# INTRODUCTION TO COMPUTER MODELING OF NEURONAL SYSTEMS

Special Topics in Neural Science :V80.0302001/G80.3042001

3 points. Spring term, 2009.

Monday, 4:00-6:00, Meyer Rm 815.  J. Rinzel.

Prerequisite:  Calculus I-II.  (seek consent of instructor if in doubt).

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**

**Neurons in Action2**  by JW Moore and AE Stuart.  Sinauer 2007, Book &  Disk.

**Spikes, Decisions, and Actions: The Dynamical Foundations of Neuroscience** by HR Wilson. Oxford University Press 1999, Book & Disk.

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**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/
- Electrophysiology of the Neuron  (EOTN) by J Huguenard & D McCormick. http://tonto.stanford.edu/eotn/   The NEURON version by Arthur Houweling: http://www.cnl.salk.edu/~arthur/MyFirstNEURON.html
- HHSim by D Touretzky et al. http://www-2.cs.cmu.edu/~dst/HHsim/

- 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/

Izhikevich, EM: Dynamical Systems in Neuroscience. The Geometry of Excitability and Bursting. MIT Press, 2007.

Wilson, HR: Spikes, Decisions and Actions. Oxford, 1999.

Strogatz, S. Nonlinear Dynamics and Chaos. Addison-Wesley, 1994.

## References on Cellular Neuro, w/ modeling.

Koch, C. Biophysics of Computation, Oxford Univ Press, 1998.

Koch & Segev (eds): Methods in Neuronal Modeling, MIT Press, 1998.

# Computational Neuroscience

What "computations" are done by a neural system?

How are they done?

WHAT?

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

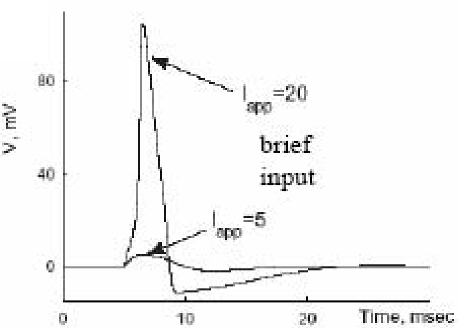
Statistics of spike trains
Information theory
Decision theory
Descriptive models

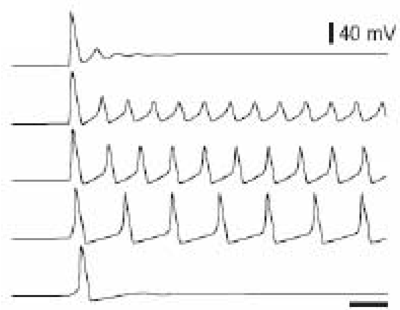
HOW?

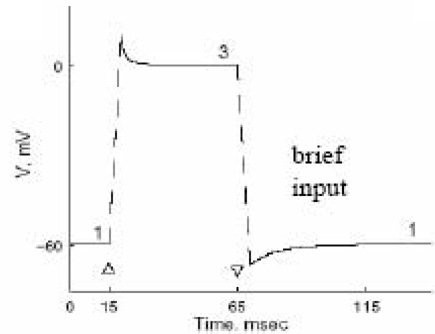
Molecular & biophysical mechanisms at cell & synaptic levels – firing properties, coupling.
Subcircuits.
System level.

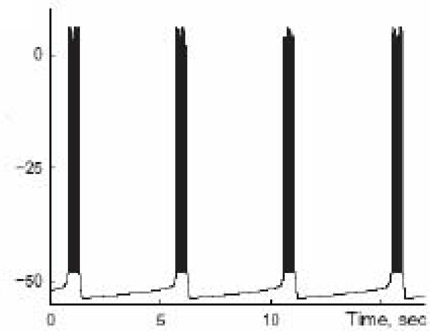
# Nonlinear Dynamical Response Properties

Cellular: "HH"



