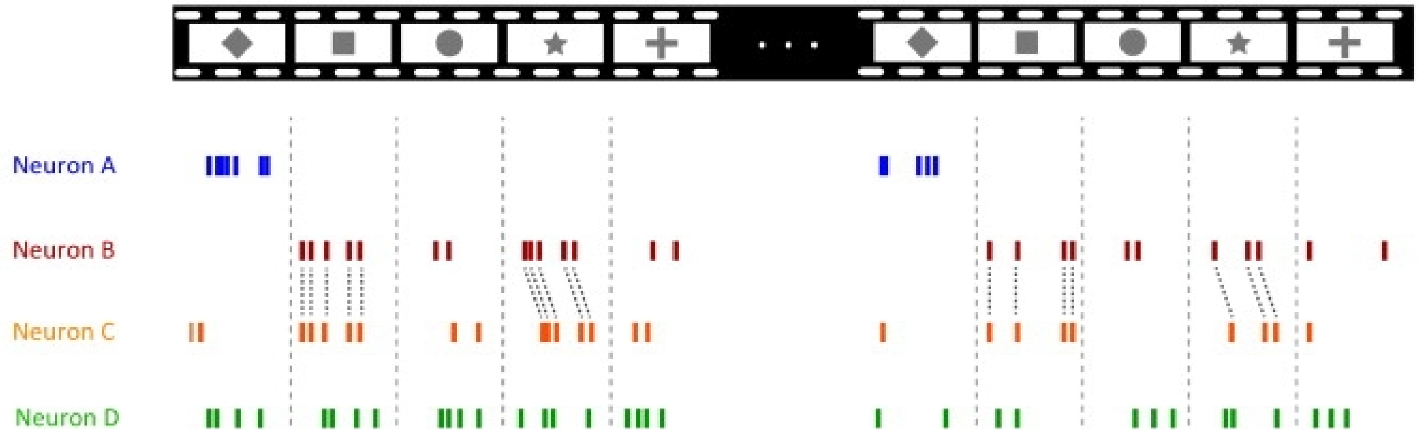
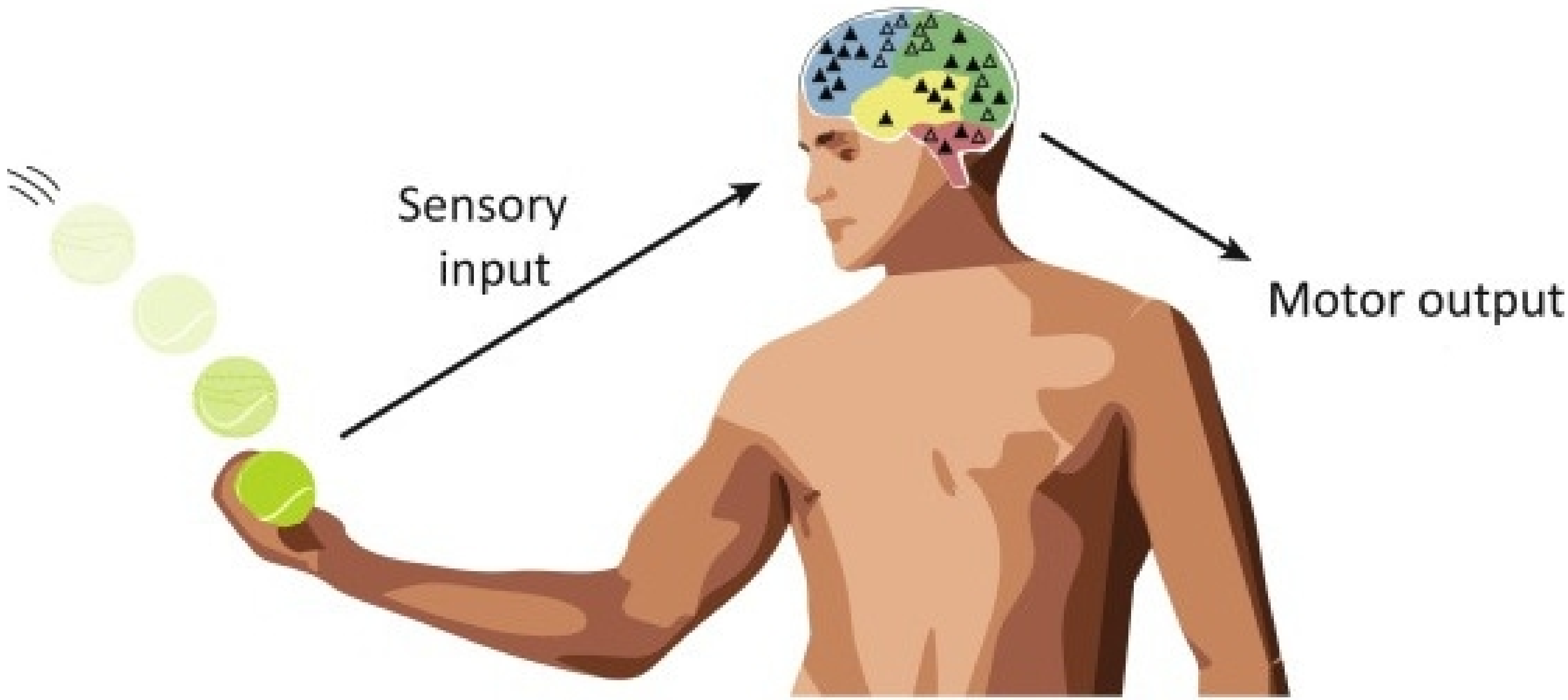


Neural coding and cortical architecture

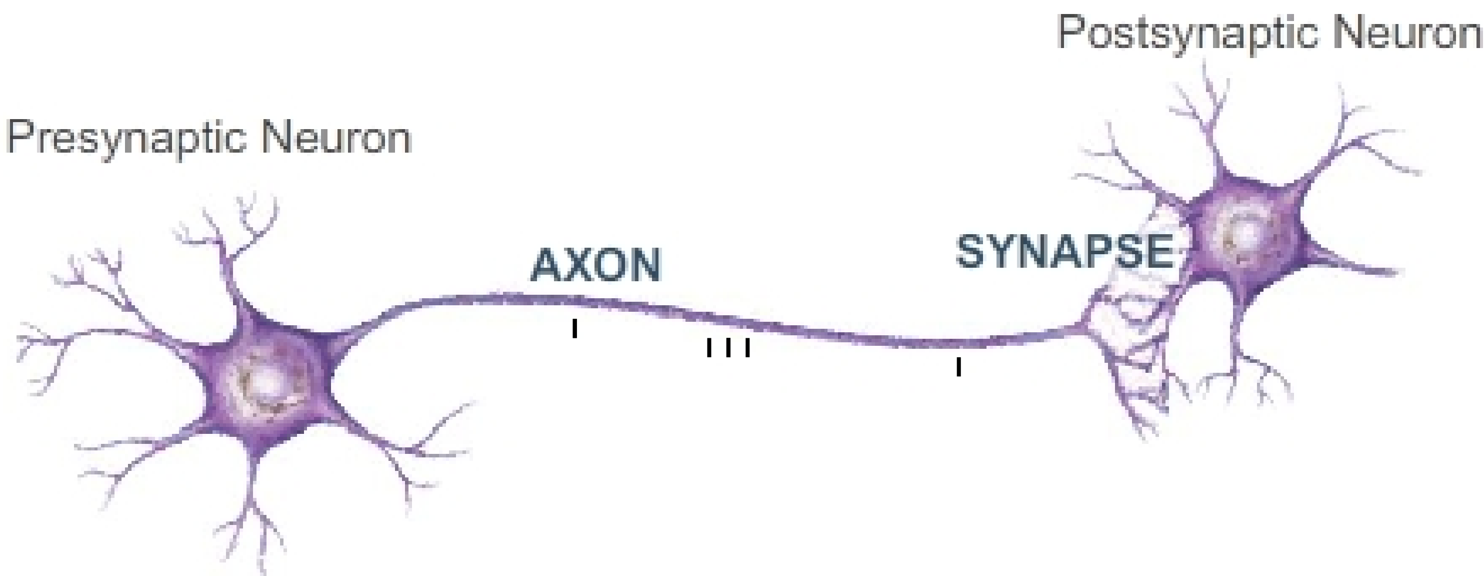
AIL087
Ján Antolík
MFF UK, 2019

Perkel and Bullock (1968): The problem of neural coding is to elucidate "the representation and transformation of information in the nervous system."

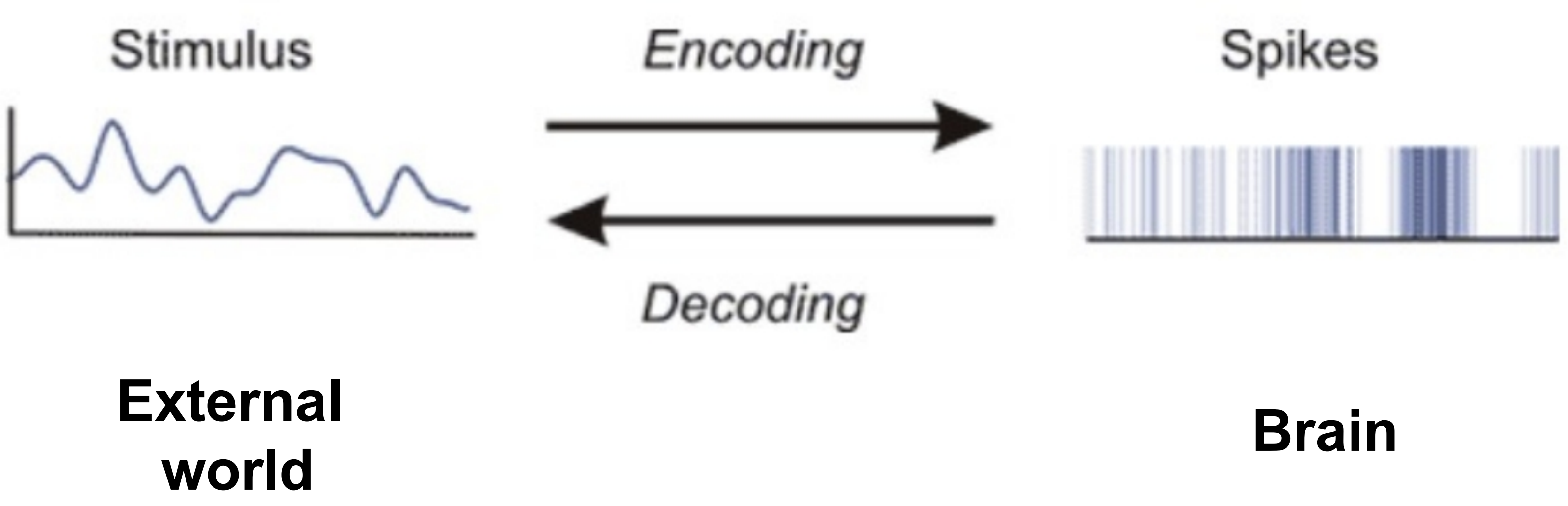
The sensory–motor arc



Spike as an elementary unit of information transmission



Encoding vs. Decoding



- ENCODING: How is information about stimulus transformed into spikes
- DECODING: How to infer stimulus (or output variable) given spikes

Encoding vs. Decoding

S – Stimulus
R – Response

Encoding		*Decoding*
$P(R \mid S)$	vs	$P(S \mid R)$

Encoding vs. Decoding

S – Stimulus
R – Response

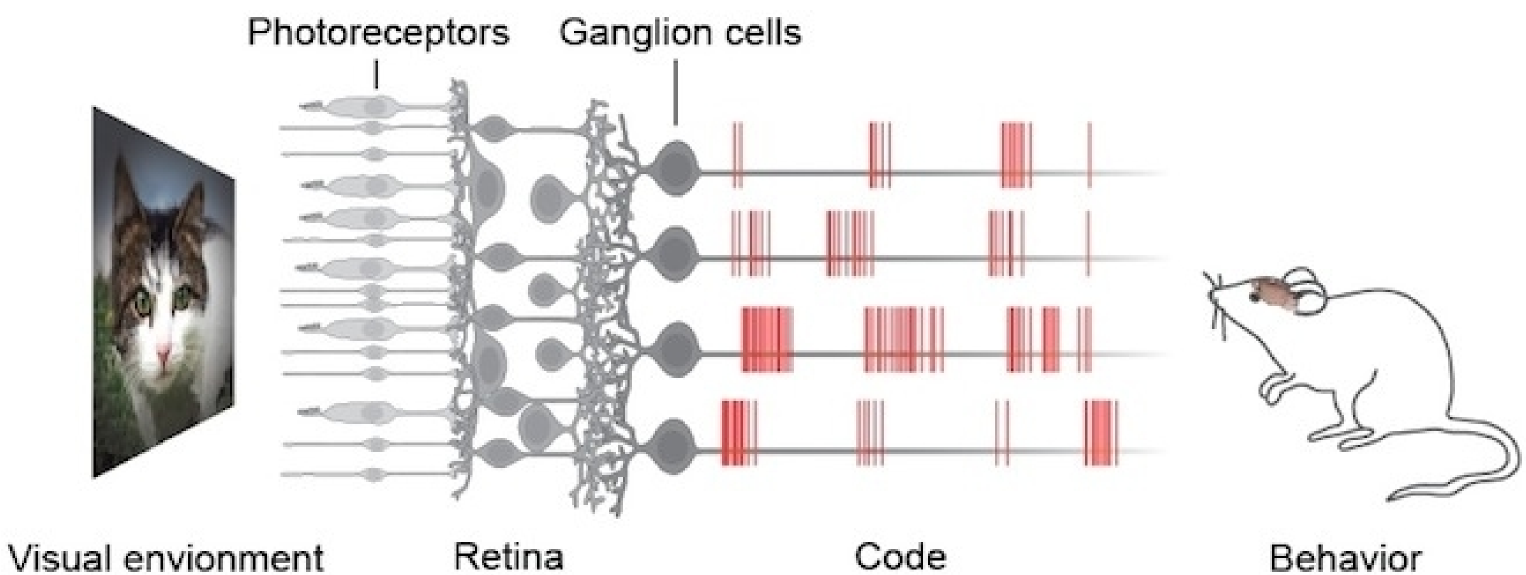
Encoding $P(R|S)$ vs *Decoding* $P(S|R)$

Encoding and decoding are related by **Bayes theorem**:

