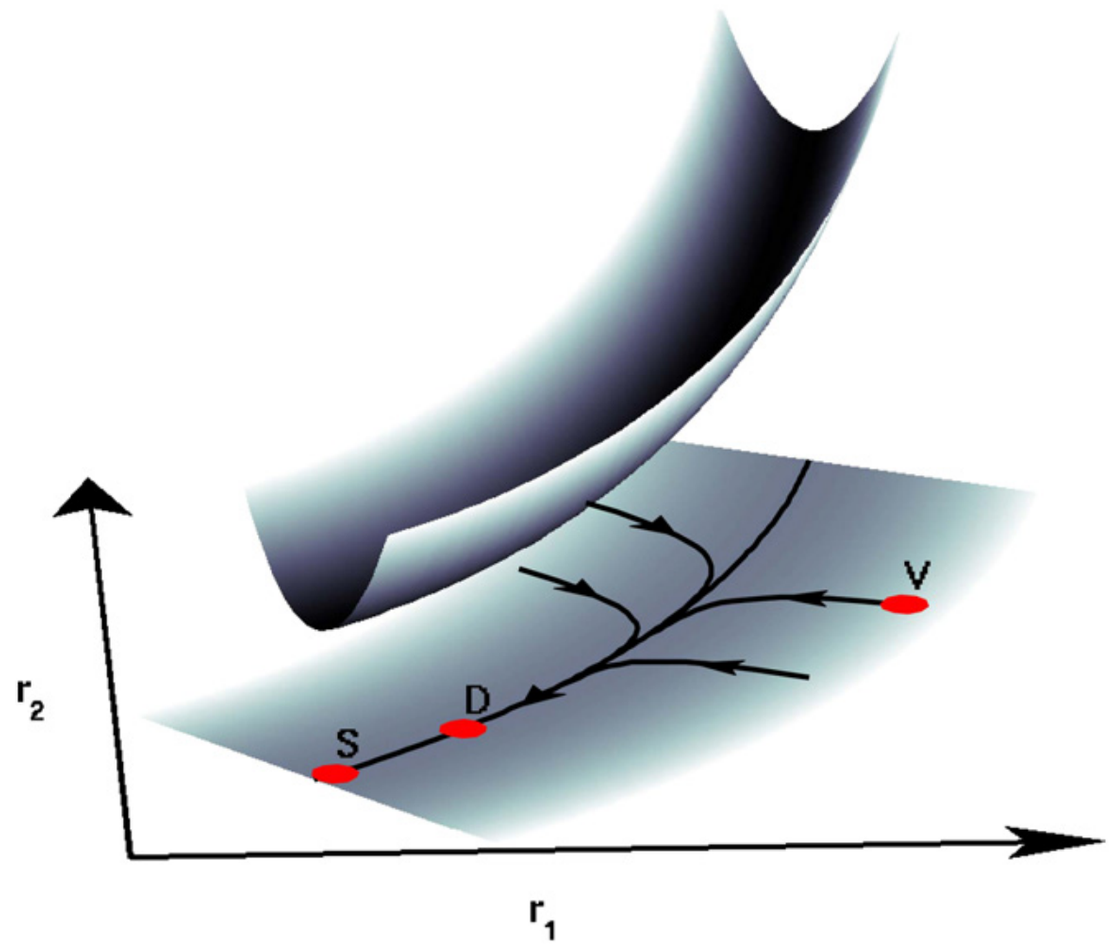
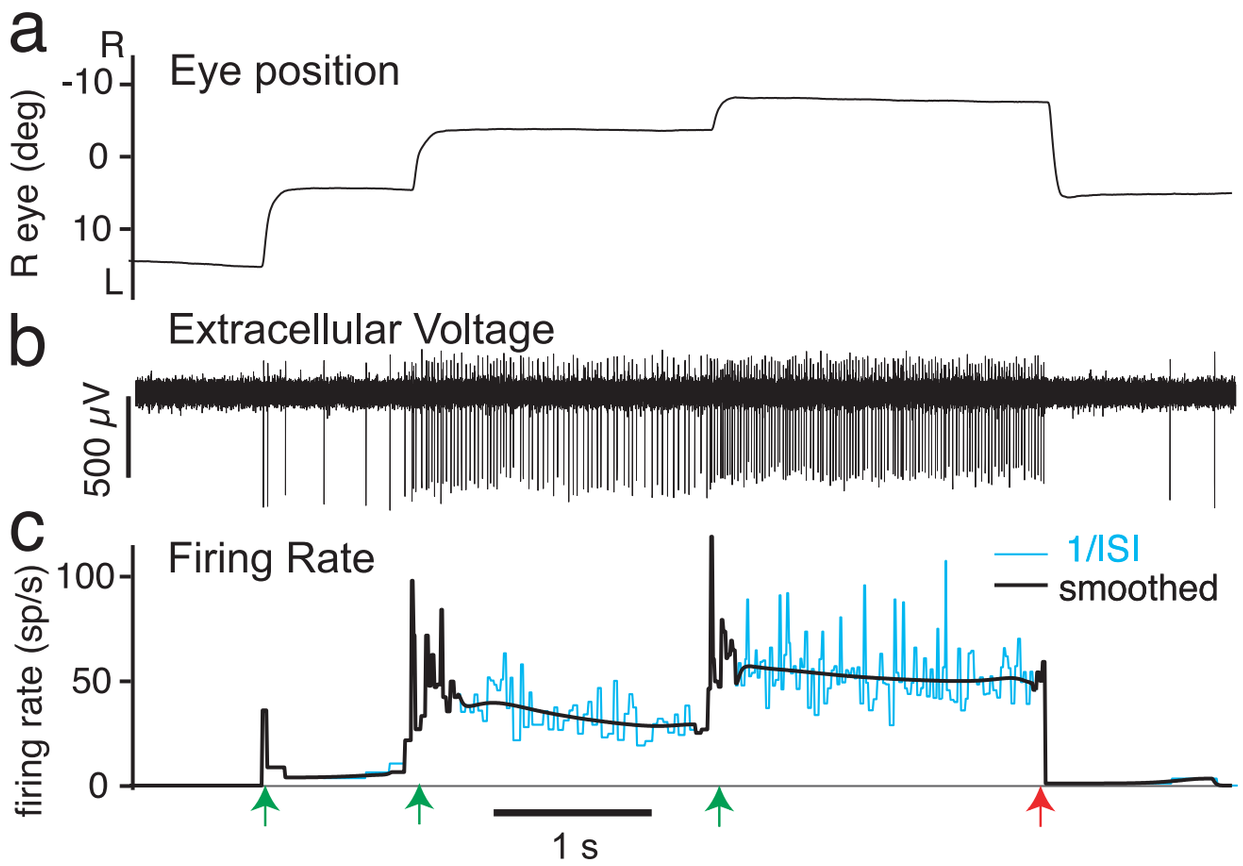
Working Memory and attractor models

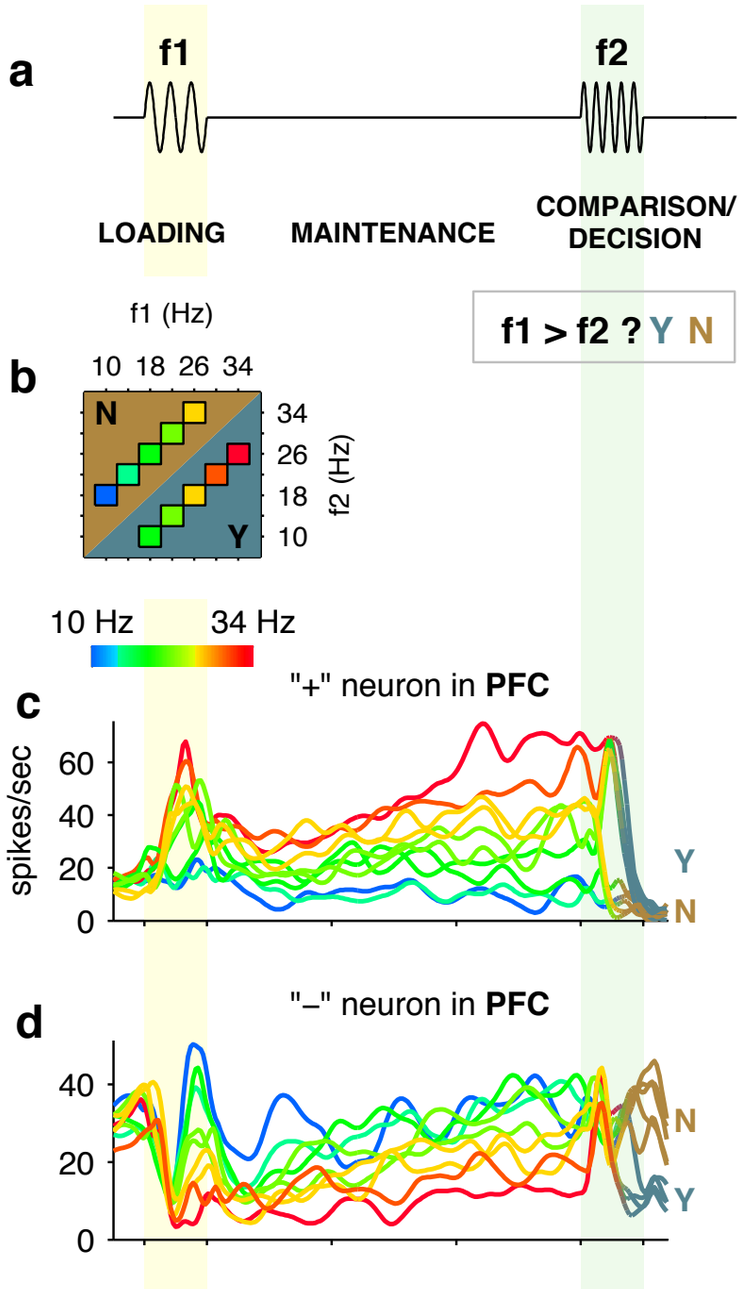
One dimensional dynamics to encode a continuous variable



