Theoretical Neuroscience tutorial: coding, tuning curves, maps, and decoding

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Coding

is about how stuff outside the organism/nervous system is “represented” by inside the nervous system
what is the inner “state” of the nervous system?

- the spiking activity of neurons and its statistics?
- the electrical state inside the membrane?
- (where along the dendritic-soma-axonal structure?)
neuronal recording as estimates of that state

- extra-cellular recording of spike events
- intra-cellular recording membrane potentials
neuronal recording
neuronal recording

- e.g., extra-cellular recording from trigeminal ganglion cell in rat
- as tooth is tapped
- as whisker is bent

credit: http://faculty.washington.edu/chudler/introb.html
Dependence

- neuroscientists look for the dependence of measured neural activity with external states (stimuli or movements)
theoretical framework for studying this question

- communication theory (coding)
- information theory (decoding)
coding: basics from communication theory

sender → message → receiver
allowable messages: $m_1, m_2, \ldots, m_n$

with probabilities $p_1, p_2, \ldots, p_n$

information when message $m_i$ is sent: $I_i = \log_2(1/p_i)$ [bits]
communication theory

- **coding**: a mapping from the space of messages to a code space
  - **example Morse code**
    - **space of messages**: all letters A, B, ..., Z
    - **code space**: strings of length 1 to 4 of “dit” and “da”
  - Morse code maps each letter onto a code word
- **the mapping must be one-to-one (invertible)**
communication theory

- efficient coding: use less energy/space for more probable messages
  - e.g., “dit” for frequent letter “e” vs. “da-da-dit-dit” for rare letter “z”

- channel limitations, Shannon’s theory

- optimal coding given noise on the channel

- etc.
communication theory

- communication theory is based on knowledge of possible messages!

- what does that mean for organisms/nervous systems?
hypothesis: rate code

- e.g., sensory cell, say a mechano-receptor
- space of messages: different levels of the physical variable, say, of tension in muscle
- code space: different levels of firing frequency
- (cf. Braitenberg lecture)
stochastic nature of spiking

- networks of neurons are noisy
- (although individual neurons can be highly deterministic as well)
- => averaging across many trials (PSTHs)
firing rate

or:
temporal filtering
spike rates of 23 neurons in mouse barrel cortex as a function of the frequency of stimulation of a whisker.
hypothesis: space code

- also called: labelled lines
- based on neuronal tuning
tuning curve

example: primary visual cortex (monkey)
tuning curve

Example: primary motor cortex (monkey)
space code

- each neuron represents its “preferred” message
- the presence it indicates through supra-threshold firing
space code

- space of messages: e.g., orientations of edges or directions of arm movement
- code space: ensemble of neurons and their state ("on" vs. "off" or graded state)
- principle of "equivalent nervous energy"
often neurons are systematically arranged on the cortical surface as a function of their “preferred” parameter value: topographic map
topographic map

- example: distribution of receptive field centers on primary visual cortex (macaque)
even when neurons are not topographically arranged, the ensemble of neuronal activity may be thought to represent the message space
other coding hypothesis

- firing duration code
- phase code
- coding through firing pattern/fine structure ("synfire")

in each case: coding in the sense that these measures depend on the stimulus, so that a mapping between the stimulus (message space) and the measure (code space) might exist
“these neurons code for x” often simply means: their [firing rate, intra-cellular potential, synchronicity] depends on x

by the same logic, a falling stone’s velocity when it hits the surface depends on the initial height... so does the stone’s velocity “code for” the initial height?
hidden is an assumption about nervous systems as “computing” from input (message space) some output (code)....

or as “representing” something about the world out there
critique

later we will see another problem:

- coding is linked to forward networks…
  while neural dynamics are primarily recurrent…

- neuronal interaction: neural measure may have different values for same message depending on the “state” of the CNS

- Braitenberg: neuronal interaction is dominant)