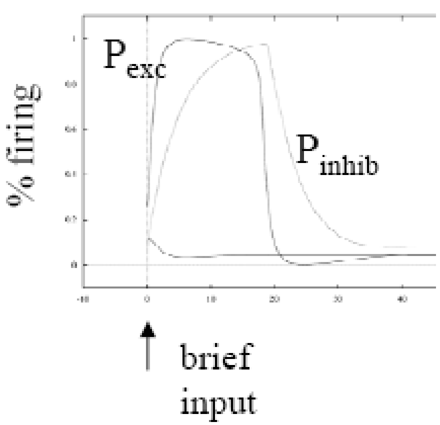



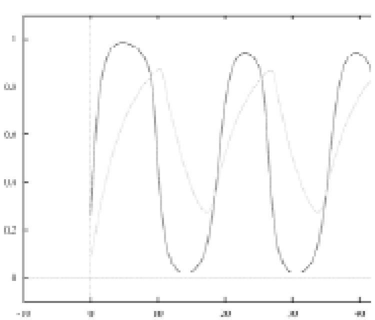



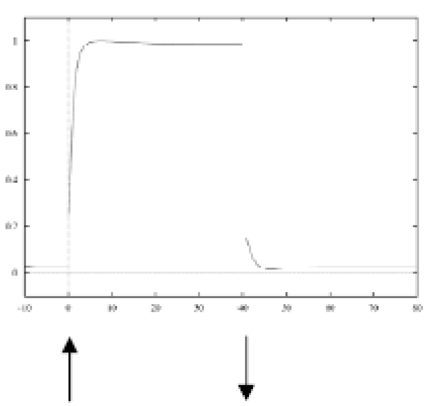

Excitability | Repetitive activity | Bistability | Bursting

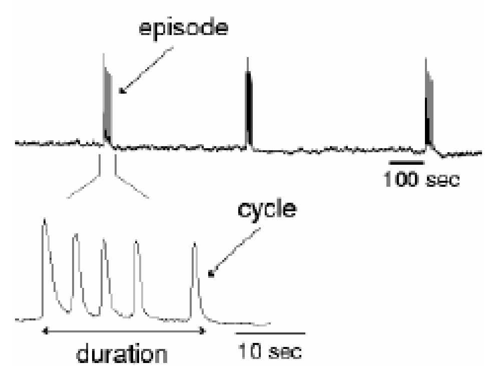
Network: Wilson-Cowan

(Mean field)



