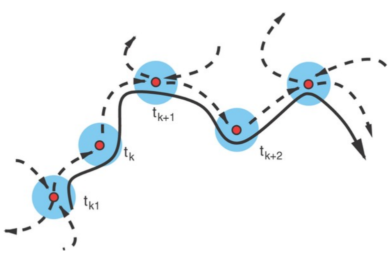
Winnerless Competition in Neuroscience



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The Team

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Pablo Varona
YuriArshavsky
Allen Selverston

Reading List

- **Vision:**

  Rabinovich MI, Huerta R, Laurent G. Transient Dynamics for Neural Processing, Science 321: 48, 2008.

- **Maths:**

  Afraimovich VS, Rabinovich MI, Varona P. Heteroclinic Contours in Neural Ensembles and the Winnerless Competition Principle. International Journal of Bifurcation and Chaos,Vol. 14(4): 1195-1208, 2004.

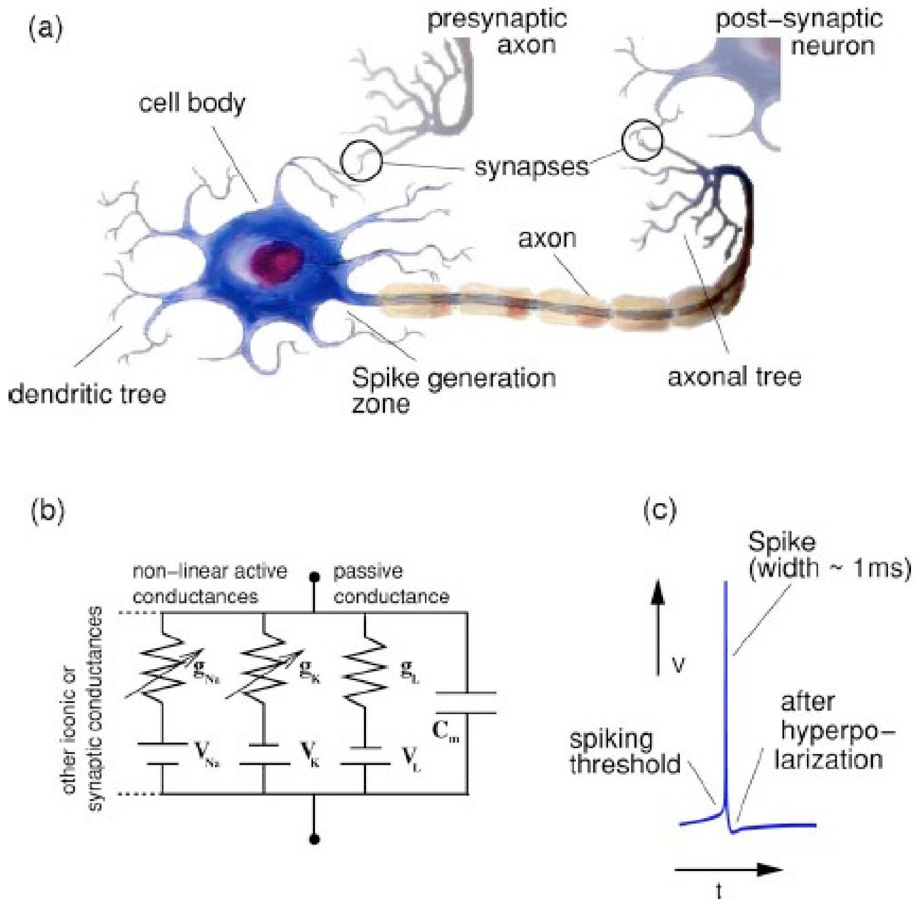
- **Neuroscience:**

  Rabinovich MI, Varona P, Selverston AI, Abarbanel HDI. Dynamical Principles in Neuroscience. Reviews of Modern Physics 78(4): 1213, 2006.

The Plan

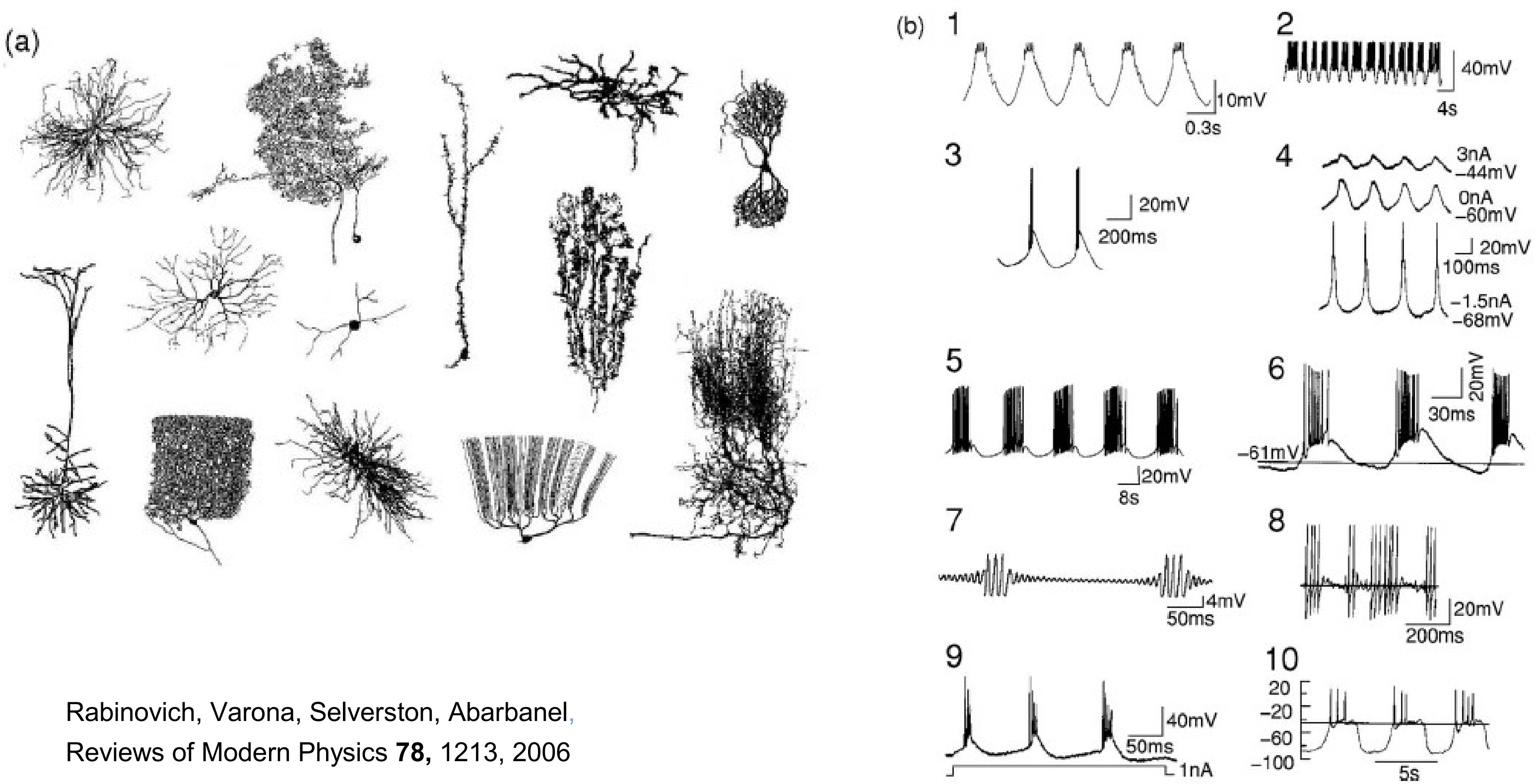
1. Transient dynamics and winnerless competition in neuroscience
2. Heteroclinic sequencies in asymmetric networks
3. Beyond the rate model

Single neurons: modelling



Rabinovich, Varona, Selverston, Abarbanel, Reviews of Modern Physics **78,** 1213, 2006

