**MATH-GA 2855-002/NEURL-GA 3041-001**
**SPECIAL TOPICS IN MATHEMATICAL PHYSIOLOGY:**
**Neuronal Networks.**
**Fall 2017.**
Wednesday, 1:25pm -3:15pm, WWH 517.  J. Rinzel.
First class:  Sept 6, 2017

**SYLLABUS**

1.  (06sept) Goals/Overview -- preview of types of problems/phenomena
    a.  Emphasis on dynamics of networks and mechanistic modeling: firing rate/mean field (MF): Wilson-Cowan (WC);  cell/biophys-based: HH-like
    b.  General principles/features: neuronal competition, rhythms, synchrony or not, effects of architecture/spatial structure, multiple time scales, multistability, noise (helpful or problematic)
    c.  Applications… primarily, using firing rate models
        i.  Competition models (CPG – half-center, perceptual bistability – alternations, perceptual grouping)
        ii.  Spontaneous rhythms/synchronization (CPGs, development, brain states, gamma oscillations)
        iii.  Decision-making/evidence accumulation (Newsome et al: drifting dots, Romo et al: vibro-tactile, drift-diffusion model, biophys models (Wang), free-choice)
        iv.  Distributed computation: Persistent activity - working memory/bumps; cortical/thalamic waves; sensory receptive fields; perceptual ambiguity (Heeger; barber pole/tritone paradox); hallucinations.
        v.  Cell-based networks: spike-spike synch; Wang: decision making; gamma oscillations; balanced states.
    d.  Basics of Cell Neurophysiology: Neuronal/synaptic biophysics; IF-like models; HH-models (excitability, repetitive firing); ML model (phase plane, Types I & II)

2.  (13sept)  JR away.  Possible tutorial on cell-based network modeling.

3.  (20sept) Firing rate models: intro & qualitative dynamics (ref'ce: E&T: 11.1, 11.3)
    a.  Heuristic derivation of WC: synaptic drive and mean V-formulation; hybrid MF: rate&synaptic gating.
    b.  Derivation based on asynchrony or slow synapses (Hold for later?)

4.  (27sept) Phase plane analysis of WC, e-i and other configurations: nullclines, stability.

5.  (04oct) Neuronal competition
    a.  Perceptual bi/multi-stability: mutual inhibition; oscillator & noise-driven alternations; vision & audition; fast/slow analysis; escape & release; build-up
    b.  Winnerless competition: heteroclinic cycles

6.  (11oct) CPG half-center oscillator: PRCs, weak coupling, sync patterns (crayfish, lamprey).

7.  (18oct) Spontaneous states
    a.  Episodic rhythm in developing spinal cord, e-e with synaptic depression

b. Spontaneous low firing rate in cortex (Latham); criticality, Deco/Jirsa/He? (Hold for later?)

8. (25oct) Decision making/evidence accumulation
   a. Two-alternative forced choice: moving dots, Newsome/Shadlen.
      i. Firing rate competition models: Wong & Wang.
      ii. Drift diffusion model, accuracy/speed tradeoff: Wong & Holmes
      iii. Ramping or trial-averaged discrete stepping? Latimer Pillow etal
   b. Two-interval discrimination: Machens, Romo & Brody.

9. (01nov) Persistent activity/working memory; Line attractors.
   a. Motivation/background.
   b. Integrators: rate encoding of stimulus (parametric working memory). Network based and/or cellular based. Eg head/eye direction: Tank/Goldman/Askry – goldfish
   c. Introduction of spatially distributed WC-like rate models.

10. (08nov) Distributed networks: Bump attractors. (ref'ce: Gerstner et al: 18.3 ; E&T: 12.4) Sensory receptive fields – perception.
    a. Bump attractors: location encoding of stimulus (spatial working memory). Eg, delayed-match-to-sample (Goldman-Rakic); Brunel-Wang-Camperi-Compte.
    b. Analysis of Amari bump model
    c. Visual: orientation tuning: input driven; Mexican hat; Sompolinsky et al. (ref'ce: Gerstner et al, section 18.2)
    d. Auditory: frequency tuning, Reyes.  Co-tuning.

11. (15nov) Spike-based, rate-based sync & async patterns.  (SFN mtg Washington DC; class?)
    a. Derivn of rate model from async spiking (if not covered previously).
    b. Propagating (slow) waves: thalamic lurching waves; Sync'zn depends on tau_syn.
    c. [maybe: e-e (E&T: 12.3)]
    d. Cell/spike-based networks: Dynamics of synchrony - spike-spike (vanVreeswjck et al), pacemaker slow waves (Terman), respiratory CPG (-- the XPP anim'n); [maybe: Stability of async state]
    e. Gamma oscillations:
       i. Wang/Buzsaki, Kopell et al (PING/ING) [maybe: Wang/Brunel,]
       ii. Spike and Rate models for gamma (Keeley&JR)

(22nov) Thanksgiving break; No class.

12. (29nov & 06dec) Distributed networks, cont'd:
    a. Auditory: Stimulus specific adaptation: novelty detection
    b. Auditory: context effects tone discrimination and frequency change detection – Huang et al (2015).
    c. Competition waves: Bressloff on Heeger binocular rivalry; barberpole illusion (Rankin et al, 2014)
    d. Hallucinations (E&T: 12.5)
    e. Feedforward networks, syn-fire chains

13. (13dec) guest lecturer.

Additional topics:

14. Cell-based networks:
    a. Deriv'n of rate from cell-based spiking: Latham et al (2000); Pinto/GBE/Simon; Latham et al(2014): async assumption for varying input.
    b. balanced states: high variability, low correlations. (Ref'ce: vanVreeswjck & Sompolinsky; Scholarpedia by Okun&Lampl)
    c. Up/down states (spiking and rate models – de la Roche etal, D Levenstein; Async/sync states: spiking & rate models.

15. Large scale network modeling:


(15dec) Last day of classes

xxxdec: 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.  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.
Gerstner W, Kistler WM, Naud R & Paninski L. [Gerstner etal]  Neuronal Dynamics.
Cambridge, 2014.