Math-GA 2855-001 Special topics in mathematical physiology:
Neuronal Networks.
Fall 2019.
Wednesday, 1:25pm -3:15pm, WWH 517. J. Rinzel.
First class: Sept 4, 2019

Prerequisites. Math: familiarity with applied differential equations or permission of instructor; Neurobiology: most background will be provided.

This course will involve the formulation and analysis of differential equation models for neuronal ensembles and neuronal computations. Spiking and firing rate mechanistic treatments of network dynamics as well as probabilistic behavioral descriptions will be covered. We will consider mechanisms of coupling, synaptic dynamics, rhythmogenesis, synchronization, bistability, adaptation,… Applications will likely include: central pattern generators and frequency control, perceptual bistability, working memory, decision-making, feature detection in sensory systems, cortical dynamics (gamma and other oscillations, up-down states, balanced states,…), time estimation and learning a rhythm. Students will undertake computing projects related to the course material: some in homework format and a term project with report and oral presentation.

SYLLABUS

1. (04sept) Goals/Overview -- preview of types of problems/phenomena; basics of cell neurophysiology and cell-level models. (ref'ce: B&R) Tutorial on ODES if needed.

2. (11sept) Firing rate models: intro & qualitative dynamics (ref'ce: E&T: 11.1, 11.3)
    a. Ad hoc derivation/formulations of Wilson & Cowan (WC) e-i models; inclusion of rate & synaptic gating.
    b. Derivation based on asynchrony and/or slow synapses

3. (18sept) Analysis of WC models: stability, phase planes, e-i and other configurations.

4. (25sept & 02oct) Neuronal competition
    a. Perceptual bi/multi-stability – phenomenological models: mutual inhibition+adaptation+noise; fast/slow analysis
    b. Sensory-based competition models: auditory bistability; binocular rivalry
    c. Build-up: signal detection and evidence accumulation models
    d. Winnerless competition: heteroclinic cycles
    e. Demo of XPP

5. (9oct) Central Pattern Generator (CPG), half-center oscillator models: PRCs, weak coupling, sync patterns (crayfish, lamprey).

6. (16oct & 23oct) Decision making/evidence accumulation
    a. Two-alternative forced choice task: moving dots, Newsome/Shadlen.
        i. Firing rate competition models: Wong & Wang.
        ii. Drift diffusion model, accuracy/speed tradeoff: Wong, Holmes, Eckoff
        iii. Ramping or trial-averaged discrete stepping? Latimer Pillow etal

b. Two-interval discrimination: Machens etal

7. (30oct) Slow rhythms.
    a. Episodic rhythm in developing spinal cord, e-e with synaptic depression
    b. Up/down states – non-REM sleep; rate models: e-e w/ adaptation, e-i balanced state, oscillatory or noise-induced transitions
    c. i-i slow oscillation (Wang&Rinzel); propagating (slow) thalamic waves; cortical waves (here or later?)

8. (06nov & 13nov) Fast oscillations - gamma-like.
    a. Motivation about gamma oscillations
    b. Spiking models: Wang/Buzsaki; PING/ING (Kopell et al); Wang/Brunel: asynchronous irregular firing
    c. Firing rate models for gamma (Keeley/Rinzel); coexistent fast and slow gamma

9. (20nov) Cell-spike-based network modeling
    a. Tutorial on implementation
    b. Balanced state: high variability, low correlations; vanVreeswjck & Sompolinsky
    c. Dynamics of synchrony - spike-spike (vanVreeswjck et al)
    d. Derivation of rate from cell-based spiking: Latham et al (2000, 2014) – low spont rate w QIF units; exact reduction for special heterogeneity (Ott, Antonsen etal).

27nov --- Thanksgiving

10. (04dec) Distributed networks: Working memory, persistent activity. (ref'ce: Gerstner et al: 18.3 ; E&T: 12.4)
    a. Formulation of distributed WC networks; demos.
    b. Bump attractors: spatial working memory; Brunel, Wang etal.
    b. Analysis of Amari bump model
    c. Line attractors: parametric working memory; Tank, Goldman, Askry – goldfish.
    d. Visual perception: orientation tuning: input driven; Sompolinsky et al
    e. Auditory perception: frequency tuning, Reyes.

11. (11dec) Large scale network modeling. (XJ Wang?) or Time estimation & learning to keep a rhythmic beat

(16dec) Last day of classes

12. (18dec) **Projects. (written report and oral presentation)**

Some references.

Strogatz, S. Nonlinear Dynamics and Chaos. Addison-Wesley, 1994.
Ermentrout & Terman. [E&T] Mathematical Foundations of Neuroscience. Springer, 2010.
Borisyuk A & Rinzel J. [B&R] Understanding neuronal dynamics by geometrical dissection of minimal models. In Chow et al, eds: Models & Methods in Neurophysics, Elsevier, 2005, 19-72
Gerstner W, Kistler WM, Naud R & Paninski L. [Gerstner etal] Neuronal Dynamics. Cambridge, 2014.