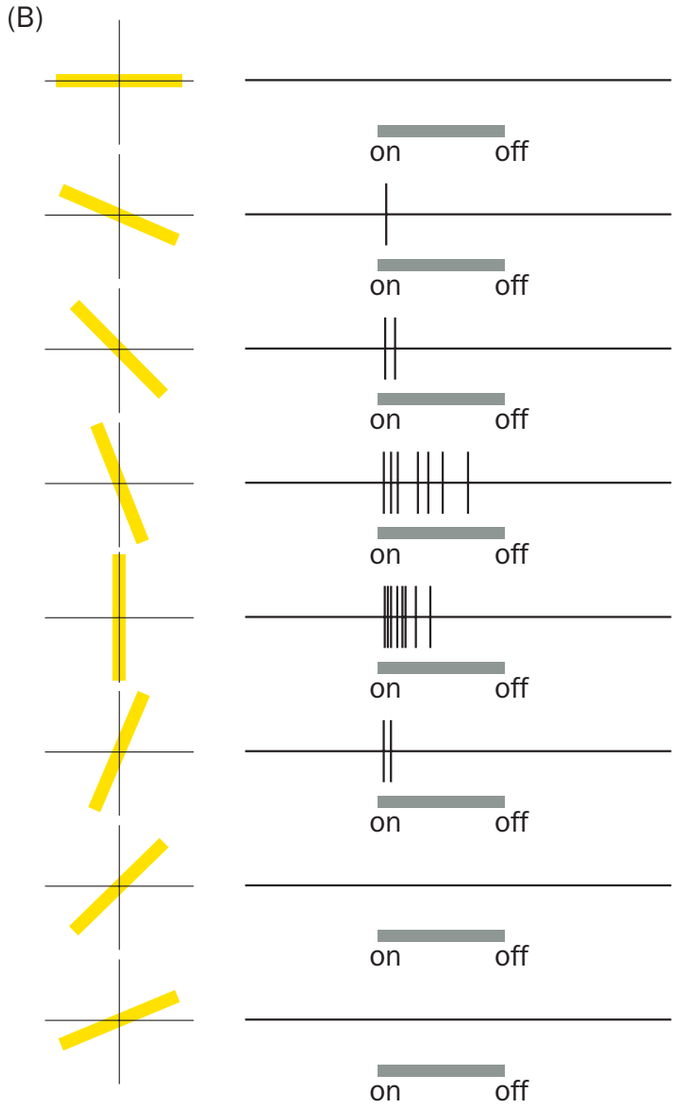
Persistent activity in neurons encoding eye position



A parametric working memory task



Orientation Tuning in the Visual Cortex



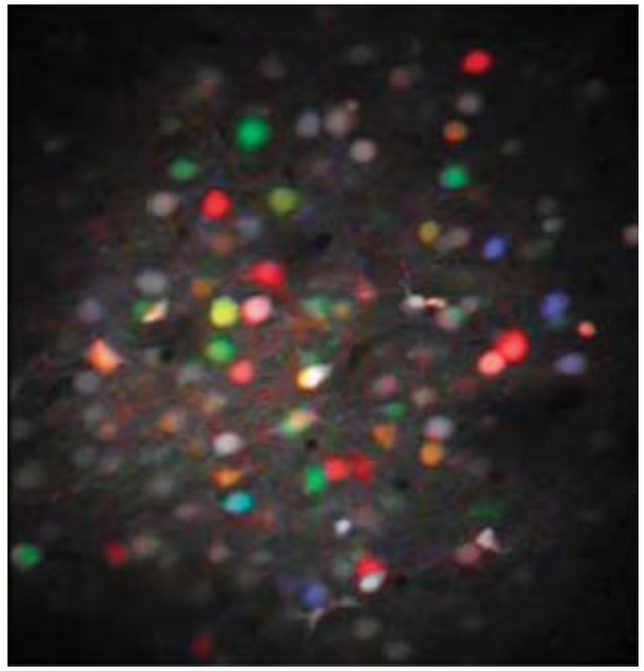
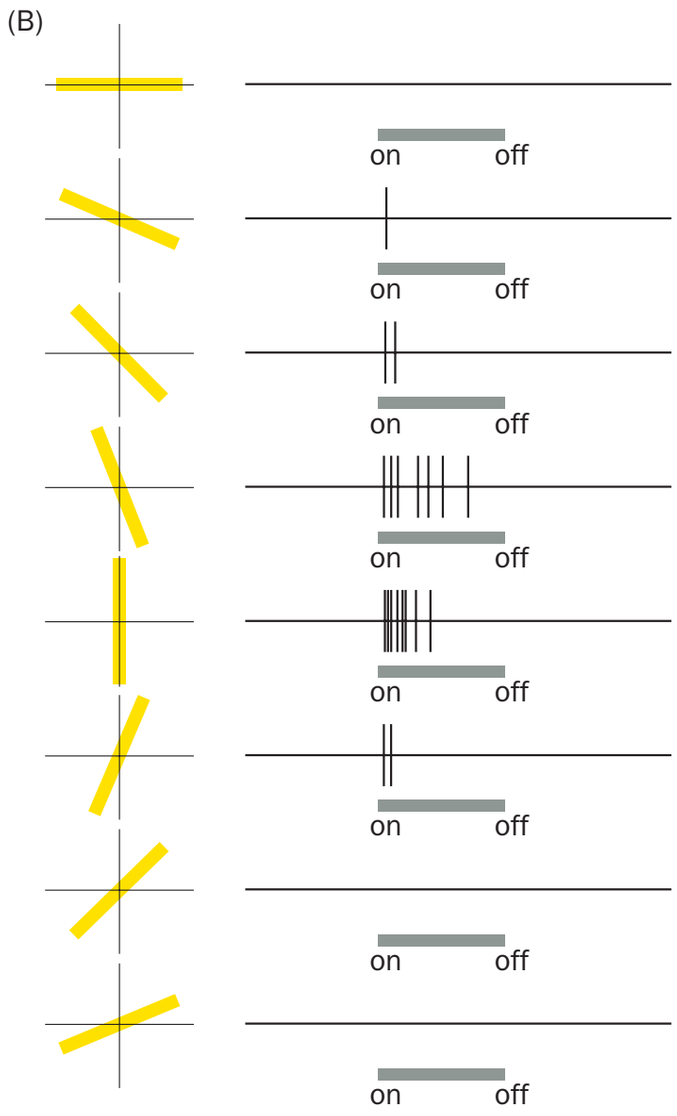
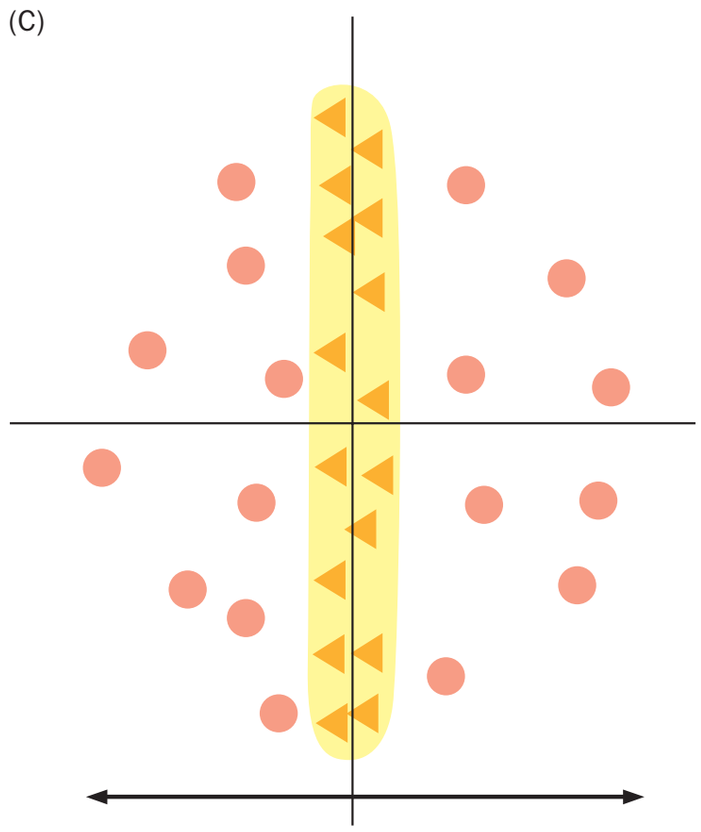


Figure 4–44 Orientation-selective cells in the rat primary visual cortex. Cells are color coded according to their orientation selectivity (below). In the rat, cells with the same orientation do not form organized columns but instead appear scattered. (From Ohki K, Chung S, Ch'ng YH et al. [2005] *Nature* 433:597–603. With permission from Macmillan Publishers Ltd.)

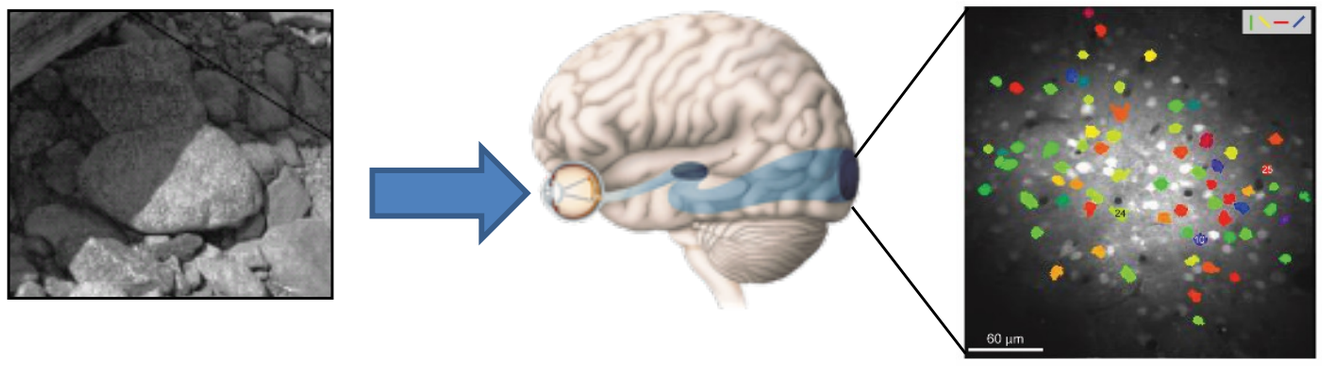
Simple cell receptive field in the cat primary visual cortex