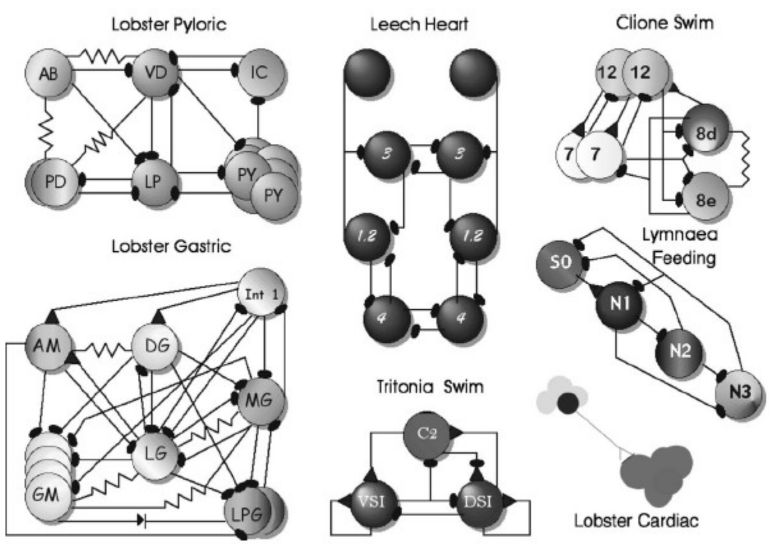
Single neurons: diversity



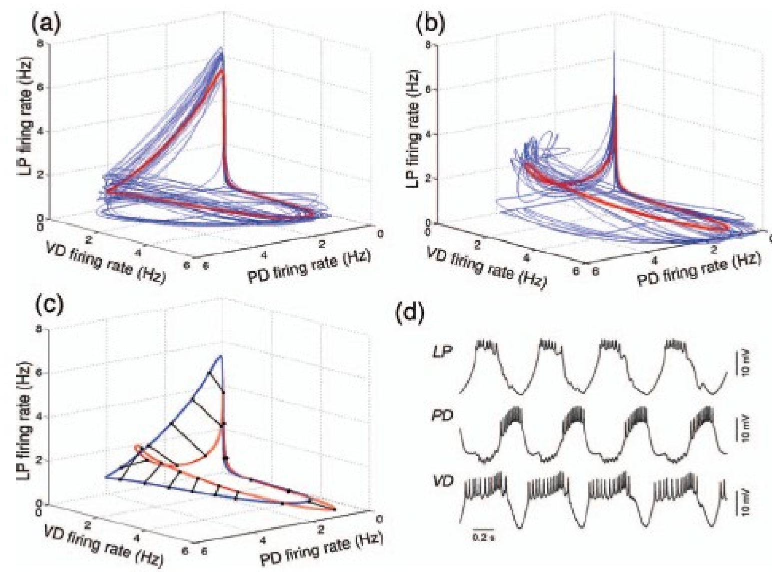
Rabinovich, Varona, Selverston, Abarbanel,
Reviews of Modern Physics **78,** 1213, 2006

Small scale: mini-circuits

Invertebrate CPGs



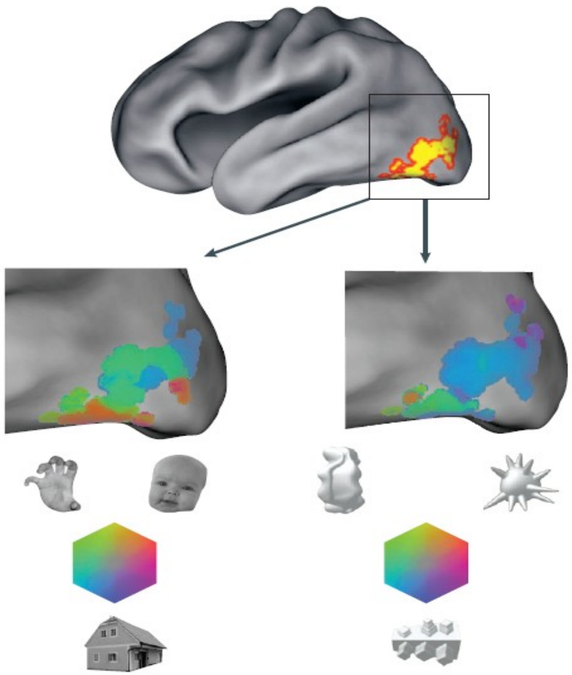
Rev. Mod. Phys., Vol. 78, No. 4, October–December 2006



