Dynamic Field Theory: Neural basis

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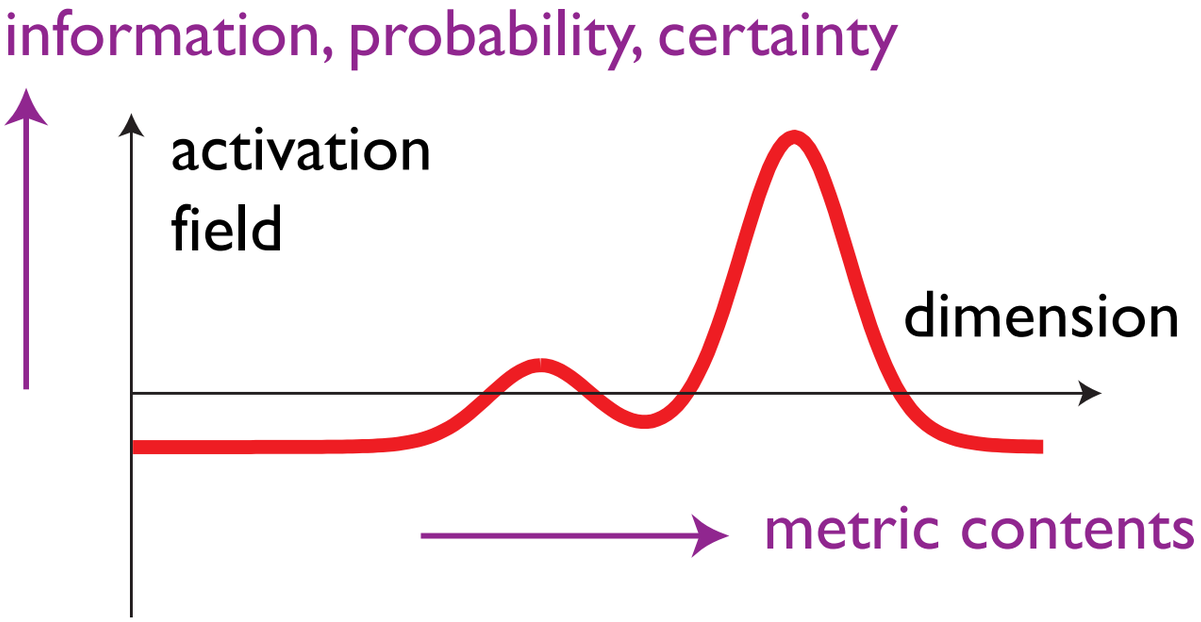
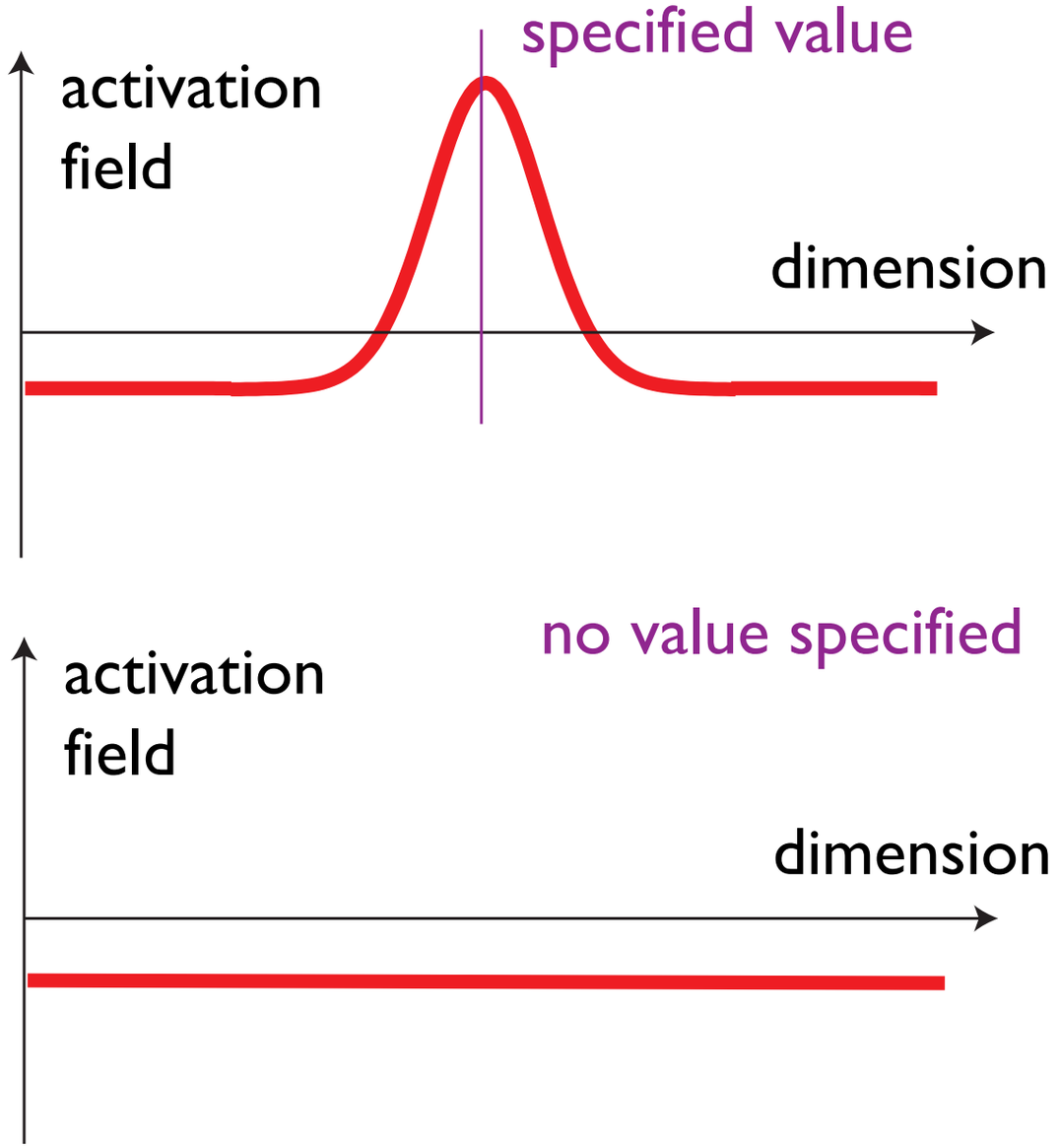
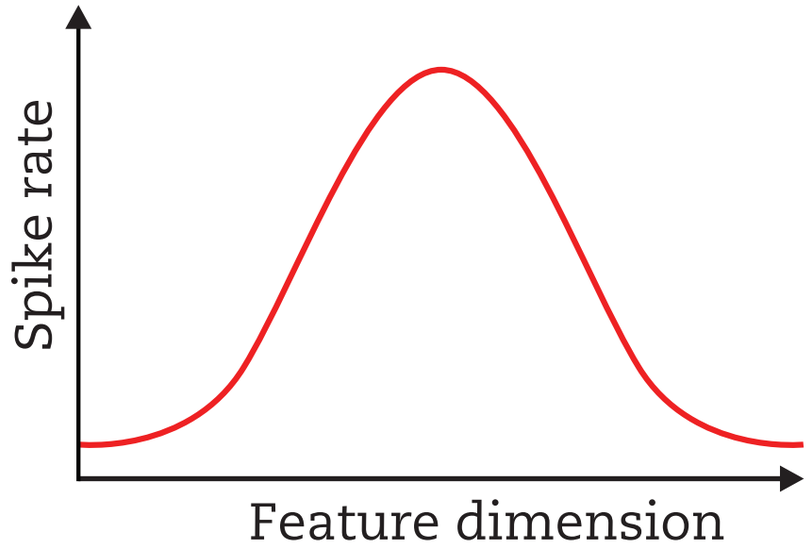
Activation fields… peaks as units of representation