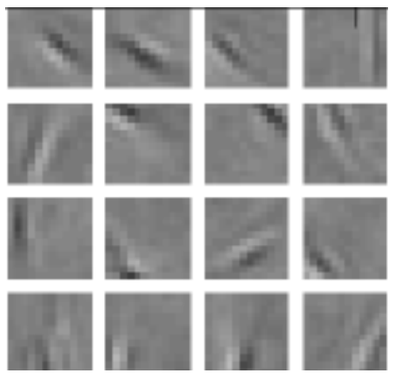
Hubel and Wiesel, 1959 Journal of Physiology

Working memory and sensory representation

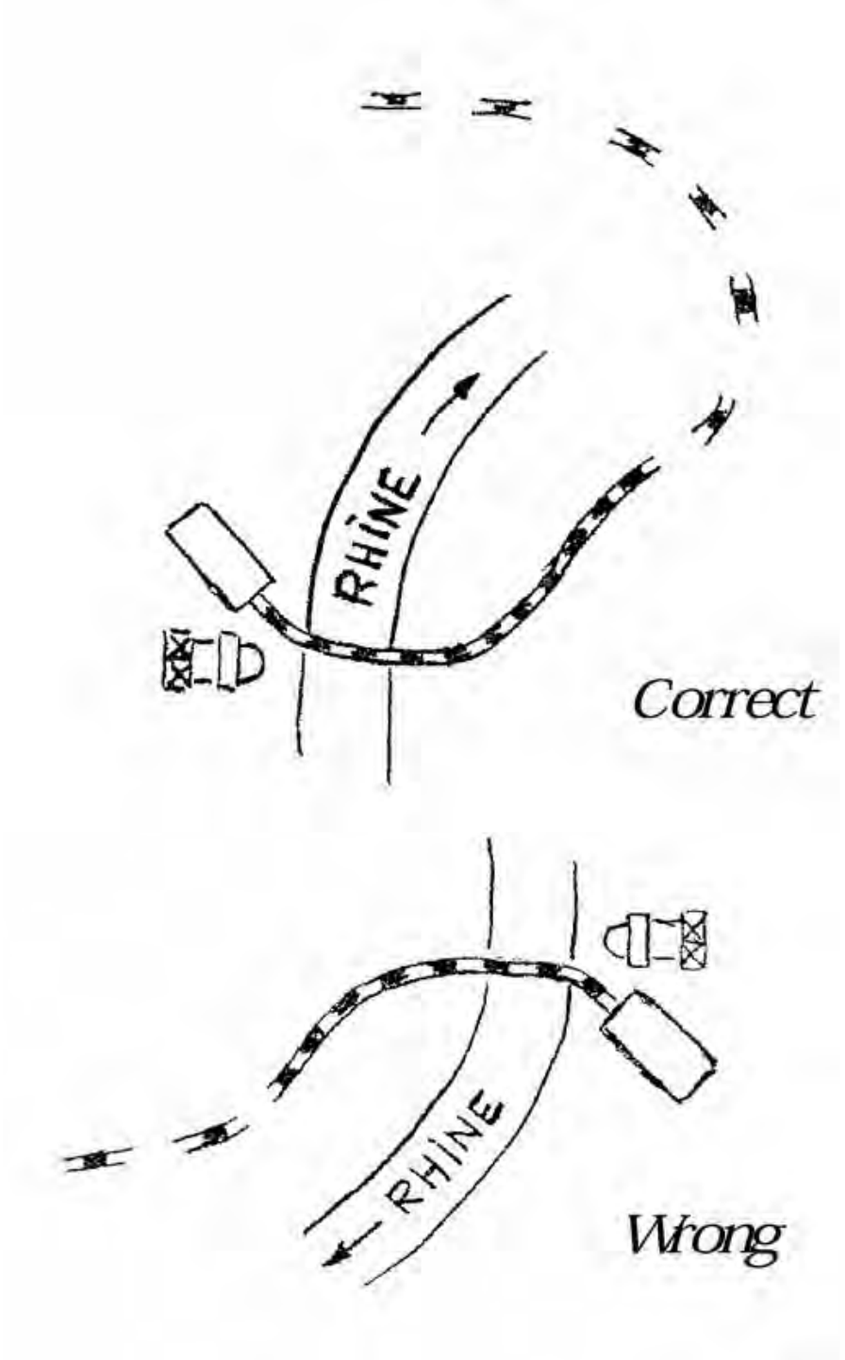


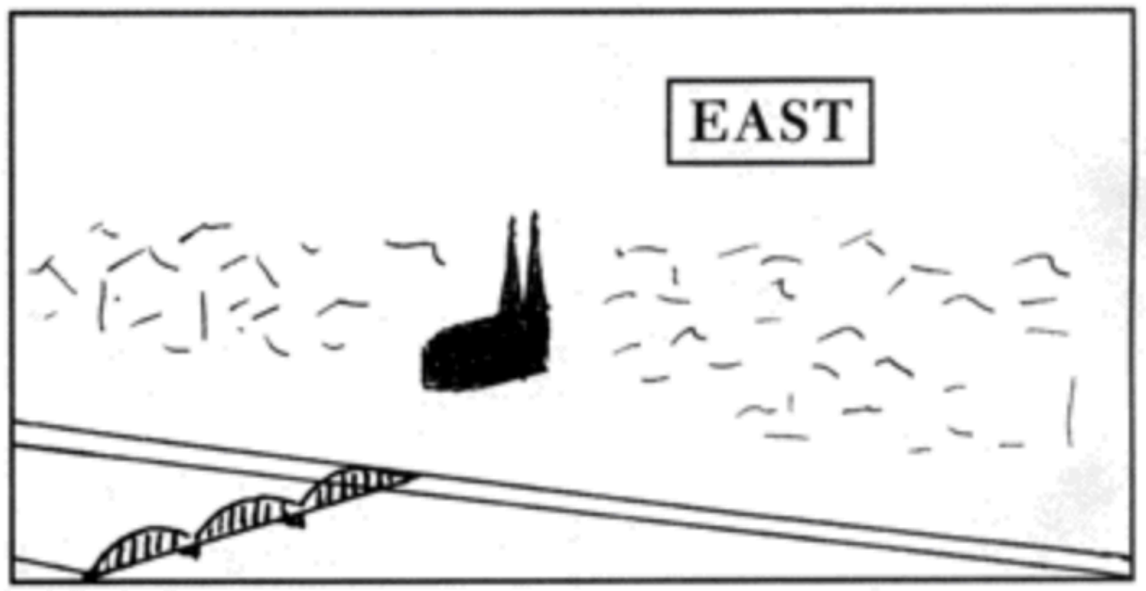
$$\mathbf{s} \approx \sum_{i=1}^{N} r_i(t)\mathbf{d_i}$$

