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

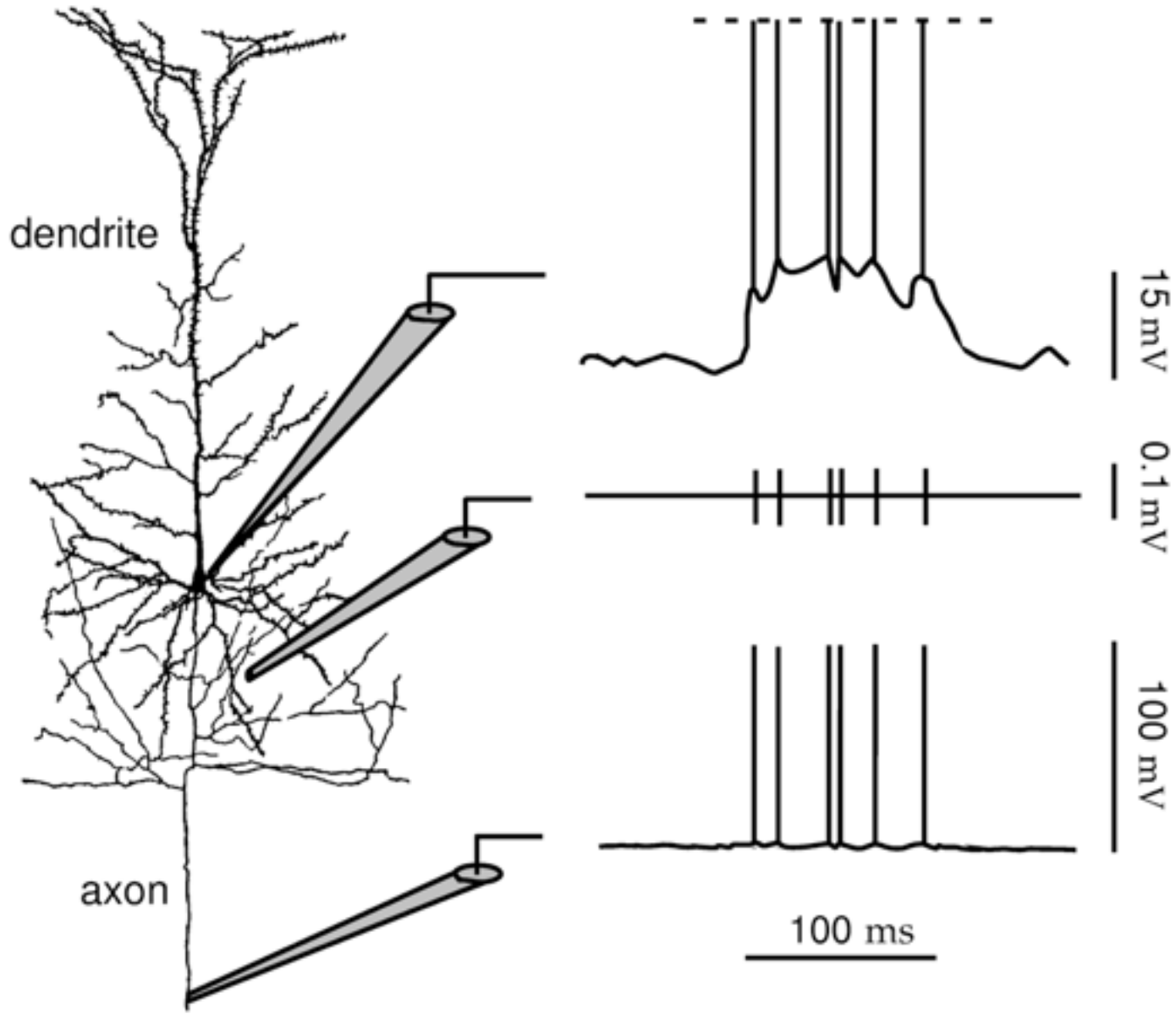
what is the inner "state" of the nervous system?