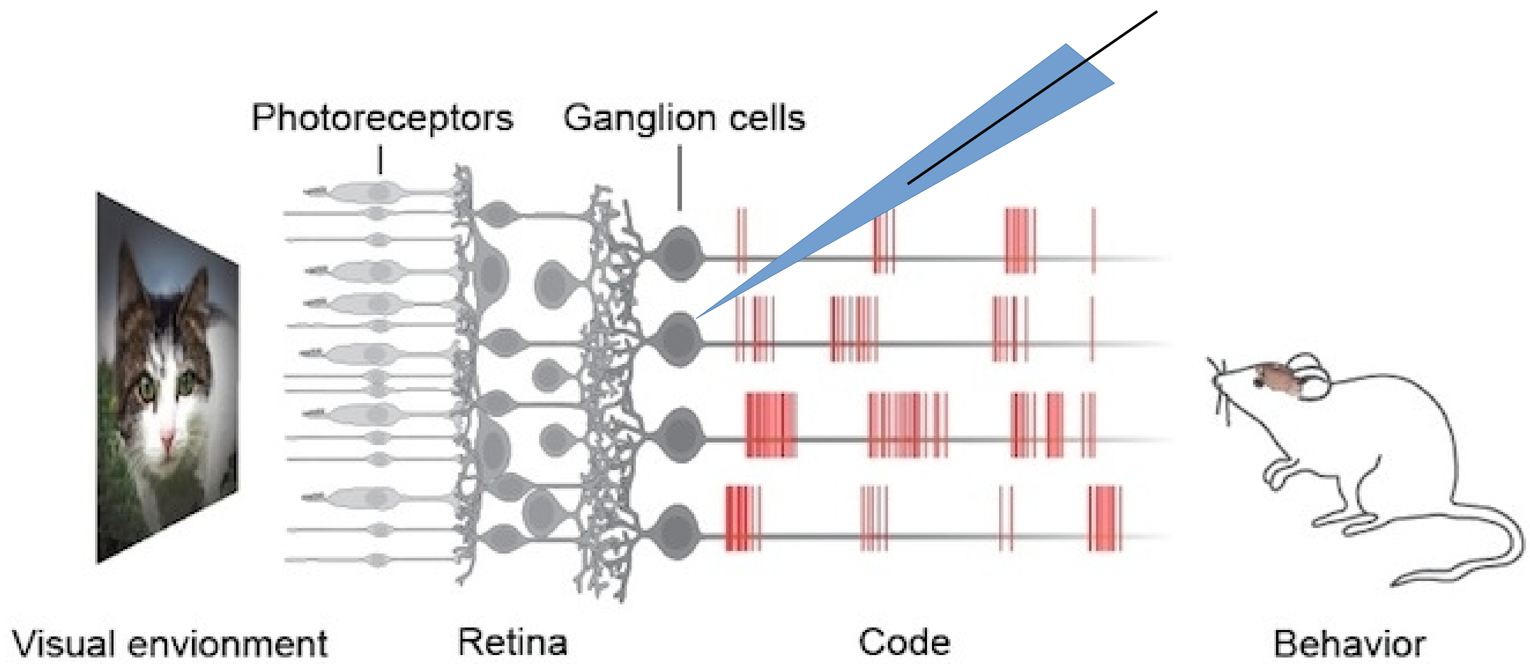
$$P(R,S) = P(R|S)P(S) = P(S|R)P(R)$$

$$P(S|R) = \frac{P(R|S)P(S)}{P(R)}$$

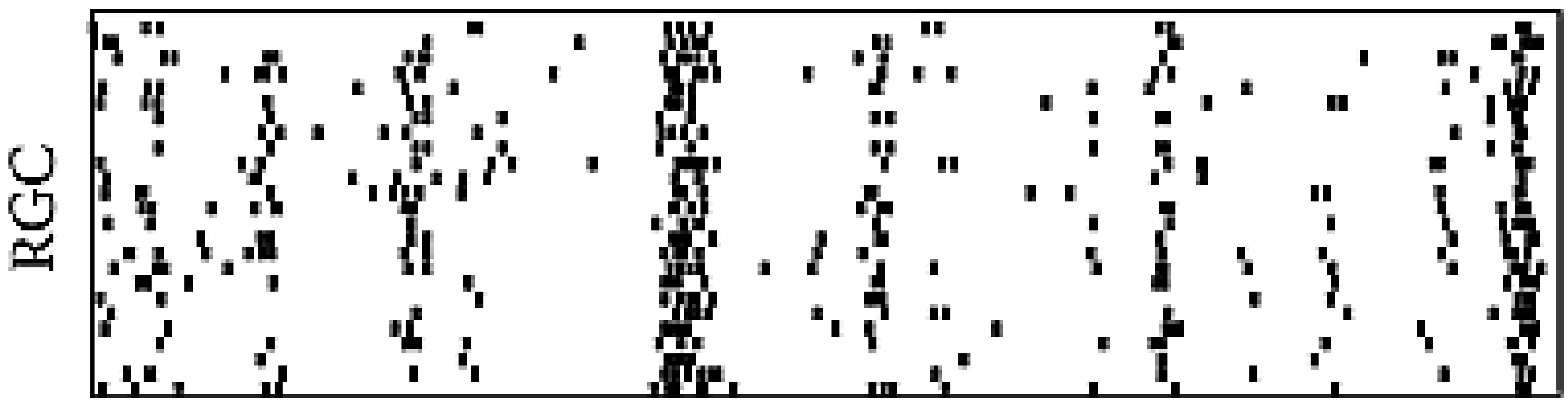
Let’s brainstorm!
How could this retinal ganglion cell encode information?



Let's brainstorm!
How could this retinal ganglion cell encode information?



Let's brainstorm!
How could this retinal ganglion cell encode information?



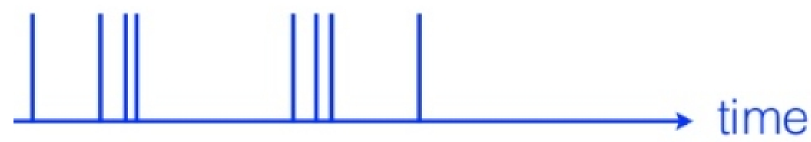
RATE CODE

Firing–rate hypothesis

- Only the frequency is important
  - small vs. large change of *s(t)* causes small vs. large change in the firing frequency: **rate code** [Abott I/37]

Representation of spike trains

$$\rho(t) = \sum_{i=1}^{n} \delta(t - t_i)$$



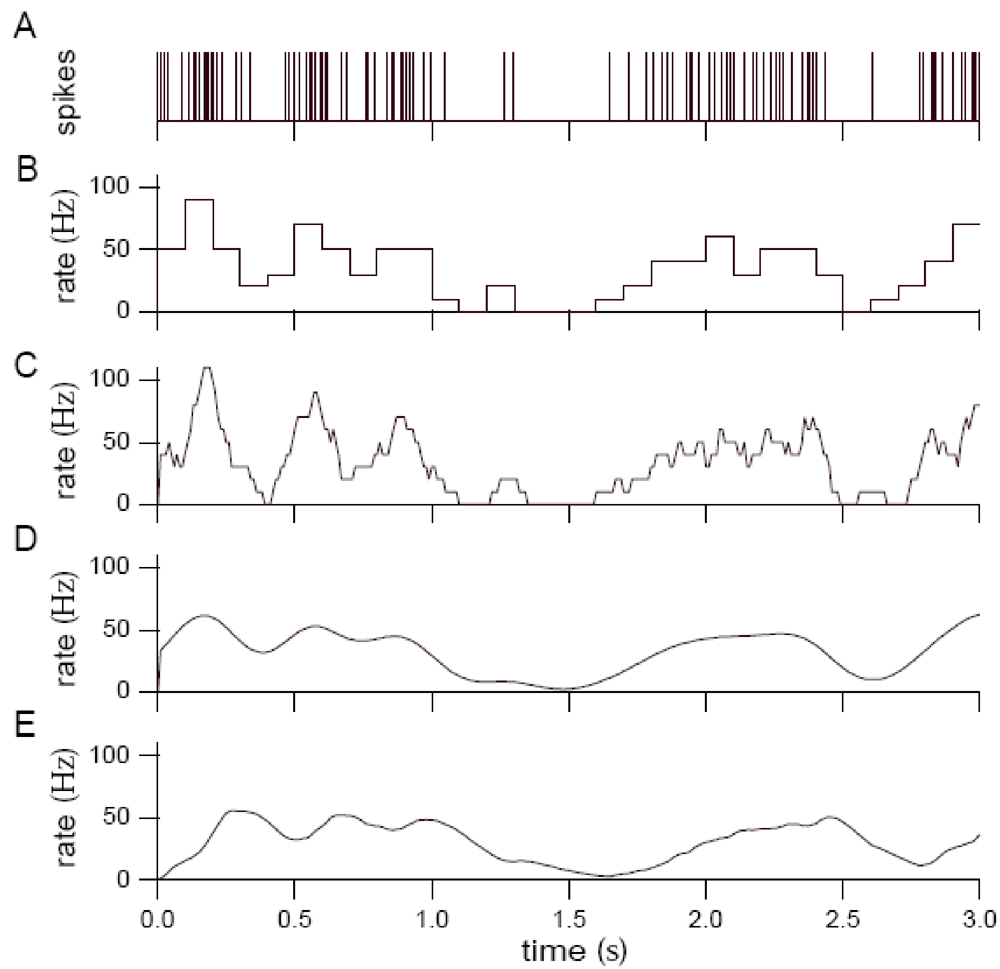
$$\sum_{i=1}^{n} h(t - t_i) = \int_0^T d\tau\, h(\tau)\rho(t - \tau)$$

$$\mathrm{r}(t)\Delta t = \int_t^{t+\Delta t} d\tau\, \langle \rho(\tau) \rangle$$

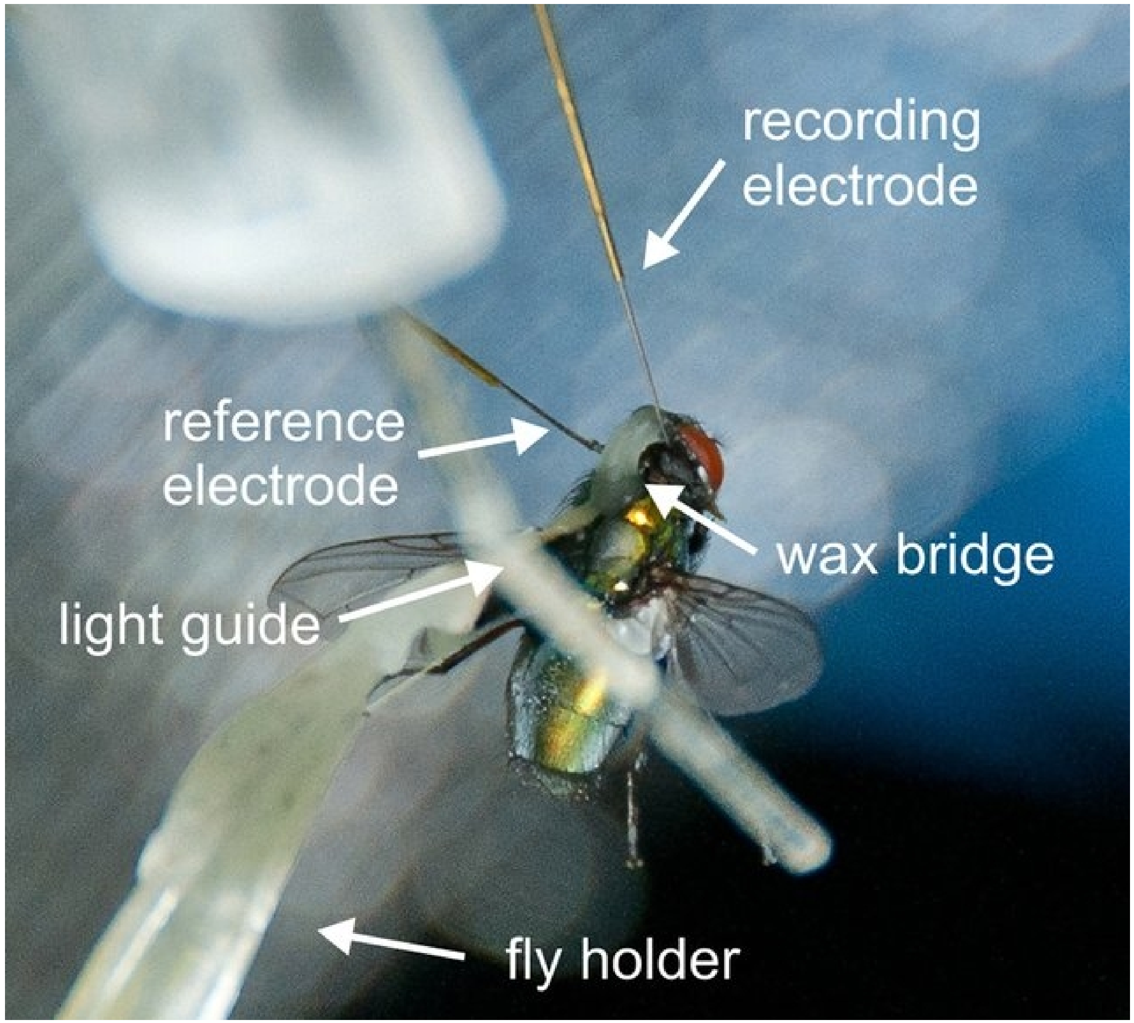
Rate–code in detail

- Spiking -> rate code
- Options
  - bin
  - sliding a window
  - filter kernel:
    - Gauss vs. alpha