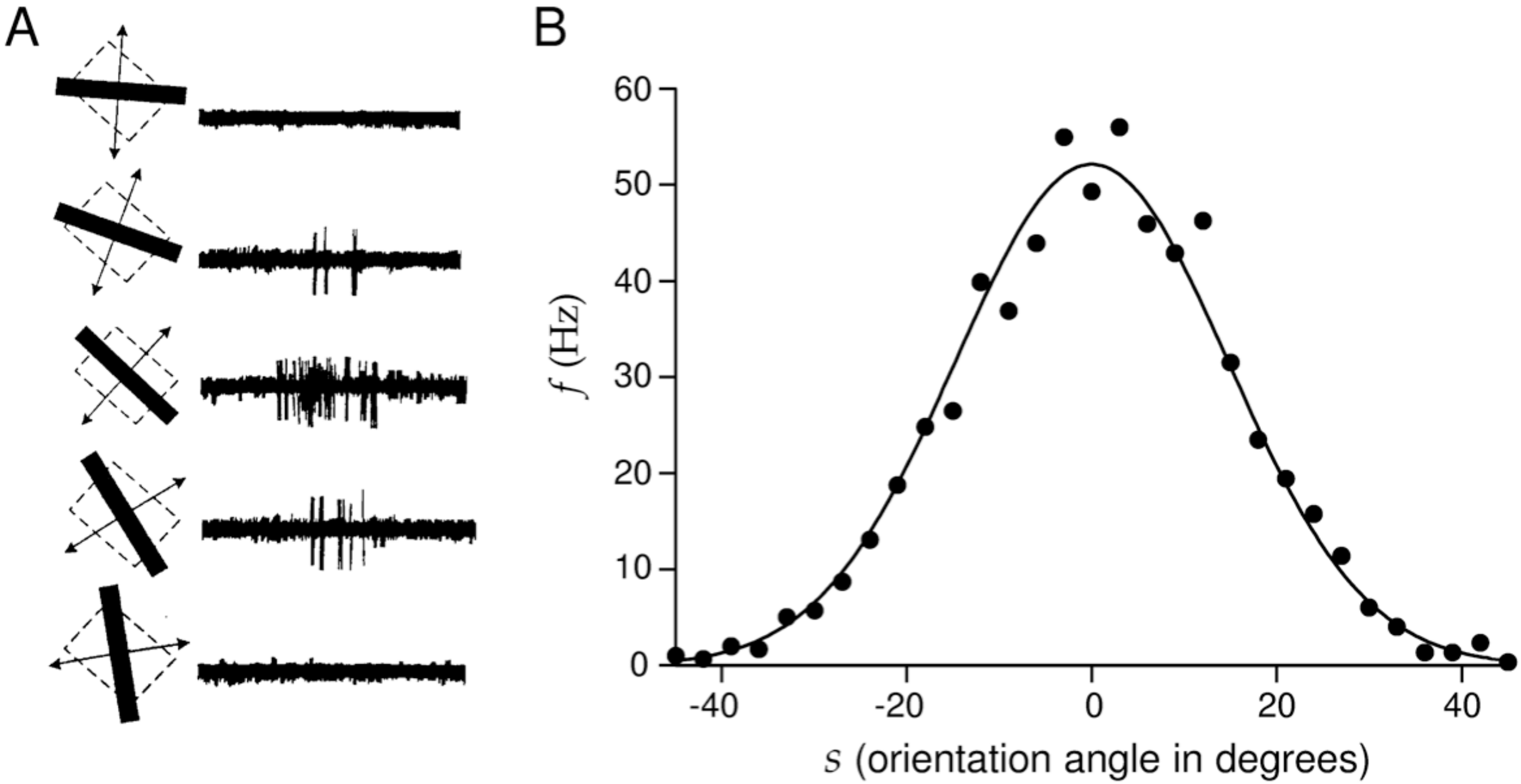


Formalizing the link between DFT and neurophysiology

- 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

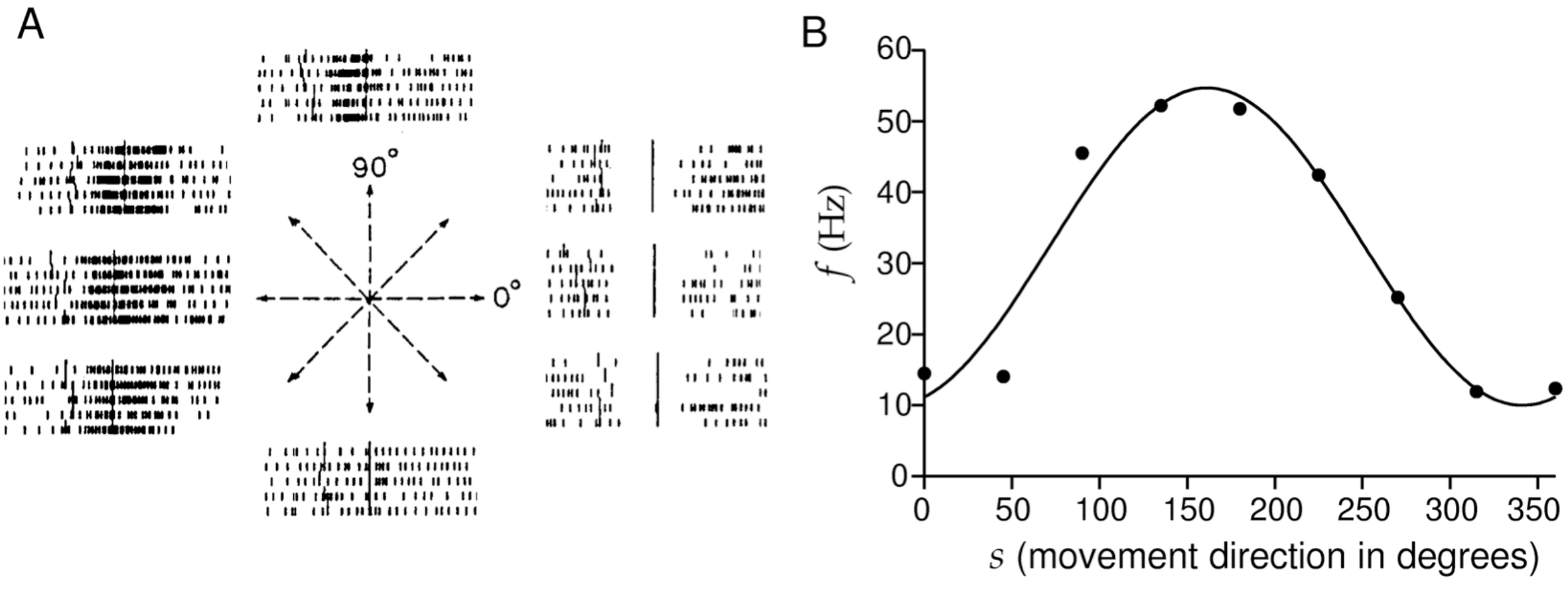


Example tuning curve in primary visual cortex (monkey)



[Hubel, Wiesel, 1962]

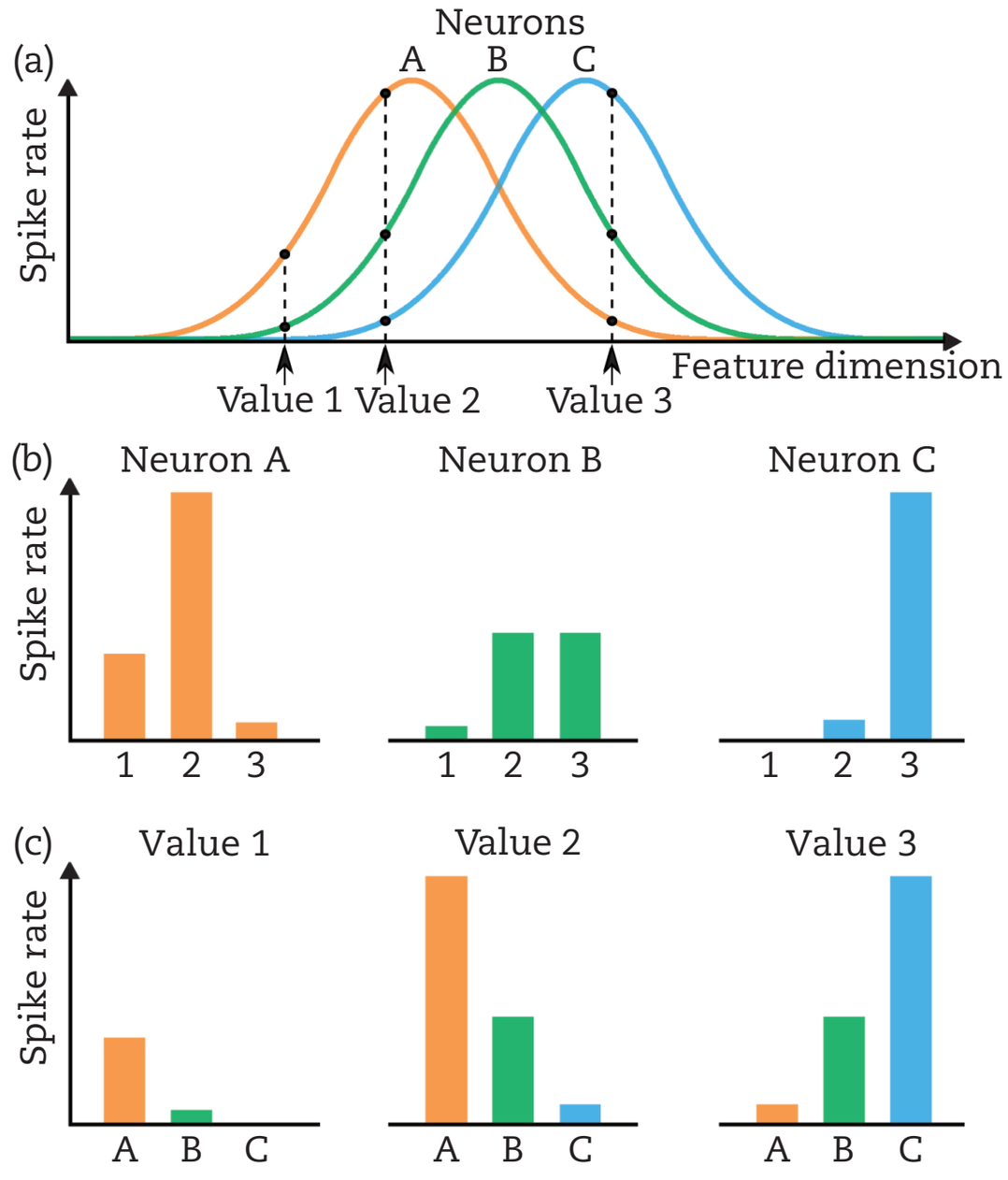
Example: tuning curve in primary motor cortex (monkey)



[Georgopoulos, Schwartz, Kalaska, 1986]

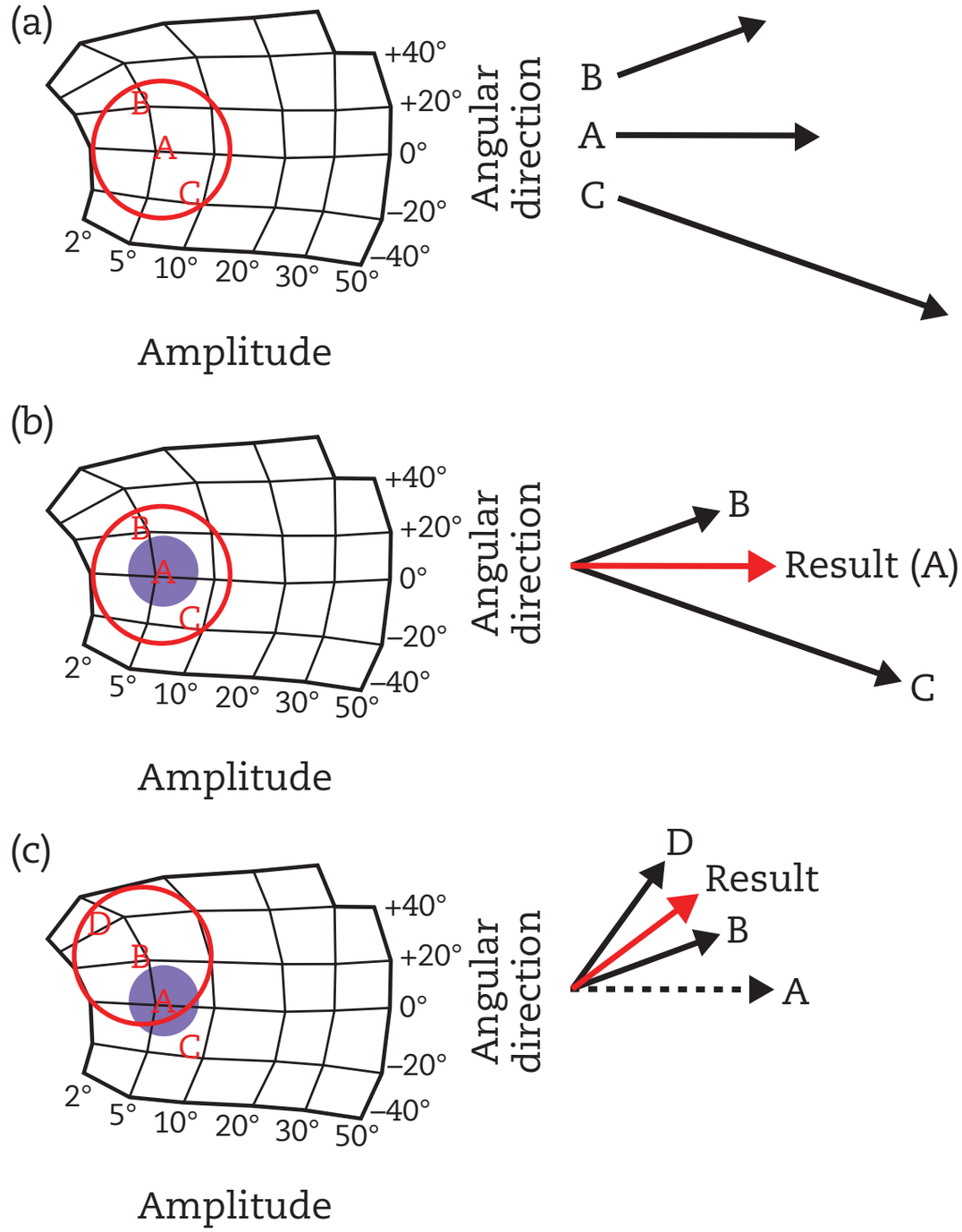
What do populations of neurons represent?