- 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

communication theory

- allowable messages: m_1, m_2, ... m_n
- with probabilities p_1, p_2, ... 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

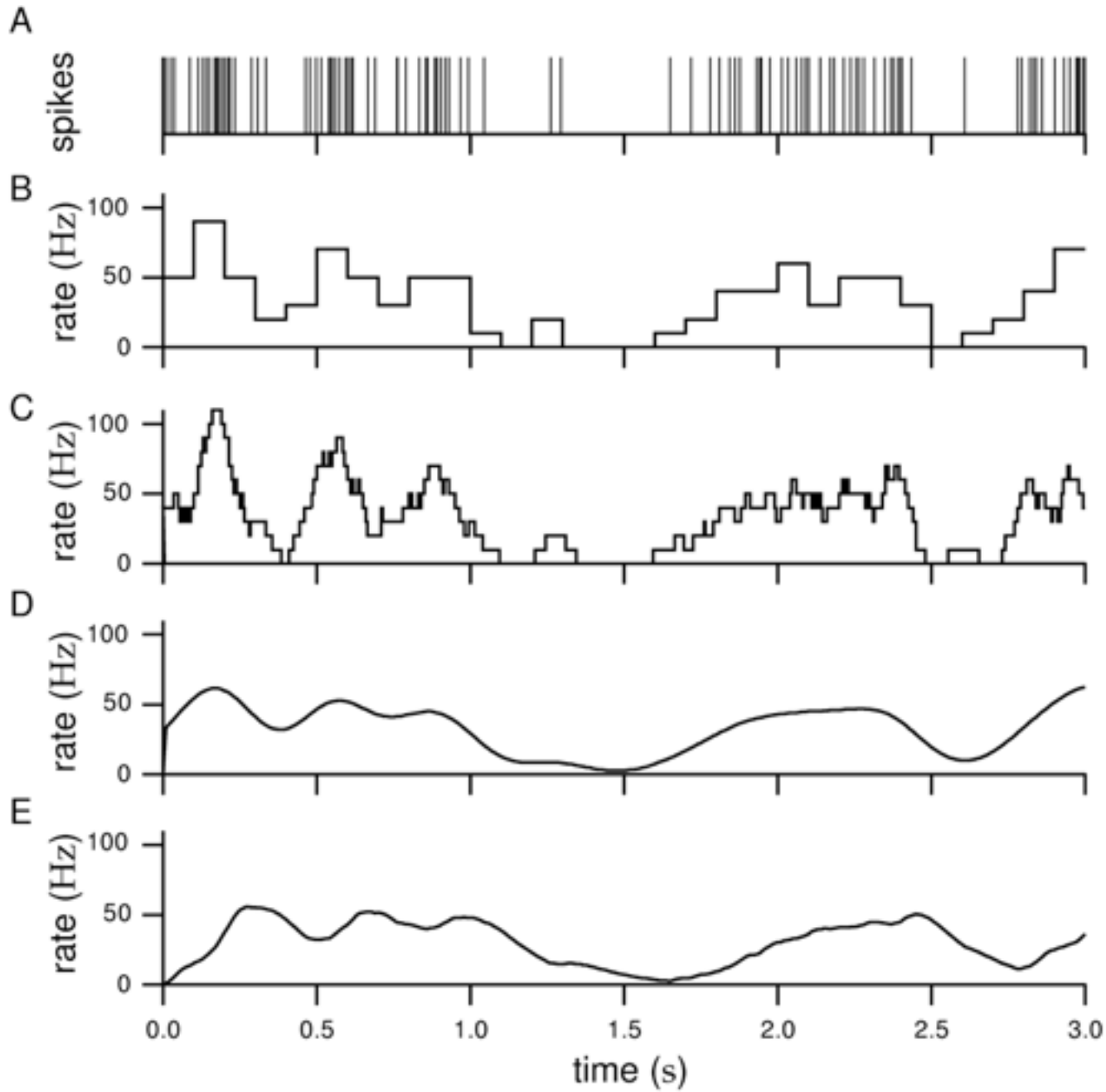
- e.g., sensory cell, say a mechano-receptor
- space of messages: different levels of the physical variable, say, of tension in muscle
- code space: different levels of firing frequency
- (cf. Braitenberg lecture)