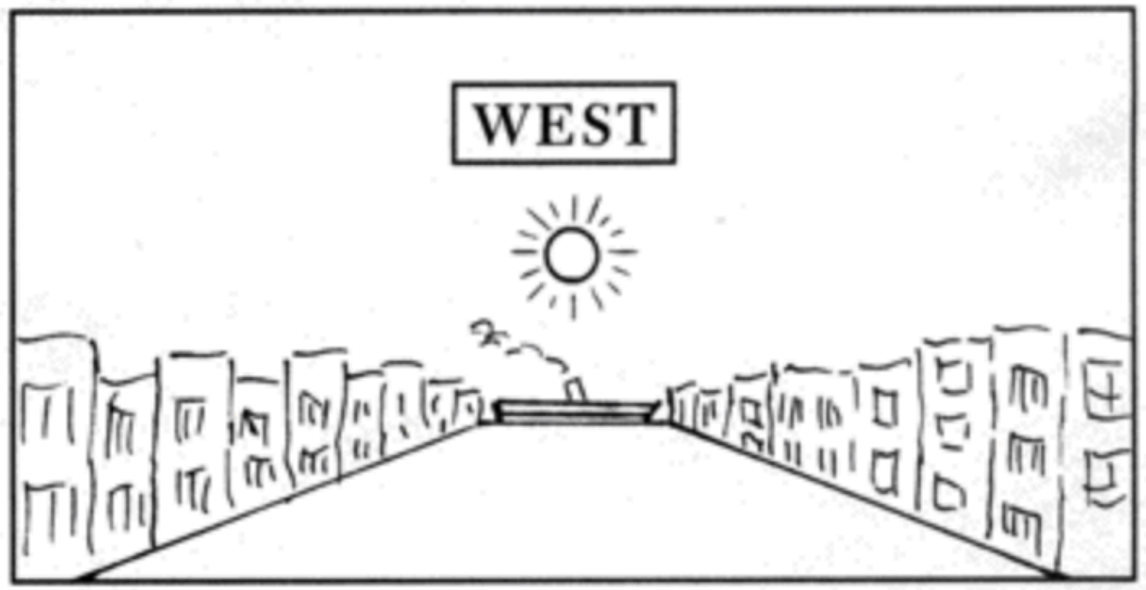
$\mathbf{d}_{1:N}$



Cologne, Germany

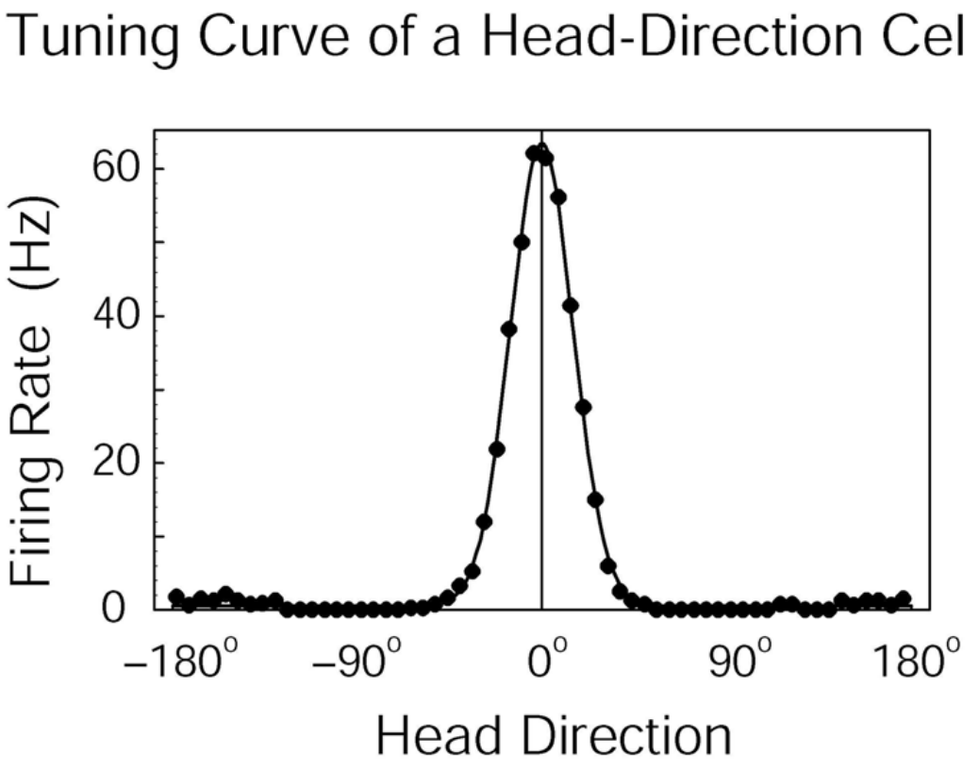


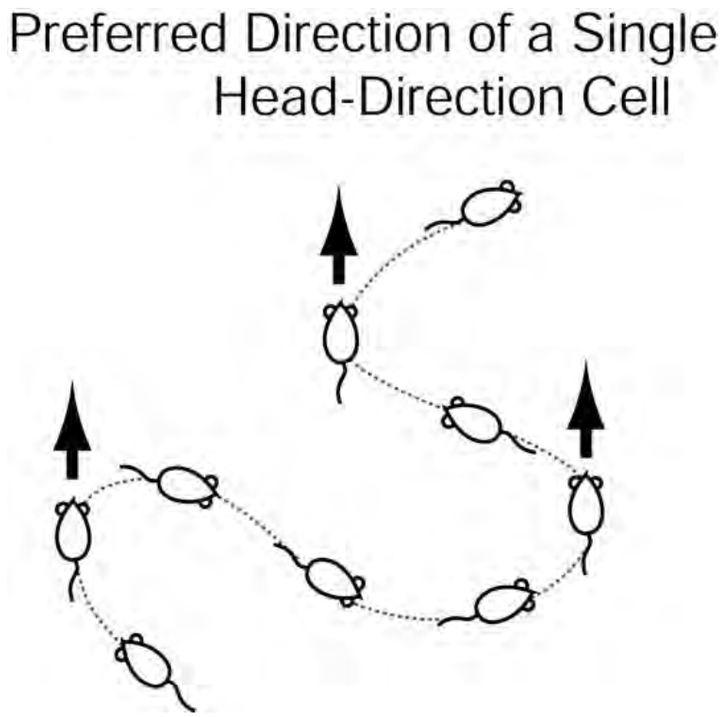




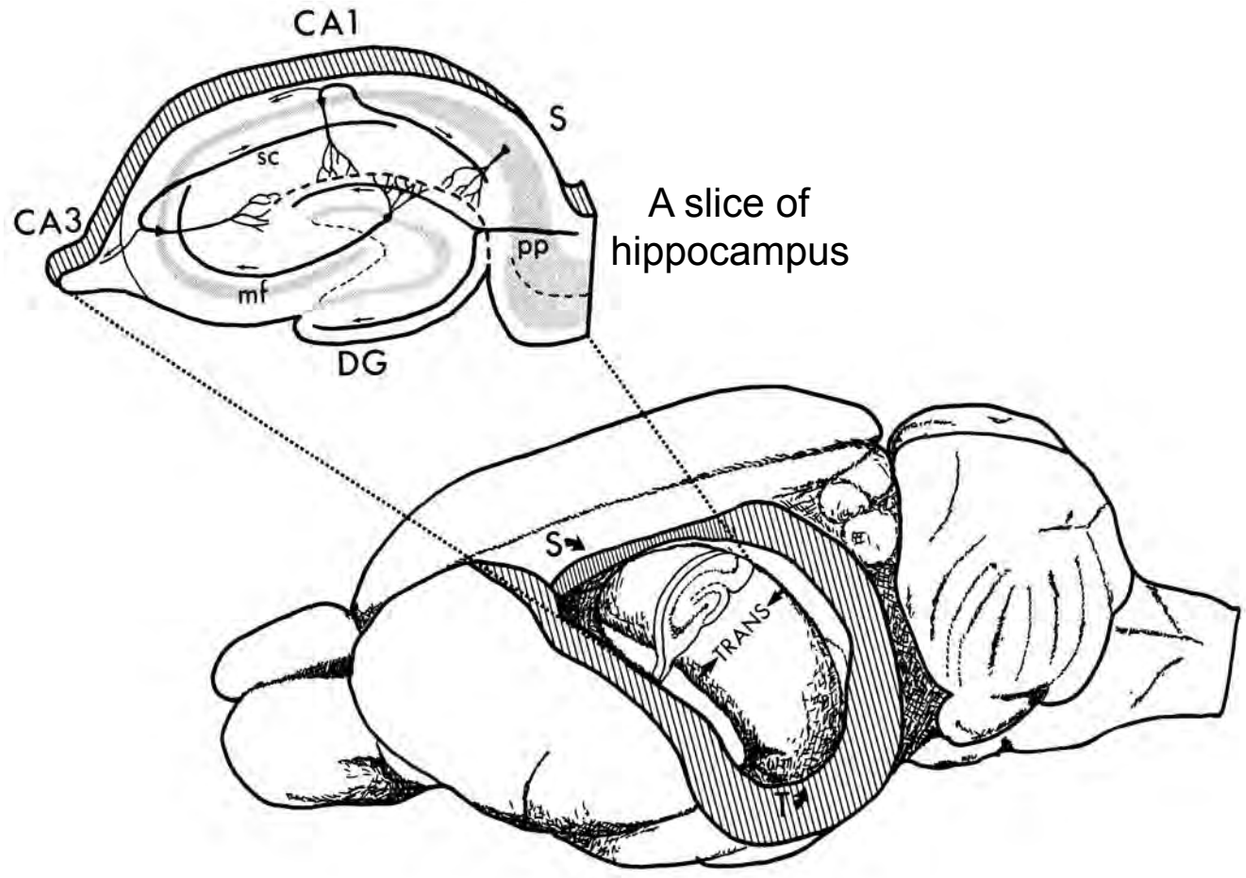
Inner Navigation: why we get lost in the world
Eric Johnson

Head direction cell





Hippocampus

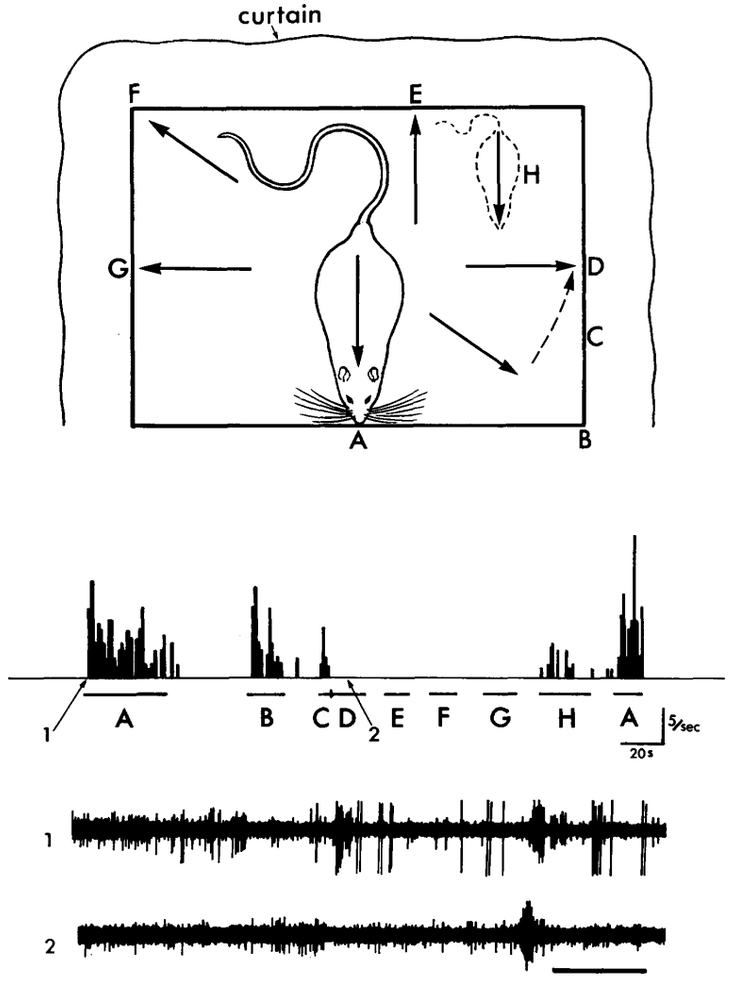


A slice of hippocampus

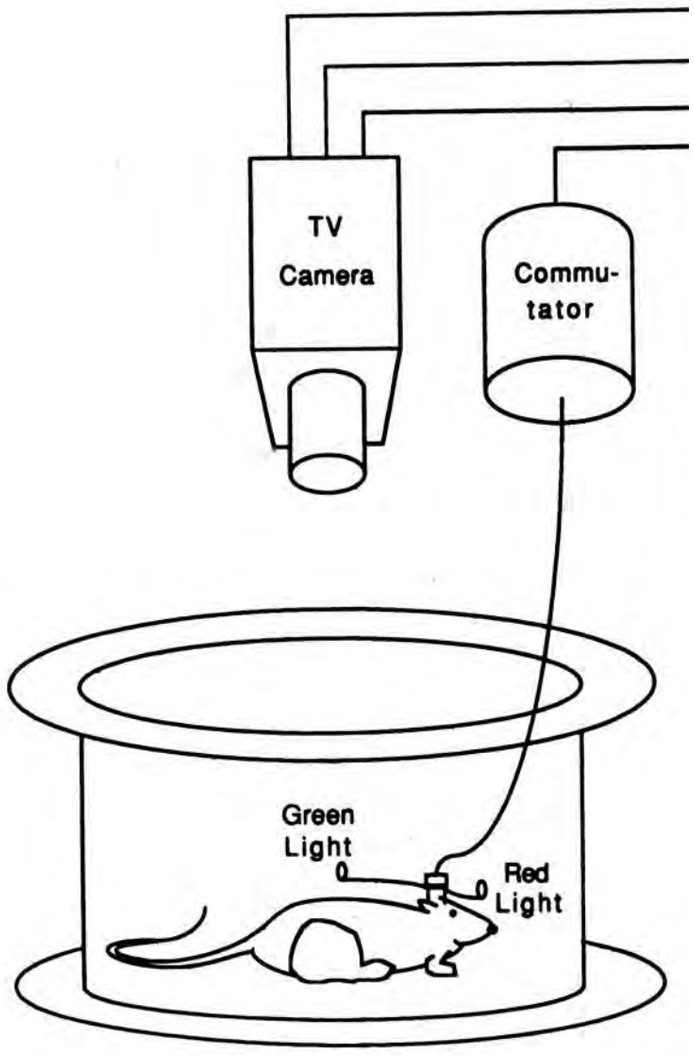
Cortex is cut out to reveal the left hippocampus