- 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



[after Lee, Rohrer, Sparks: Nature (1988) in Chapter 3 of the book]

=> population code

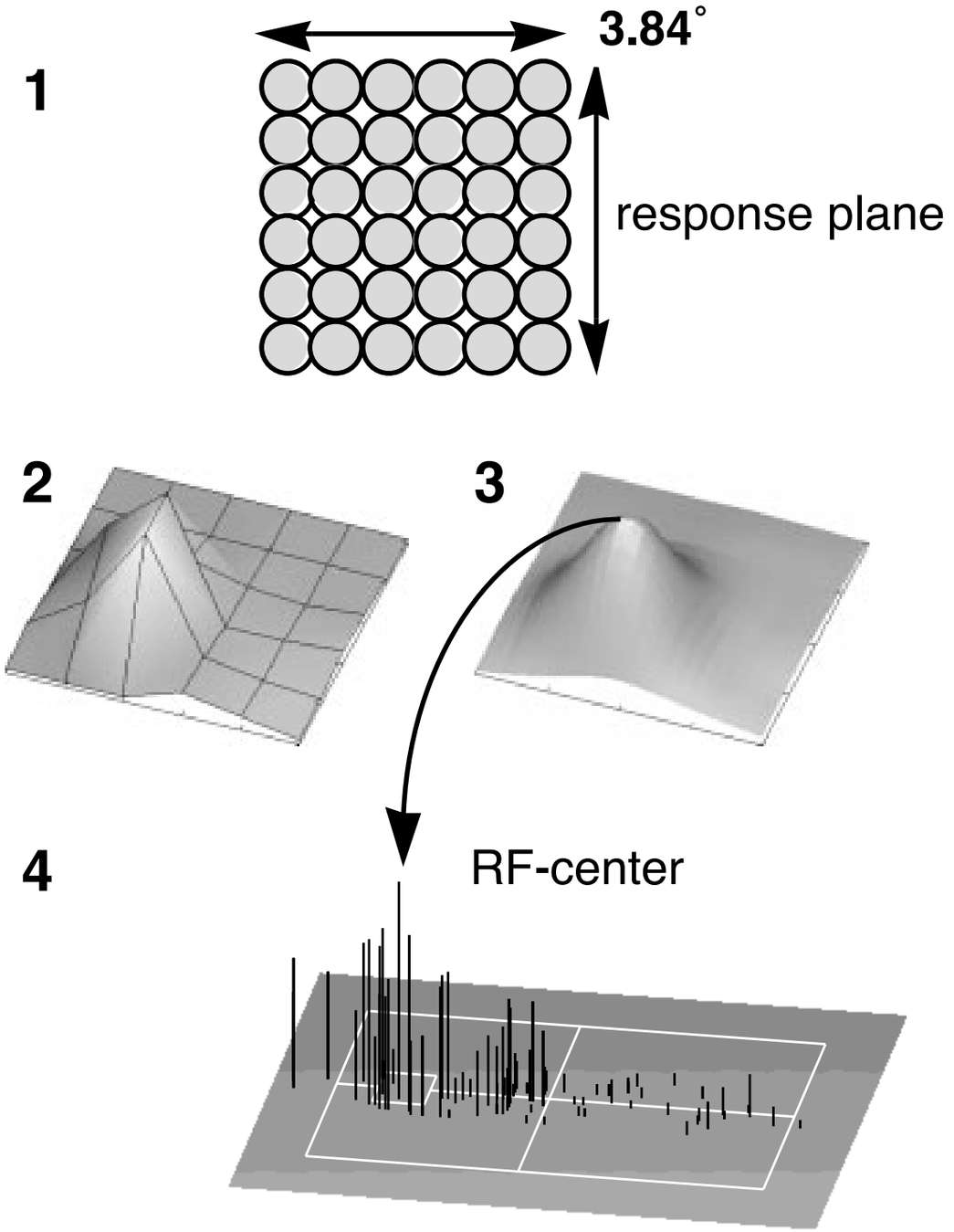
- similar work in MT
  - Purushothaman, G., & Bradley, Da. C. (2005). Neural population code for fine perceptual decisions in area MT. Nature Neuroscience, 8(1), 99–106.
- consensus, that localized populations of neurons best correlated with behavior
  - there are subtle issues of noise and correlation in populations
  - e.g., Cohen, Newsome J Neurosci 2009: about 1000 neurons needed to match behavioral performance
  - review: Shamir, M. (2014). Emerging principles of population coding: In search for the neural code. *Current Opinion in Neurobiology*, *25*, 140–148.

Neurophysiological grounding of DFT

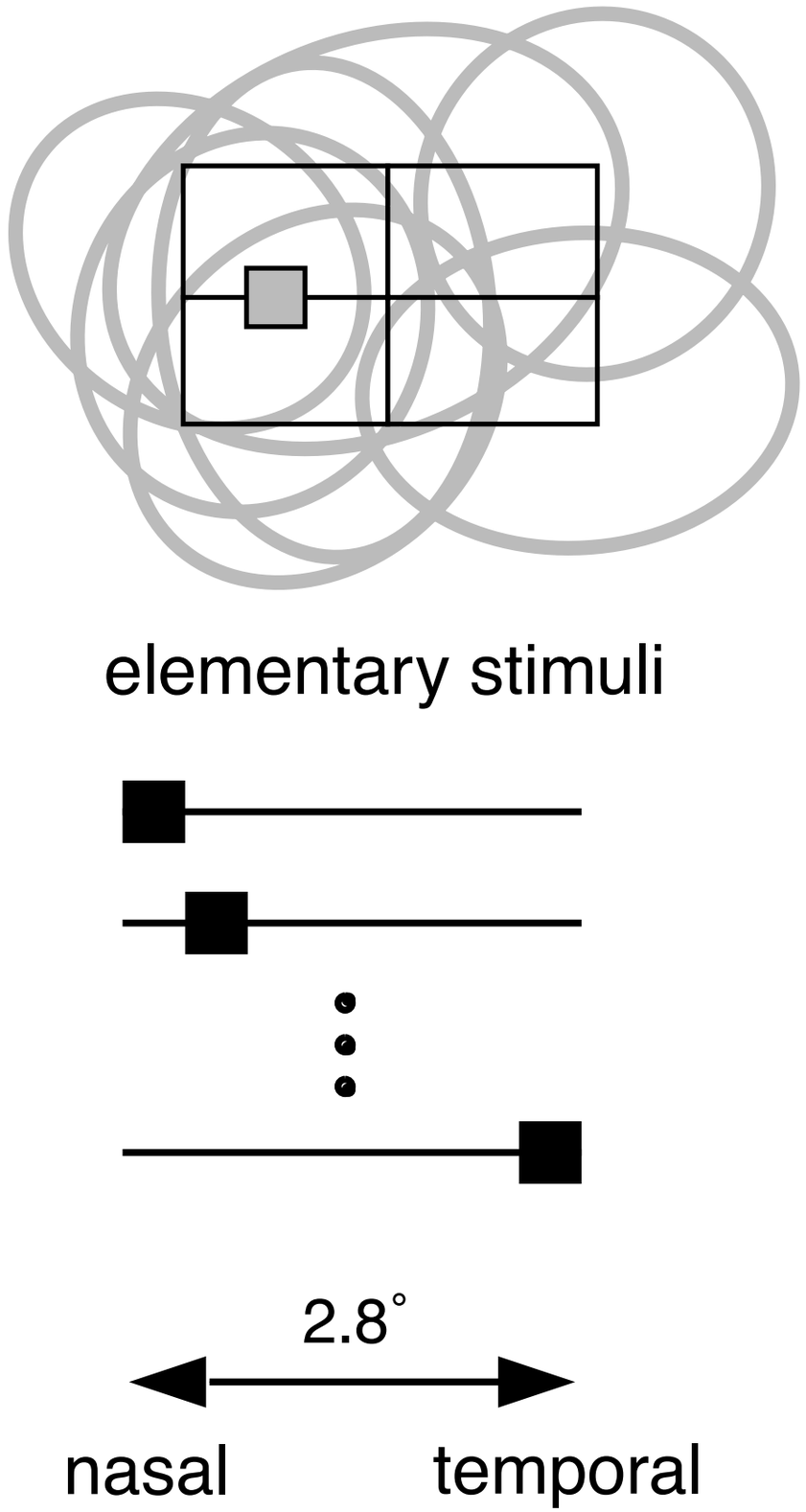
- Example 1: primary visual cortex A17 in the cat, population representation of retinal location