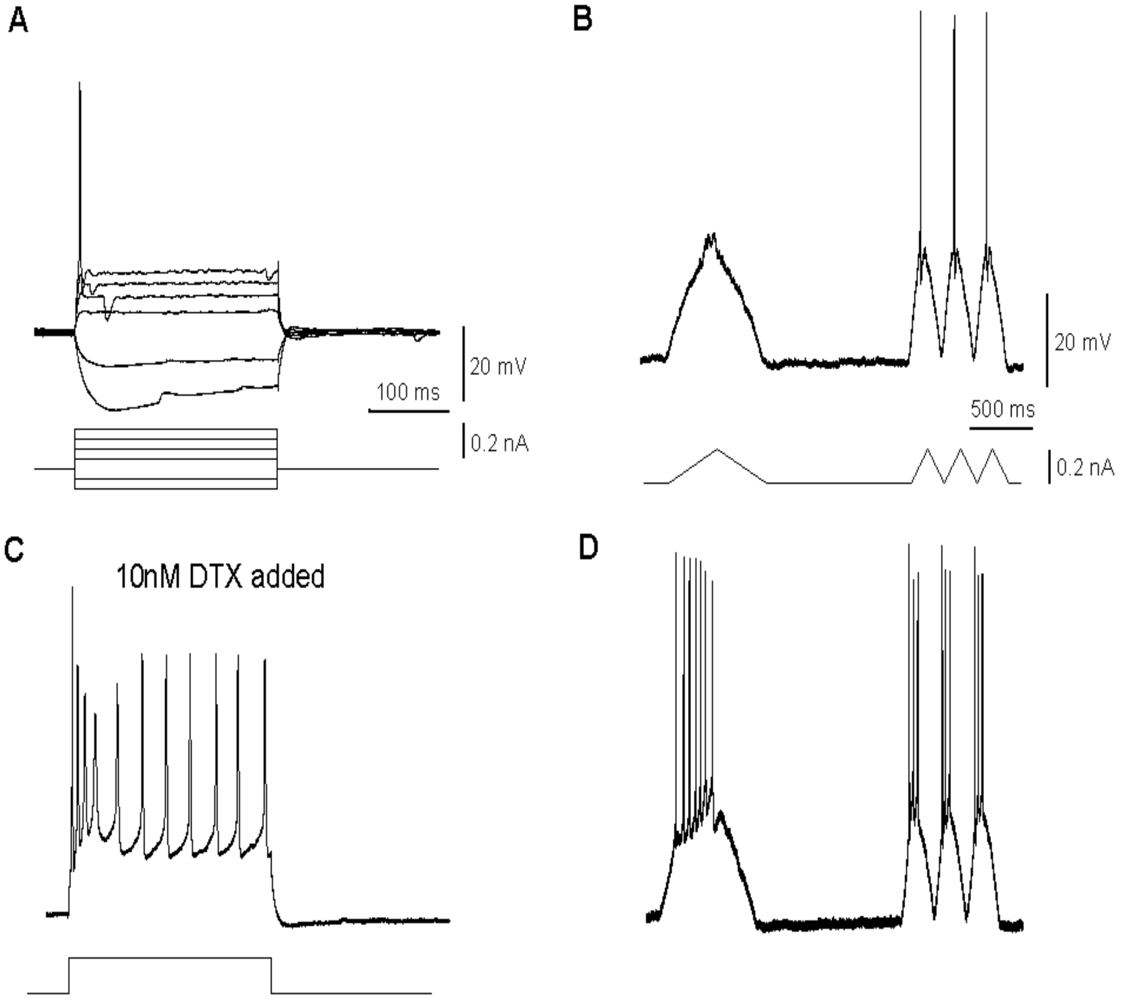







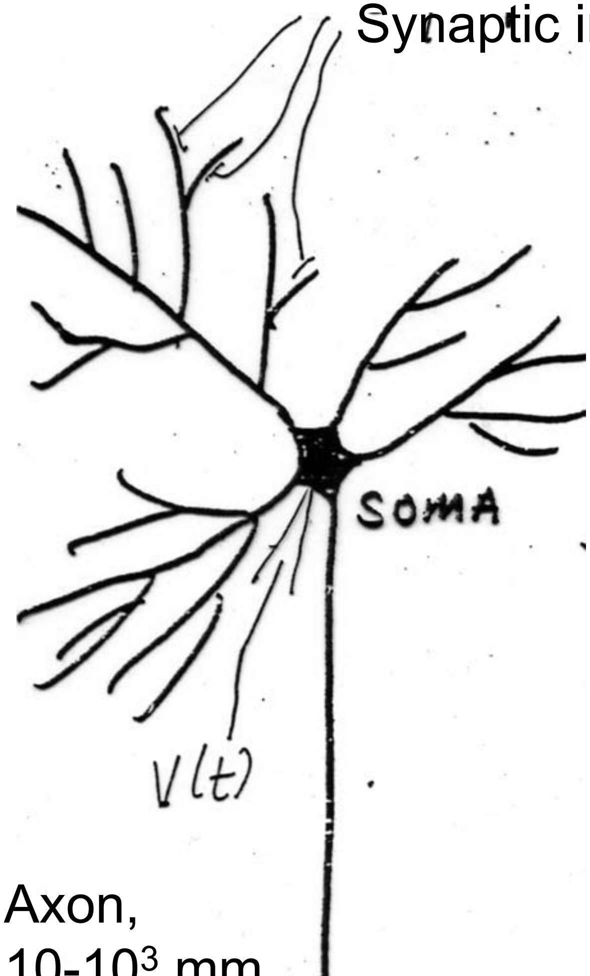
Auditory brain stem neurons fire phasically, not to slow inputs. Blocking $I_{KLT}$ may convert to tonic.