Brain Research, 34 (1971) 171–175

The hippocampus as a spatial map. Preliminary evidence from unit activity in the freely-moving rat



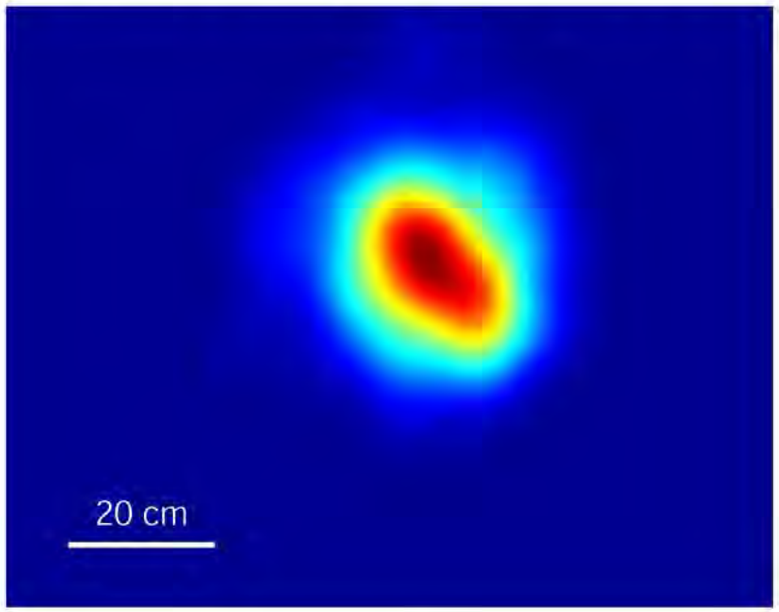
J. O'KEEFE
J. DOSTROVSKY*

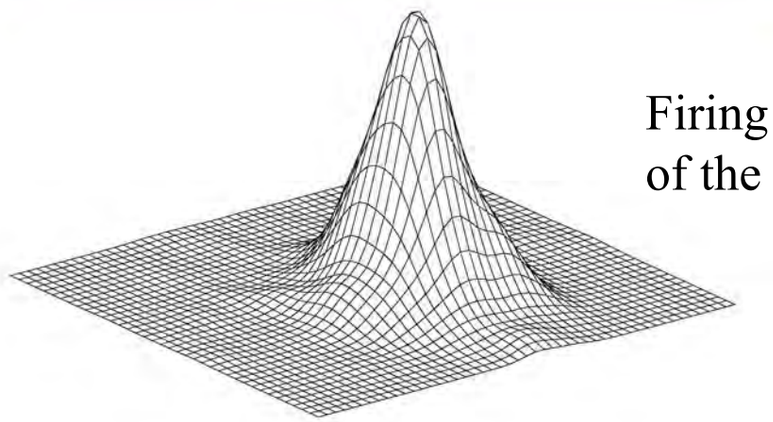


Typical setup for tracking a freely moving animal while recording from a single cell

(Muller et al. 1990)