Large scale: the brain

fMRI: activation patterns

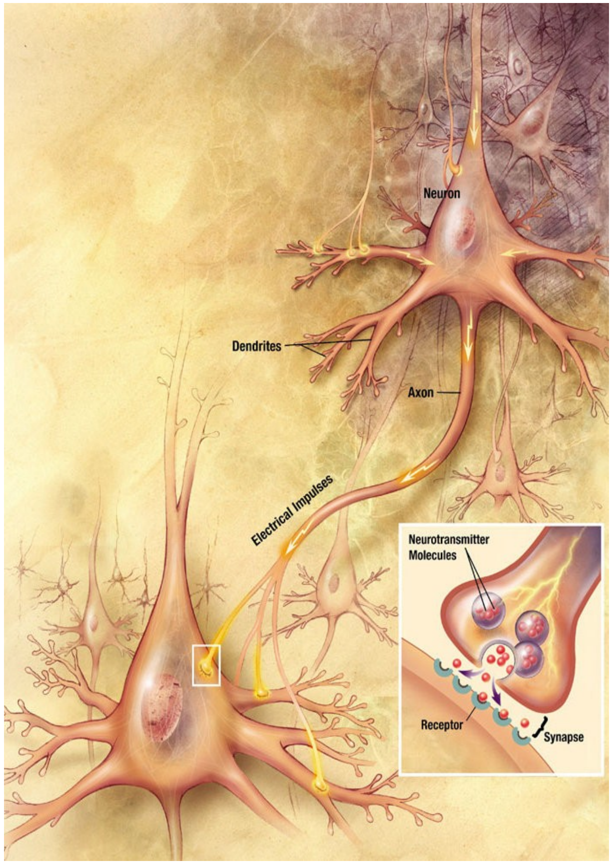
Familiar objects



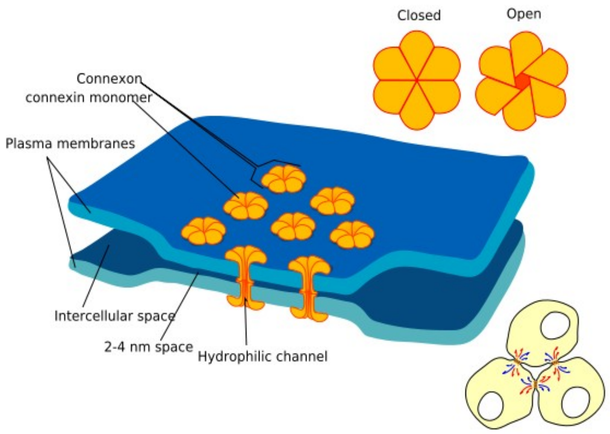
Novel objects

De Beeck, Haushofer, Kanwisher,
Nature Reviews Neurosciense, **9,** 123, 2008

Synapses



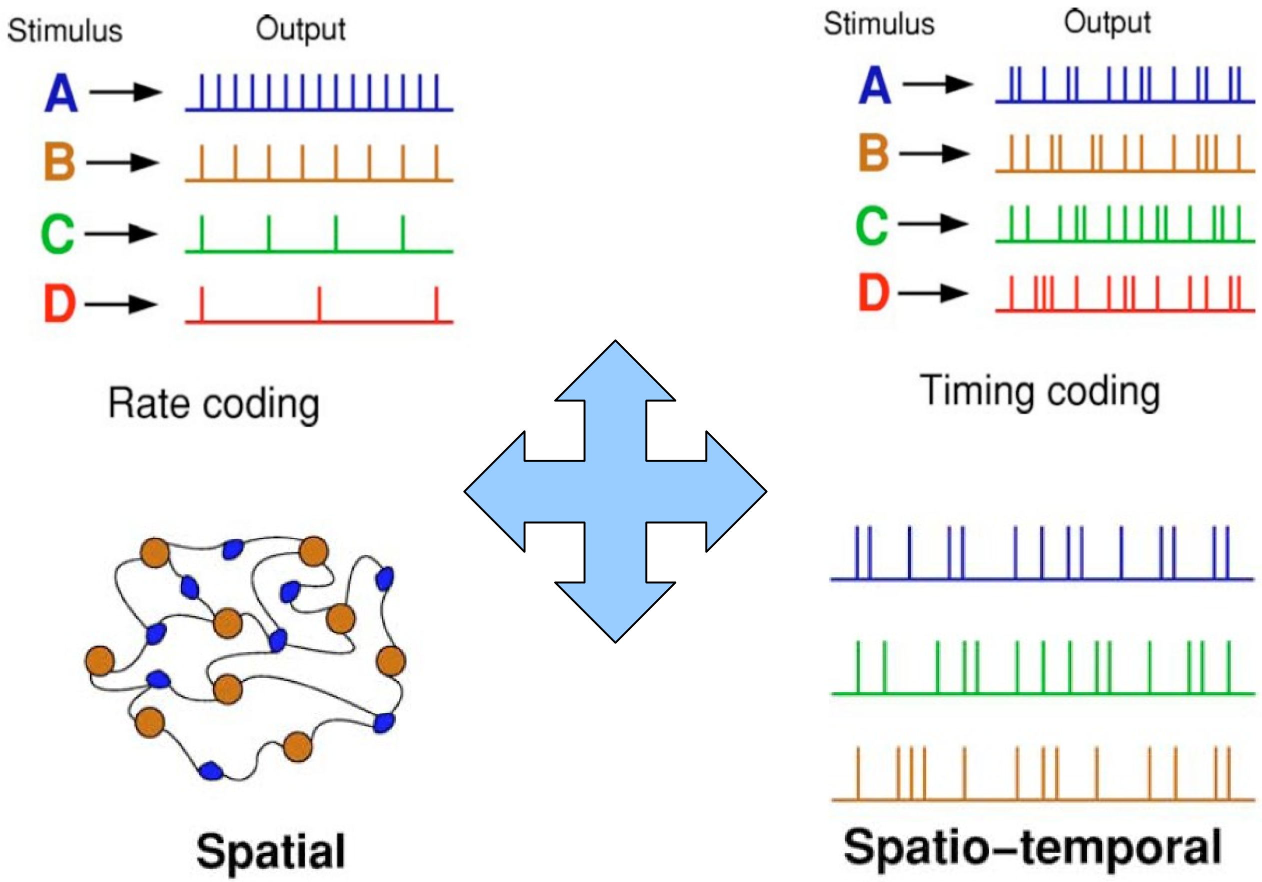
Electrical



Chemical

Excitatory Inhibitory

Coding



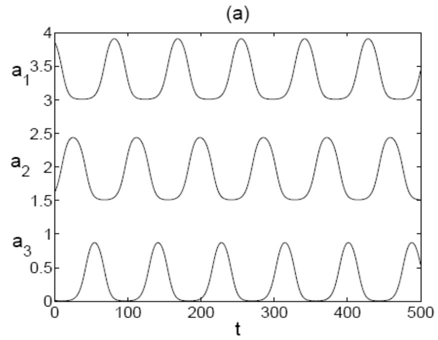
Rabinovich, Varona, Selverston, Abarbanel,
Reviews of Modern Physics **78,** 1213, 2006

Models: neurons

Rate models

$$\dot{a}_i(t) = F_i(a_i(t))[G_i(a_i(t)) - \Sigma_j \rho_{ij} Q_j(a_j(t))]$$

$a_i(t) > 0$ is the spiking rate of the ith neuron or cluster; ρ_{ij} is the connection matrix; and F, G, Q are polynomial functions.



Hodgkin-Huxley

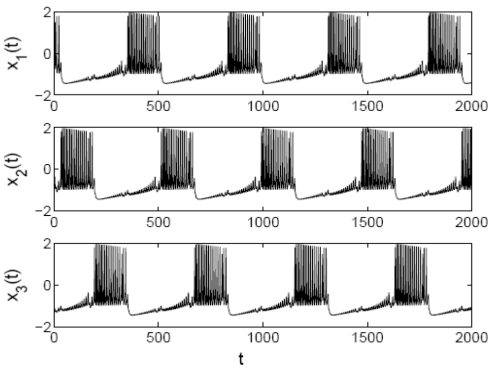
$$C\dot{v}(t) = g_L[v_L - v(t)] + gN_a m(t)^3 h(t)[vN_a - v(t)] + gKn(t)^4(v_K) - v(t) + I,$$

$$\dot{m}(t) = \frac{m_\infty(v(t)) - m(t)}{\tau_m(v(t))}$$

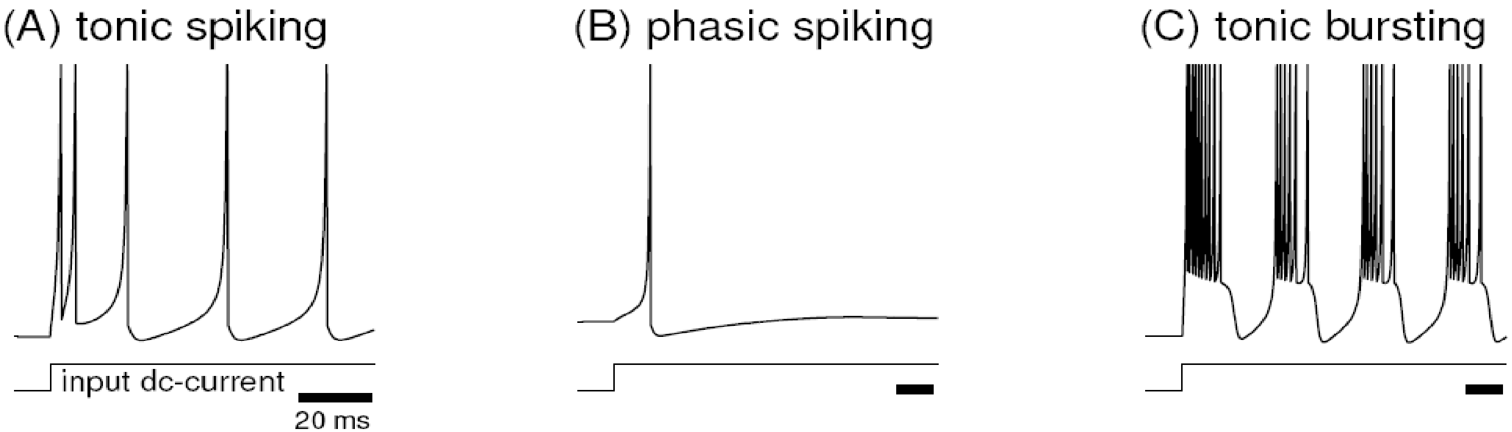
$$\dot{h}(t) = \frac{h_\infty(v(t)) - h(t)}{\tau_h(v(t))}$$

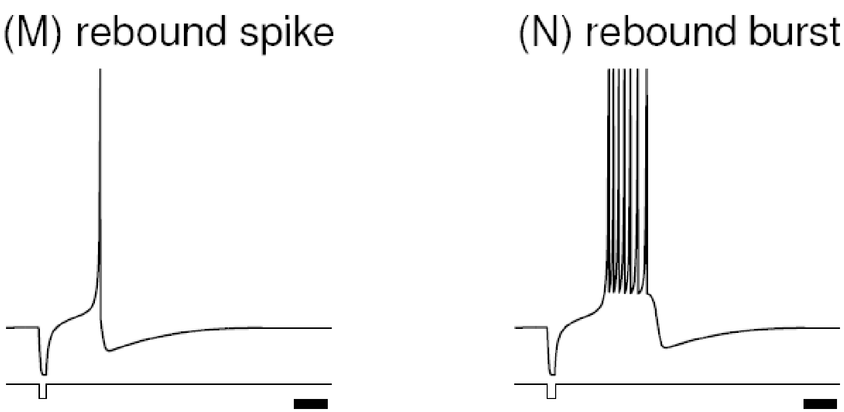
$$\dot{n}(t) = \frac{n_\infty(v(t)) - n(t)}{\tau_n(v(t))}$$

$v(t)$ is the membrane potential, $m(t)$, and $h(t)$, and $n(t)$ represent empirical variables describing the activation and inactivation of the ionic conductances; I is an external current. The steady-state values of the conductance variables $m_\infty, h_\infty, n_\infty$ have a nonlinear voltage dependence, typically through sigmoidal or exponential functions.