stochastic nature of spiking

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

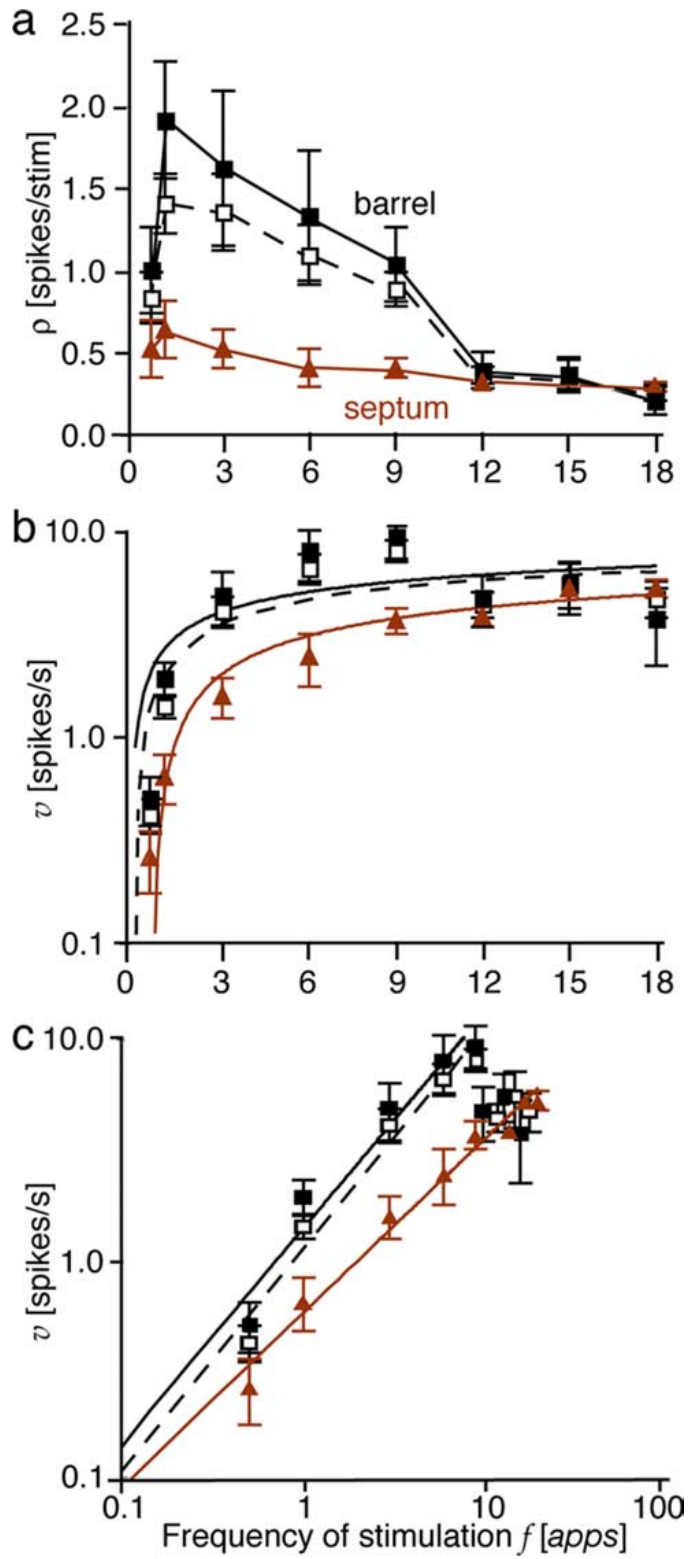
firing rate

- or: temporal filtering



Example

- spike rates of 23 neurons in mouse barrel cortex as a function of the frequency of stimulation of a whisker