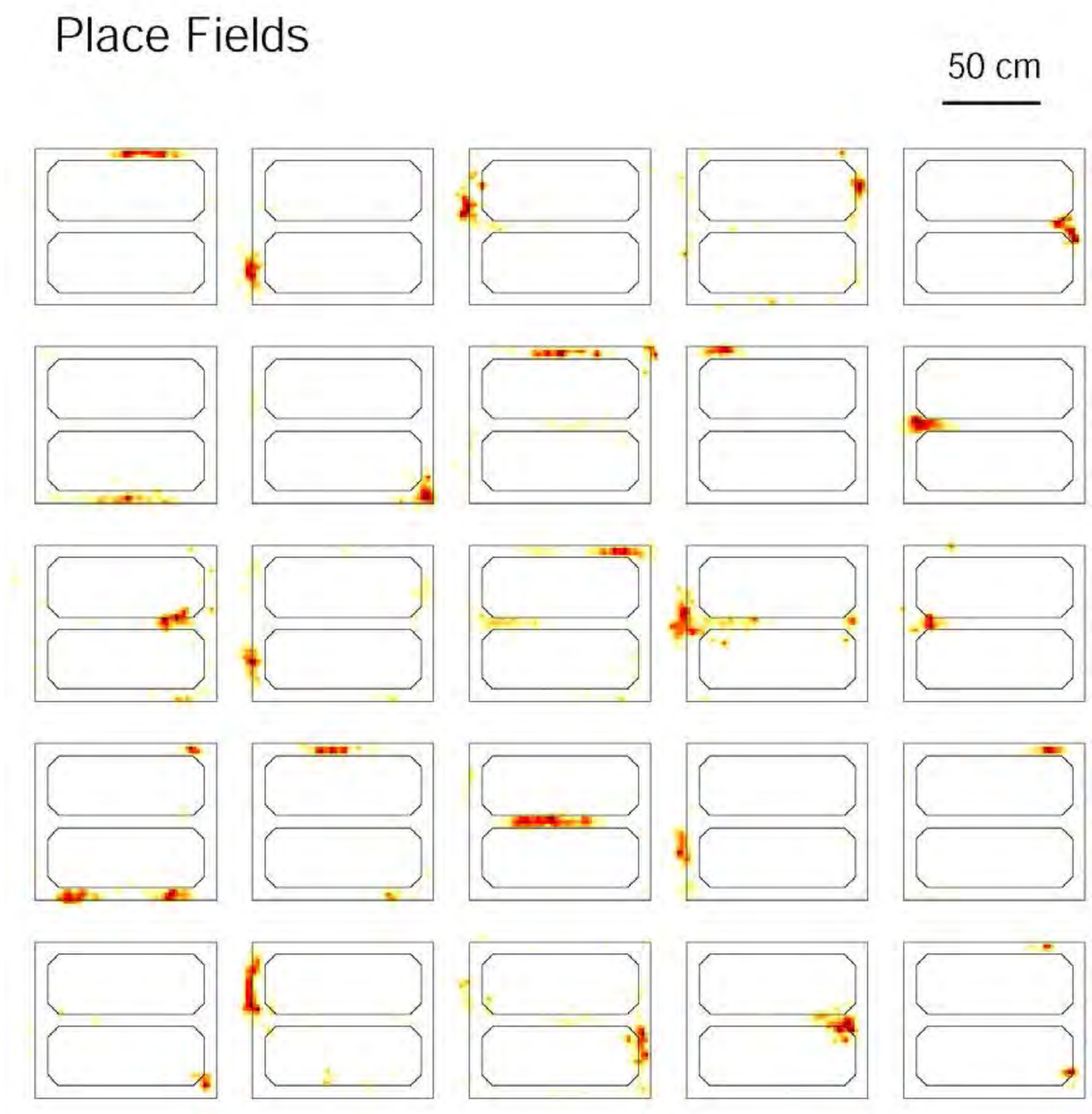
Hippocampal Place Field





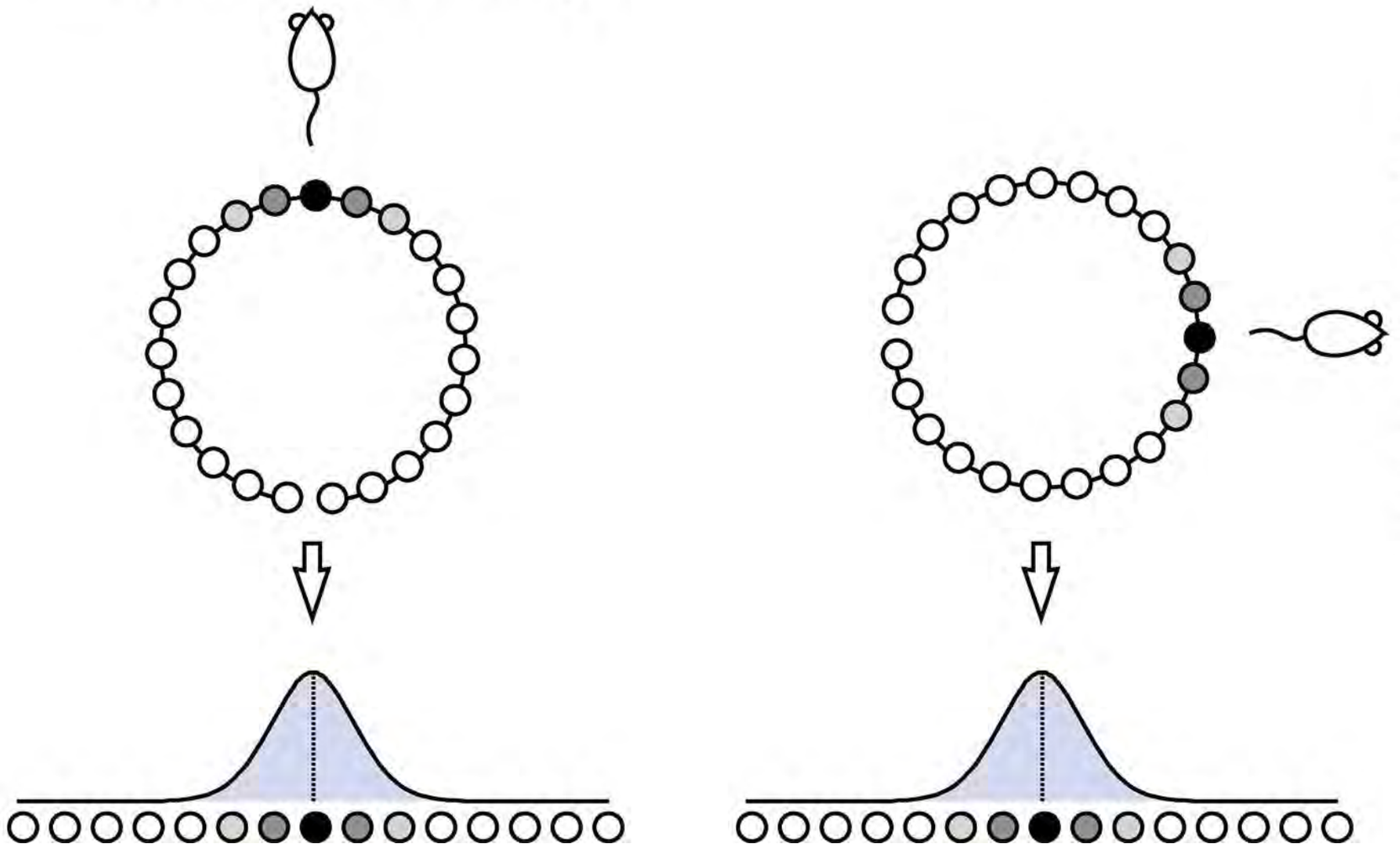
Firing rate as a function of the animal's position

Hippocampus as a spatial map



25 simultaneously recorded place cells

A ring attractor model

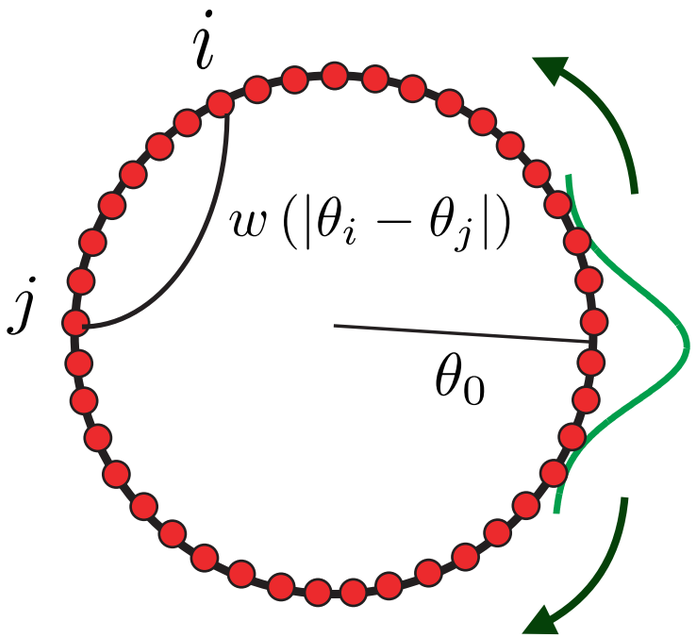


Ben-Yishai, Bar-Or, Sompolinsky, PNAS (1995)

Zhang, J. Neurosci. (1998)

Xie, Hahnloser, Seung, Phys. Rev. E (2002)

A ring attractor model



firing rate

$u_i = f(\theta_i - \theta_0)$

Solution:

A continuum of steady states

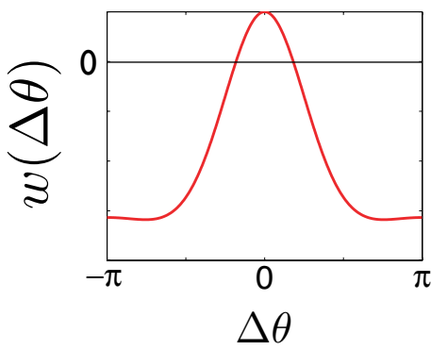
encode a continuous parameter (angle)

e.g., $u(\theta) = a + b\cos(\theta - \theta_0)$

local excitation, long range inhibition

$$\tau \frac{du_i}{dt} = -u_i + \left[\sum_{j=1..N} w_{ij}u_j + I_i^0\right]_+$$

$$w_{ij} = w_{ji} = \frac{1}{N} J(|\theta_i - \theta_j|)$$

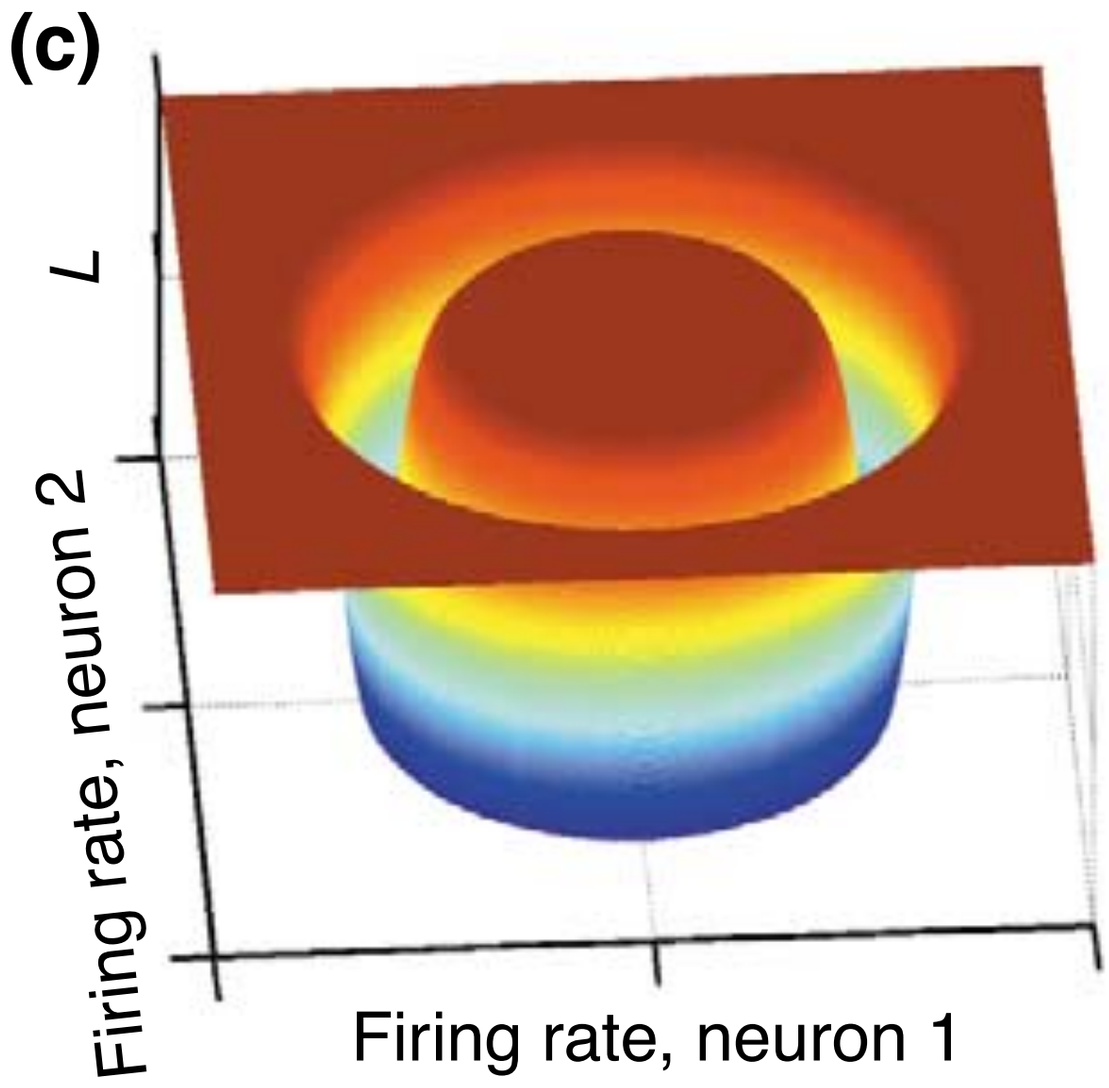


$$J = J_0 + J_1 \cos\theta$$

Let $N \to \infty$

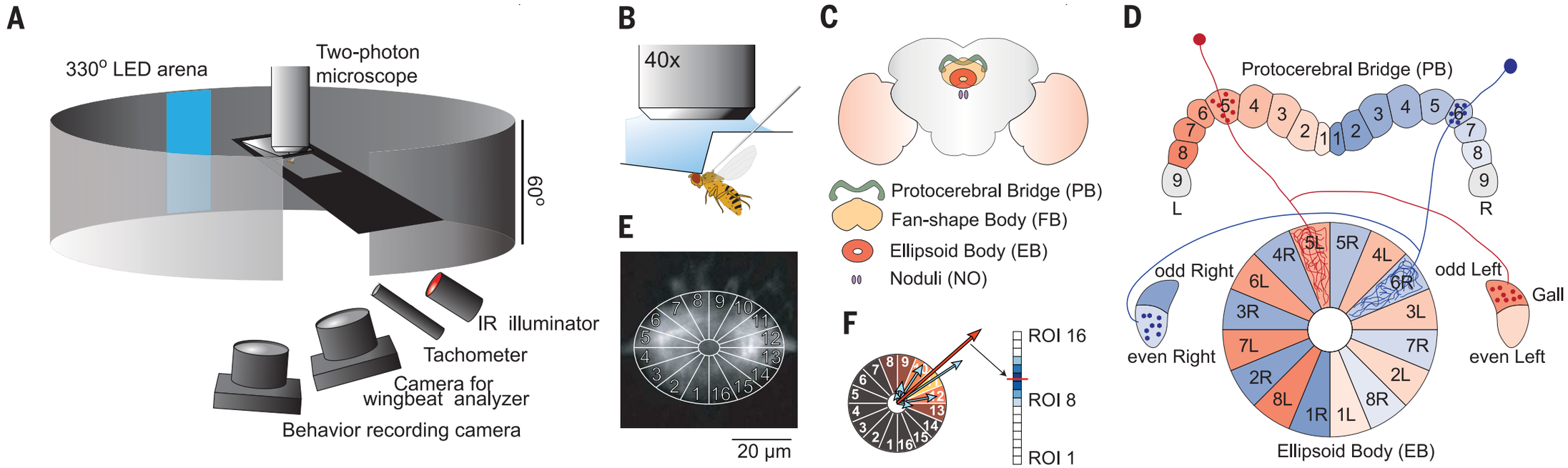
$$\tau \frac{\partial u(\theta, t)}{\partial t} = -u(\theta, t) + \left[\frac{1}{2\pi}\int_{-\pi}^{\pi} J(\theta - \theta')u(\theta', t)d\theta' + I^0(\theta)\right]_+$$