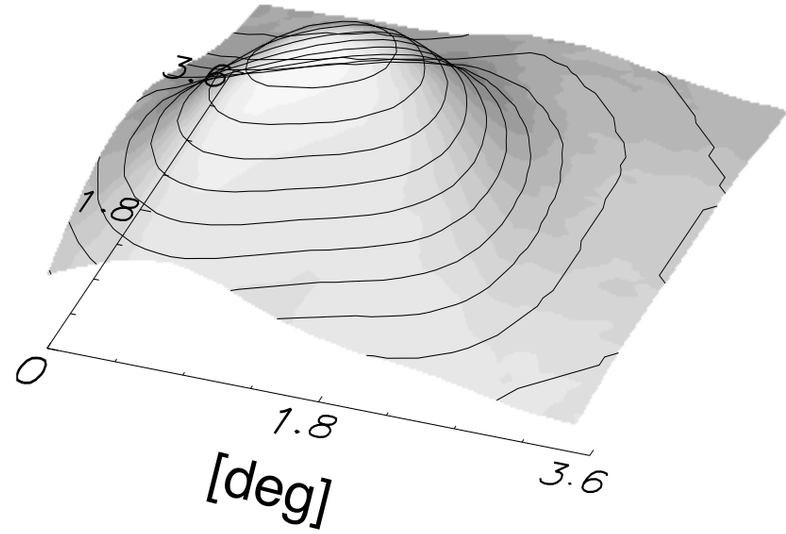
Jancke, Erlhagen, Dinse, Akhavan, Giese, Steinhage, Schöner JNsci 19:9016 (99)

- determine RF profile for each cell
- it's center determines what that neuron codes for
- compute a distribution of population activation by superposing RF profiles weighted with current neural firing rate

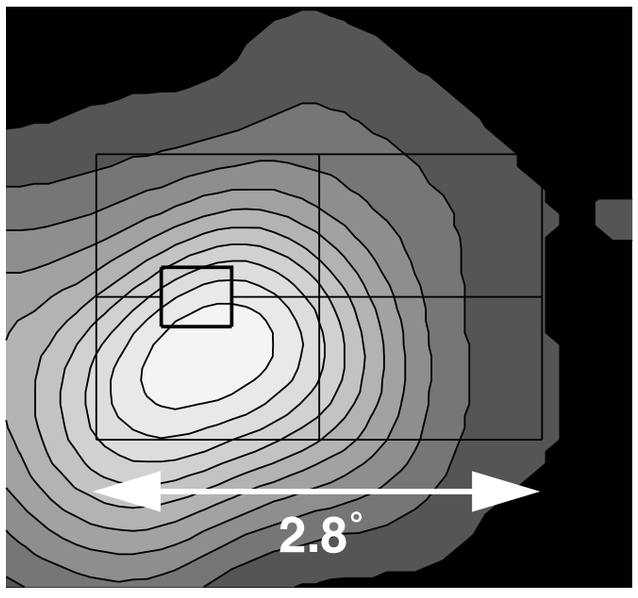


- The current response refers to a stimulus experienced by all neurons
- Reference condition: localized points of light





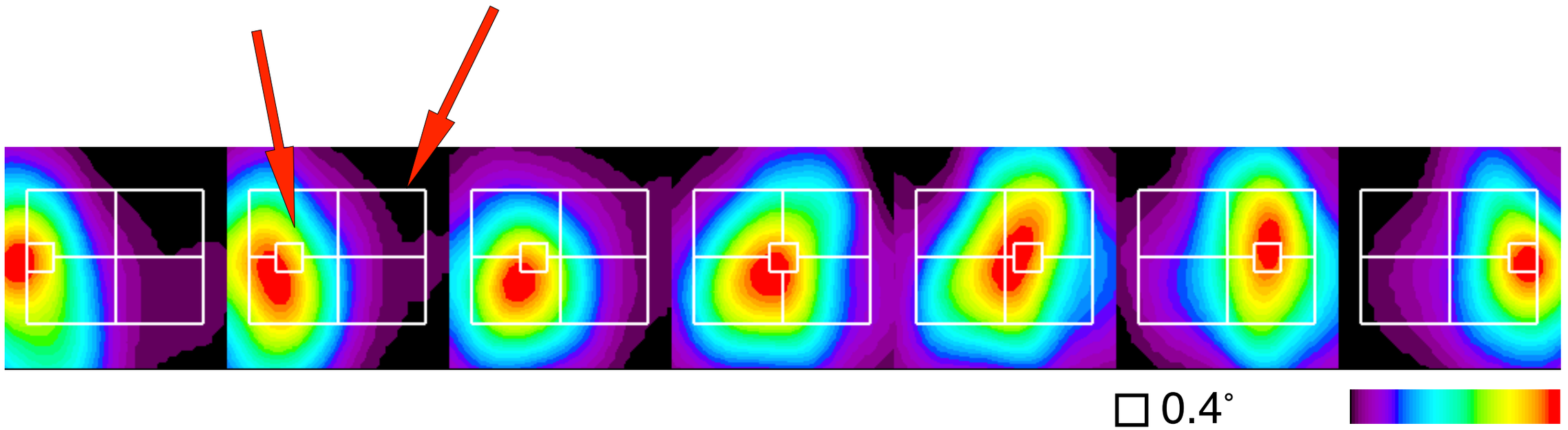
- result: population distribution of activation defined over retinal space = representation of visual location



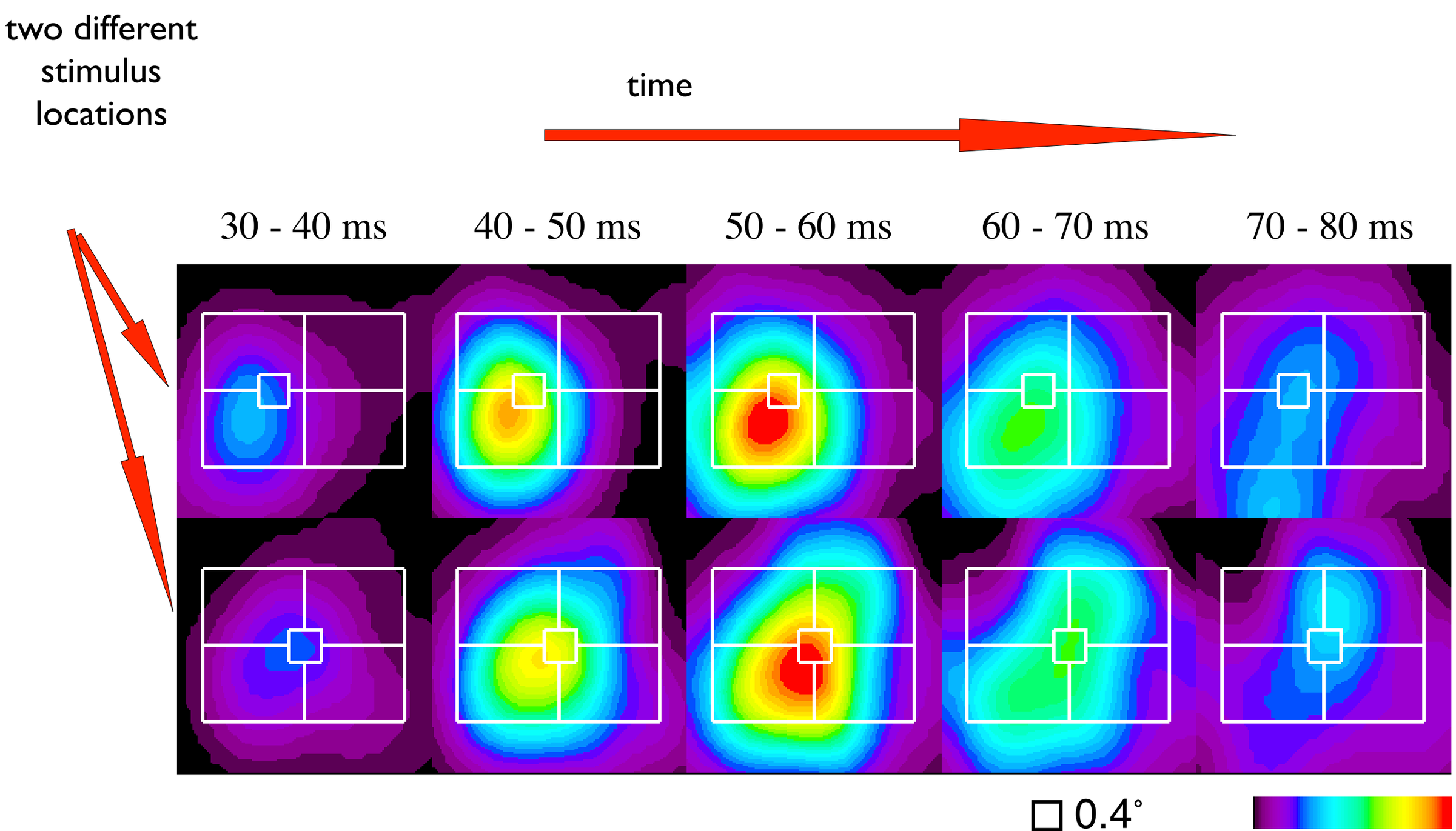
=> does a decent job estimating retinal position

current stimulus:
square of light

range of retinal field
sampled by neurons



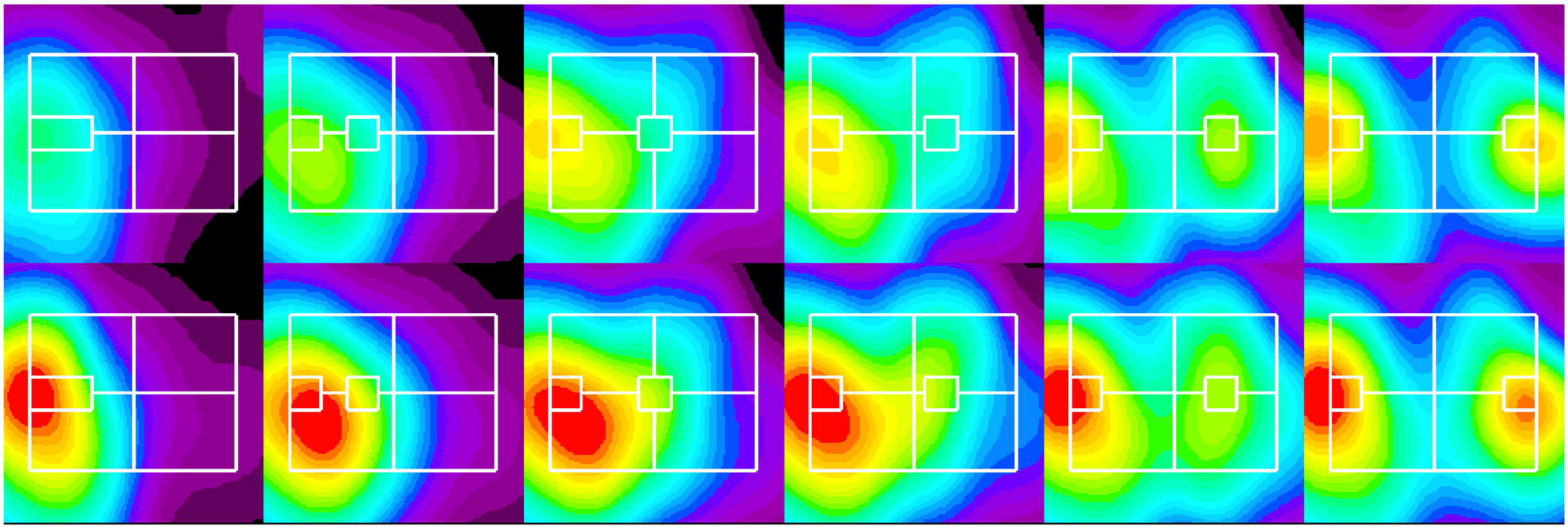
- Extrapolate measurement device to new conditions
- e.g., time resolved