Types





Izhikevich, IEEE Trans. Neural Networks, 2004

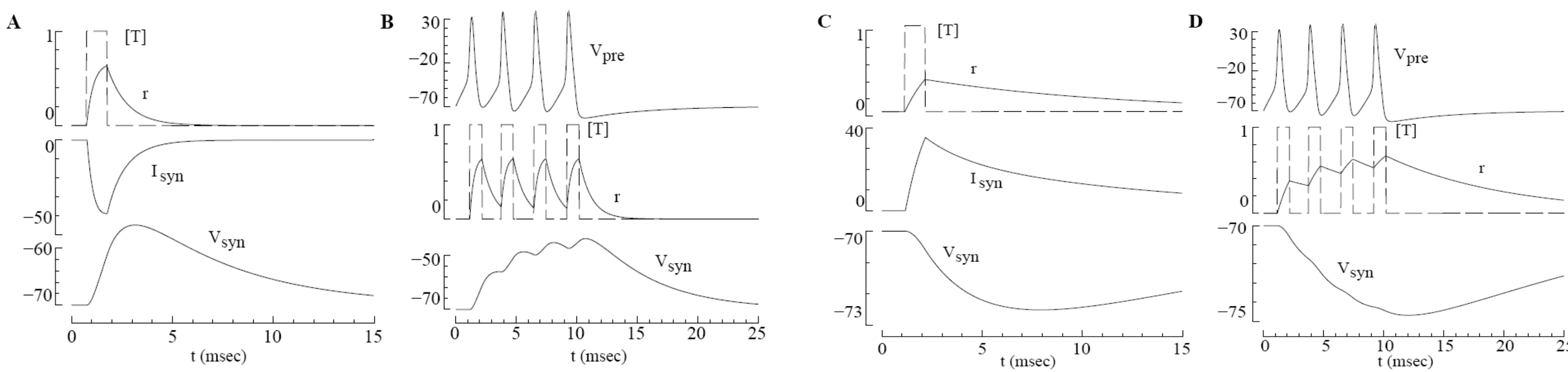
Models: synapses

Electrical: diffusive $I_{syn}(t)=g_{syn}(V_{post}-V_{pre})$

Chemical: integrators $I_{syn}(t)=g_{syn}r(t)(V_{post}-E_{syn})$; $dr/dt=a[T](1-r)-br$

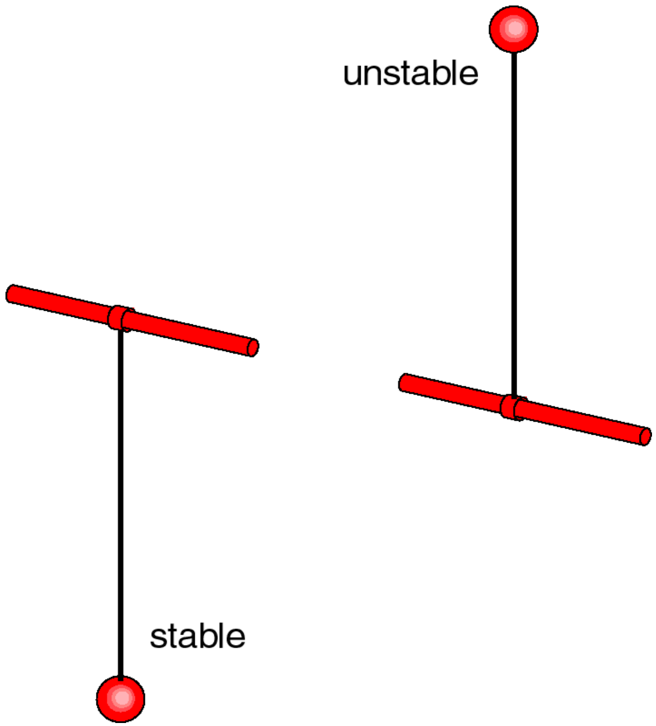
Excitatory

Inhibitory



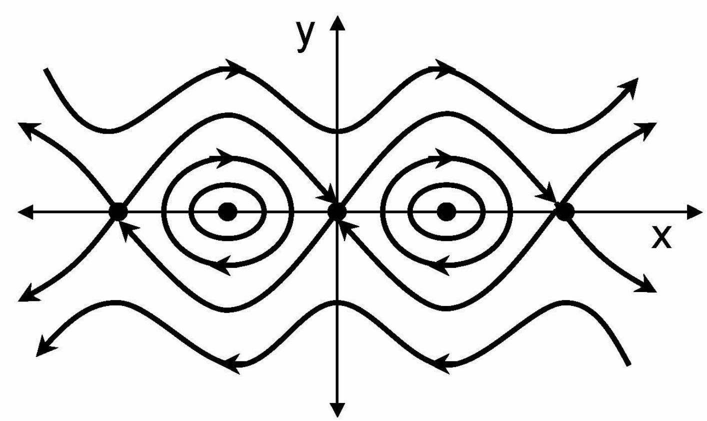
Destexhe, Mainen, Sejnowsky, Neural Comp., 1994

Dynamical systems



$$x'' + \sin(x) = 0$$

$$\begin{aligned} x' &= y \\ y' &= -\sin(x). \end{aligned}$$

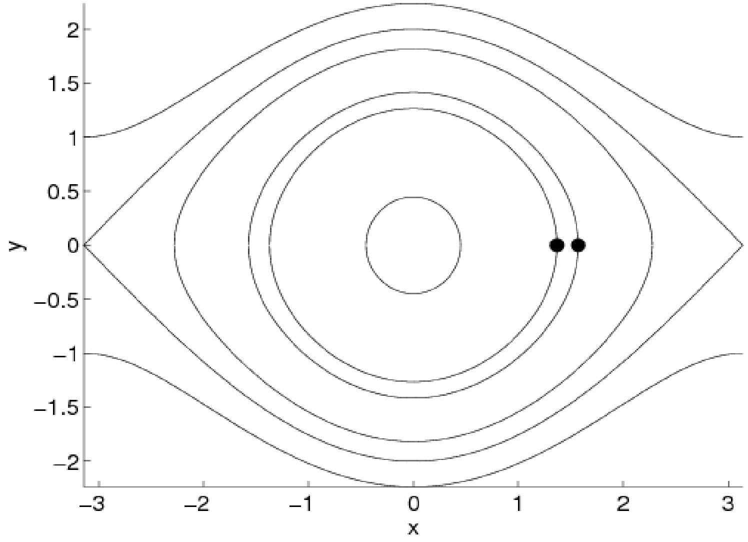


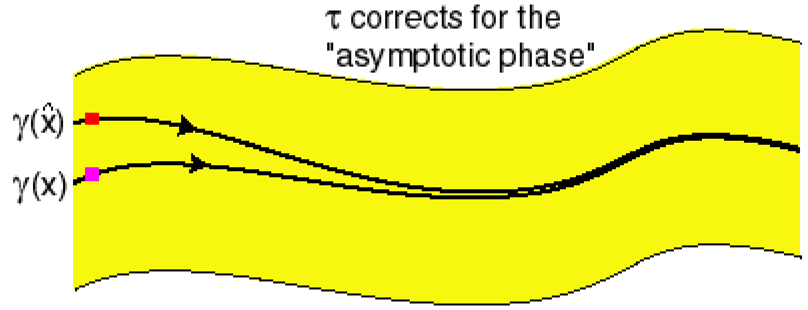
1. Equilibria: centre (stable), saddle (unstable)
2. Periodic orbits
3. Heteroclinic/Homoclinic trajectories