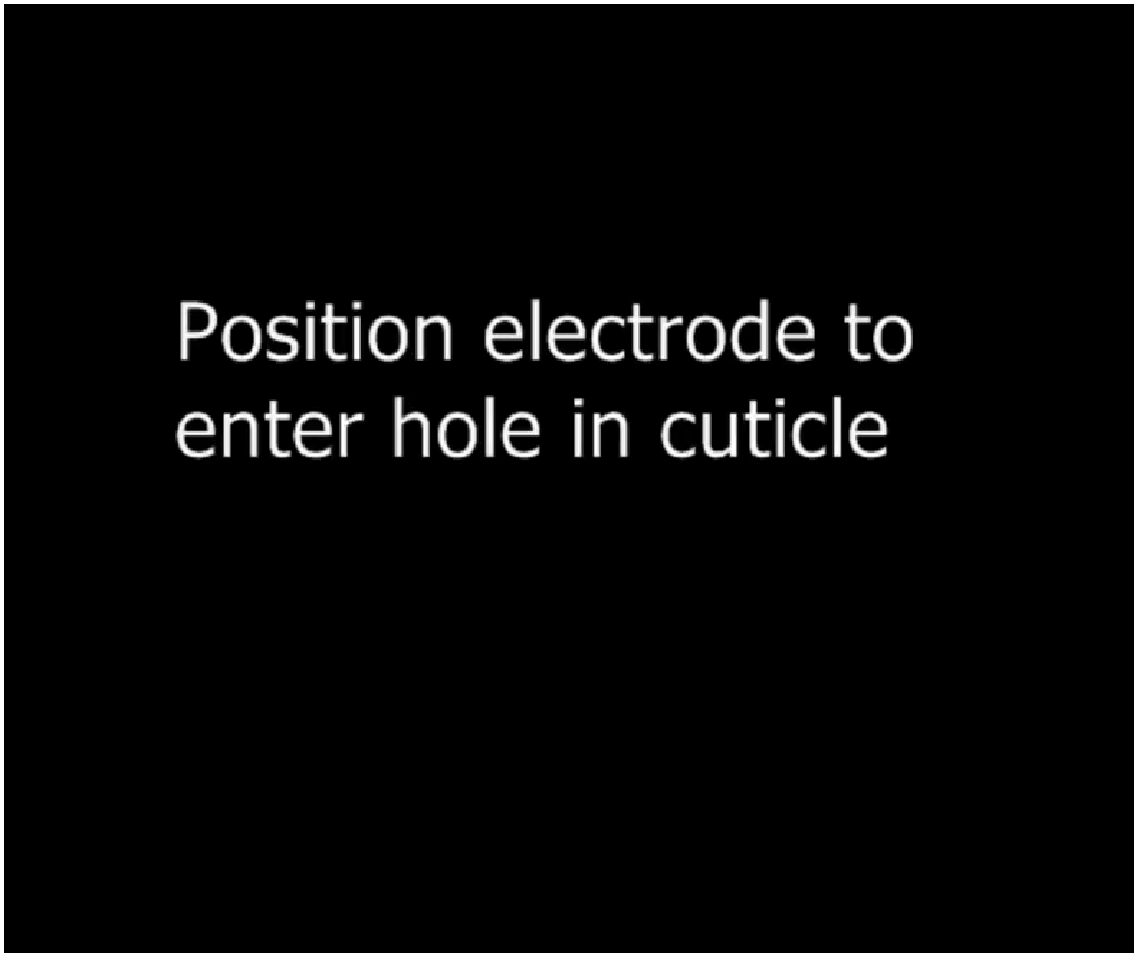
$$r_{\text{approx}}(t) = \int_{-\infty}^{\infty} d\tau\, w(\tau)\rho(t-\tau)\,.$$



Rate–code example: blowfly

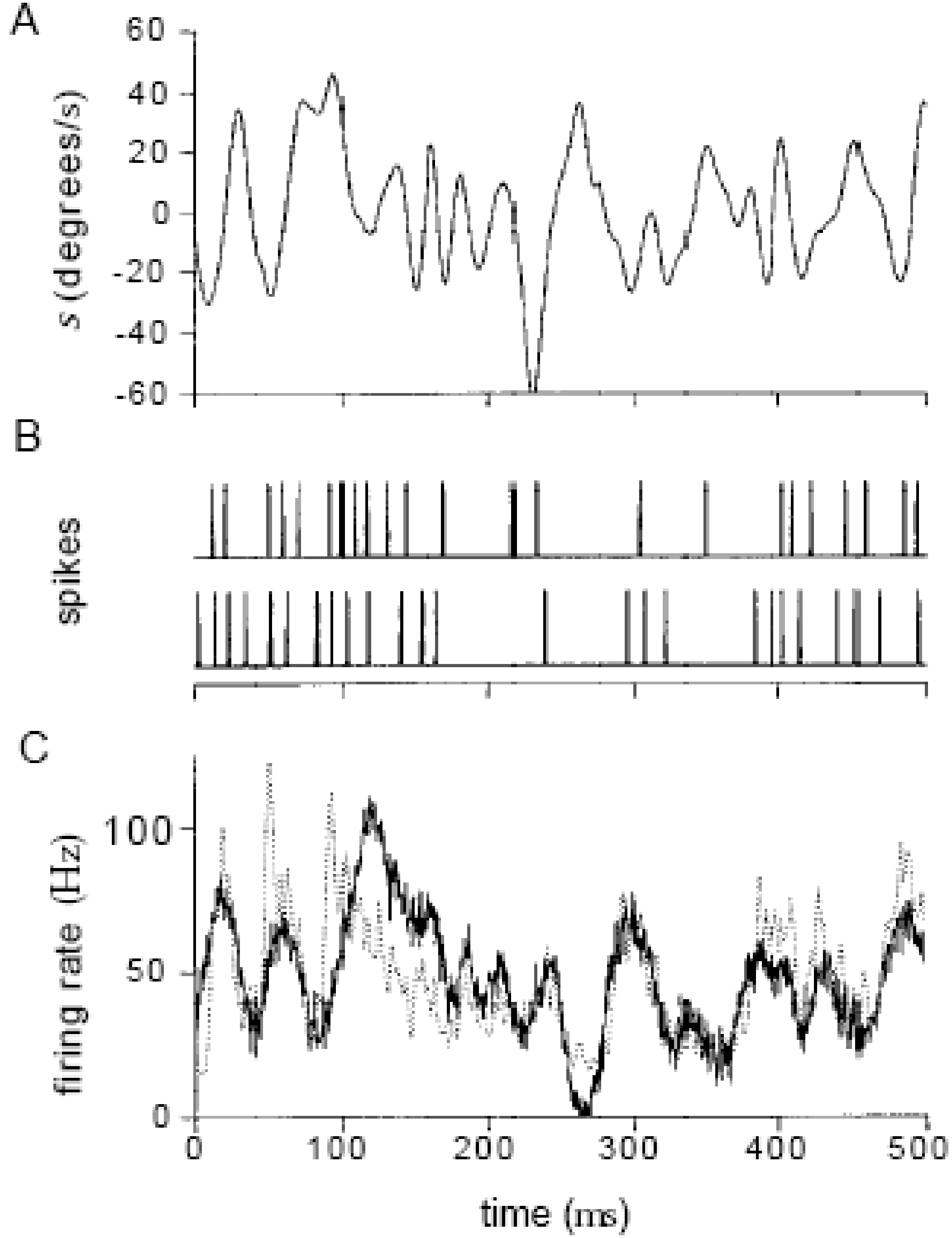


Rate–code example: blowfly



Rate–code example: blowfly

- H1 movement-sensitive visual neuron of a blowfly [Abbott, I/22]
- Artificial, continuously changing stimulus $s(t)$: changing „landscape“ [angular velocity]


A
60
40
20
0
-20
-40
-60
s (degrees/s)
B
spikes
C
100
50
0
firing rate (Hz)
0
100
200
300
400
500
time (ms)

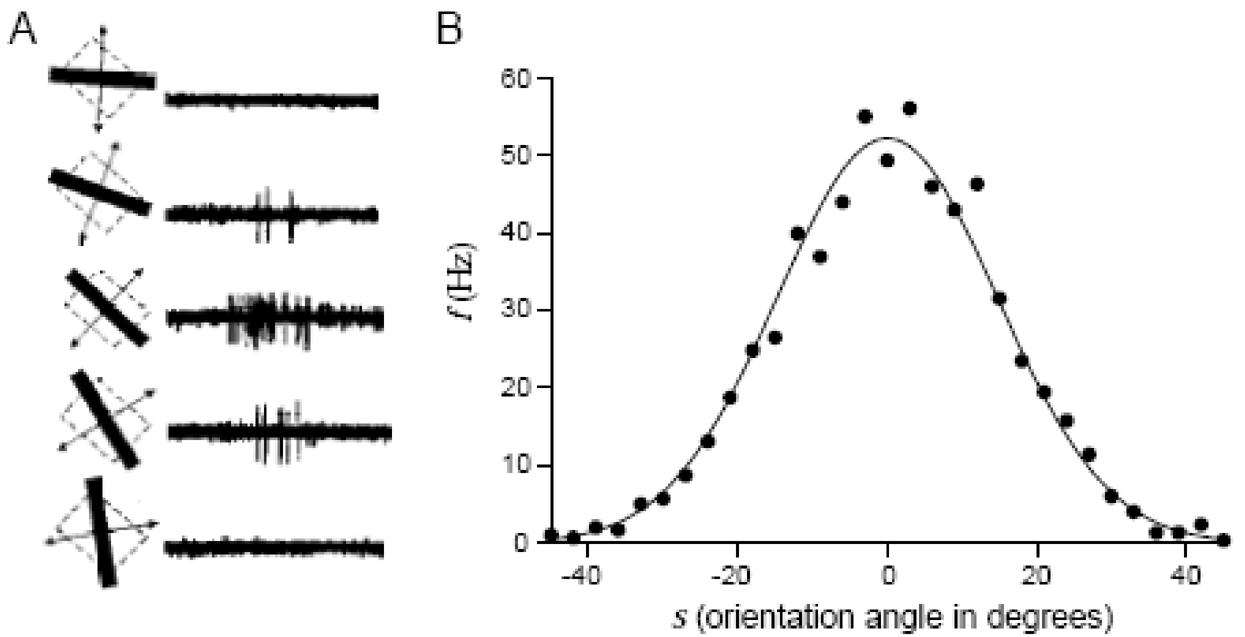
Rate–code example: blowfly

- H1 movement-sensitive visual neuron of a blowfly [Abbott, I/22]
- Artificial, continuously changing stimulus *s(t)*: changing „landscape" [angular velocity]
- Issues:
  - does H1 respond systematically on *s(t)*?
  - predicting a firing frequency of H1 based on *s(t)*
  - predicting s(t) based on a firing pattern of H1
  - now the same, but with two neurons responding to opposing angular velocities

Tuning Curve
and
Receptive Field

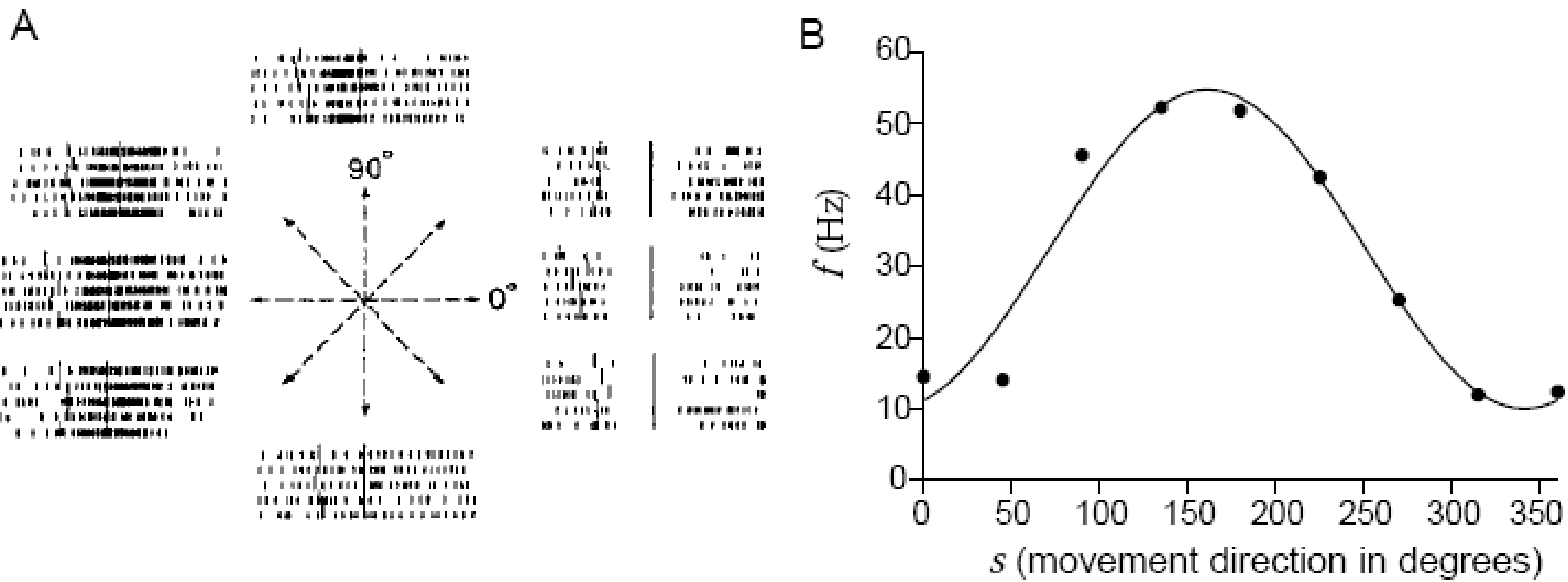
Tunning curves

- Descriptive models of neuronal responses on a particular set of stimuli
- V1, monkey: angular orientation of a moving bart in the neuron's receptive field
  - Gauss