J Neurosci, 2002



Synaptic input – many, O($10^3$ to $10^4$)

# “Classical” neuron




Dendrites, 0.1 to 1 mm long

Signals: $V_m$ ~ 100 mV membrane potential
O(msec) to longer
ionic currents

Membrane with ion channels –
variable density over surface.

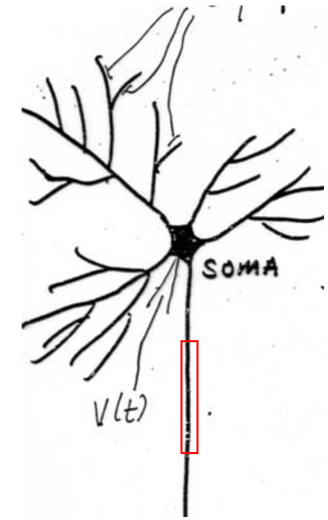
Dendrites – graded potentials,
linear in classical view

Axon – characteristic impulses, propagation

Axon,
10-$10^3$ mm

neurons,
muscles

# 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:

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

capacitive — channels — cable properties — other cells

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Coupling: $\sum_j g_{c,j}(V_j - V)$ "electrical" - gap junctions

other cells

$\sum_j g_{syn,j}(V_j(t))\,(V_{syn} - V)$ chemical synapses

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

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

channel types

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

gating dynamics

J. Physiol. (1952) 117, 500–544

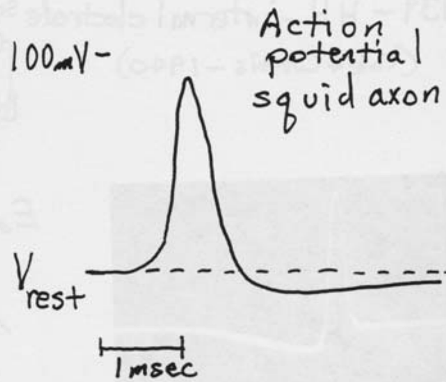
# A QUANTITATIVE DESCRIPTION OF MEMBRANE CURRENT AND ITS APPLICATION TO CONDUCTION AND EXCITATION IN NERVE

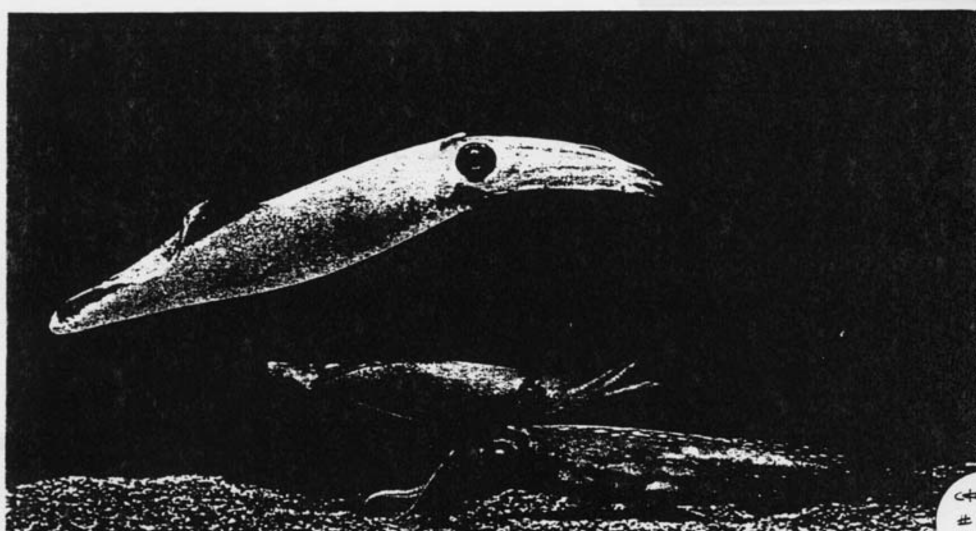
By A. L. HODGKIN and A. F. HUXLEY
*From the Physiological Laboratory, University of Cambridge*

(*Received* 10 *March* 1952)


Alan Lloyd Hodgkin


Andrew Fielding Huxley



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.