We will use neural modeling software (and pre-written Matlab codes) to understand how neurons, synapses, and networks/systems work. We will simulate cellular neurophysiology experiments to explore resting and action potentials, firing properties, synaptic conductances and integration. Idealized models (firing rate and probability-based functional descriptions) will be used for system-level and network properties including receptive fields, perceptual and cognitive dynamics including decision-making, perceptual grouping and multistability. The software will include dynamic visualization and animation tools. The course will involve classroom lectures and interactive computing lab sessions, homework and a simulation project. No programming experience is necessary.

Books: **NIA** and **SDA**
John Rinzell CNS, Rm 1005 & Courant, Rm 421
rinzel@cns.nyu.edu
x83308

Class organization and grades:
• participation, presentation of material – NIA tutorials/SDA text
• modeling project: written report and oral presentation
• some Homeworks

Resources:
• Course text books: NIA and SDA
• ModelDB (data base) http://senselab.med.yale.edu/ModelDB/

• NYU Blackboard for this course.
References on Nonlinear Neuronal Dynamics

Rinzel & Ermentrout. Analysis of neural excitability and oscillations. In Koch & Segev (see below). Also as “Meth3” on www.pitt.edu/~phase/


References on Cellular Neuro, w/ modeling.


Computational Neuroscience

What “computations” are done by a neural system?

How are they done?

WHAT?

Feature detectors, e.g., visual system.
Coincidence detection for sound localization.
Memory storage.
Code: firing rate, spike timing.

Statistics of spike trains
Information theory
Decision theory
Descriptive models

HOW?

Molecular & biophysical mechanisms at cell & synaptic levels – firing properties, coupling.
Subcircuits.
System level.
Nonlinear Dynamical Response Properties

Cellular: “HH”

Excitability
Repetitive activity
Bistability
Bursting

Network: Wilson-Cowan
(Mean field)
Auditory brain stem neurons fire phasically, not to slow inputs. Blocking $I_{KLT}$ may convert to tonic.

J Neurosci, 2002
Synaptic input – many, $O(10^3 \text{ to } 10^4)$

“Classical” neuron

Dendrites, 0.1 to 1 mm long

Signals: $V_m \sim 100 \text{ mV}$ membrane potential
$O(\text{msec})$ to longer ionic currents

Membrane with ion channels – variable density over surface.

Dendrites – graded potentials, linear in classical view

Axon – characteristic impulses, propagation
Electrical Activity of Cells

• $V = V(x,t)$, distribution within cell
  • uniform or not?, propagation?
• Coupling to other cells
• Nonlinearities
• Time scales

Current balance equation for membrane:

$$C_m \frac{\partial V}{\partial t} + I_{ion}(V) = \frac{d}{4R_i} \frac{\partial^2 V}{\partial x^2} + I_{app} + \text{coupling}$$

Coupling:

- $\sum_j g_{c,j}(V_j-V)$ “electrical” - gap junctions
- $\sum_j g_{syn,j}(V_j(t))(V_{syn}-V)$ chemical synapses

$I_{ion} = I_{ion}(V,W)$ generally nonlinear

$$= \sum_k g_k(V,W)(V-V_k)$$

$\frac{\partial W}{\partial t} = G(V,W)$

gating dynamics
A QUANTITATIVE DESCRIPTION OF MEMBRANE CURRENT AND ITS APPLICATION TO CONDUCTION AND EXCITATION IN NERVE

BY A. L. HODGKIN AND A. F. HUXLEY

From the Physiological Laboratory, University of Cambridge

(Received 10 March 1953)

100 mV

Action potential squid axon

V_rest

1 msec

Nobel Prize, 1959
Warmups… animations created with NIA/NEURON simulations
These are from the MiniMovies collection in NIA.

Spike generation in single compartment (patch) model: threshold and latency.

Spike – propagating along an axon, 50 microns diameter.

Synaptic integration and spiking in an idealized motoneuron model.

Saturation of EPSP as \( g_{exc} \) increases.
NEURON simulations of synaptic integration and dendritic spiking in “realistic” models of hippocampal neurons (Kath et al).

http://people.esam.northwestern.edu/~kath/dual.html

http://people.esam.northwestern.edu/~kath/gating.html.