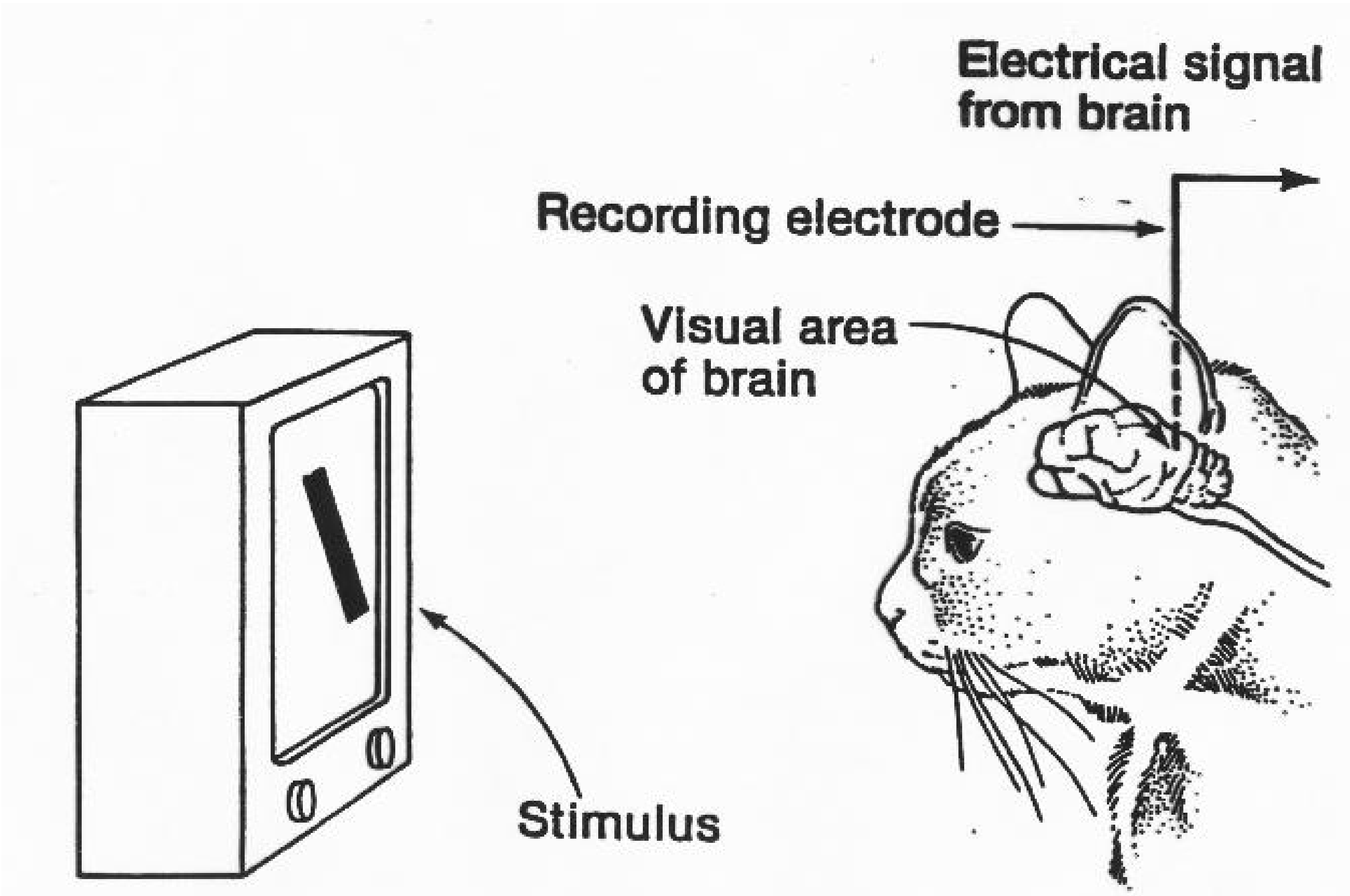


Tunning curves: motor cortex

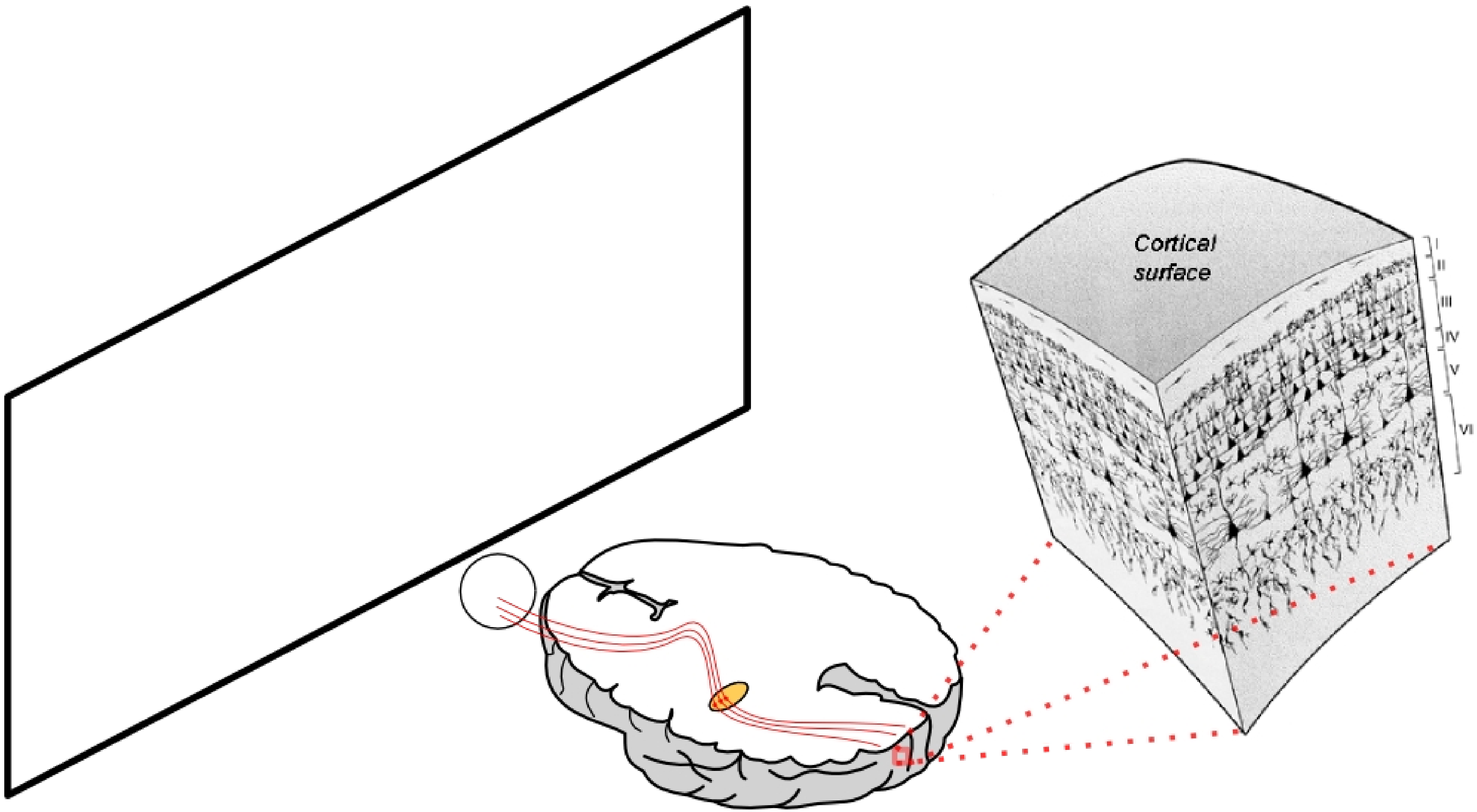
- Primary motor cortex of a monkey: arm-reaching task
  - sin, cos, $[\ .\ ]_+$ $$f(s) = [r_0 + (r_{\max} - r_0)\cos(s - s_{\max})]_+ .$$