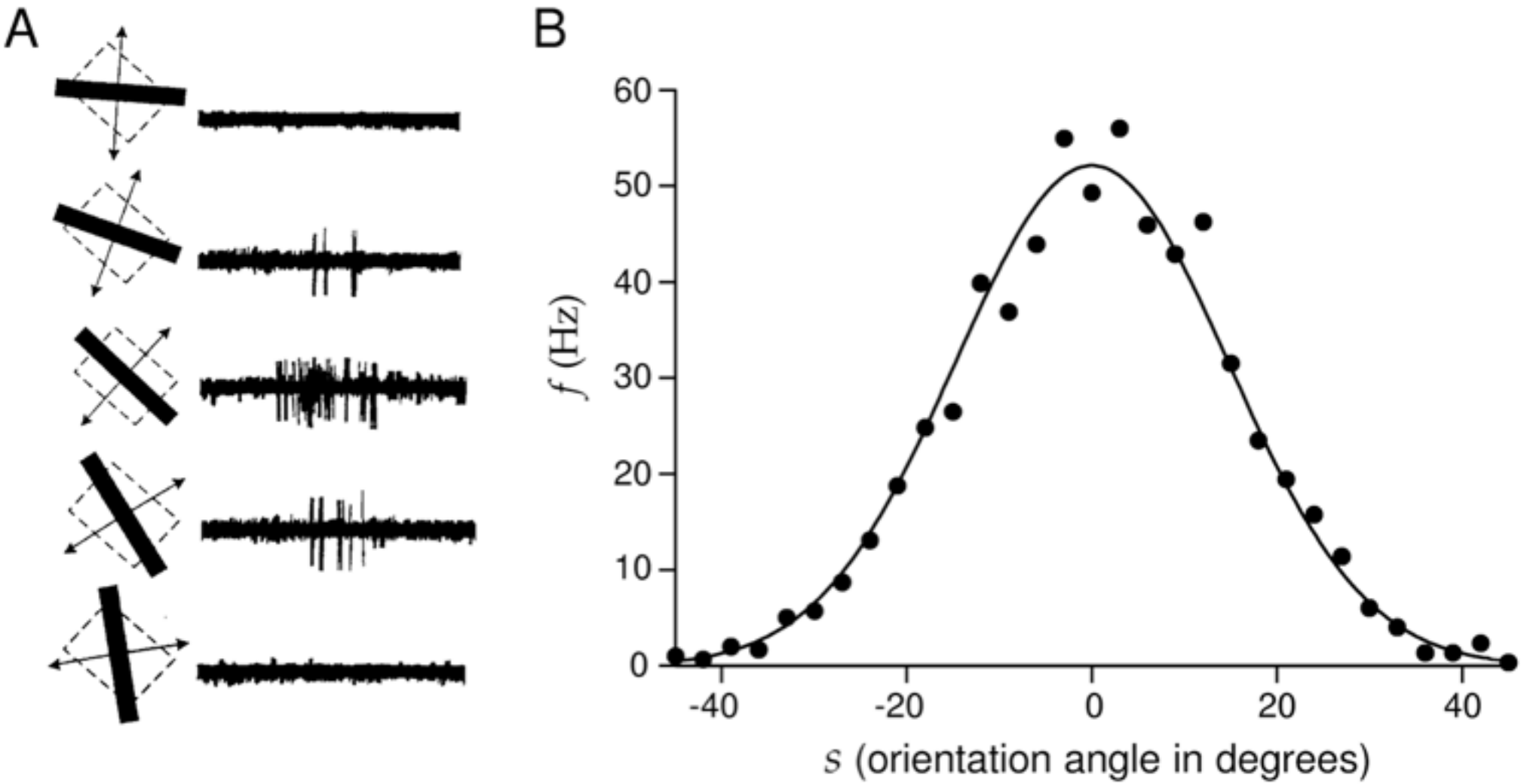
[from: Melzer, EtAl, J.Neurosci. (2006)]

