job estimating retinal position

current stimulus: square of light
range of retinal field sampled by neurons

□ 0.4°
Extrapolate measurement device to new conditions

- e.g., time resolved

Two different stimulus locations

30 - 40 ms 40 - 50 ms 50 - 60 ms 60 - 70 ms 70 - 80 ms

40 - 50 ms 50 - 60 ms 60 - 70 ms 70 - 80 ms
When complex stimuli are presented (here: two spots of light), the composite responses exhibit superposition of responses to each elemental stimulus. As the distance between the two spots increases, the superposition becomes more apparent, with increased separation and inhibition (45–80 ms). This is consistent with predictions from a neural inhibition model.
by comparing DPA of composite stimuli to superposition of DPAs of the two elementary stimuli to obtain evidence for interaction

- early excitation
- late inhibition
DPA: interaction

activation level in the DPA at the location of the left component stimulus

response to composite stimuli

superposition of responses to each elemental stimulus

evidence for inhibitory interaction

time [ms]
model by dynamic field:

stimulus

experiment

DFT model
Neurophysiological grounding of DFT

Example 2: primary motor cortex (M1), population representation of movement direction of the hand

Bastian, Riehle, Schöner, 2003
center-out movement task for macaque

with varying amounts of prior information

Bastian, Riehle, Schöner, 2003
Tuning of neurons in MI to movement direction

Trials aligned by go signals, ordered by reaction time
Distribution of population activation =
\[ \sum_{\text{neurons}} \text{tuning curve} \times \text{current firing rate} \]

[Bastian, Riehle, Schöner, 2003]
look at temporal evolution of DPA

or DPAs in new conditions, here: DPA reflects prior information
Theory-Experiment

[Text and diagrams related to theoretical and experimental comparisons, including graphical representations of activity measures over time. The text references a study by Bastian, Riehle, Erlhagen, Schöner, 1998.]
Distributions of Population Activation are abstract

- neurons are not localized within DPA!

- cortical neurons really are sensitive to many dimensions
  - motor: arm configuration, force direction
  - visual: many feature dimensions such as spatial frequency, orientation, direction...

- => DPA is a projection from that high-dimensional space onto a single dimension
... back to the activation fields

- that are “defined” over the appropriate dimension just as population code is...

- in building DFT models, we must ensure that this is actually true by setting up the appropriate input/output connectivity