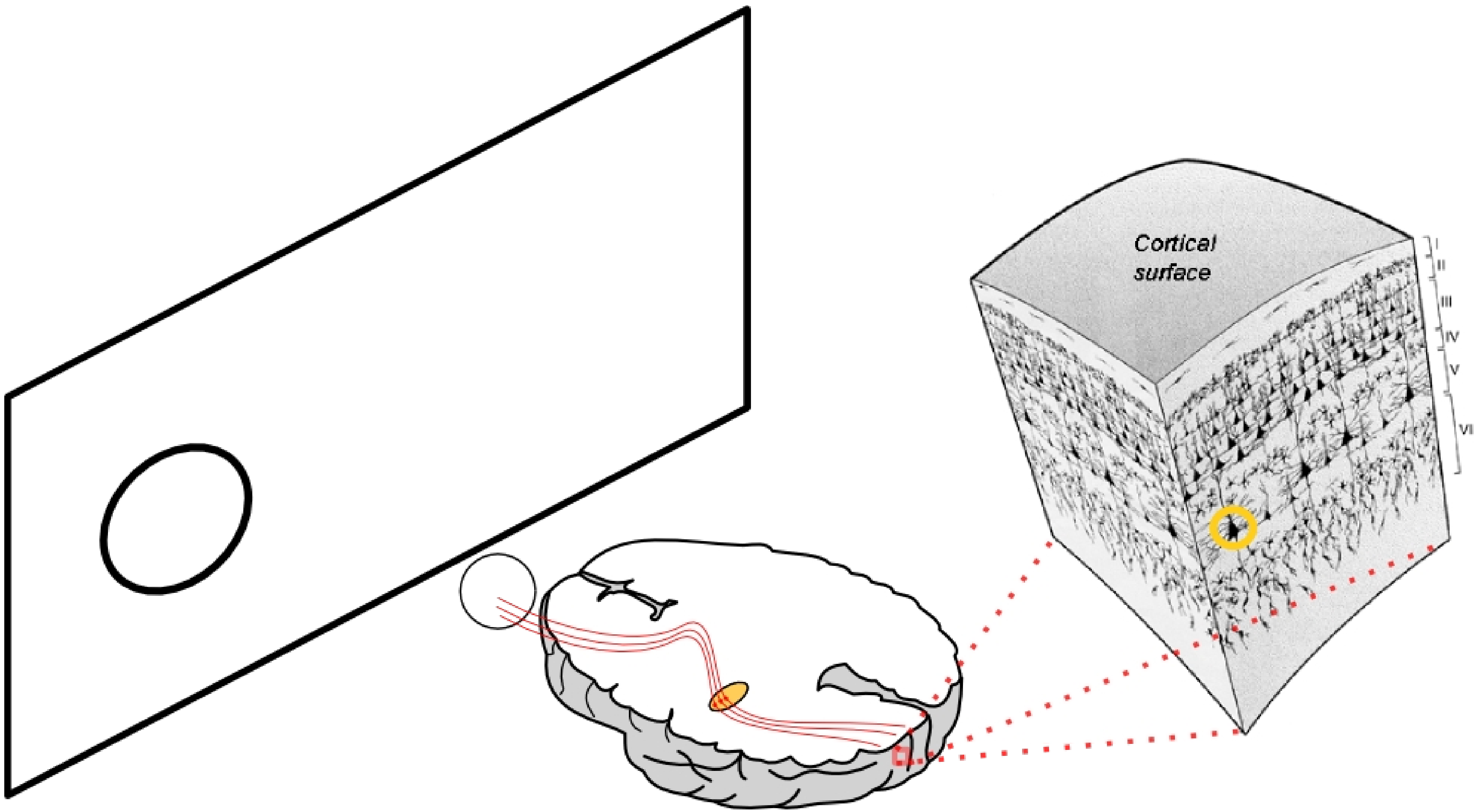
Receptive Field Concept



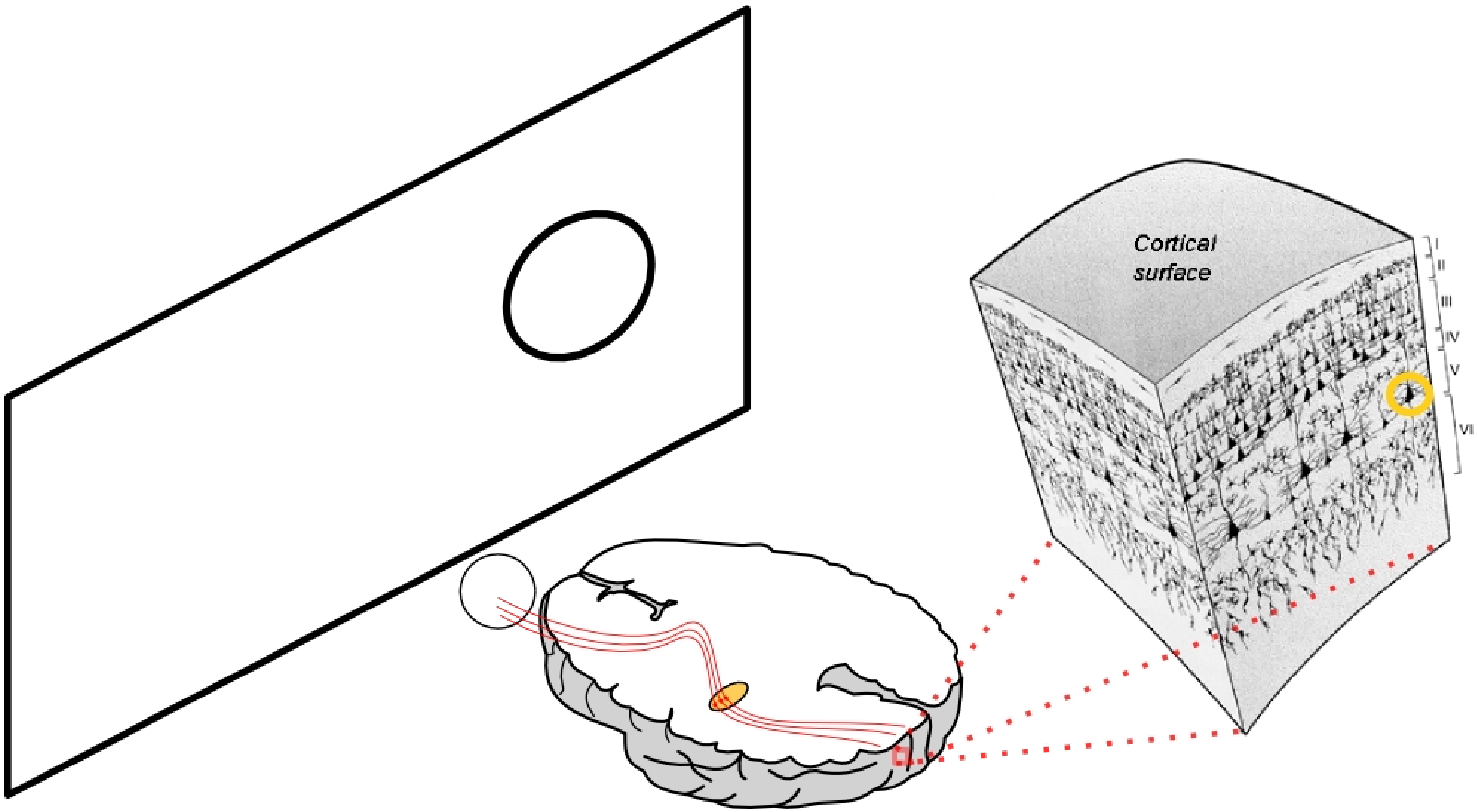
The Receptive Field concept



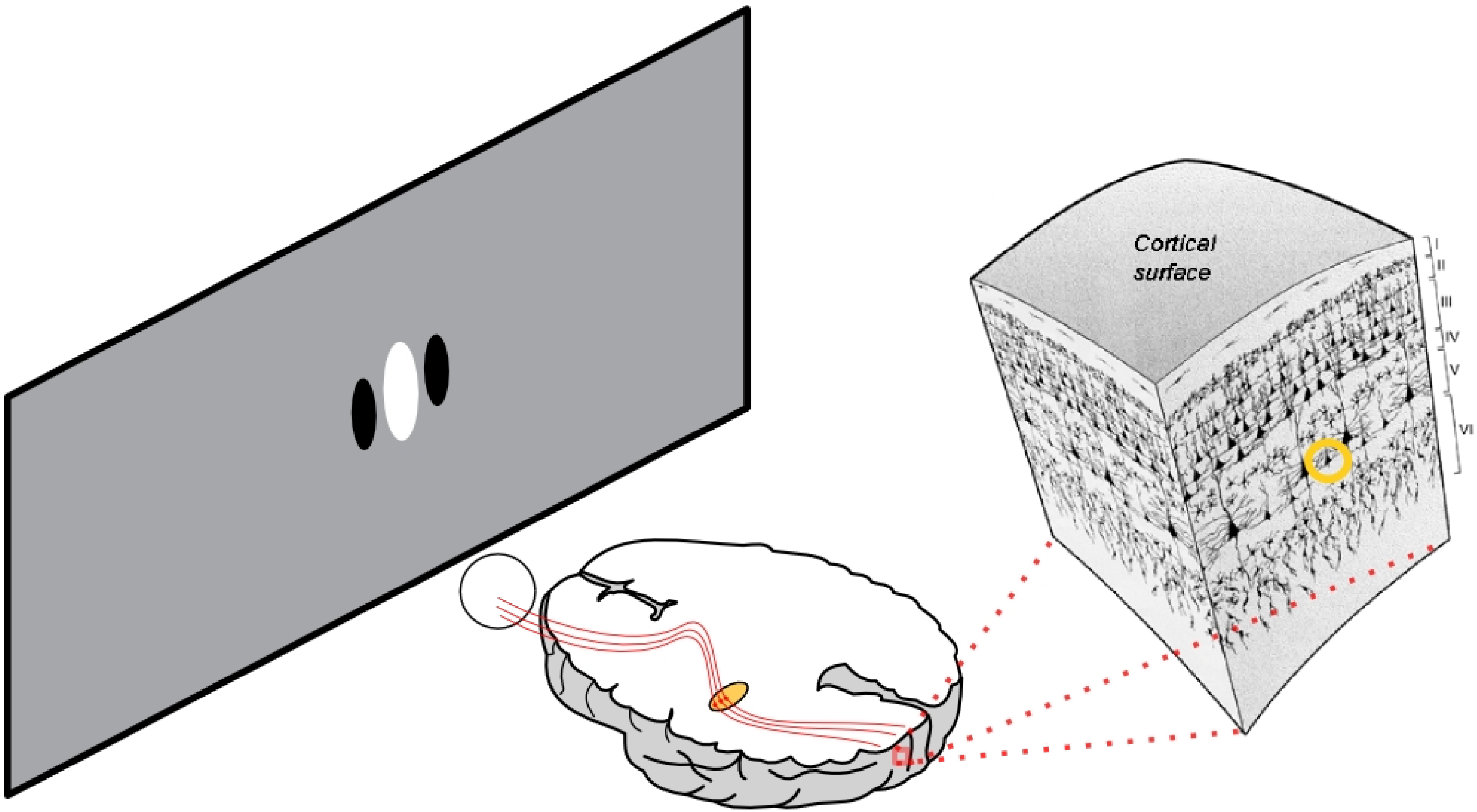
The Receptive Field concept



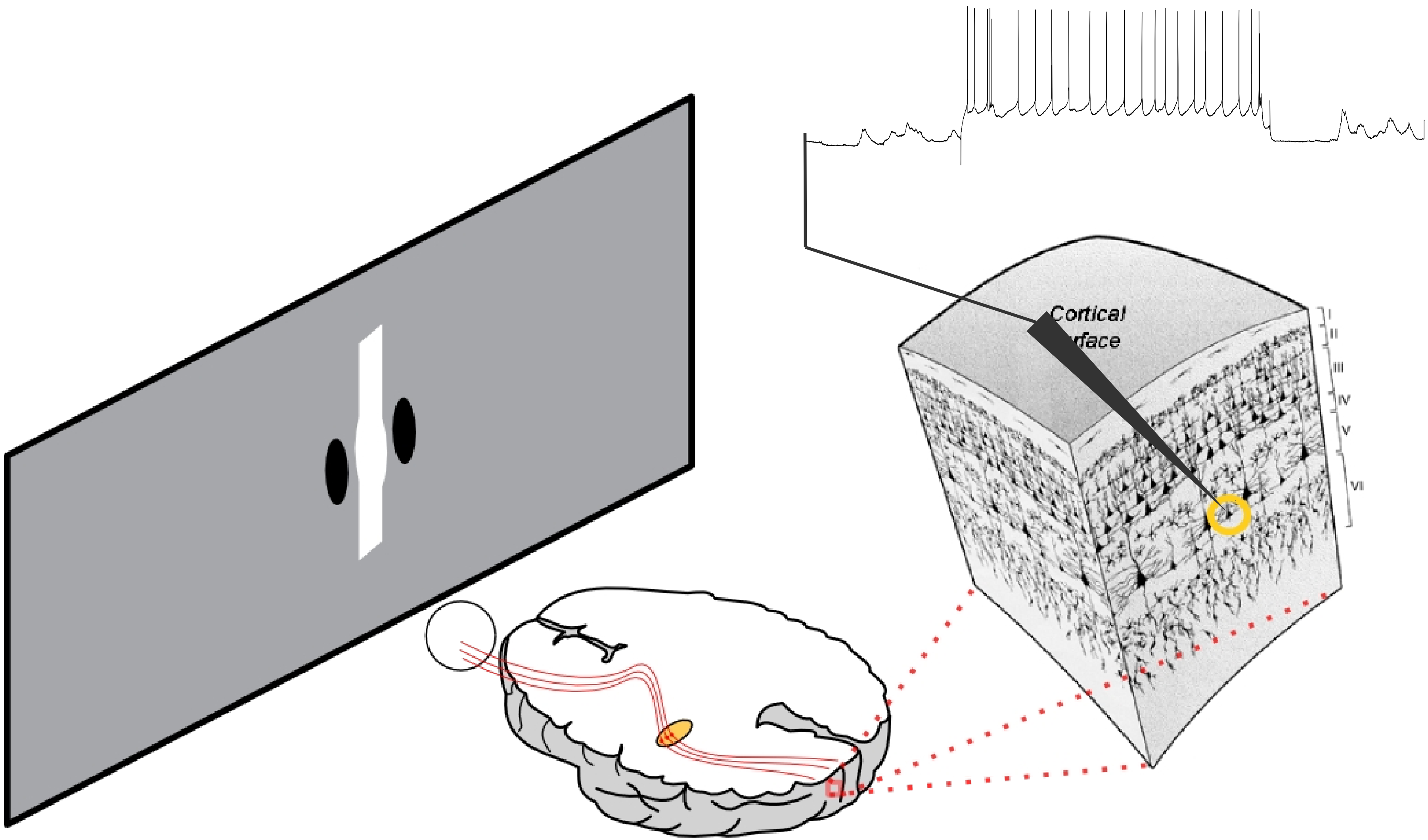
The Receptive Field concept



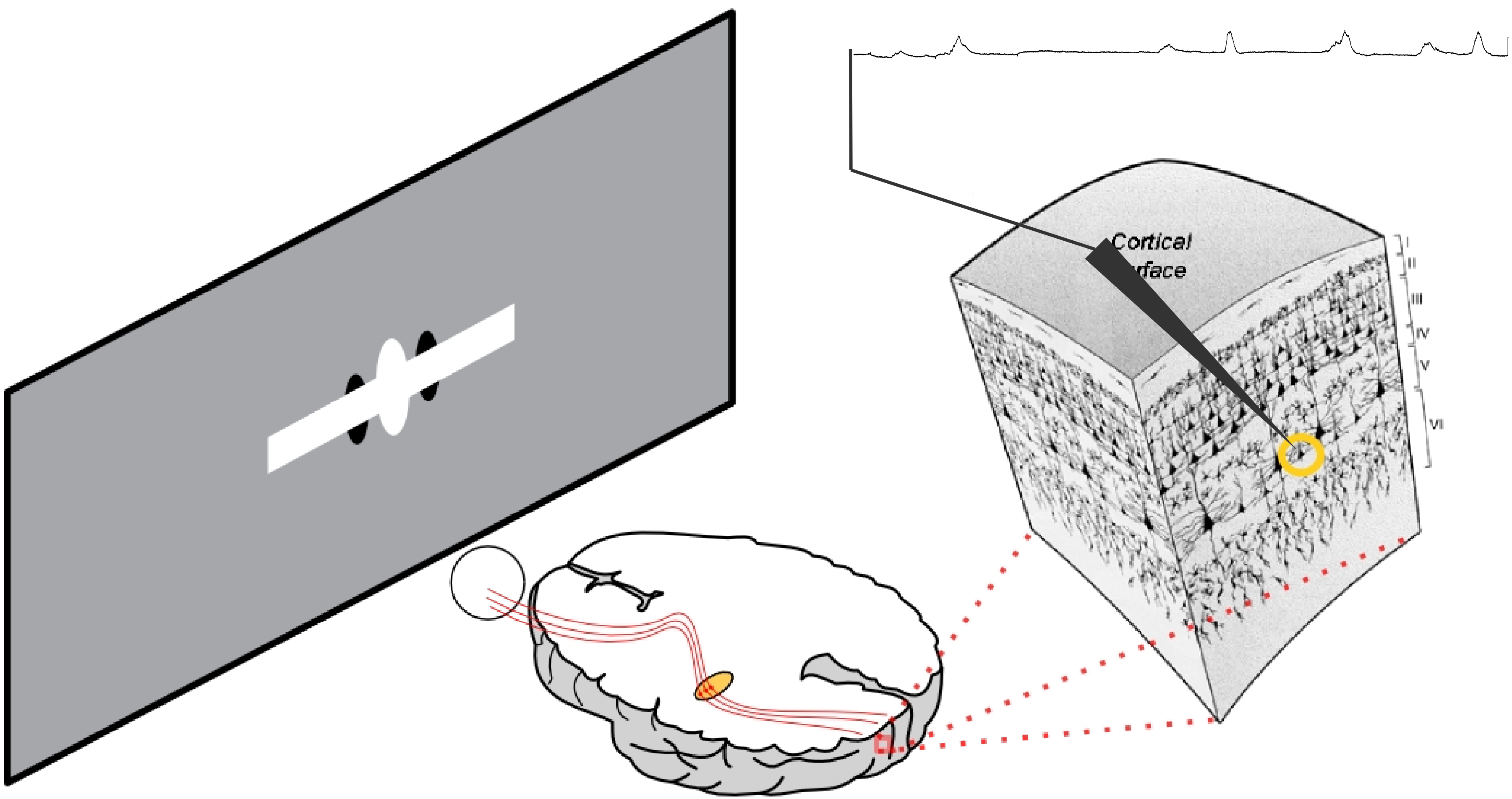
The Receptive Field concept