hypothesis: space code

- also called: labelled lines
- based on neuronal tuning

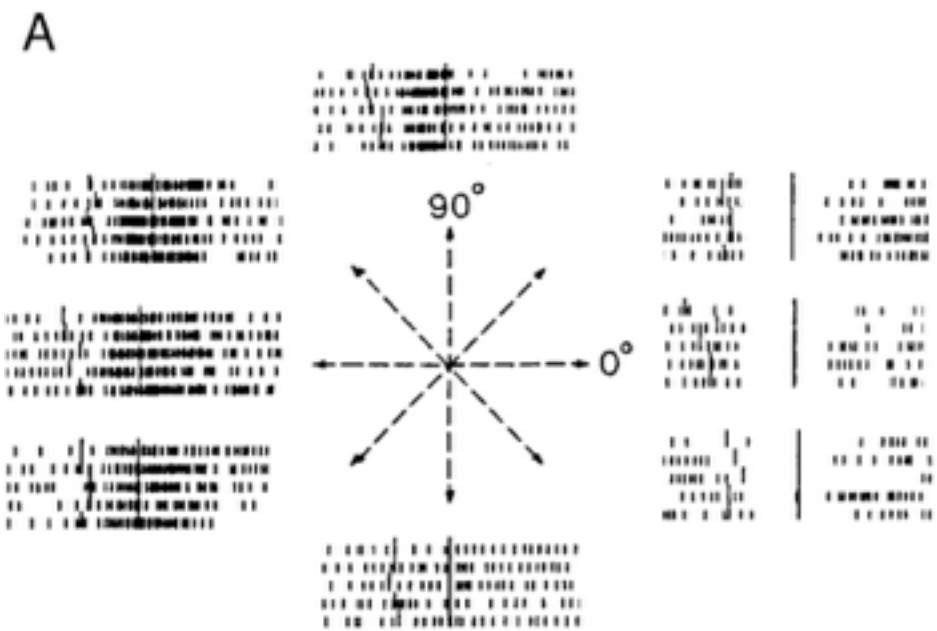
tuning curve

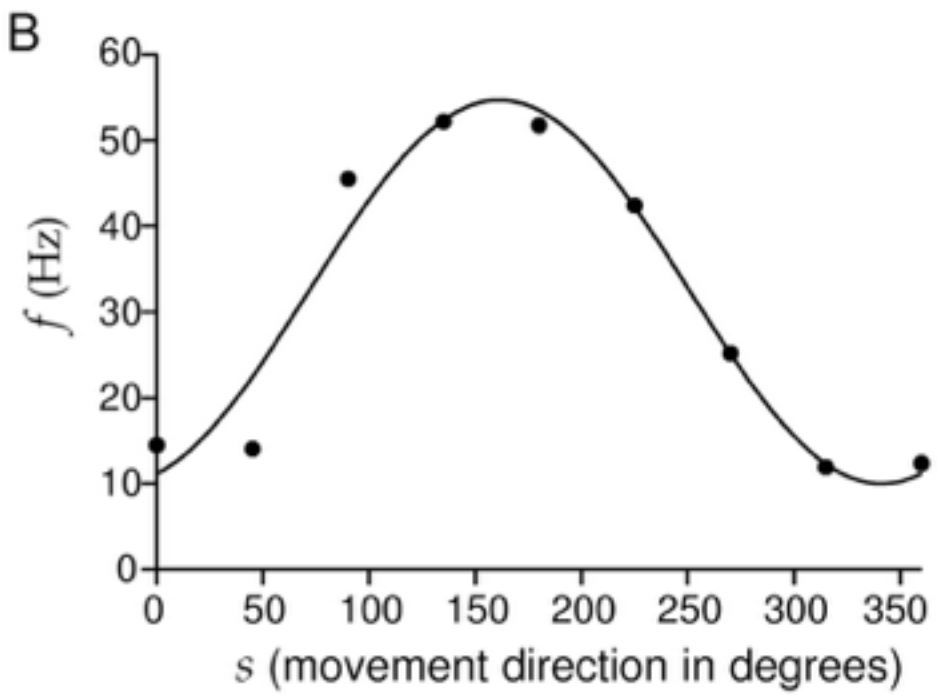
- example: primary visual cortex (monkey)