Energy landscape

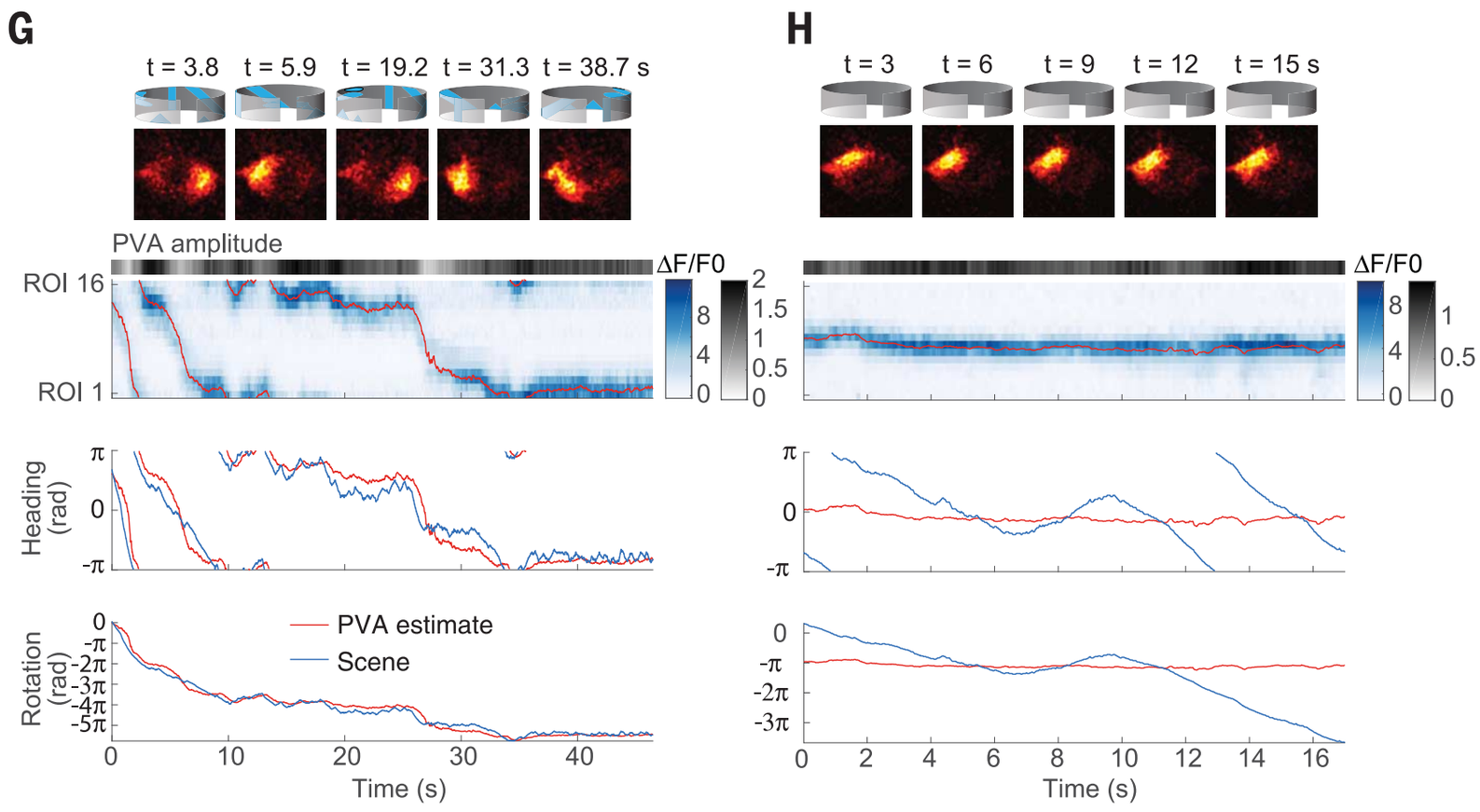


Kepecs and Brody, Current Opinion in Neurobiology 2003

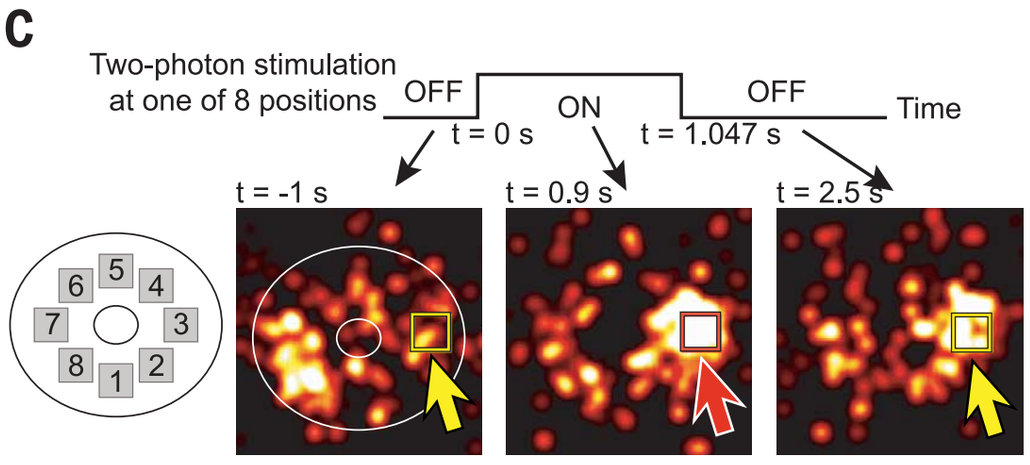
Ring attractor dynamics in fly brain

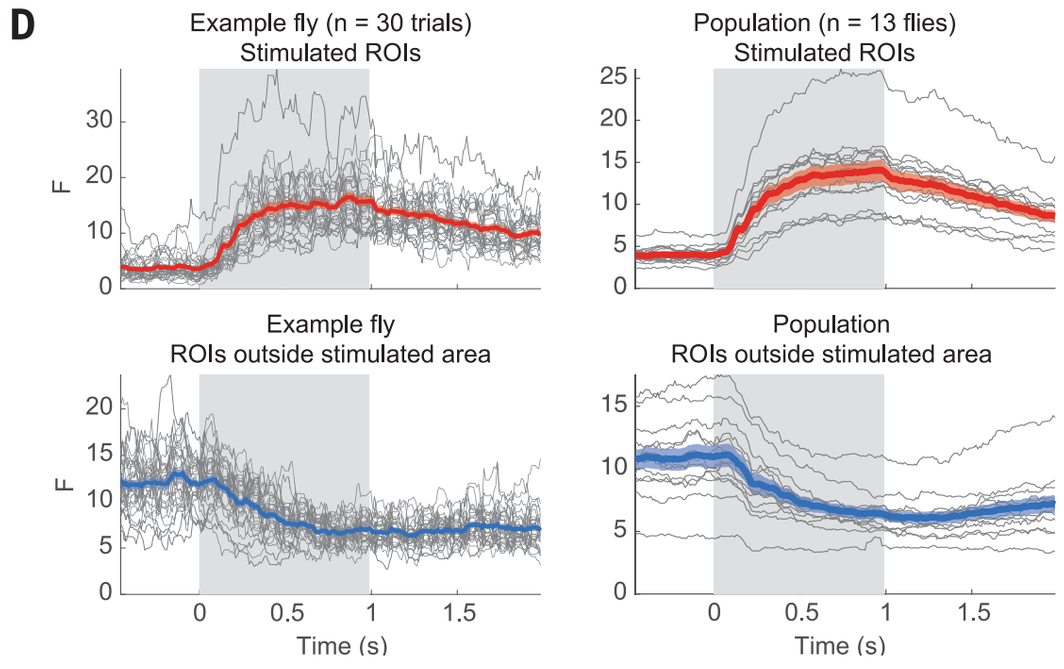


Ring attractor dynamics in fly brain

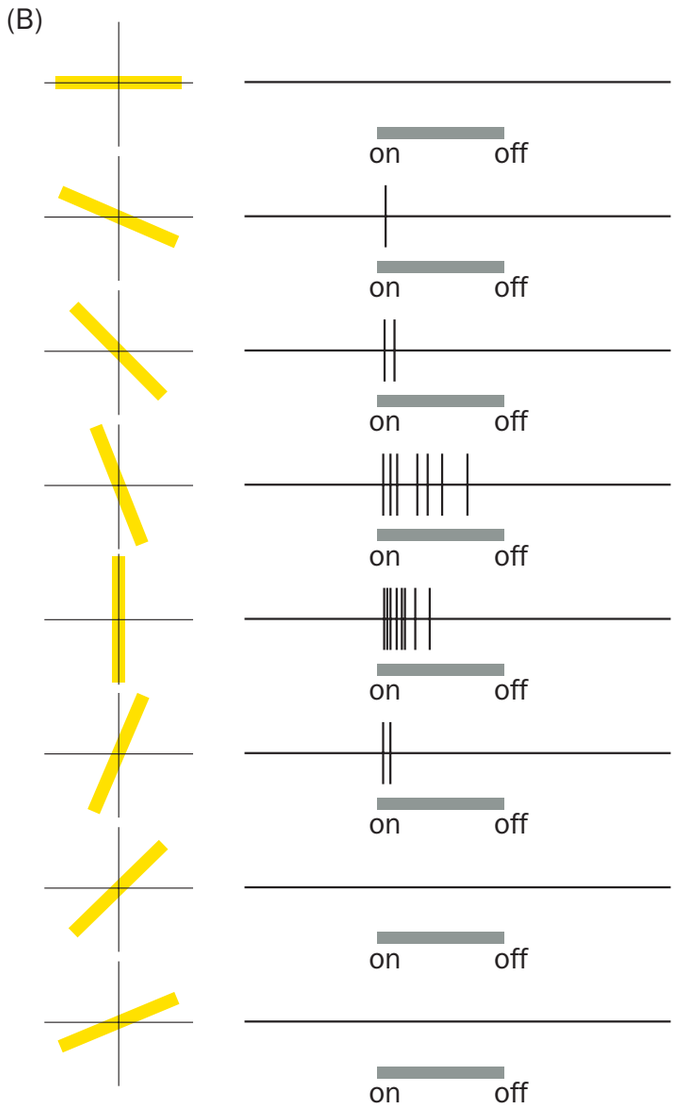


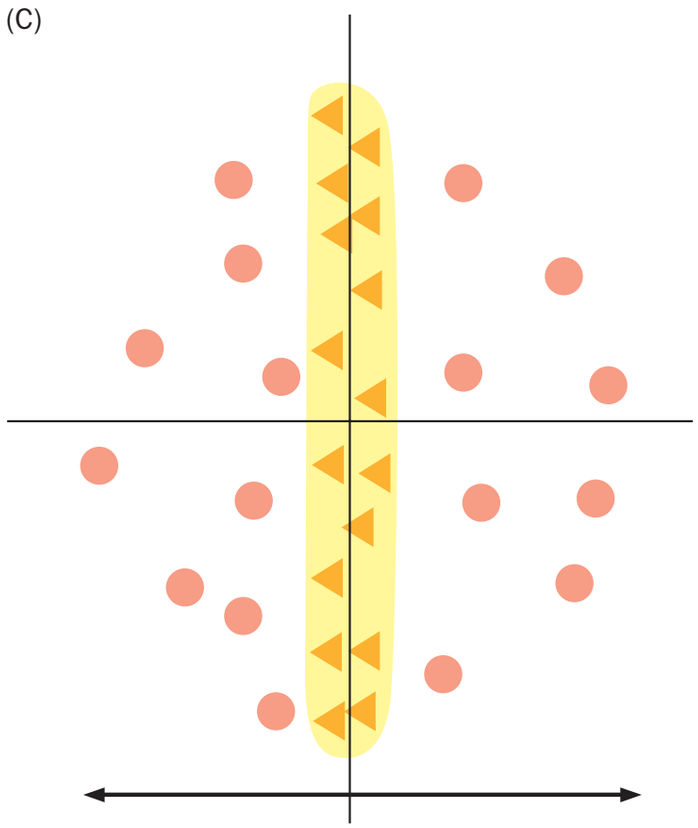
Ring attractor dynamics in fly brain

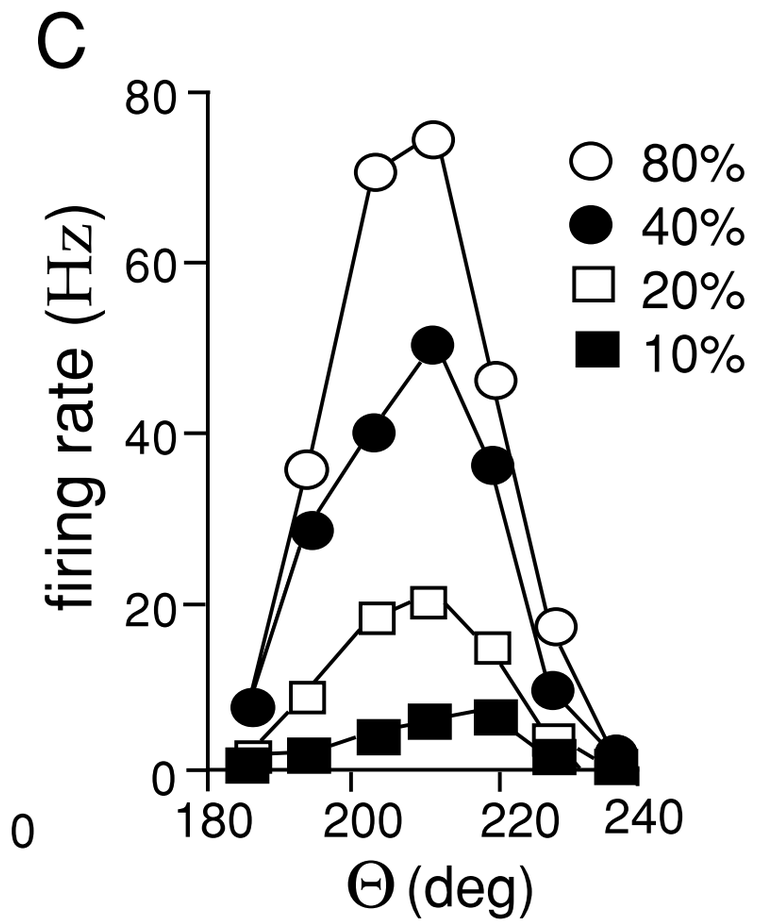




Contrast dependent receptive field







Fixed points and stability

Global stability: starting from **any** initial condition

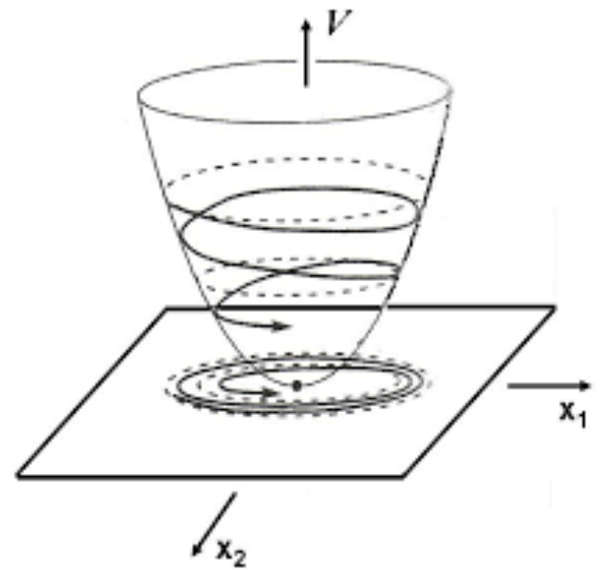
$$\frac{d\mathbf{u}}{dt} = \mathbf{f}(\mathbf{u})$$

Lyapunov function $V(u)$

$V(u) \geq \mathrm{V}_0$, has a lower bound

$$\frac{d}{dt}V(u(t)) \leq 0$$

$$\frac{d}{dt}V\big(u(t)\big) = 0 \Rightarrow \nabla V(u) = 0$$