The Receptive Field concept

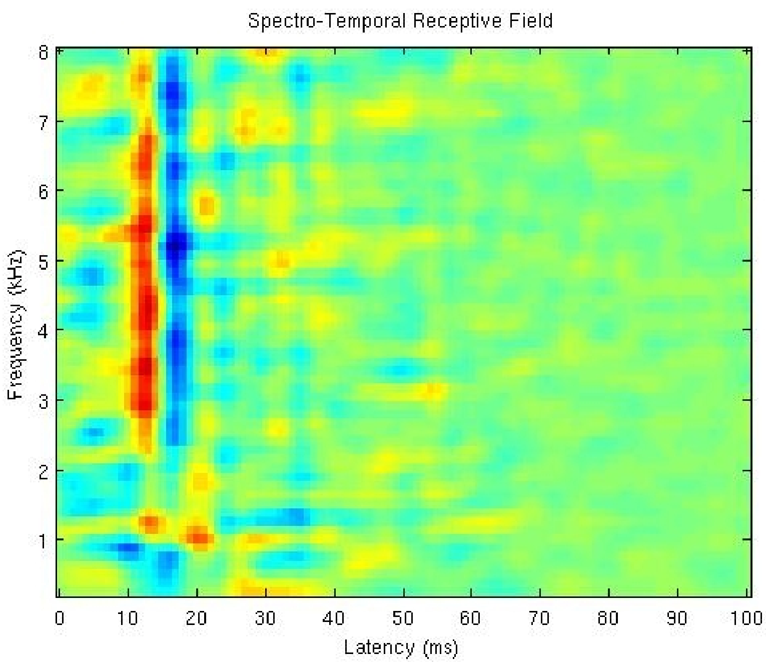


The Receptive Field concept

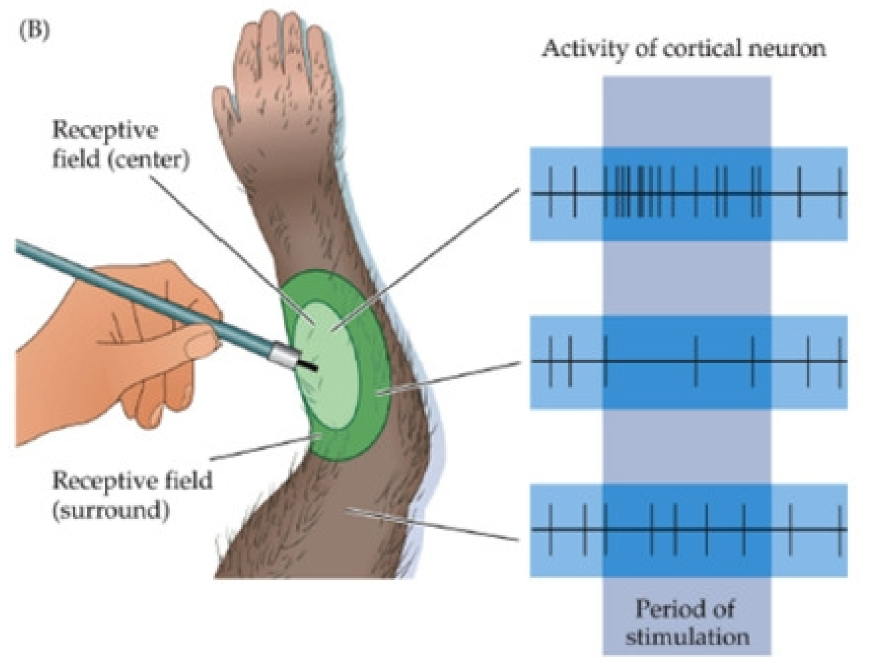


Receptive fields in other modalities

auditory receptive field

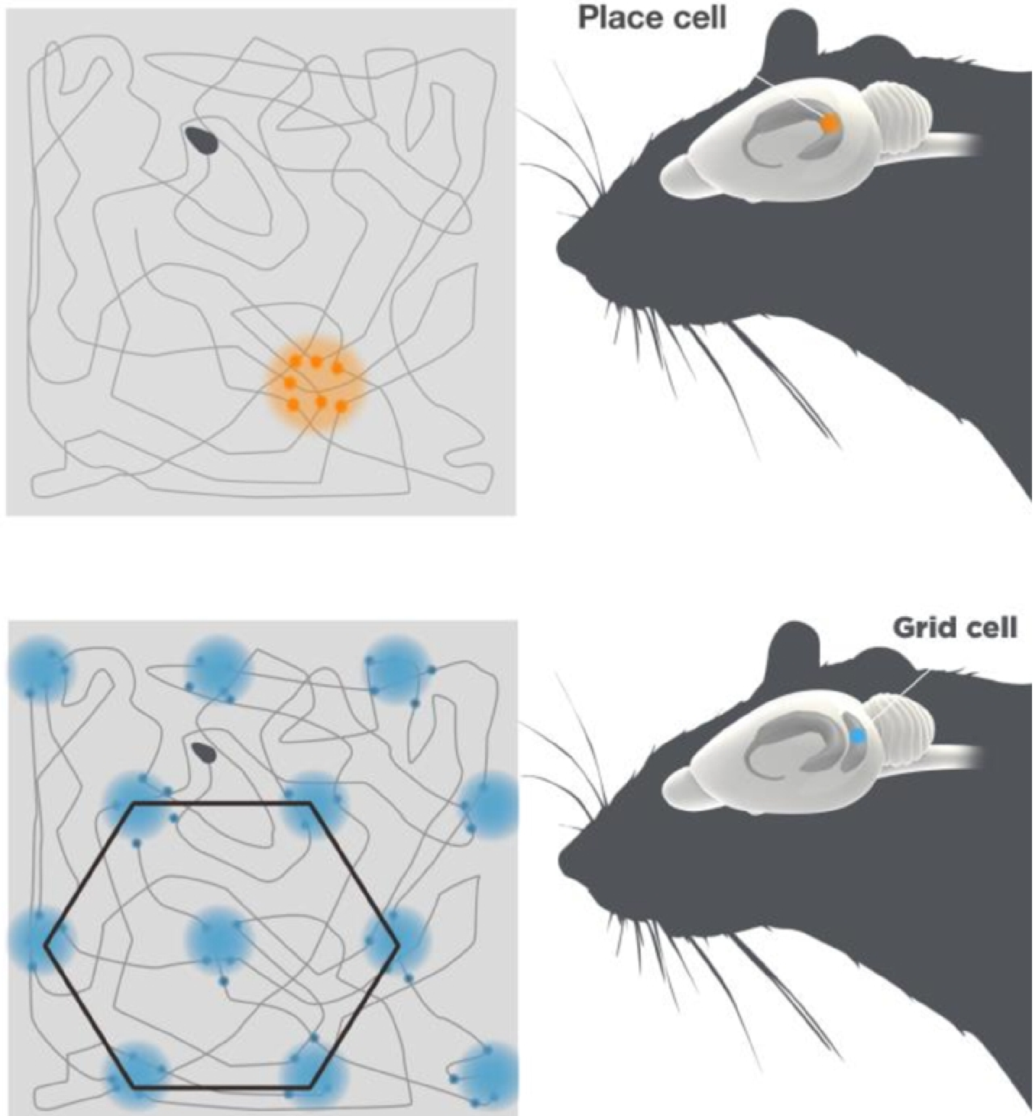


somato-sensory receptive field

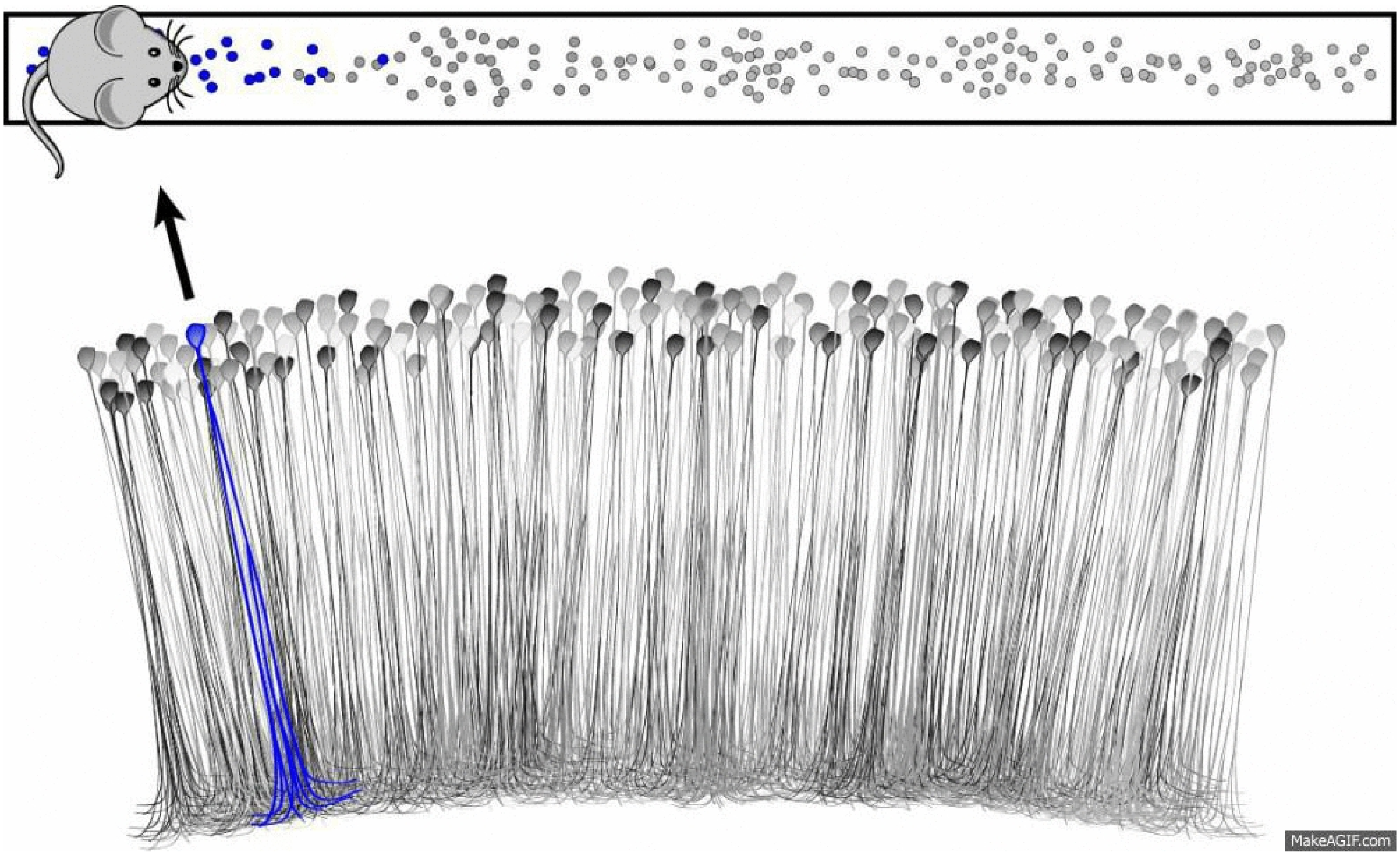


NEUROSCIENCE, Fourth Edition, Figure 1.13 (Part 2)

