# Introduction to Computational Neuroscience - Web course

## COURSE OUTLINE

This course introduces the emerging field of "Computational Neuroscience". It also provides some neurobiology background necessary to understand computational models of the brain.

The course starts with a discussion of a single neuron and the four signaling components that occur in a neuron:

1) dendritic processing,

2) spatiotemporal summation in the soma,

3) axonal propagationand

4) synaptic transmission.

Detailed models of each of these mechanisms are presented.

Next, we present some basics of neuroanatomy and neurobiology. A discussion of various forms of learning-classical, instrumental etc is introduced. Then we begin a discussion of neural network models: feedforward networks, recurrent networks, selforganizing maps, reinforcement learning models etc.

Case studies drawn from models of sensorimotor function are provided for each of these network models. The course also includes a brief mathematical appendix.

## COURSE DETAIL

| S.No. | Topic | No. Of Classes |
|---|---|---|
| **1.** | **Introduction** | **2** |
| | History of neuroscience. | 1 |
| | History of computational | 1 |

NPTEL

http://nptel.iitm.ac.in

## Biotechnology

**Pre-requisites:**

1. Basic neuroanatomy and neurobiology (desirable).
2. Linear algebra, dynamical systems.

**Additional Reading:**

1. Eric Kandel, James Thomas Schwartz, Jessel, Principles of Neural Science,*4th ed.* McGraw-Hill, New York.
2. Computational neuroscience: a comprehensive approach, Edited by J. Feng, Chapman & Hall/CRC, 2004.
3. **Randall C. O'Reilly, Yuko Munakata,** Computational explorations in cognitive neuroscience: understanding the mind, **MIT Press, 2000.**

**Hyperlinks:**

1. http://en.wikipedia.org/wiki/ **Computational_neuroscience**
2. http://www.scholarpedia.org/article/ **Encyclopedia_of_computational_neuroscience**
3. http://home.earthlink.net/~perlewitz/

**Google Book:**

**Computational Neuroscience, Edited by Eric Schwartz.**

1. http://books.google.co.in/books?id=LZ4sBy0kyRoC&printsec=frontcover&dq=computational+neuroscience&&q&f=false

**Coordinators:**

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| | neuroscience. | |
| **2.** | **Mathematical Preliminaries** | **4** |
| | Linear algebra - eigenvalues and eigenvectors for symmetric matrices. | **1** |
| | Quadratic forms, solving a system of linear equations - 3 cases. | **1** |
| | Dynamical systems - types of fixed pts, bifurcation map in terms of trace and determinant. | **1** |
| | Phase plane analysis - null clines - Hopf bifurcation and limit cycles. | **1** |
| **3.** | **Organization of nervous system and Neuroanatomy** | **1** |
| **4.** | **Hodgkin Huxley model** | **5** |
| | Neuron - axons, dendrites etc, the four components of Neural Signaling. | **1** |
| | Neurotransmission: neurotrasmitter, receptor, ion channel, channel gating. | **1** |
| | Electrophysiology - Nernst potential, resting potential, Goldman-Hodgkin-Katz voltage equation, outline of the Hodgkin-Huxley model. | **1** |
| | Modeling ion | **1** |

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| | channel kinetics, activation and inactivation gates. | |
| | Complete formulation of Hodgkin-Huxley model. Relation between output firing and constant input current. Discussion of regimes. Software demo. | **1** |
| **5.** | **Biophysical models of Single neuron** | **6** |
| | Derivation of the cable equation - defining axial, radial resistance and membrane capacitance, defining quantities in terms of per unit length. | **1** |
| | Steady state Solution for Infinite cable and semi-infinite cable. | **1** |
| | Solution for Finite cable: sealed end, killed end and arbitrary boundary conditions. | **1** |
| | Time-dependent solution for impulse input. Propagation delay, pseudo-velocity. Relation between cable diameter and conduction velocity. | **1** |
| | Branched cables and Rall's condition. | **1** |
| | Modeling synaptic transmission. | **1** |
| **6.** | **Simplified neuron models** | **4** |

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| | Fitzhugh-Nagumo neuron model - phase-plane analysis, showing excitability, bistability and oscillations. | **2** |
| | Integrate and fire neuron, resonate and fire neuron, Izhikevich models. | **2** |
| **7.** | **Learning mechanisms** | **2** |
| | Classical conditioning and instrumental condition. Sensitization, habituation and priming. | **1** |
| | Cellular correlates of learning. Hebbian learning, Long-term Potentiation (LTP) and Long-term Depression (LTD). | **1** |
| **8.** | **Neural networks**. | **15** |
| **a)** | Perceptron. | **1** |
| **b)** | **MLP** | **3** |
| | Backpropagation algorithm. | **1** |
| | Case studies: Past tense learning, NetTalk, biological plausibility of backpropagation algorithm. | **2** |
| **c)** | **Hopfield network** | **3** |
| | Discrete model formulation - Lyapunov or Energy function, the concept of memory capacity. | **1** |

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| | Continuous models of associative memory, bi-directional associative memory. Case study: memory storage in hippocampus. | **2** |
| **d)** | **Unsupervised learning** | **6** |
| | Competitive learning and Self-organizing map. | **1** |
| | Case studies: somatosensory map adaptation, auditory cortex of bats, orientation maps in mammalian visual cortex. | **2** |
| | **Hebbian learning** | |
| | Hebbian learning and PCA. | **1** |
| | Variations of Hebbian learning. | **1** |
| | Linsker's model of the visual system. | **1** |
| **e)** | Reinforcement Learning. | **1** |
| **f)** | Spiking neuron networks. | **2** |
| **9.** | **Conclusions** | **1** |
| | **Total** | **40** |

**References:**


1. Peter Dayan & LF Abbot**, Theoretical Neuroscience:** Computational and Mathematical Modeling of Neural Systems**,** MIT

Press. ISBN 0-262-04199-5.

2. Patricia Churcland & Terence Sejnowski, **Computational Brain**, MIT Press.
3. Christof Koch, **Biophysics of computation**: information processing in single neurons, Oxford University Press, 2005.