Stability

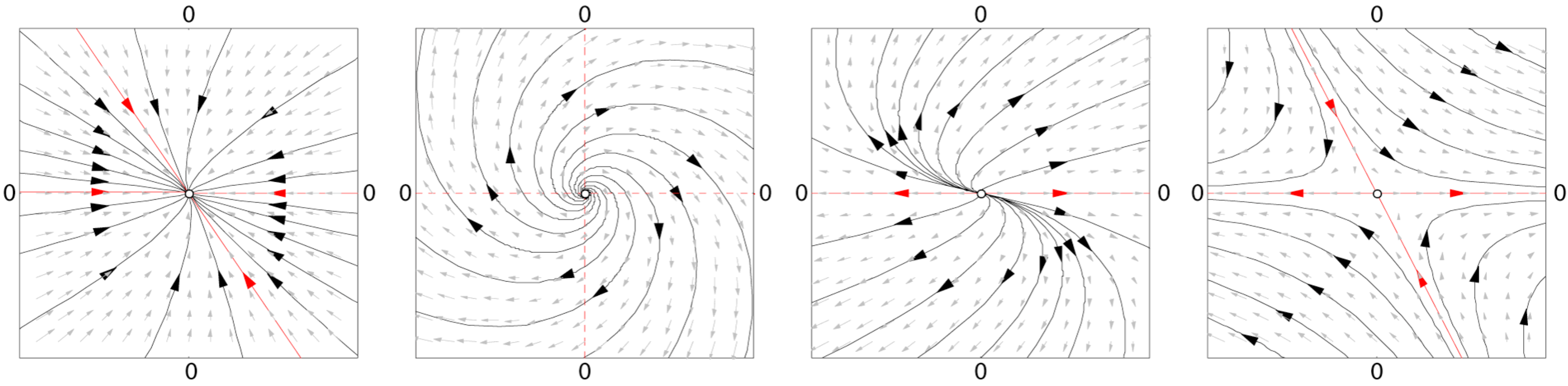
Lyapunov

Stability





Equilibria in 2D



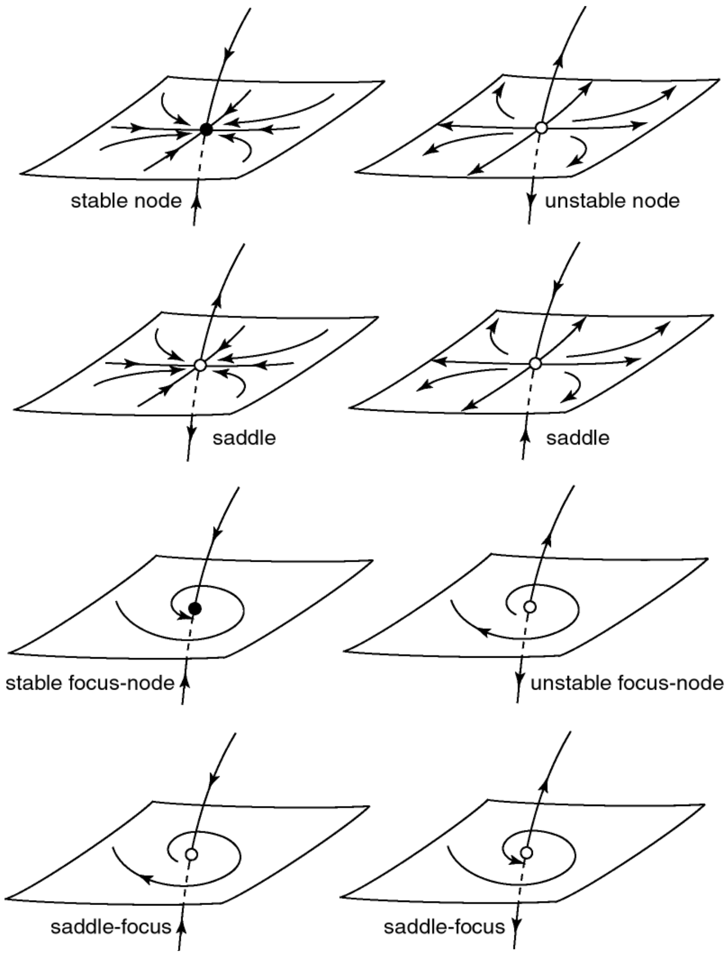
Stable node

Stable focus

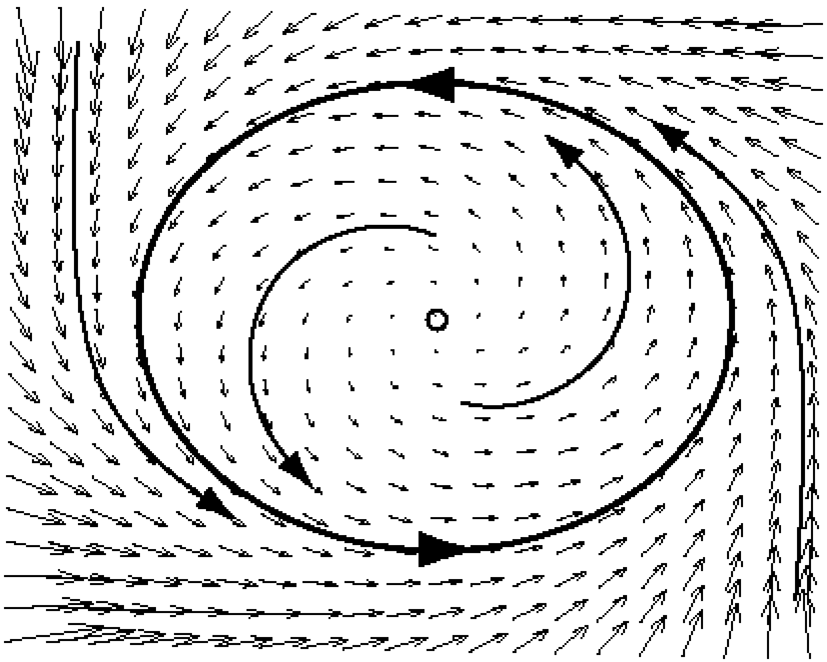
Unstable node

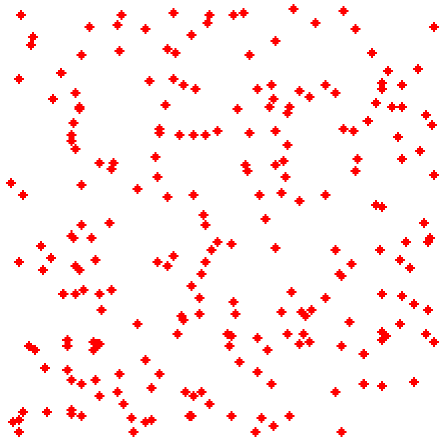
Saddle

Equilibria in 3D

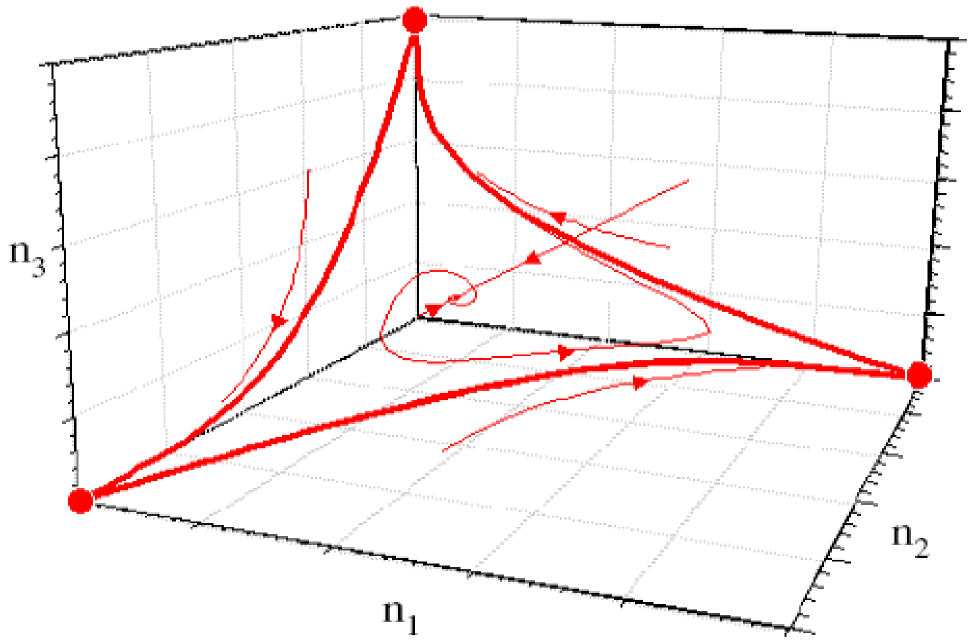


Limit cycles





Heteroclinic sequences



Lottka-Volterra model:
competition between three species

$$\dot{a}_1 = a_1[1 - (a_1 + \rho_{12}a_2 + \rho_{13}a_3)]$$

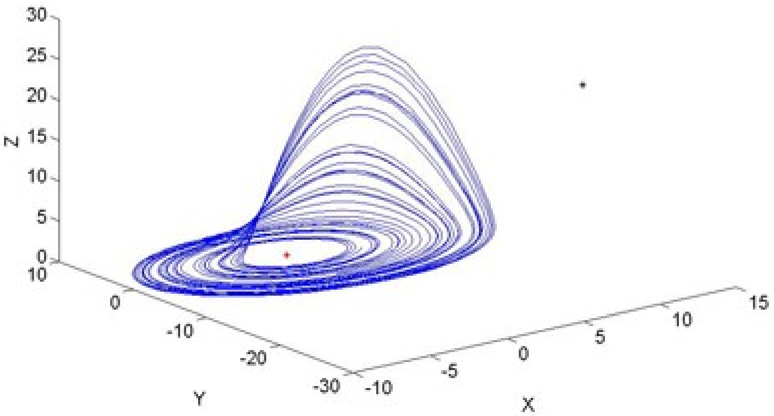
$$\dot{a}_2 = a_2[1 - (a_2 + \rho_{21}a_1 + \rho_{23}a_3)]$$

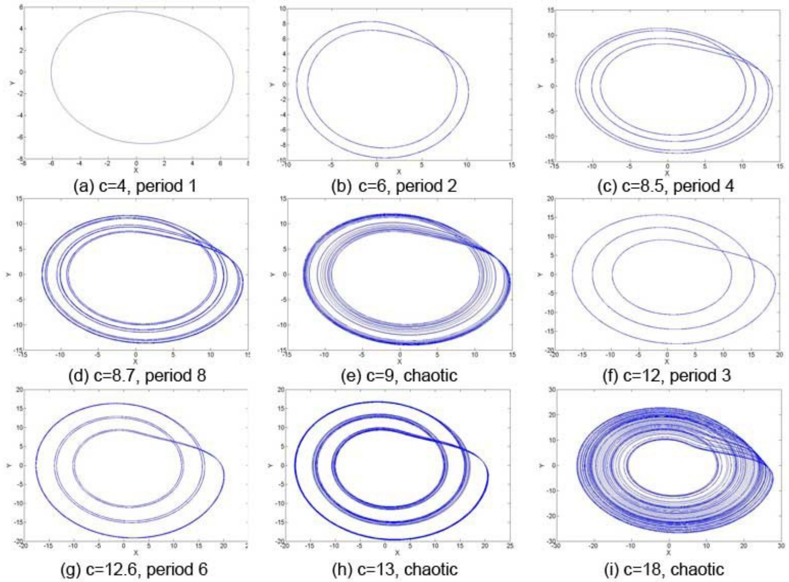
$$\dot{a}_3 = a_3[1 - (a_3 + \rho_{31}a_1 + \rho_{32}a_3)]$$

May and Leonard, 1975

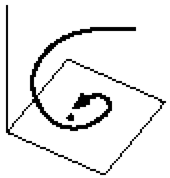
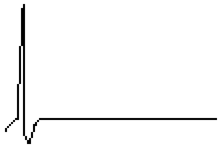
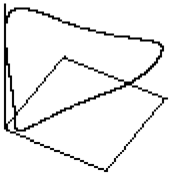
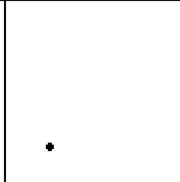
