Simulating networks
Neural networks

- Gelly fish, radial symmetry
Aplysia

- sea slug (sjöhare)
Experimental systems

- leech
- crayfish stomatogastric ganglion
- C. elegans
- aplysia, hermissenda, clione
- lamprey

- rat, mouse, cat
- primate, human
Network strategies

- small hard-wired network with few individual neurons
- large network with groups of “similar” cells. Precise structure affected by individual experience.
- Topographic map
- Labeled lines, specificity of projection
Coding

- frequency
- spiking duration
- number of spikes
- burst frequency
- burst duration

- population code
- interval coding
- place coding
- coarse – fine coding
- feature detectors
- synchronisation
Simulating a system

• total simulation (1-1)

• selecting a part

• subsampling

• population coding
Synaptic connectivity

- logical: cell A – cell B, group X – group Y
- geometrical: gaussian prob.
  - mexican hat

- beware, gaussians have infinite tails
- random numbers get very variable for small N
Corrections for subsampling

- larger synaptic conductances
- more synapses per cell
- higher firing frequency
- increased frequency dynamics
Changing the model

- from a sub-sample model to
  - pool of neurons
  - equivalent unit
Unit models
Visual system

Figure 2.1: The visual pathway in the cat.

Figure 2.2: Receptive fields. A) On-center and Off-center cells. Both types occur in the retina (RGCs) and in the LGN. B) Simple cell receptive fields. A light spot on areas marked with crosses will excite the cell. A dark spot will inhibit it. A dark spot on areas marked with triangles will excite the cell, while a light spot will inhibit it.
Orientation tuning

Hypothesis

Figure 3.1: Schematic view of three classes of models for the generation of orientation tuning in simple cells. a) The classical Hubel and Wiesel model only considers feedforward excitation. b) Wörgötter and Koch’s model adds inhibition. c) Somers’, Sompolinsky’s and the current model also supply recurrent excitation.
RGC model

lattice of RGC neurons

Difference of Gaussians

Figure 4.1: Comparison between model and real retinal activity. The figure shows the response of real retinal ganglion cells and model cells to a dark rectangular bar moving with 10°/s. The response is shown in four pairs of spike histograms. The upper two pairs show the response to a bar of width 0.5 deg, the lower 5°. The left pairs show the response of an ON-cell with an OFF-cell to the right.
LGN model

• dynamic compression (make difference between low and high smaller)
• log-like function $R(c) = 15 + 25 \log_{10}(c)$
• c.f. auditory system 10x -> doubling
V1 layer IV models

Ion channels of HH type for Na, K, Ca, K(Ca)

Figure 4.2: Schematic drawing of cell models used in the simulations. Each initial segment has an area of 1/10 of the soma. Each dendritic compartment has an area of 4 times the soma. A. The excitatory cell with a soma diameter of 21 μm. B. The inhibitory cell. Soma diameter is 7 μm. s = soma, i = initial segment, a = “apical dendrite”, b = “basal dendrite”; Synaptic input: open small circle = local excitatory input, black filled circle = local inhibitory input, grey filled circle = thalamic input
Simulation output

Figure 6.3: Somatic membrane potential for a neuron in the center of the cortical patch. The potential is plotted against time during an interval of 450 ms. Stimulus onset was at 100 ms. Stimulus duration was 250 ms.

Figure 6.2: Orientation sensitive mode of the network. Stimulus was on between $t = 100$ ms and $t = 350$ ms.
Orientation tuning of one cell

With recurrent connections
Response to input ±90 deg from optimal orientation

Without recurrent connections

Figure 6.6: Orientation tuning curve with full intracortical connectivity; single neuron in the center of the cortical patch. The vertical axis shows the mean firing frequency during stimulus presentation averaged over three presentations. The horizontal axis shows the angular deviation of the stimulus from the preferred orientation. Error bars show standard deviation.

Figure 6.7: Orientation tuning curve without excitatory and inhibitory intracortical feedback; single neuron in the center of the cortical patch. Geniculocortical synapse conductances were adjusted to high values (g = 150 nS) in order to obtain the same firing rates as with the intracortical connectivity in place. Axes as in figure 6.6.
Large systems

• Statistical mechanics, mean field theory
• consider a neuron in an infinite lattice of neurons
• assume all-to-all connectivity, e.g. infinite
• cell activity is stochastic, so input to one cell is $N$ stochastic non-linear eq.
• compute the average input using the central limit theorem, now $N$ nonlinear eq
• assume a uniform state*/average state, now 1 nonlinear eq. This can be solved!
• *in magnetic materials, this corresponds to the state under the critical temperature $T_c$
Oscillator models

- Assume continuously driven cells with frequency $f$ and phase $\theta \in [0, 2\pi]$
- $\theta = \omega$, $\omega = 2\pi f$
- $\theta = \omega t + \theta(0)$
- 2 cells: $\theta_1 = \omega_1 + h_{12}(\theta_1, \theta_2)$, $\theta_2 = \omega_2 + h_{21}(\theta_1, \theta_2)$
- fasskillnad $\phi = \theta_1 - \theta_2$, $\phi = \theta_1 - \theta_2$
- assume $h$ depends only on $\phi$ and $h=0$ when $\phi=0$
Oscillator models

- Example: $h_{ij} = a_{ij} \sin(\theta_j - \theta_i)$
  
  $$= (\omega_1 - \omega_2) - (a_{12} + a_{21}) \sin(\phi)$$

  special case: assume $\phi = 0$, e.g., phase lock
  
  $$\phi = \arcsin \left[ (\omega_1 - \omega_2) / (a_{12} + a_{21}) \right]$$

- case 1: weak coupling, ratio > 1
  e.g., no solution, oscillators drift relative each other
Oscillator models

\[ \phi = \arcsin \left[ \frac{(\omega_1 - \omega_2)}{(a_{12} + a_{21})} \right] \]

case 2: ratio = \pm 1 e.g. phase lock

case 3: positive net coupling (nominator > 0), fast oscillator leads 0 - 90 degrees

case 4: negative net coupling (nominator < 0 ), fast oscillator “leads” by -90 - 0 degrees e.g. slow oscillator leads by 90 - 180 deg.
special case: \( \omega_1 = \omega_2 \), we get lock at 0 deg. for sync and 180 deg. for antisync.
Lamprey

simple vertebrate swimming like Eel swimming *in vitro*
So how does it look during simulations?

An 86 compartment model

A cubic mm of tissue

A full scale simulation (10000 cells) of the lamprey spinal cord swimming rhythm generating network showing alternating left-right activity spreading from head-to-tail