- or when complex stimuli are presented (here: two spots of light)

response to composite stimuli

increasing distance between the two squares of light



superposition of responses to each elemental stimulus

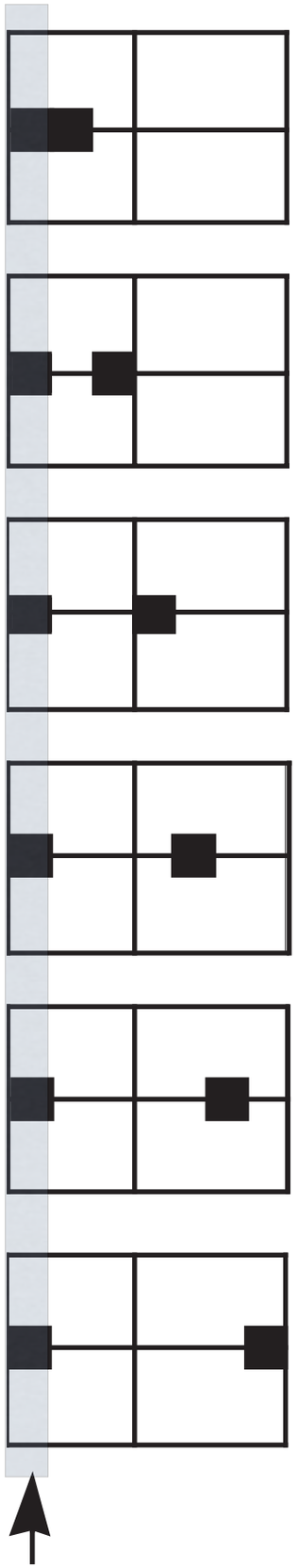
0.4°

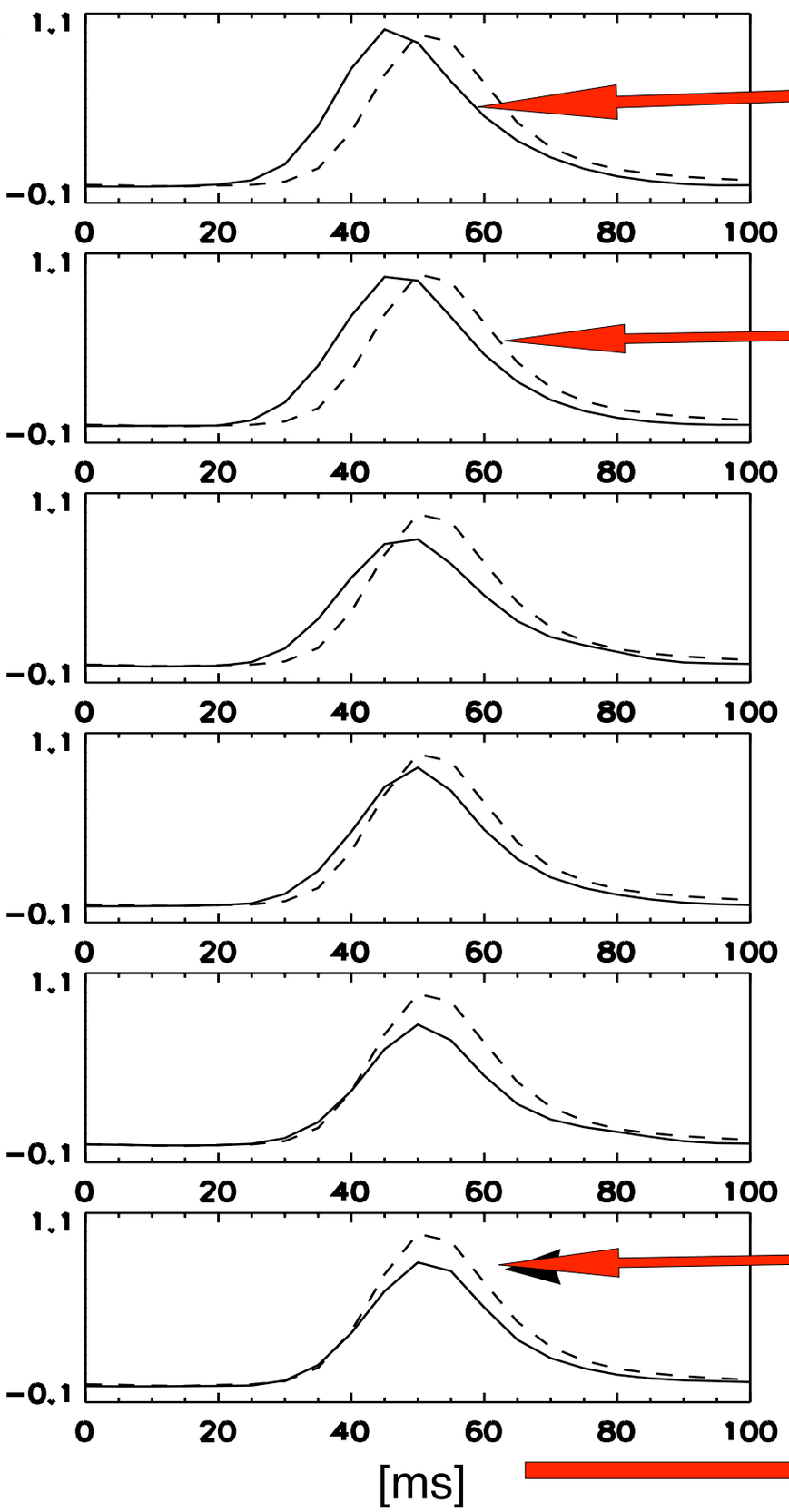
- by comparing DPA of composite stimuli to superposition of DPAs of the two elementary stimuil obtain evidence for interaction
  - early excitation
  - late inhibition

DPA: interaction

activation level in the DPA

at the location of the left component stimulus





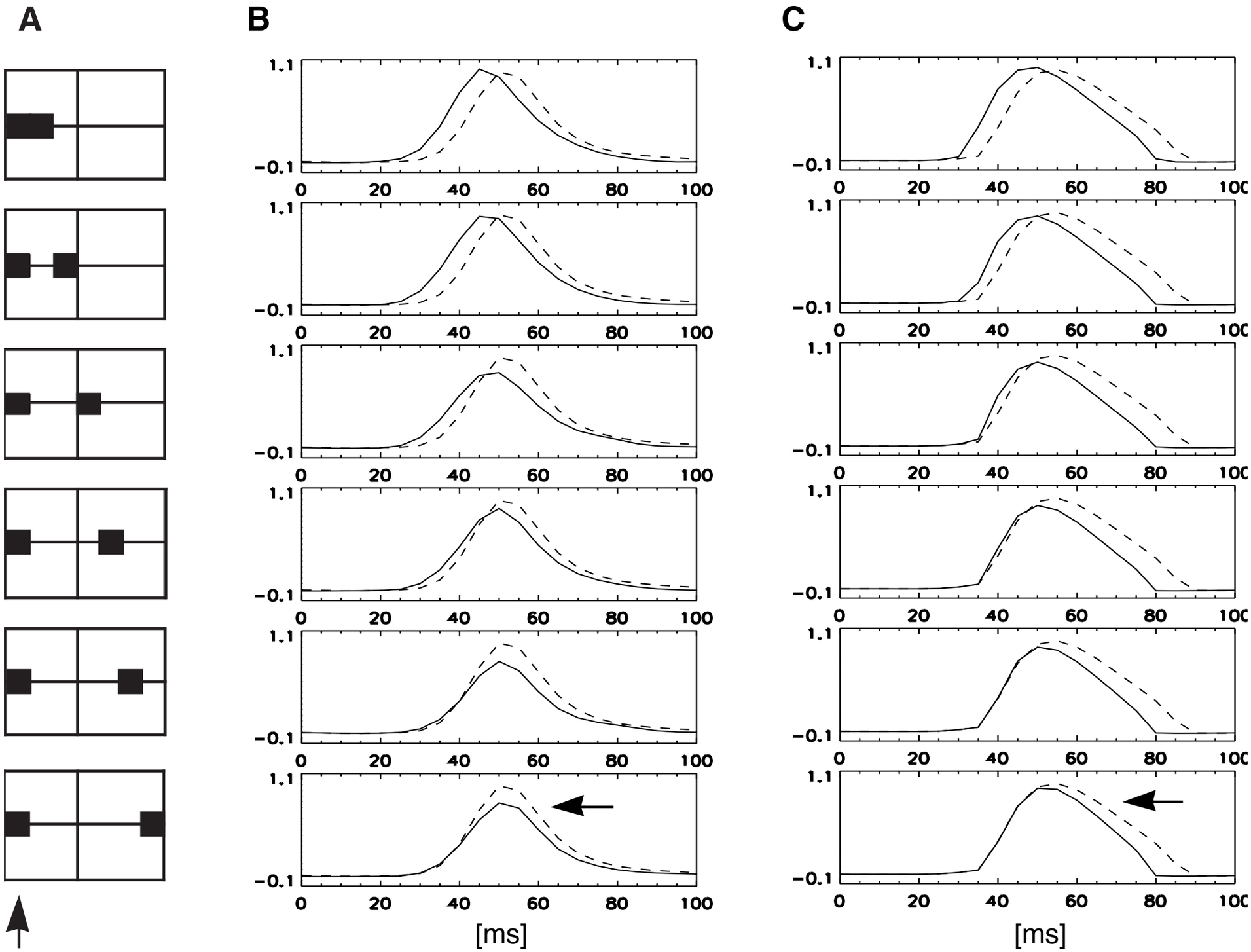
response to composite stimuli

superposition of responses to each elemental stimulus

evidence for inhibitory interaction

time

model by dynamic field:



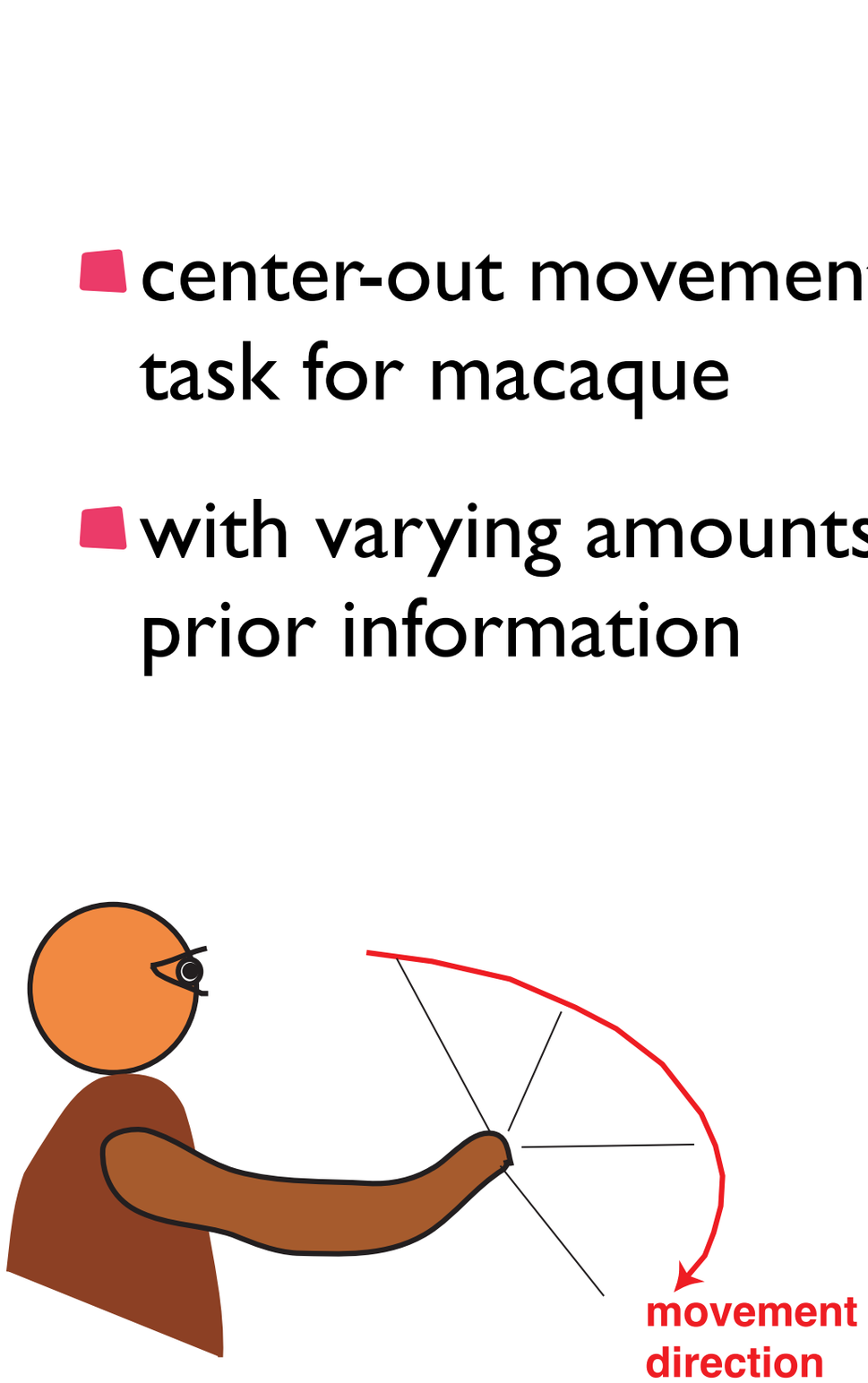
Neurophysiological grounding of DFT

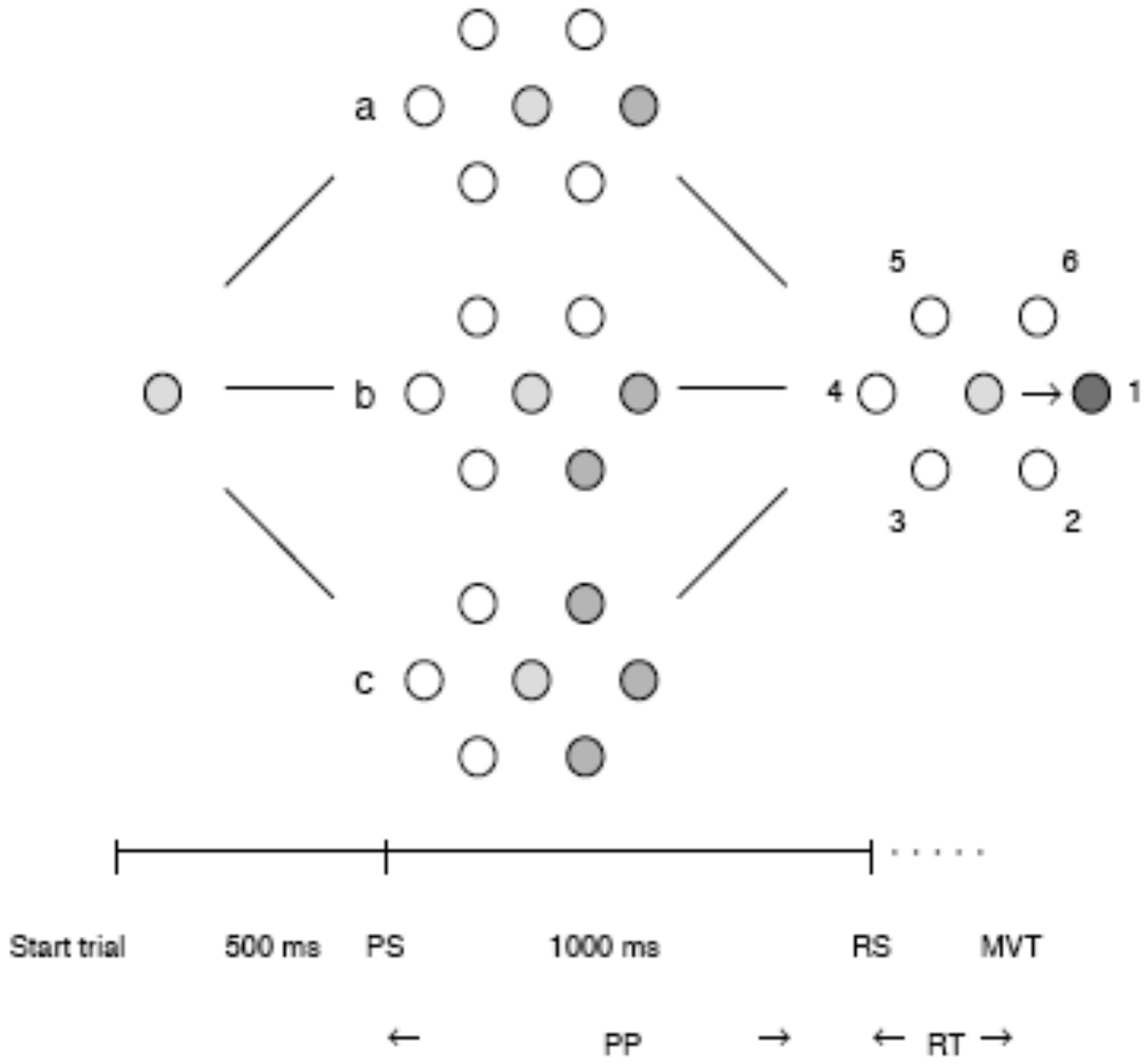
- Example 2: primary motor cortex (M1), population representation of movement direction of the hand

Bastian, Riehle, Schöner, 2003

Task

- center-out movement task for macaque
- with varying amounts of prior information