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

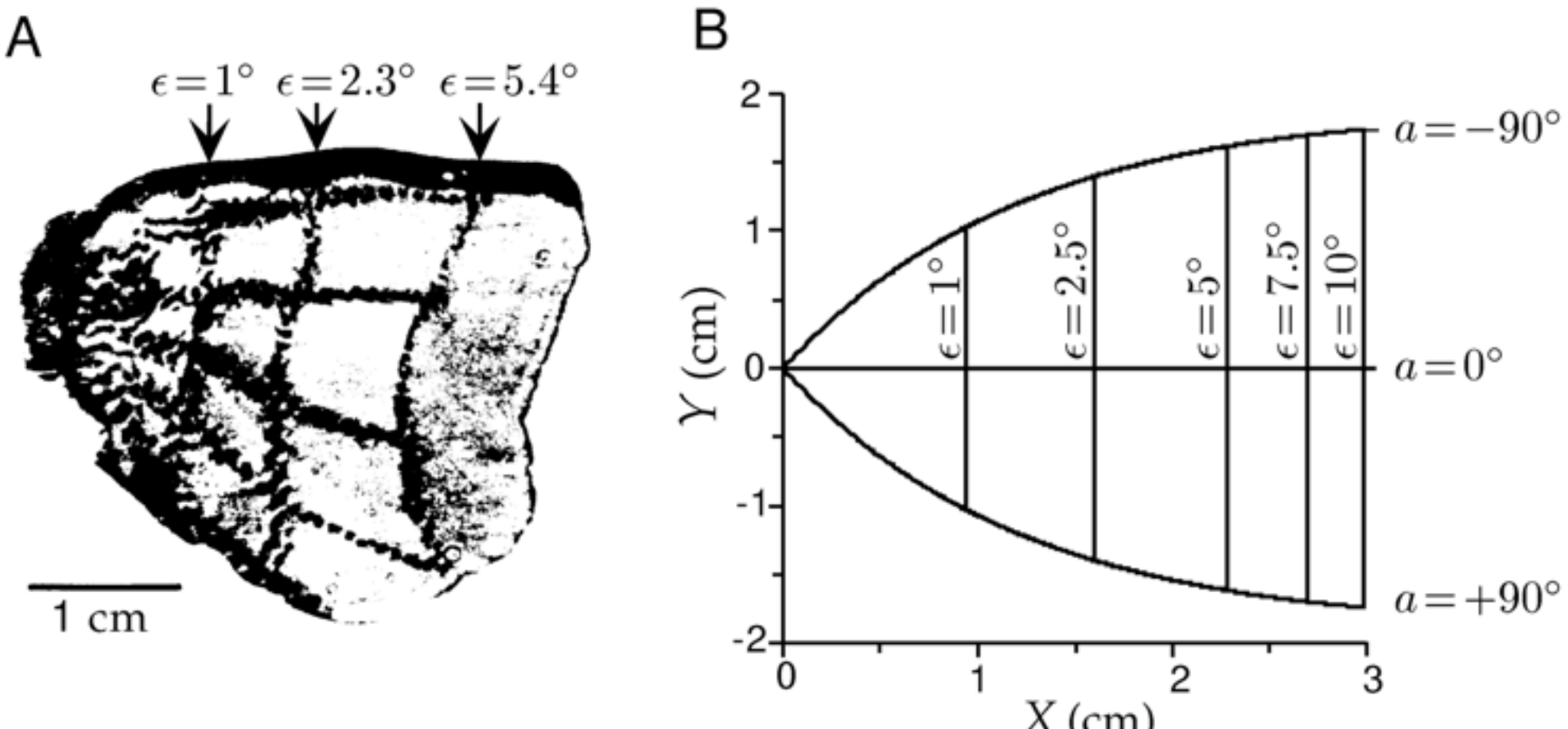
- space of messages: e.g., orientations of edges or directions of arm movement
- code space: ensemble of neurons and their state (”on” vs. “off” or graded state)
- principle of “equivalent nervous energy”

space code

- 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)



population code

- 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

critique

- "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?

critique

- 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)