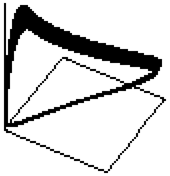
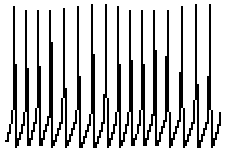
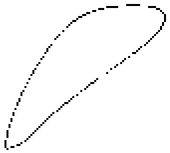
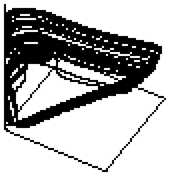
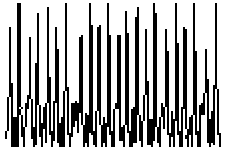
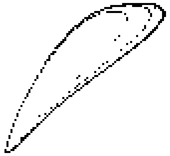
Chaotic attractors

Rossler attractor





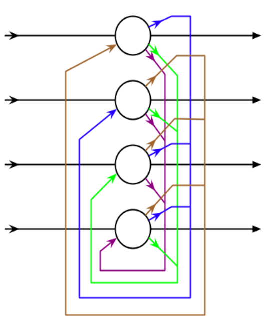
Hodgkin-Huxley model

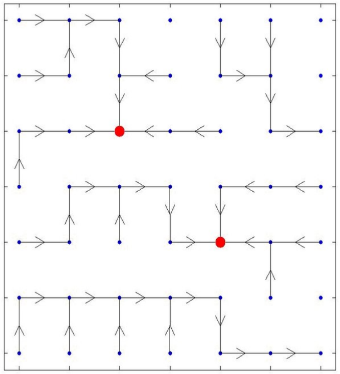
Attractors	Dynamics	Trajectories in State Space	Time Series	Topological Structure	Dimension	Lyapunov Spectrum	Poincare Section
Equilibrium Point	Static			**Point**	0	$\lambda_i<0$	
Limit Cycle	Periodic			**R/Z**	1	$\lambda_1=0$ $\lambda_i<0$ $(i \neq 1)$	
Torus	Quasi-Periodic			$\mathbf{R^k/Z^k}$	k	$\lambda_i=0$ $(i=1,2,\dots,k)$ $\lambda_i<0$ (otherwise)	
Strange Attractor	Chaotic			**Fractal**	Real Number	$\lambda_i>0$ $(i=1,2,\dots,n)$ $\lambda_i=0$ $(i=n+1,\dots,m)$ $\lambda_i<0$ (otherwise)	