Place/grid cells

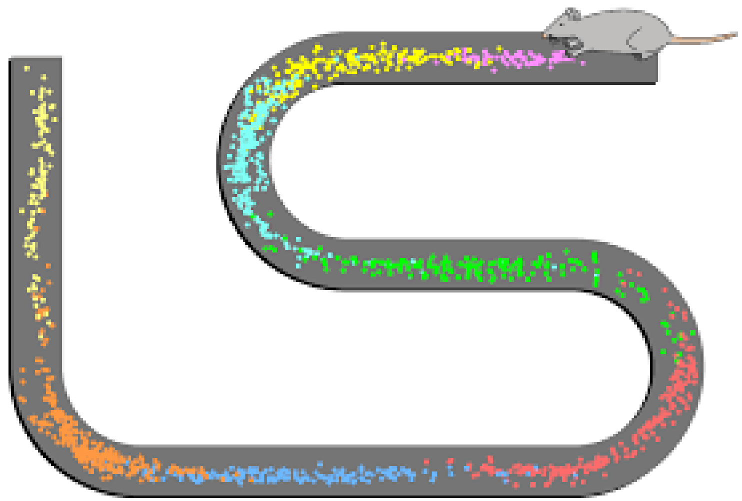


Place cells

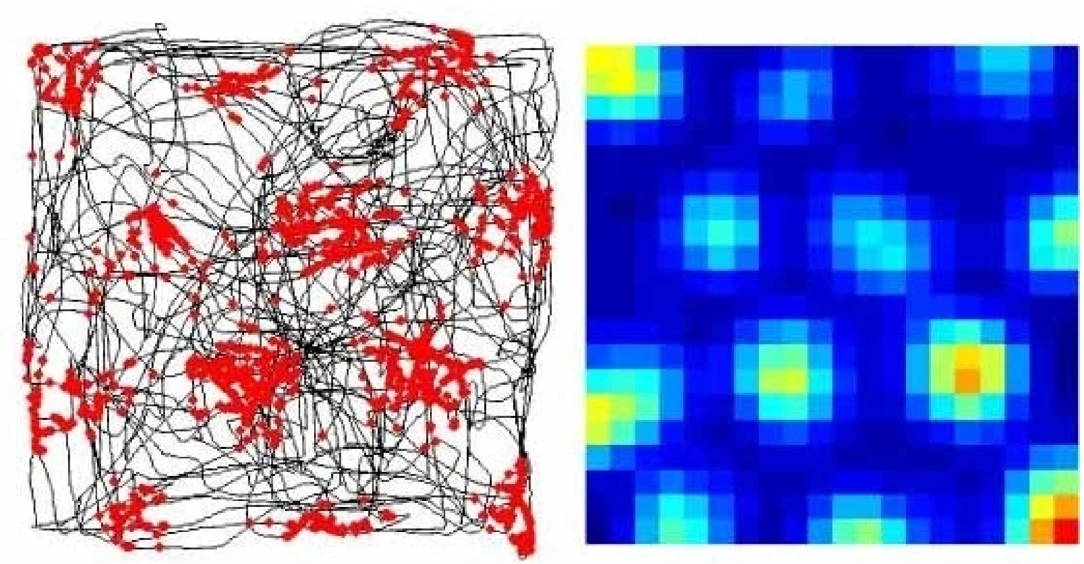


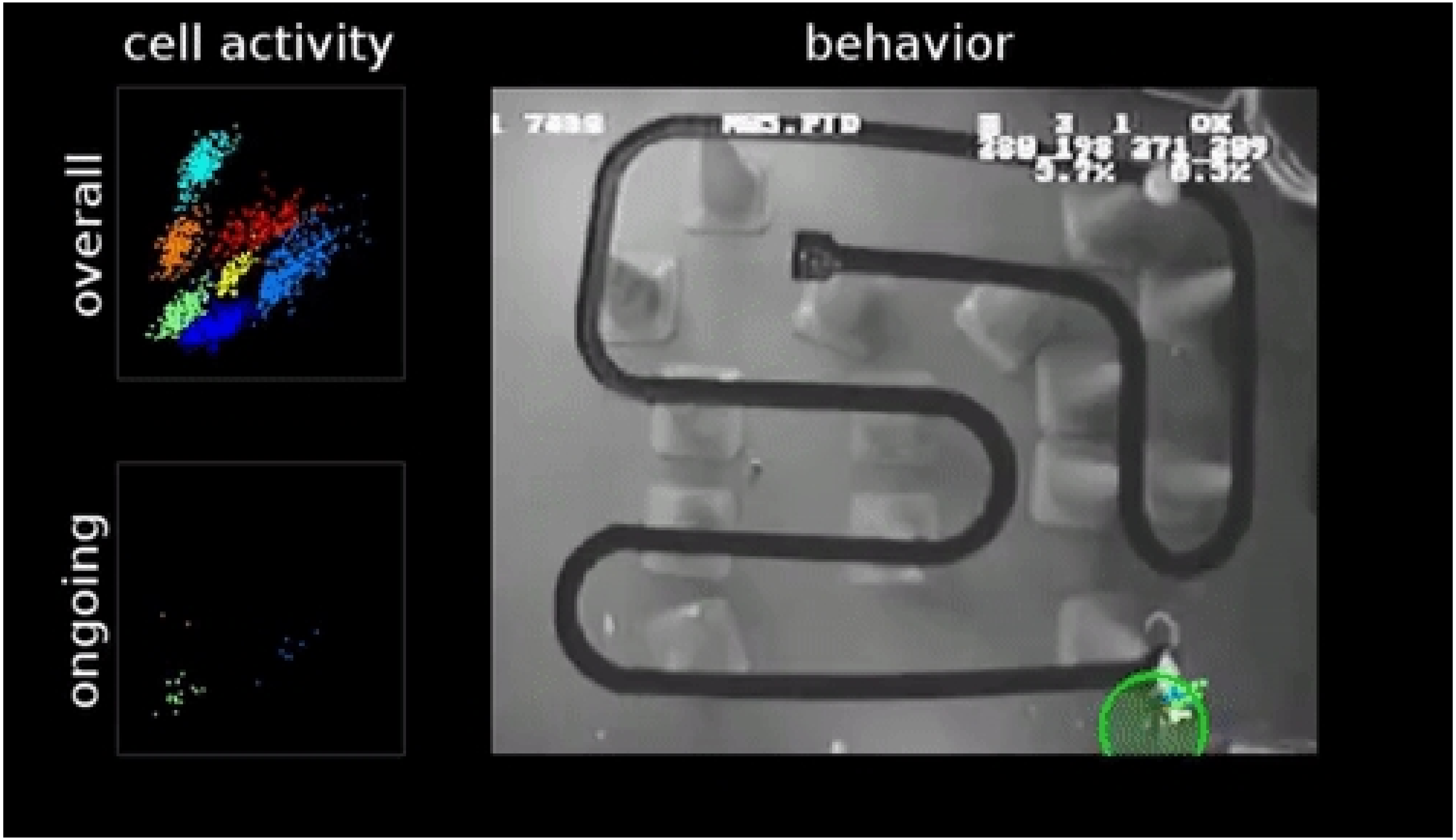
Place/grid cells

Place cell



Grid cell



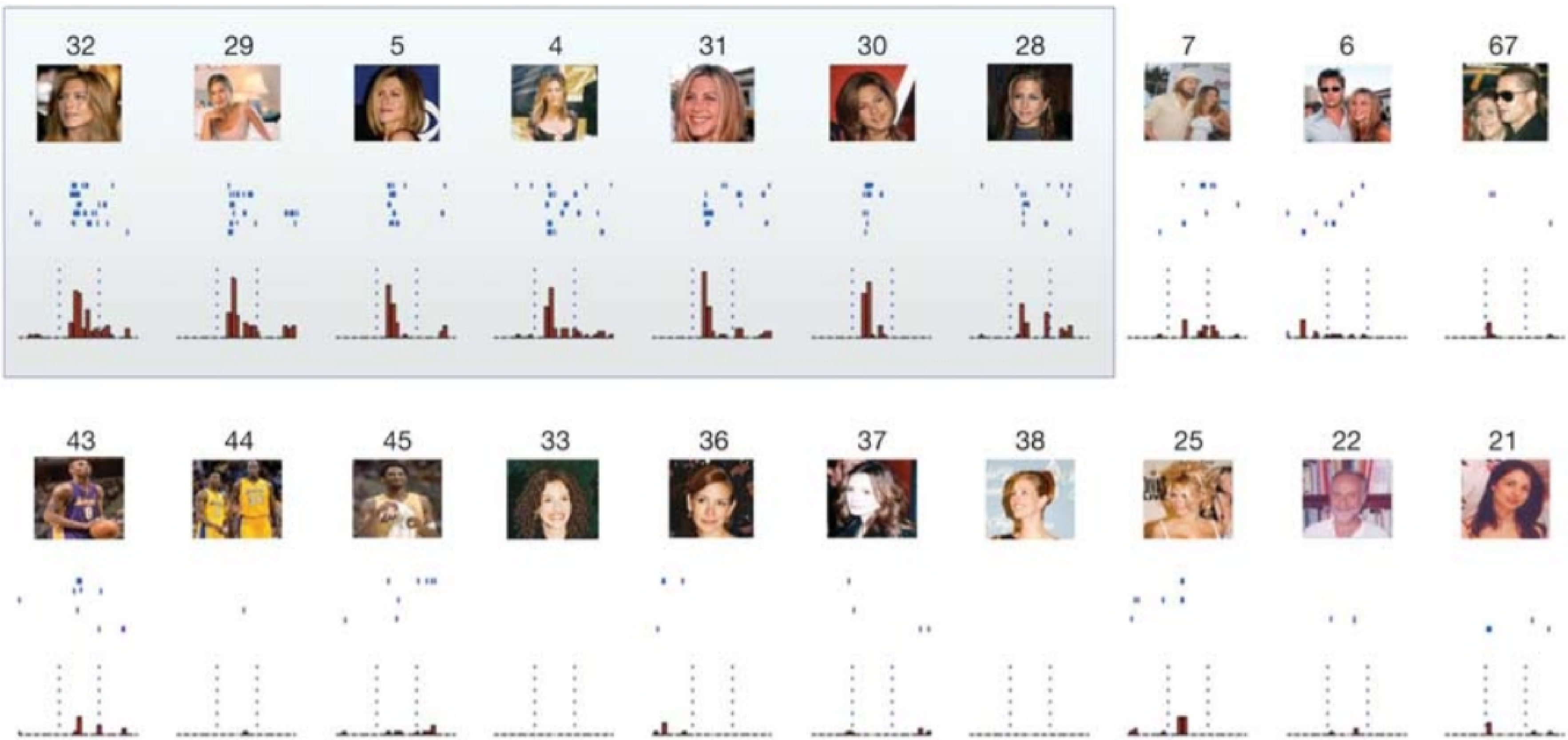

cell activity
behavior
overall
ongoing

POPULATION CODE

Population coding

- Let us have feature F: how is it coded by a neural vector R?
- Local representation: $<0, 0, .., 0, r_i, 0, .. 0>$
  - “grandma” neuron, cardinal cells, ...
-

Jennifer Aniston Neuron



Population coding

- Let us have feature F: how is it coded by a neural vector R?
- Local representation: $<0, 0, .., 0, r_i, 0, .. 0>$
  - "grandma" neuron, cardinal cells, ...
- Fully distributed: $<r_1, r_2, .. r_n>$
- Sparsely distributed: $<0, 0, r_i, 0, 0, 0, r_j, 0, .. 0, r_k, 0, .. 0>$

Decoding: population code

- Reasons
  - robustnest
    - cellular death
    - noise
  - precission
- Decoding

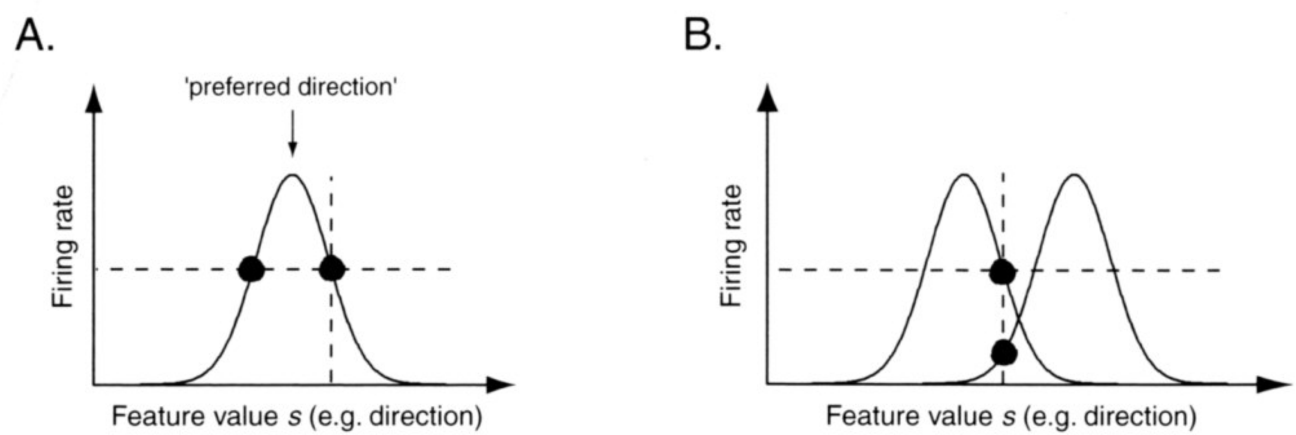
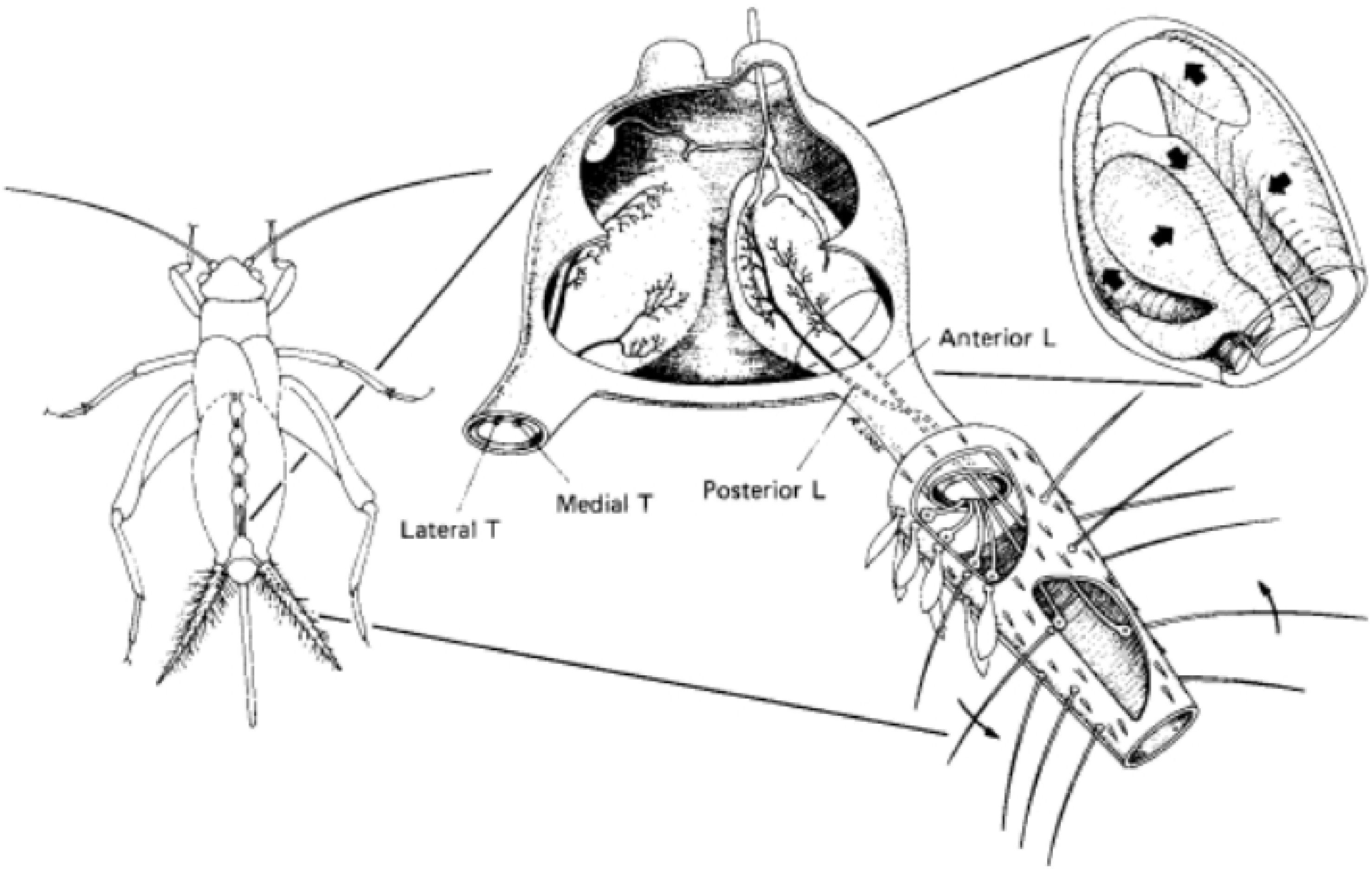
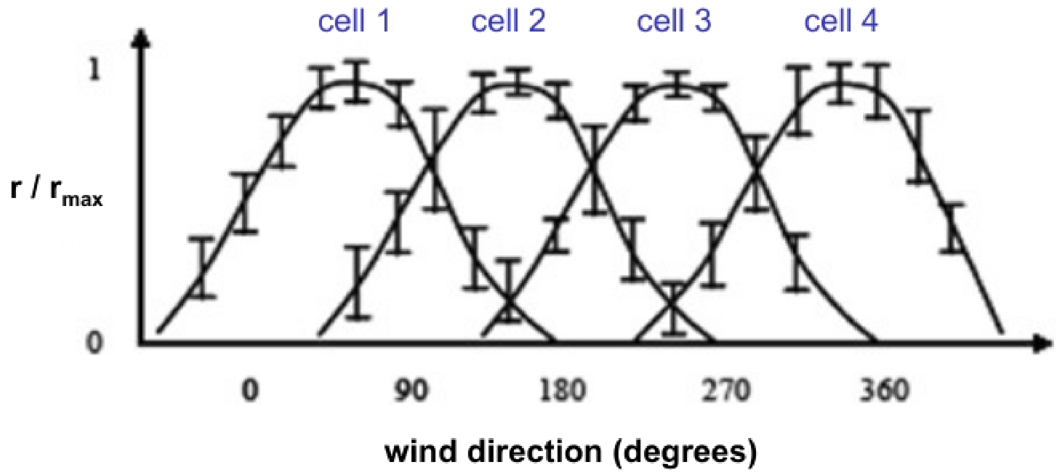


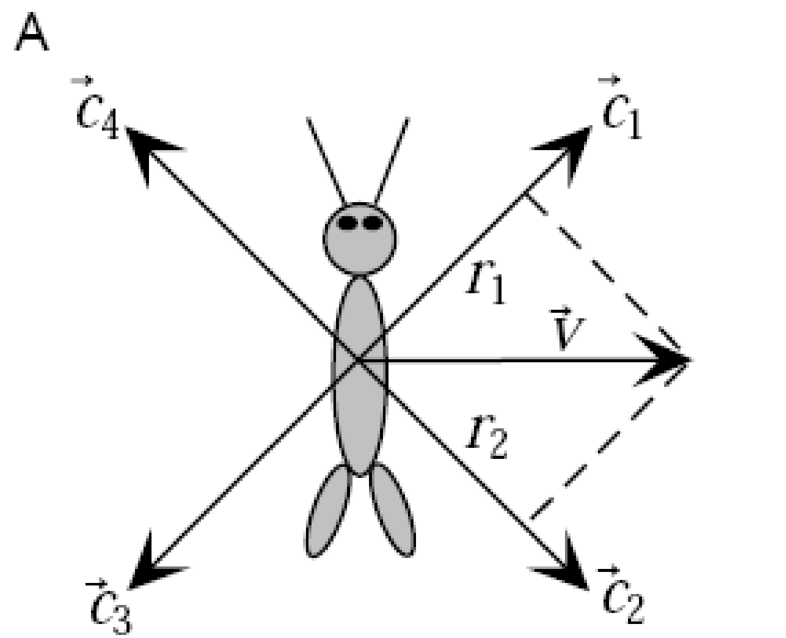
Fig. 5.13 Gaussian tuning curves representing the firing rate of a neuron as a function of a stimulus feature. (A) A single neuron cannot unambiguously decode the stimulus feature from the firing rate. (B) A second neuron with shifted tuning curve can resolve the ambiguity.