Theorem: If there exists a Lyapunov function, the system is (globally) stable where the trajectory will converge to one of the extrema of $V(u)$.

Persistent activity in neurons encoding eye position

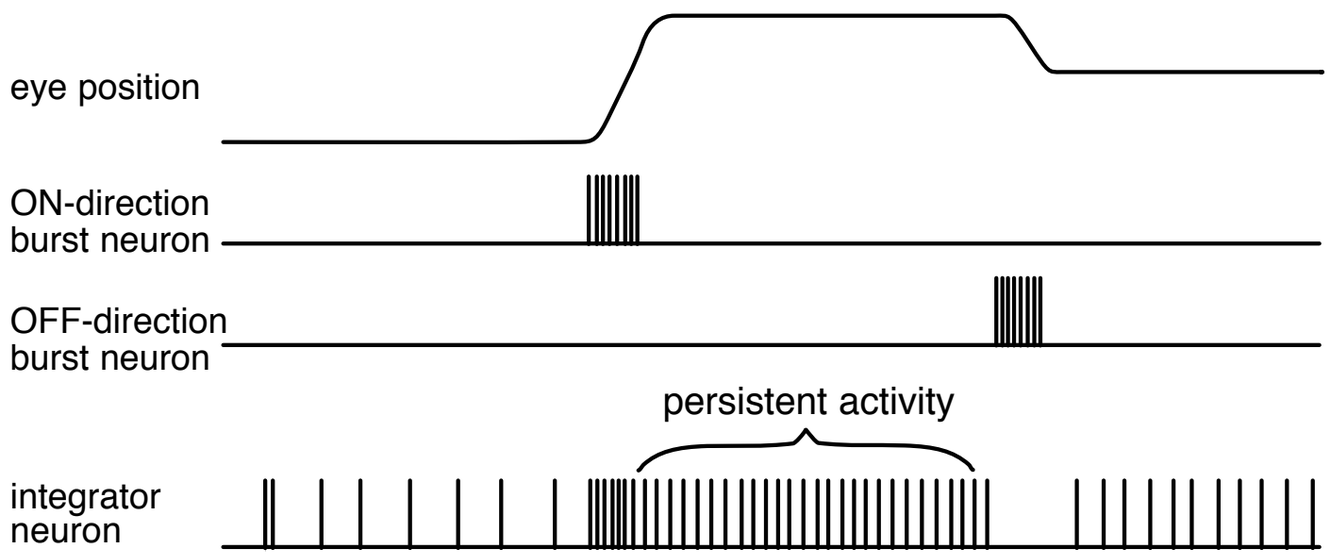


Figure 7.7: Cartoon of burst and integrator neurons involved in horizontal eye positioning. The upper trace represents horizontal eye position during two saccadic eye movements. Motion of the eye is driven by burst neurons that move the eyes in opposite directions (second and third traces from top). The steady-state firing rate (labeled persistent activity) of the integrator neuron is proportional to the time integral of the burst rates, integrated positively for the ON-direction burst neuron and negatively for the OFF-direction burst neuron, and thus provides a memory trace of the maintained eye position. (Adapted from Seung et al., 2000.)