8.581 Entropy, Information and the Brain January 1998

Lecturers:	William Bialek, NEC Research Institute
	Zhaoping Li, Brain & Cognitive Sciences
Organizers:	A. Nihat Berker and Mehran Kardar, Physics Department
Schedule:	9:30 to 11:30AM during IAP, 1998; starting on January 5
	Dr. Bialek will give 8 lectures on Mon-Thu of the first 2 weeks
	He will conduct Recitations/Discussions on Fridays 1/9 and 1/16
	Mon 1/19 is the Martin Luther King Holiday
	Dr. Berker will give 2 lectures on Tue 1/20 and Wed 1/21
	Dr. Kardar will give 2 lectures on Thu 1/22 and Fri 1/23
	Dr. Li will give 4 lectures on Mon-Thu of the last week
	There may (or may not) be a final Recitation/Discussion on Friday 1/30
Units:	12 units (can be used towards the physics PhD breath requirement)

Main Lectures (Bialek)

1. *A brief introduction*
   - (a) What do physicists want to know about the brain?
   - (b) Why might information theory help?
   - (c) Why might it fail?
   - (d) Some claims for the course
2. *Foundations*
   - (a) Entropy as the unique measure of available information
   - (b) Entropy reduction & information gain
   - (c) Maximum entropy distributions
   - (d) Looking ahead: Information about what?
3. *Electrical and chemical signals in the brain*
   - (a) Orders of magnitude
   - (b) Gated channels as circuit elements
   - (c) Nonlinear dynamics and action potentials
   - (d) Synaptic transmission
   - (e) Intracellular signalling

4. *Information transmission at the first synapse in fly vision*
    (a) Counting photons
    (b) Response functions
    (c) Noise, spectral densities, and functional integrals
    (d) Effective noise levels and information capacity
    (e) Comparison to the physical limits
5. *Optimal filtering and efficient coding*
    (a) Maximizing information transmission
    (b) A few facts about natural signals
    (c) Minimizing redundancy
    (d) Sampling and filtering in color space
6. *Information and coding in spike trains*
    (a) Classical facts about spiking neurons
    (b) 'Forward' and 'reverse' views of the code
    (c) Decomposing information: spike timing & stimulus features
    (d) Theory and experiments in neural decoding
    (e) Direct measures of entropy and information
7. *Interlude*
    (a) What have we learned by measuring information transmission?
    (b) The gap between 'low level' and 'high level' processing
    (c) Some facts about big and little brains
    (d) What notion of 'efficiency' is relevant?
    (e) Once again: Information about what?
8. *Learning from noisy examples*
    (a) A family of model problems
    (b) Least squares, maximum likelihood, and all that
    (c) Phase space factors and the complexity of models
    (d) How much can we learn?
    (e) Beyond parameterization: Field theoretic methods
9. *Predictability, complexity, and neural computation*

Neural Networks (Berker)

1. *Neural Networks*
   (a) Brain process and its condensed matter analogies
   (b) The biological system: Coupled neurons
   (c) Developing neural network models
   (d) Memory storage & retrieval: The Hopfield–Little model
   (e) Spin-glass analogy: Noise and frustration. Phase diagram
   (f) Learning and forgetting: Learning within bounds. Marginalist learning.
   (g) Correlated memories, sequential memories, and the use of projection

2. *Optimization by Simulated Annealing*
   (a) The travelling salesman problem
   (b) Computer chip design optimization
   (c) Neural network strategy for the travelling salesman problem
   (d) Looking ahead: Information about what?

3. *Information Transmission (Coding-Decoding)*
   (a) Spin-glass formulation of Sourlas
   (b) Shannon's cost -performance bond

Mammalian Visual Cortex (Kardar)

1. *Anatomy*
   (a) Eyes, retina, neurons
   (b) Optic nerves, the lateral geniculate nucleus
   (c) The primary visual cortex (V1)

2. *Physiology*
   (a) Experimental methods
   (b) Ocular dominance
   (c) Orientation selectivity

3. *Patterns and Modeling*
   (a) Labyrinthine patterns of ocular dominance bands
   (b) "Pin-wheels" in orientation selectivity columns

(c) Analogies to symmetry breaking and defects in physics
(d) Microscopic models and their limitations
(e) Macroscopic models, time-dependent Landau–Ginzburg equations

Computation and Neural Dynamics (Li)

1. Basic cortical circuits
    (a) A cortical micro-circuit — A neural oscillator
    (b) A system of coupled non-linear neural oscillators
    (c) Normal modes and their controls in the neural system
2. Olfactory computation by neural dynamics
    (a) Odor environments and olfactory tasks
    (b) Olfactory bulb and olfactory cortex
    (c) Odor detection/classification and the normal modes
    (d) Odor segmentation and adaptation by top-down feedback
    (e) A model of the olfactory cortex for odor recognition and segmentation
3. Visual computation by neural dynamics
    (a) Vision and its most difficult problems
    (b) Visual attention, grouping, and search
    (c) Sampling the visual world in the primary visual cortex
    (d) Local neural interactions for global visual grouping
    (e) An image contour — a one-dimensional problem
    (f) Two dimensional image regions
    (g) Region segmentation as translation symmetry breaking
    (h) Region segmentation and contour enhancement in the primary visual cortex
    (i) Connecting the theory and experiments