Population coding: CRICKET



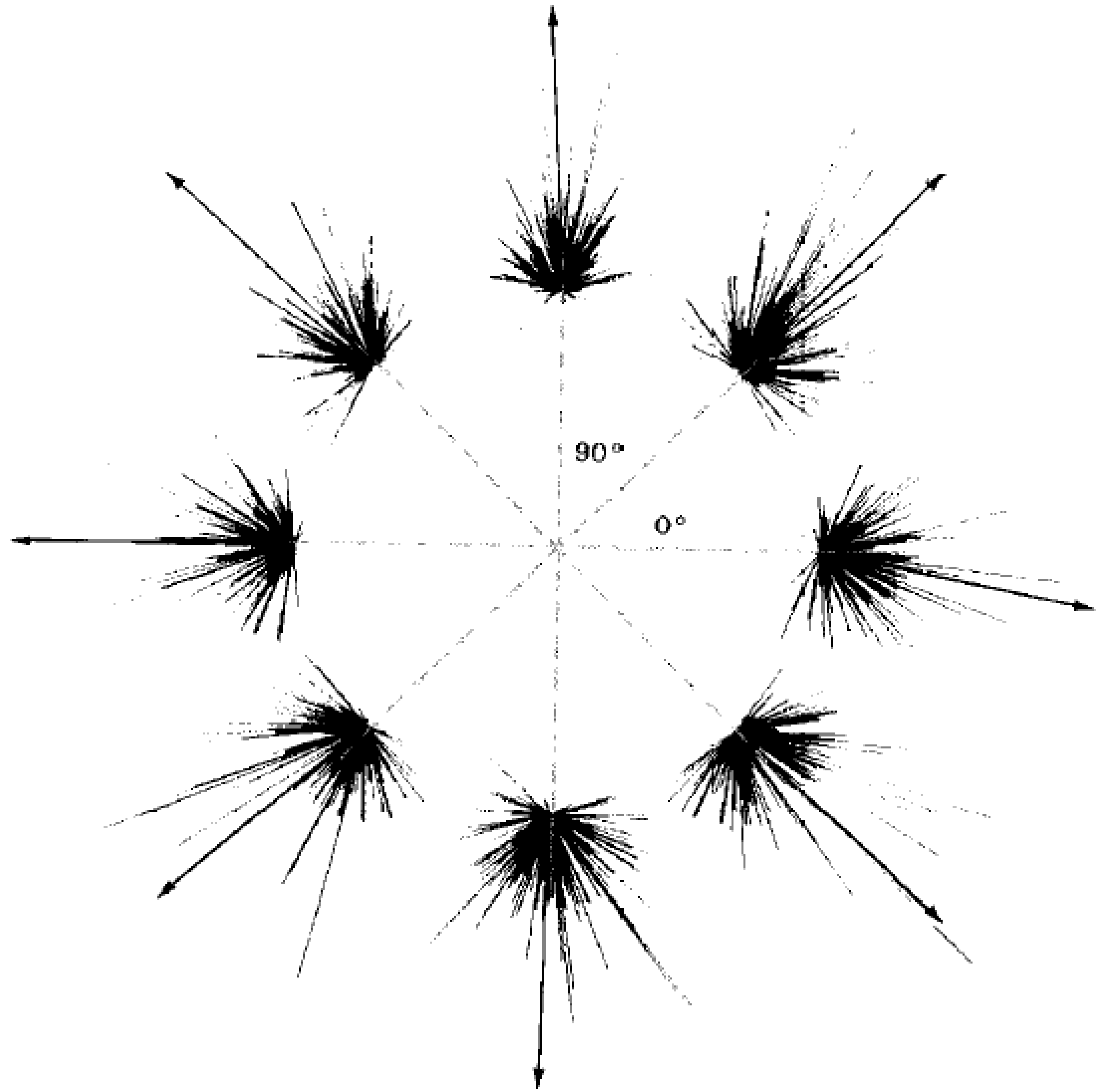
Population coding: CRICKET





Population coding: monkey motor cortex

- Hand direction



Population coding – cortical functional organization

- One neuron often codes multiple features
- More neurons code more "dense" space
  - e.g., why do we recognize more easily human faces vs. dog faces
  - Kohonen network metaphor

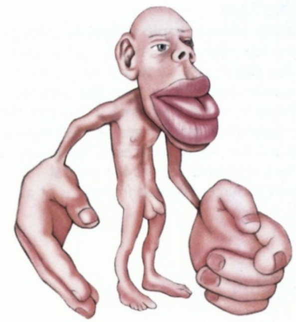


FIGURE 12.19
The homunculus.

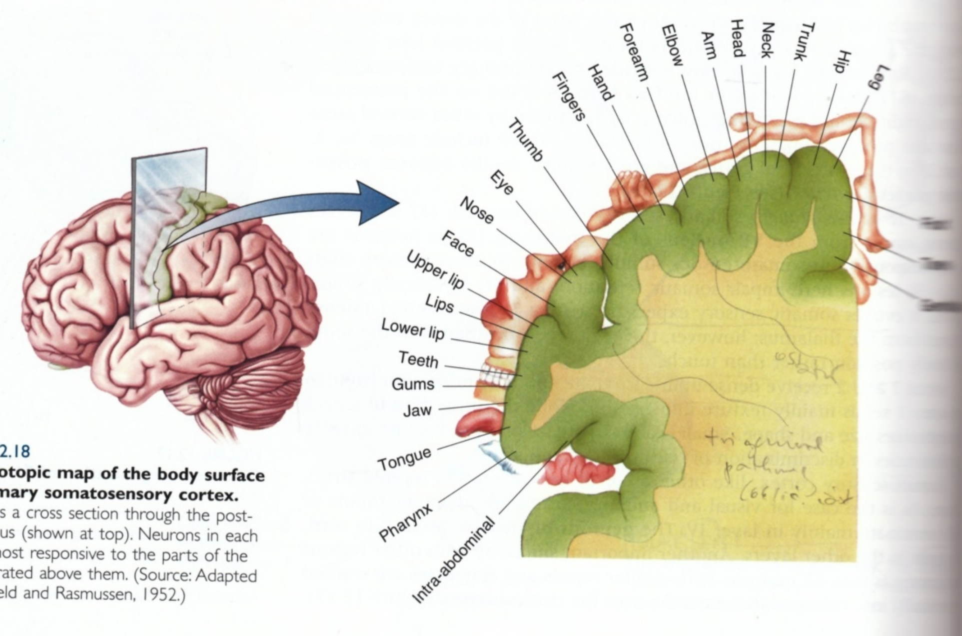
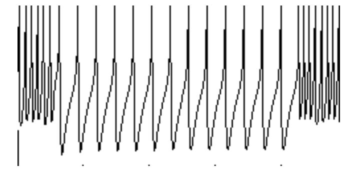


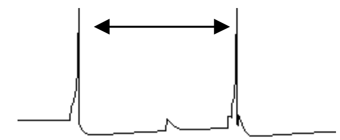
FIGURE 12.18
A somatotopic map of the body surface onto primary somatosensory cortex. This map is a cross section through the post-central gyrus (shown at top). Neurons in each area are most responsive to the parts of the body illustrated above them. (Source: Adapted from Penfield and Rasmussen, 1952.)

TEMPORAL CODING

Information coding



- Firing frequency?
- Temporal distance between spikes – cf. resonators
- Synchronization?
- The beginning of a spike pattern?
- …



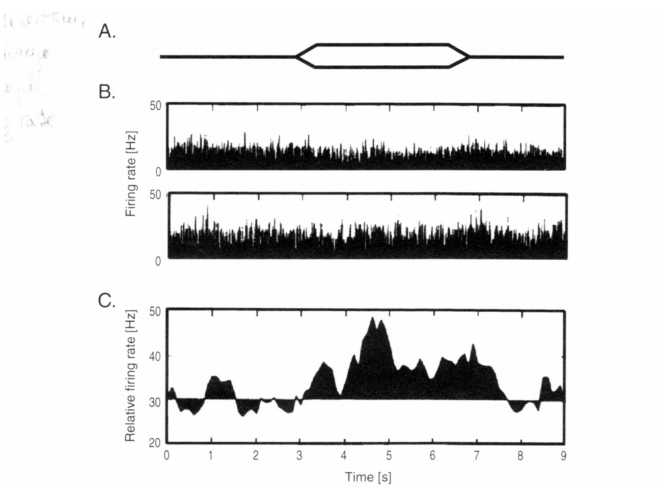


Fig. 5.3 An example of the response of some neurons in the primary auditory cortex that do not show significant variations in response to the onset of a 4 kHz tone with the amplitude envelope shown in (A). (B) Average firing rates in 5 ms bins of two different neurons. (C) Spike-triggered average rate that indicates some correlation between the firing of the two neurons that is significantly correlated to the presentation of the stimulus [from DeCharms and Merzenich, *Science* 381: 610–13 (1996)].

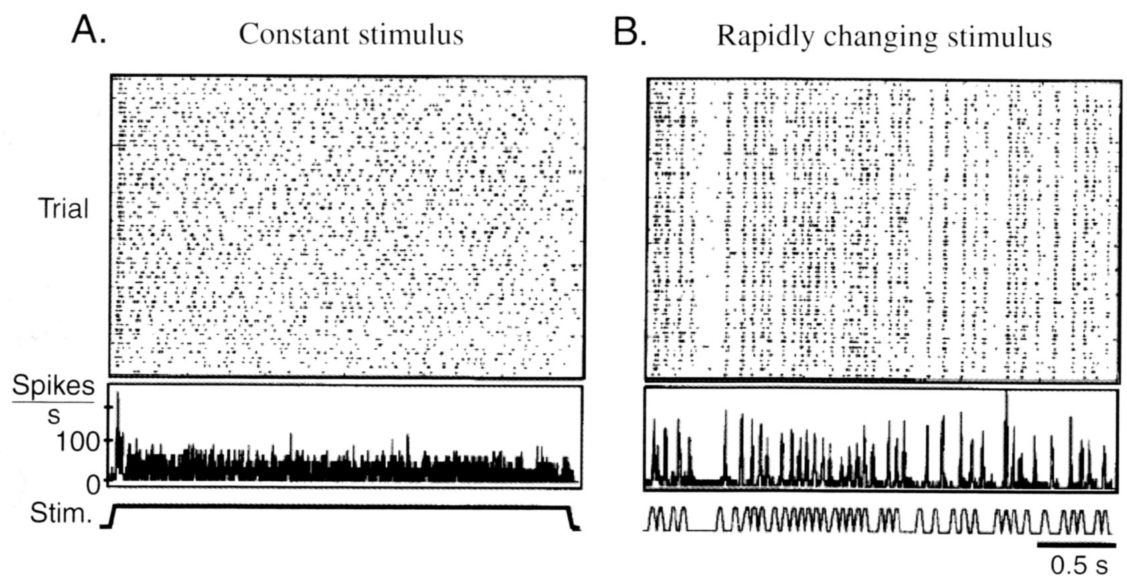
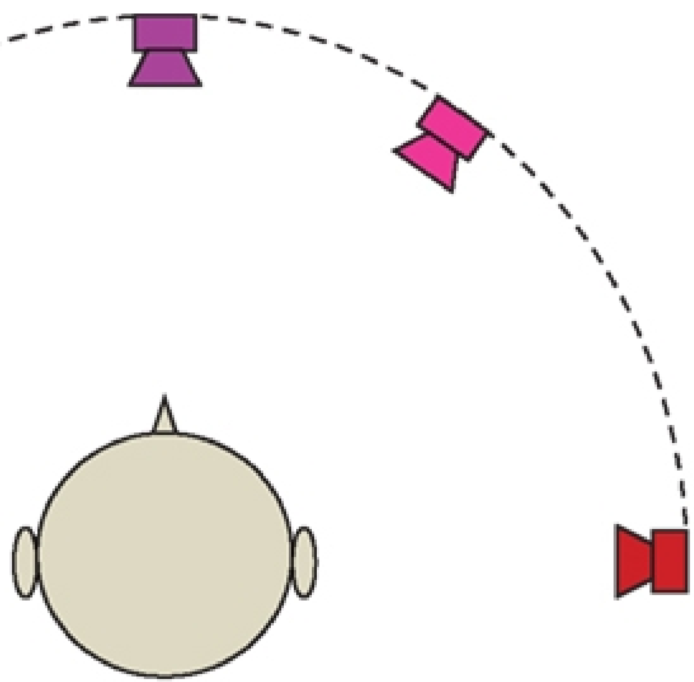
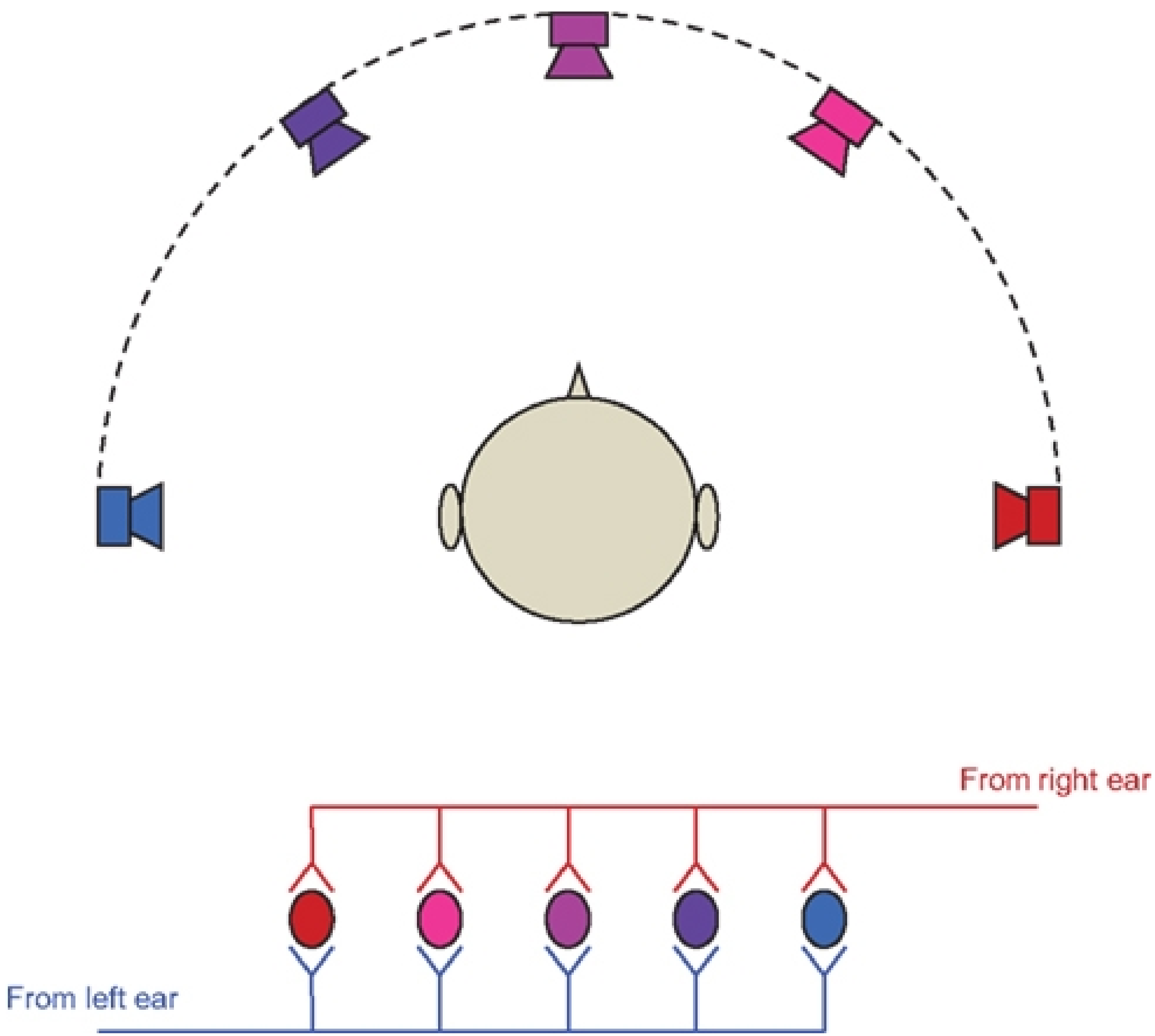


Fig. 5.5 Spike trains (top) and average response over trials (middle) of an MT neuron to a visual stimulus with either constant velocity (A) or altering velocity (B) as indicated in the bottom graph [adapted from Buračas *et al.*, *Neuron* 20: 959–69 (1998)].

Sound localization



Sound localization



Sound localization (birds)