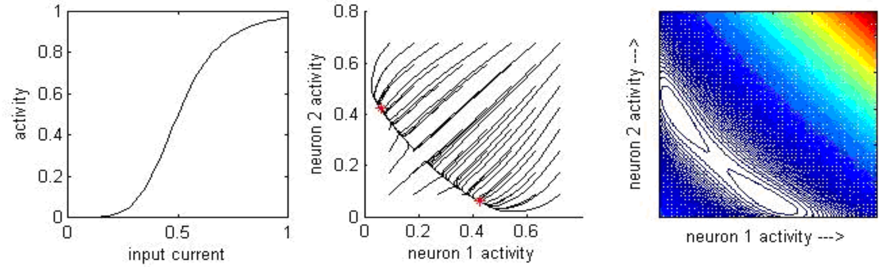
Computing with attractors

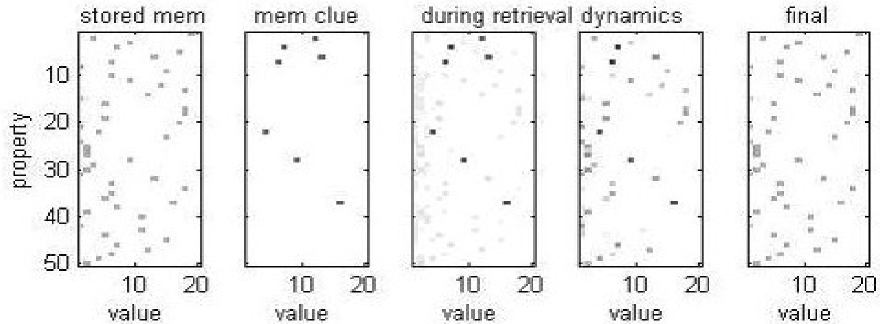
Associative memory: multi-stable system with convergence to one of the limiting sets from some initial condition/under some stimulus

Hopfield network







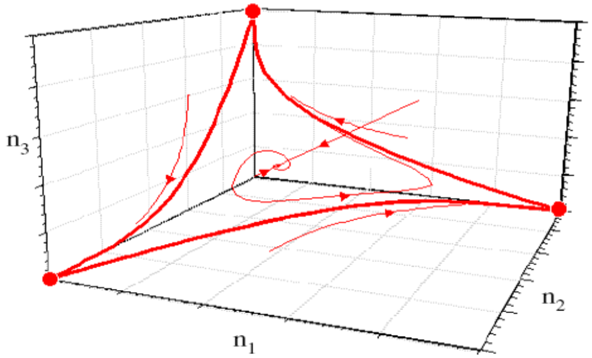


Transient dynamics

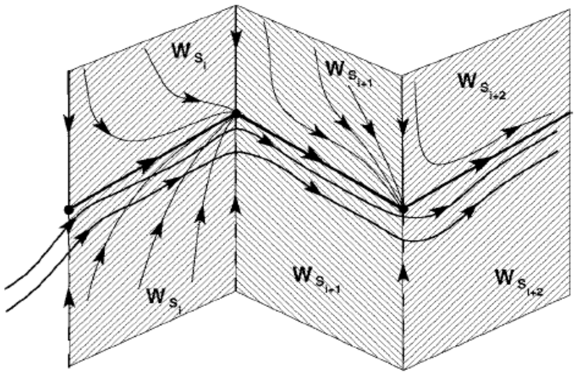
- Computation by attractors ignores dynamics, hence, is slow
- Equilibria or limit cycles cannot be realistically reached on often short timescales of neural computation
- No need for a classical attractor state
- No need for “resetting”

