Math Aspects of Neurophysiology

J Rinzel, Fall 2016
Tuesday, 1:25 pm-3:15 pm, WWH 512.

MATH-GA 2863 Advanced Topics in Math Physiology (Courant Inst)
NEURL-GA 3042 Special Topics in Neural Science (CNS)
BIOL-GA 2855 Special Topics in Math Physiology (Biology)

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1. (sept 7-14) Overview and some "toy models" (integrate & fire) [1]
2. (sept 14) Membrane biophysics [2]
    a. Electrodiffusion theory for ion fluxes: resting potential; flux through open channels (optional)
    b. Channel gating; deterministic and stochastic treatments
3. Excitability and action potentials (APs) [4-6]
    a. (sept 21) The Hodgkin-Huxley model
        i. development of the model, I-V rel'ns
        ii. phase plane treatment of V-m, and V-n/h reductions
        iii. repetitive firing, Hopf bifurc'n

    (sept 28) Dan Tranchina: numerical soln of the cable eqn

    b. (oct 5) The Morris-Lecar model
        i. phase plane analysis of AP, single and multiple steady states
        ii. repetitive firing: Type I (saddle-node), II (Hopf)
        iii. bistability of various types
    c. (oct 5) Functional diversity of currents
    d. (oct 12) Other firing dynamics
        i. onset firing: Type III, input slope detector
        ii. adaptation; post-inhibitory rebound
        iii. bursting w/ fast/slow geometric analysis
        iv. Optional: stochastic firing; phase-locking
4. Cable equation, axonal propagation [7-9]
    a. Optional: numerical methods.
    b. (oct 19) Traveling AP and AP trains; sing perturb'n treatment; dispersion relation; kinematics
    c. (oct 26) Stimulus-response properties & numerical methods

d. (nov 2) Effects of inhomogeneities; propagation in myelinated axon

5. Dendritic signaling [10-11]
    a. (nov 9) Rall's model: equivalent cylinder approximation; estimating passive neuronal parameters; compartmental treatment
    b. (nov 16) Signal attenuation in branching trees
    c. (nov 16) Active properties in dendrites

    (nov 23) Thanksgiving break

    d. (nov 30) Reduced models with few compartments; segregated currents
    e. (nov 30) Coincidence detection with dendrites; dendritic spines
6. Synaptic transmission and dynamics [12-13]
    a. (dec 7) Models for postsynaptic conductance dynamics
    b. (dec 7) Presynaptic considerations: calcium domains, pool depletion
    c. (dec 14) Facilitation, depression, plasticity (LTP, STDP, NMDA)
    d. (dec 14) Optional: Effects on cell interactions - synchronization or not.

Some references (on reserve in Courant Library)

Koch, C. Biophysics of Computation, Oxford Univ Press, 1998.
Ermentrout B & Terman D. Mathematical Foundations of Neuroscience. Springer, 2010.
Izhikevich, EM. Dynamical Systems in Neuroscience. The Geometry of Excitability and Bursting. MIT Press, 2007.
Strogatz, S. Nonlinear Dynamics and Chaos. Addison-Wesley, 1994.

Available on course web site (NYU Classes)

Rinzel & Ermentrout. Analysis of neural excitability and oscillations. In Koch & Segev (see above). Also "Live" on www.pitt.edu/~phase/
Borisyuk A & Rinzel J. Understanding neuronal dynamics by geometrical dissection of minimal models. In, Chow et al, eds: Models and Methods in Neurophysics (Les Houches Summer School 2003), Elsevier, 2005, 19-72.

Peskin lecture notes, 2000.

https://www.math.nyu.edu/faculty/peskin/neuronotes/index.html

What's expected:

- Homework: 4 or so assignments (~ 40% of grade)
- Modeling project: written and oral presentation (~ 40%)
    - Your model or from literature; your question.
    - Report: 5-7 pgs. Intro, Methods, Results, Conclusions; figs & captions.
    - Oral presentation at end of term
    - Abstract due Nov 29
- Other: participation etc (~20%)