

**Math 6780, Spring 2008**  
**Computational Neuroscience**

**Homework 2 (Due Thursday, April 10):**

**Phase oscillators:**

Do homeworks 3.1 and 3.2 from the XPP tutorial:

<http://www.math.pitt.edu/~bard/bardware/tut/xpptut4.html>

You don't have to use XPP. The task is to compute interaction function  $H(\psi)$  (in either definition) and find phase-locked states for several different models and different parameter values and to discuss your observations.

**References:**

- Derivation of phase equations
  - Method of isochrones: Y. Kuramoto. *Chemical Oscillations, waves and turbulence*. Springer-Verlag, New York, 1983
  - Fredholm alternative: G B Ermentrout and N Kopell. Multiple pulse interactions and averaging in systems of coupled neural oscillators. *J. Math Biol.*, 29:195–217, 1991.
  - F C Hoppensteadt and E Izhekevich. *Weakly Connected Neural Nets*. Springer-Verlag, New York, 1997.
- Phase-locked solutions in a weakly-coupled symmetric pair
  - C van Vreeswijk, G B Ermentrout, and L F Abbott. When inhibition not excitation synchronizes neural firing. *J. Comput. Neurosci.*, 1:313–321, 1994.
  - D Hansel, G Mato, and C Meunier. Synchrony in excitatory neural networks. *Neural Comput.*, 7:2307–2337, 1995.
- I&F with instantaneous coupling (more mathematical)
  - R E Mirollo and S H Strogatz. Synchronisation of pulse-coupled biological oscillators. *SIAM J. Appl. Math.*, 50(6):1645–1662, 1990.
- Inclusion of an axonal delay
  - S Coombes and G J Lord. Desynchronisation of pulse-coupled integrate-and-fire neurons. *Phys. Rev. E*, 55(3):R2104–R2107, 1997.
- Strong coupling
  - P C Bressloff and S Coombes. Dynamics of strongly coupled spiking neurons. *Neural Comput.*, 12:91–129, 2000.
  - P C Bressloff and S Coombes. Dynamical theory of spike train dynamics in networks of integrate and-fire oscillators. *SIAM J. Appl. Math.*, 60:828–841, 2000.
- Application to lamprey locomotion
  - A H Cohen, G B Ermentrout, T Kiermel, N Kopell, K A Sigvardt, and T L Williams. Modeling of intersegmental coordination in the lamprey central pattern generator for motion. *Trends in Neurosci.*, 15:434–438, 1992.
  - E Marder and R L Calabrese. Principles of rhythmic motor pattern generation. *Physiol. Rev.*, 76:687–717, 1996.
  - N Kopell and G B Ermentrout. Symmetry and phase-locking in chains of weakly coupled oscillators. *Comm. Pure Appl. Math.*, 39:623–660, 1986.

- Leech locomotion
  - W O Friesen and R A Pearce. Mechanism of intersegmental coordination in leech locomotion. *Semin. Neurosci.*, 4:41–47, 1993.
  - G B Ermentrout and N Kopell. Frequency plateaus in a chain of weakly coupled oscillators. *SIAM J. Appl. Math.*, 15:215–237, 1984.
  - G B Ermentrout. The analysis of synaptically generated travelling waves. *J. Comput. Neurosc.*, 5:191–208, 1998.
- Asynchronous state in networks and its destabilization
  - L F Abbott and C van Vreeswijk. Asynchronous states in networks of pulse-coupled oscillators. *Phys. Rev. E*, 48(2):1483–1490, 1993
  - W Gerstner and J L Van Hemmen. Coherence and incoherence in a globally coupled ensemble of pulse-emitting units. *Phys. Rev. Lett.*, 71(3):312–315, 1993.
- Type I resetting and type I excitability
  - Ermentrout-B, Type I membranes, phase resetting curves, and synchrony. *Neural-Comput.* 1996 Jul 1; 8(5): 979-1001

### **Learning and plasticity:**

Implement the model of Shouval et al. 2002. Do numerical experiments with single spikes, train presynaptic and postsynaptic spikes, and constant postsynaptic voltage, as was discussed in class. To illustrate the results, make figures similar to panels in figure ? from the chapter 10.3.4 from “Spiking neuron models”. Explain the results. What happens to the weights (panel B in the middle panel in Fig. ?) if you use higher frequency of pulses? (say, 3Hz, as in the dashed curve) Why?

### **References:**

- NMDA receptor-dependent, calcium-controlled model of STDP
  - H.Shouval, M.H.Bear, L.N. Cooper. A unified model of NMDA receptor-dependent bidirectional synaptic plasticity. *Proc. Natl. Acad. Sci.*, 99: 1069-1073, 2002
- STDP model with calcium-time-course control
  - Rubin, Gherkin, Bi and Chow. Calcium time course as a signal for STDP. *J. Neurophysiol.* 93: 2600-2613, 2005
- Role and mechanism of postsynaptic depolarization in STDP
  - J.E.Lisman, N. Spruston. Postsynaptic depolarization requirements for LTP and LTD: a critique of spike timing-dependent plasticity. *Nat. Neurosci.* 8: 839-841, 2005
- Hypothesis and modeling of CaMKII involvement in converting Ca signal to persistent change in synaptic strength
  - Starting on p. 40 of Paul Bressloff’s notes and references therein.
- More models of STDP
  - Song and Abbott, *Neuron*, 2001. Cortical remapping with STDP
  - Rubin, Lee, Sompolinsky, *PRL*, 2001. On additive vs. multiplicative (saturating) STDP
  - Izhikevich and Desai, *Neural Comp.*, 2003. A link between on STDP and BCM
  - Chechik, *Neural Comp.*, 2003. A link between STDP and information theory
  - Rao and Sejnowski, *Phyl. Trans. R. Soc. Lond*, 2003. STDP in prediction and reward learning

### **Some ideas for projects:**

1. Reproduce, discuss (and, possibly, extend) main ideas from one of the above (or other) papers
2. Use of PRC in an application (should involve a model, or a computation with data and discussion)
3. Use of learning rules or STDP in an application