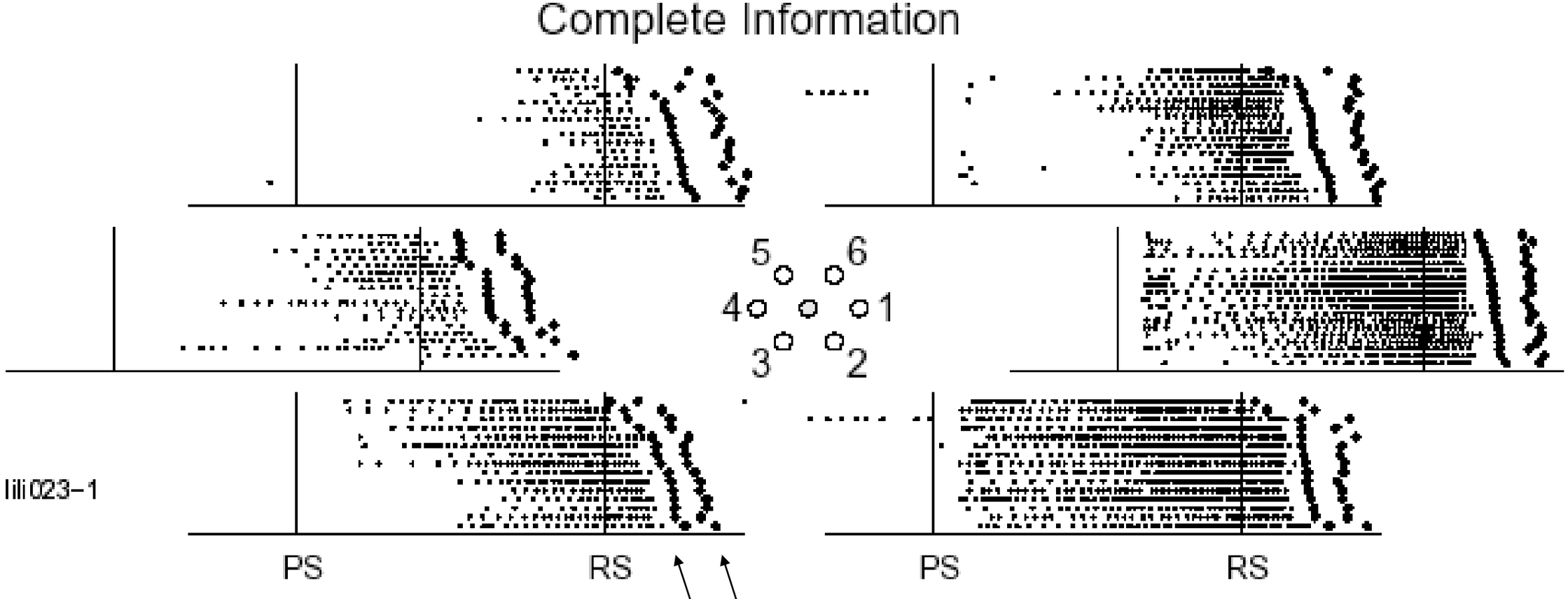




Bastian, Riehle, Schöner, 2003

Tuning of neurons in MI to movement direction

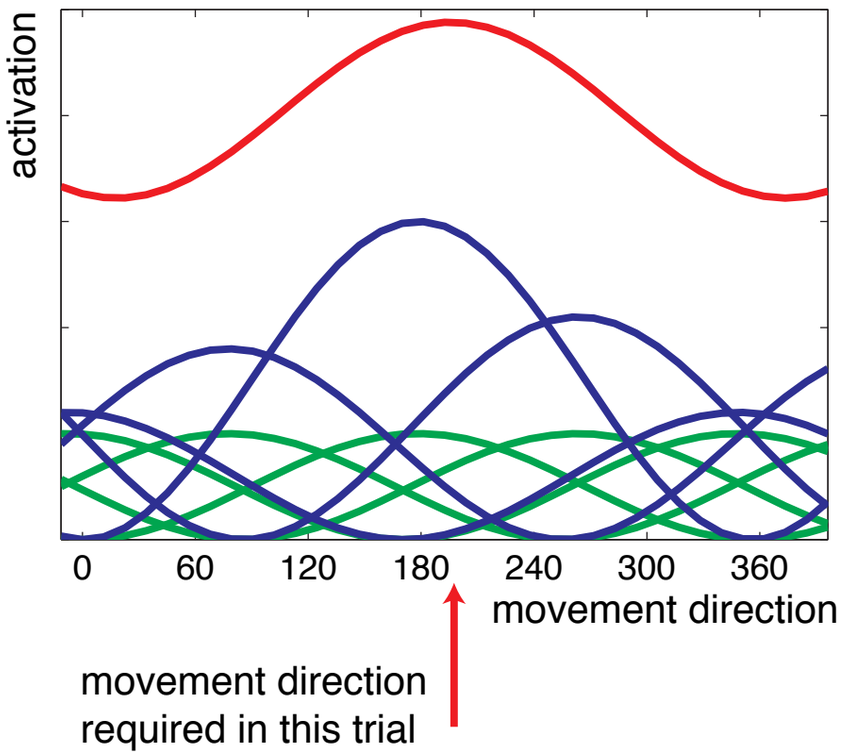
- trials aligned by go signals, ordered by reaction time

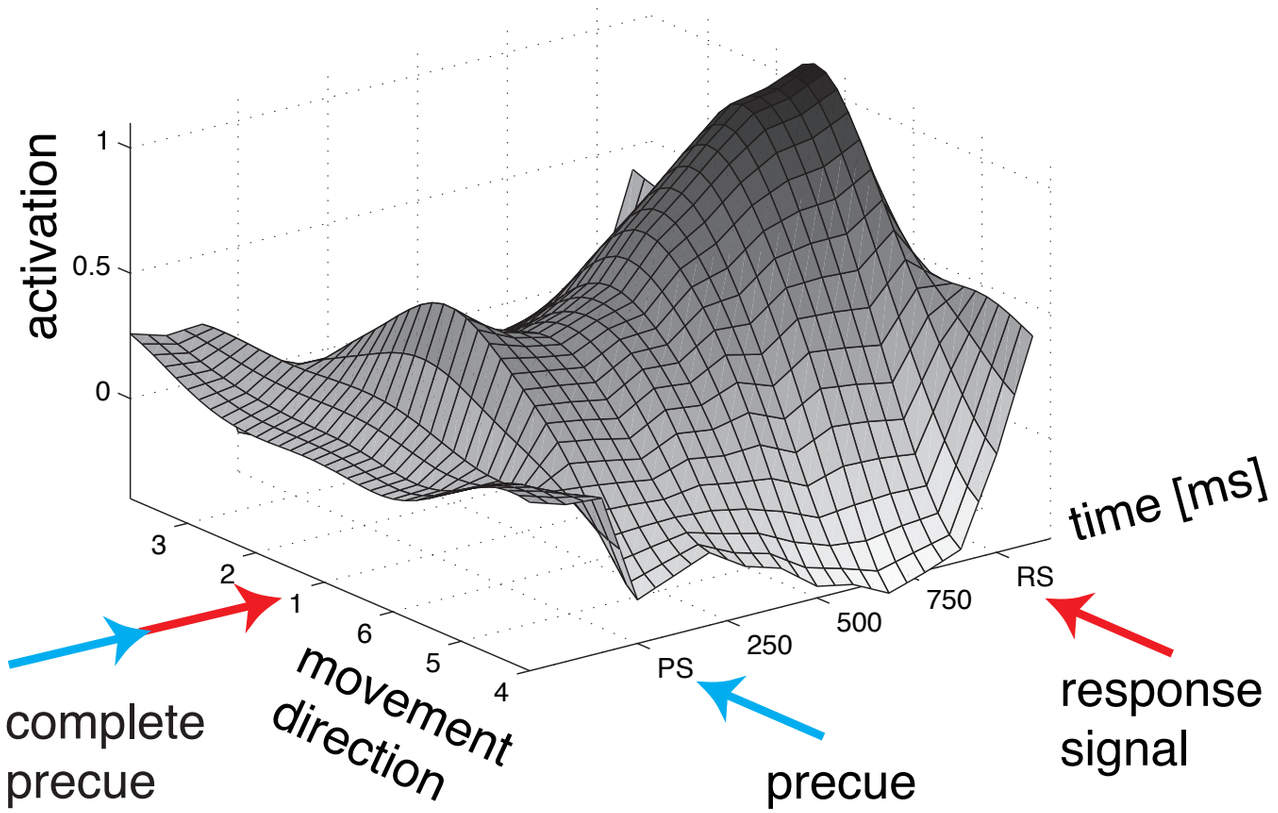


Distribution of Population Activation (DPA)

Distribution of population activation =

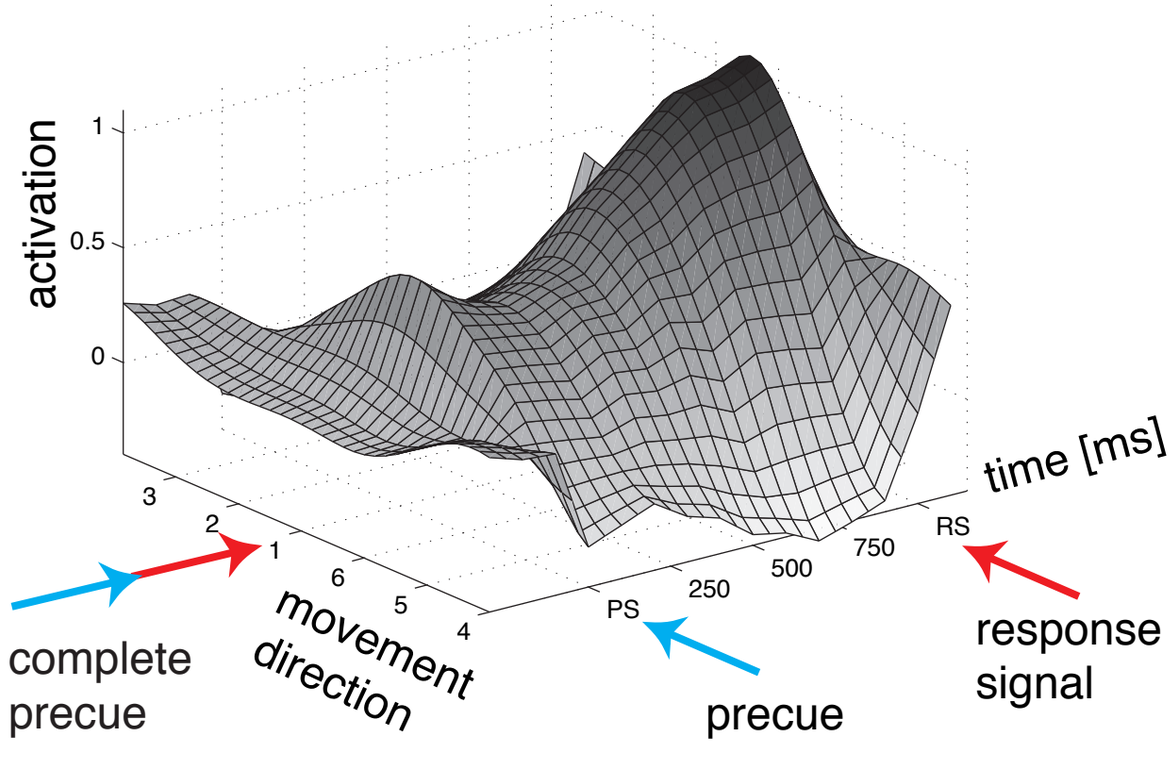
$\sum_{\text{neurons}}$ tuning curve * current firing rate