Transient dynamics

Small systems - periodic

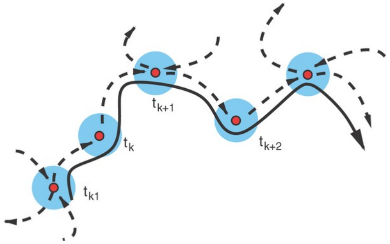


Large systems - sequential

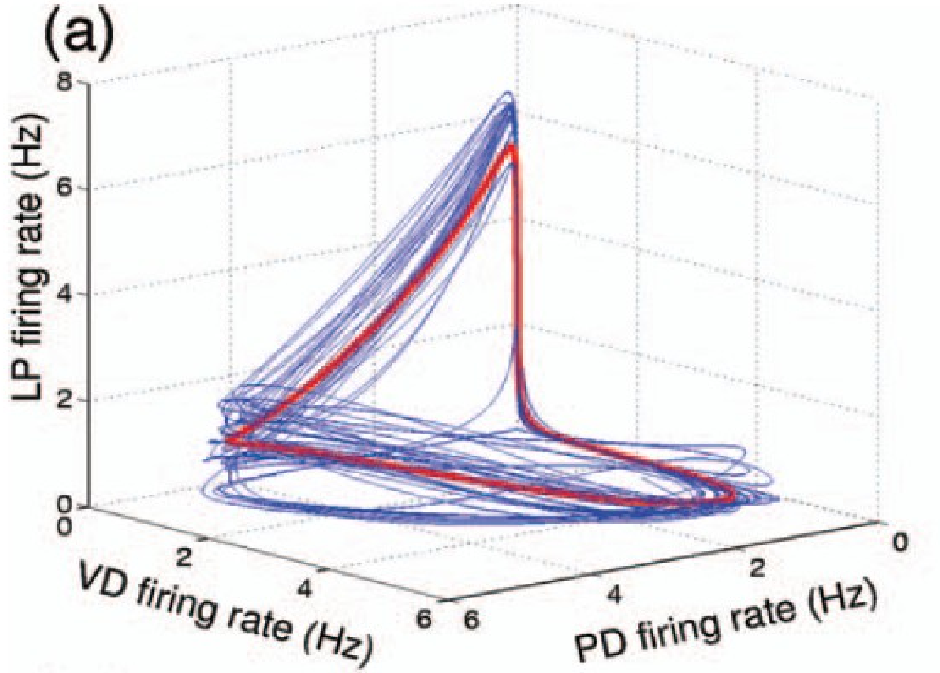


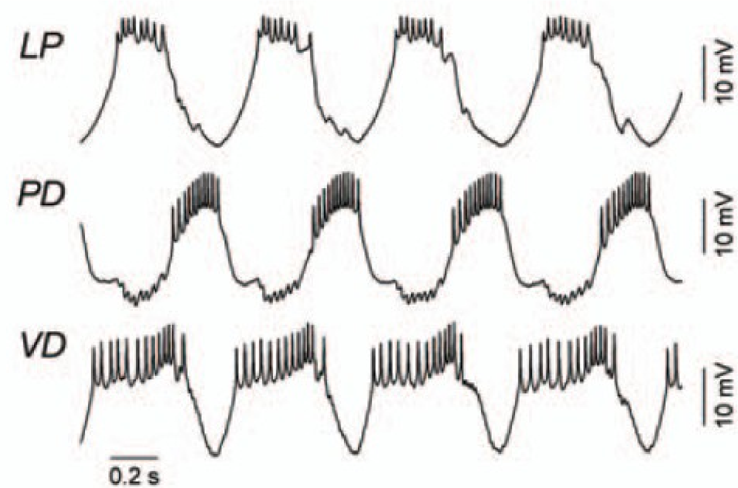
- Stability
- Robustness
- Variability

Decision-making



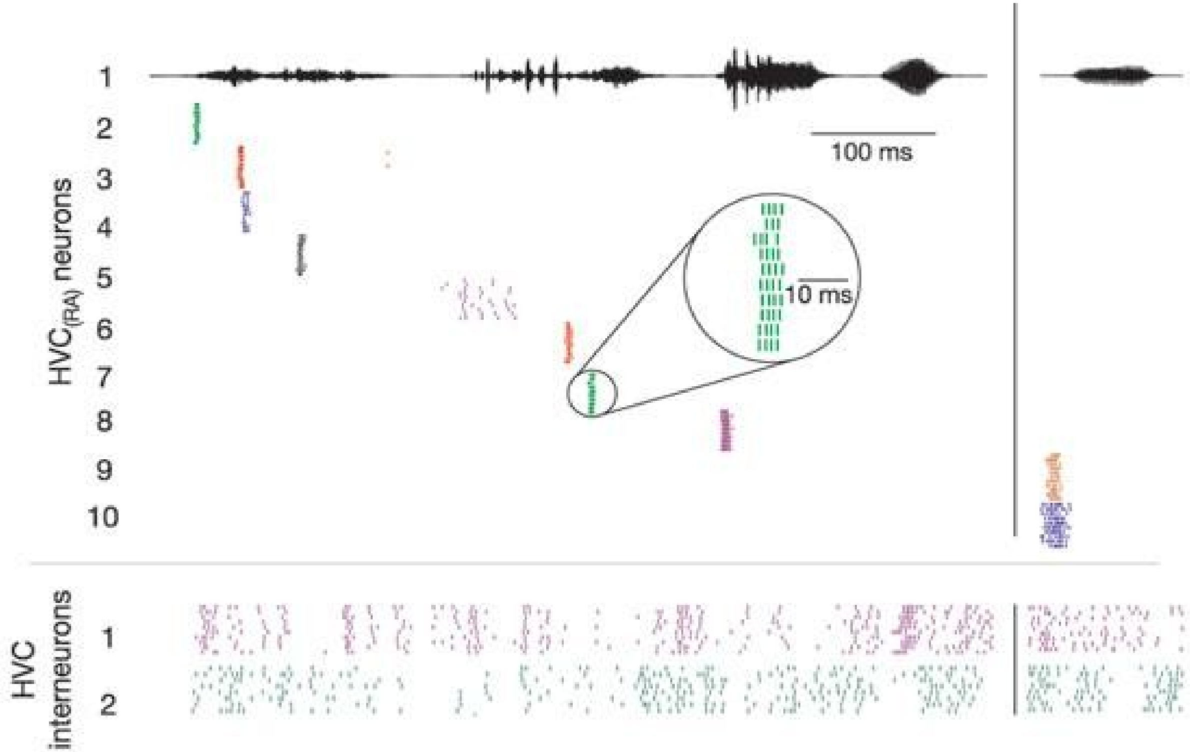
Pyloric rhythm of lobster stomatogastric ganglion



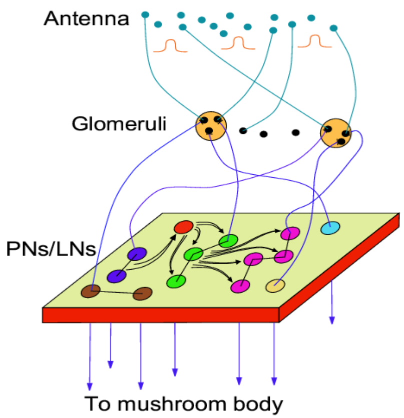


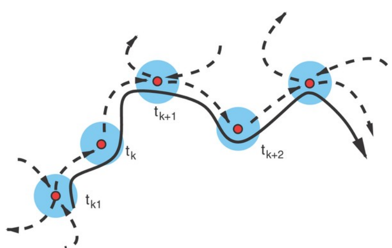
Rabinovich, Varona, Selverston, Abarbanel,
Reviews of Modern Physics **78,** 1213, 2006

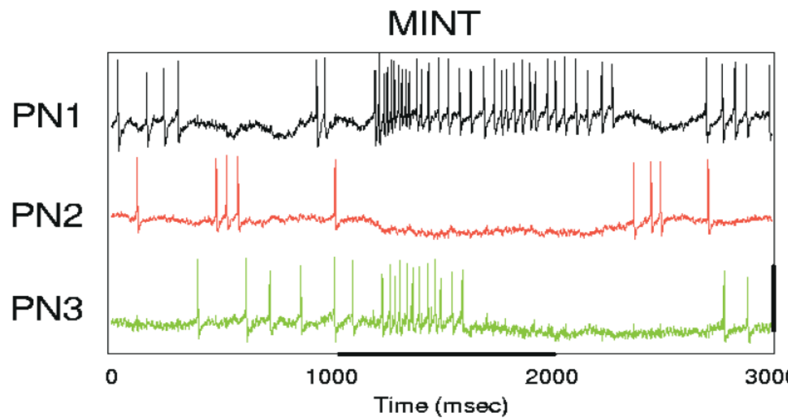
HVC Songbird patterns

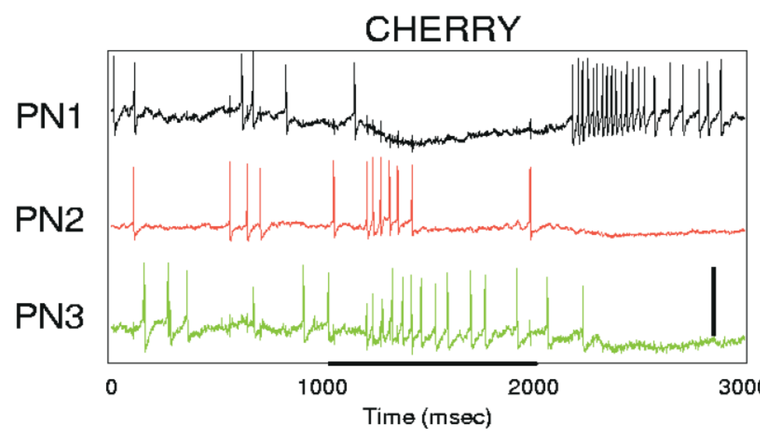


Odor sensing (locust antennal lobe)





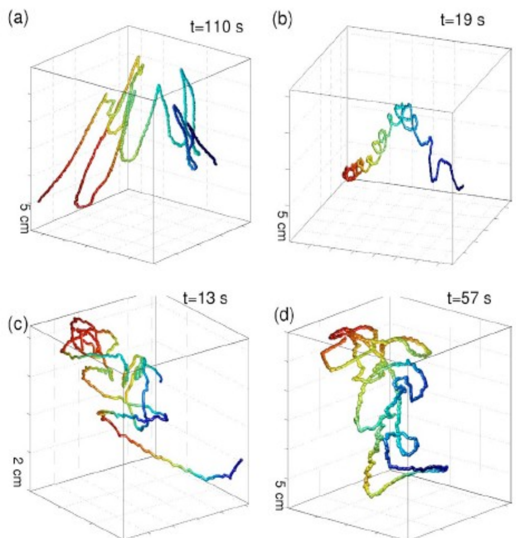


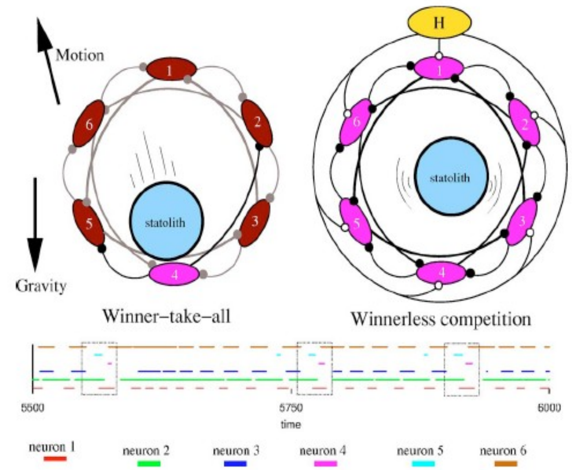


Clione's hunting

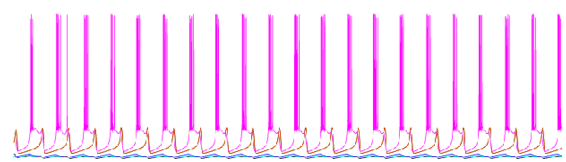
Clione (Sea angel)

Sea-butterfly

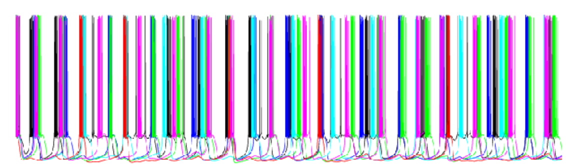




Winner-take-all



Winnerless competition



Summary

- Neurons exchange electrical signals and can be described by dynamical equations
- Neural networks: attractor computation or transient dynamics?
- Transient dynamics: robustness, reproducibility, variability
- Image: stable heteroclinic sequences
- Mathematics to follow...