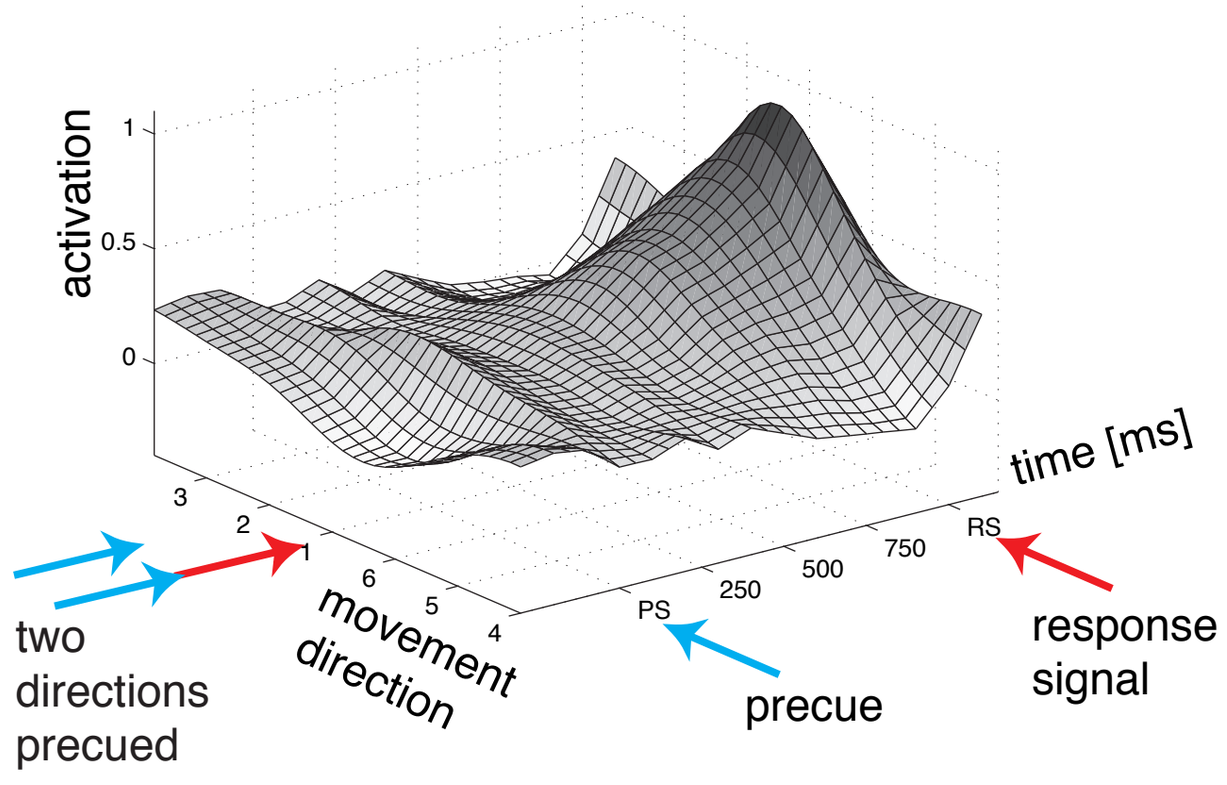




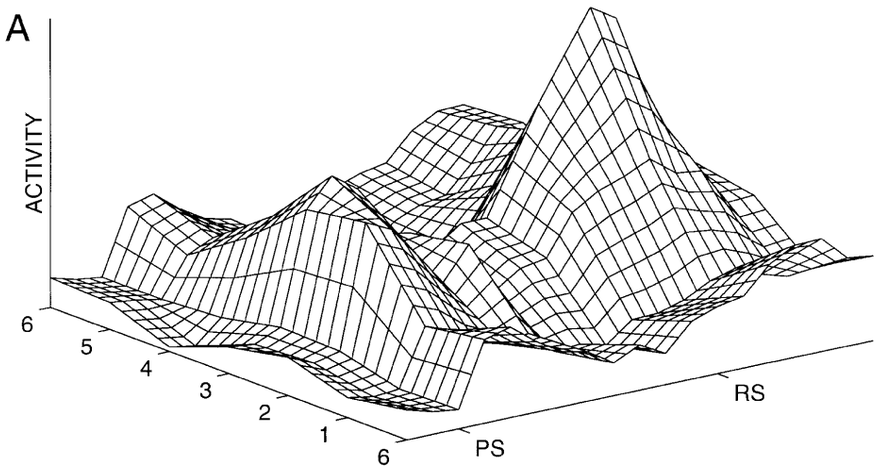
[Bastian, Riehle, Schöner, 2003]

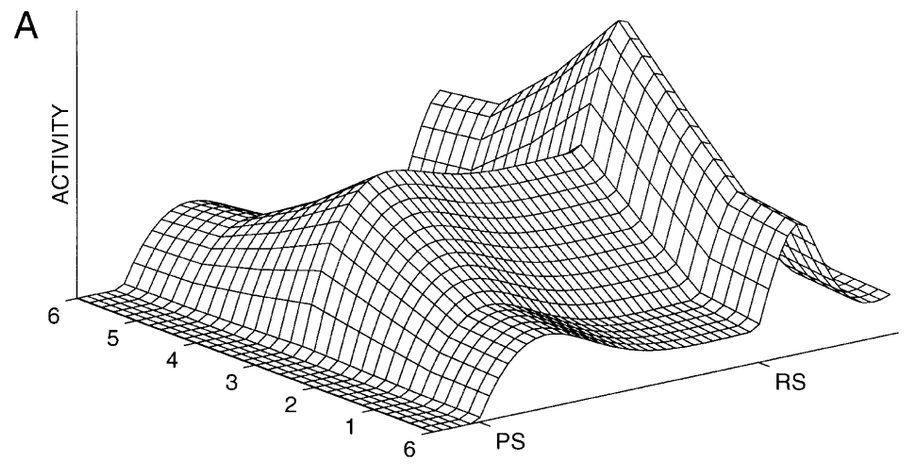
- look at temporal evolution of DPA
- or DPAs in new conditions, here: DPA reflects prior information

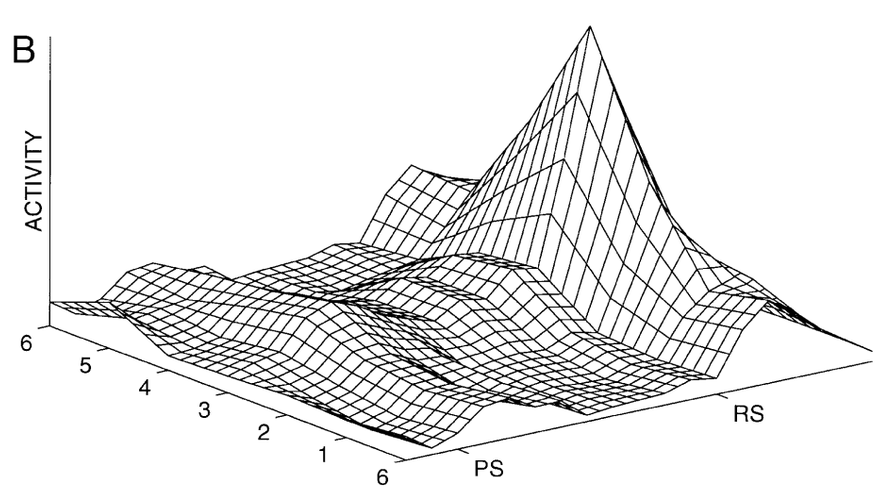


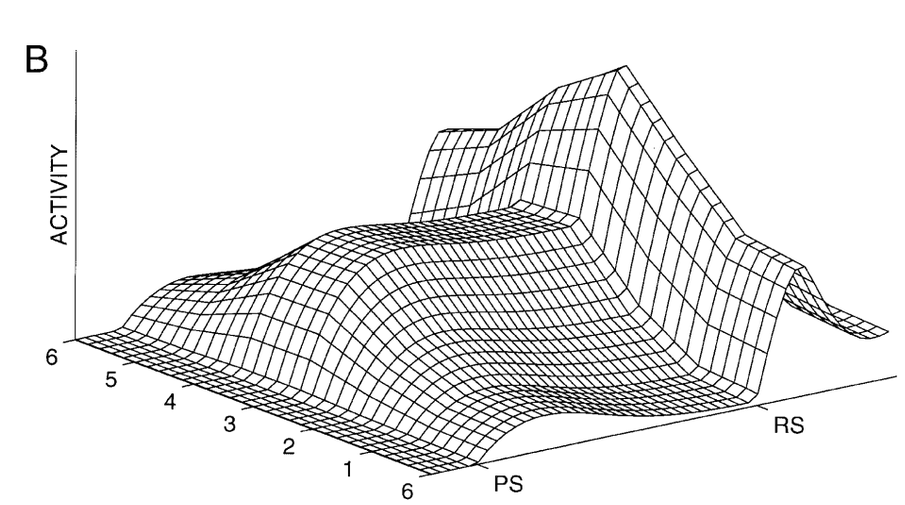


Theory-Experiment









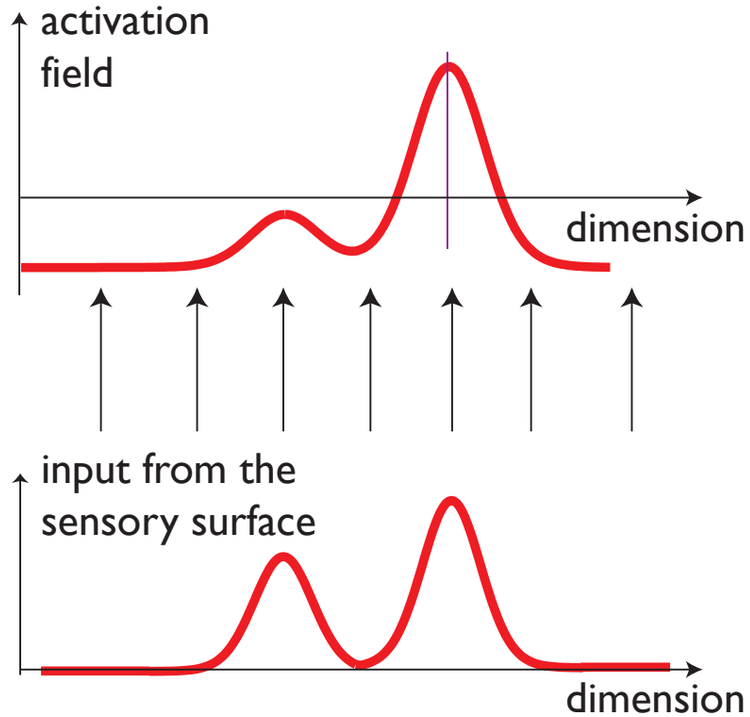
[Bastian, Riehle, Erlhagen, Schöner, 98]

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