Birla Institute of Technology & Science, Pilani
K K Birla Goa Campus

Course No. : **BITS *F317***

**Course title** : Theoretical Neuroscience

1. **Scope and Objective of the course**

The course will introduce students to modeling of brain at various levels – cellular level & system level At the cellular level, students will recognize the framework for all biophysical models of neurons, synapses & at the same time recognize that there is diversity in the response of different neurons. Dynamics of these models will be compared with those found in neurons in different parts of nervous sytem. At the system level, based on experimental data students will be able to work with descriptive models to predict response of neurons & utilize theoretical techniques (& identify experiments) for decoding.

2. **Textbook**

   i. Theoretical neuroscience, Peter Dayan & L.F. Abbott, MIT Press

3. **Reference Books**

   i. Spikes : Exploring the Neural Code, Fried Rieke, David Warland, R.D.R.V Steveninck, William Bialek, MIT Press
   ii. Principles of Computational Modelling in Neuroscience, David Sterratt, Bruce Graham, Andrew Gillies, David Willshaw, Cambridge University Press
   iii. Dynamical systems in Neuroscience, Eugene Izhikevich, MIT Press

4. **Course Plan**

| **Number of lectures** | **Learning objective** | **Topics to be covered** | **References** |
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| 1 | | Introduction to course & a bit of Neurobiology | |
| | | **Neuron Modeling (21 lectures)** | |
| 1 lecture | Introducing biology of nervous system | | |
| 2 lectures | Origin of membrane potential | Ionic concentrations; reversal potential; Membrane potential; electrical circuit representation of the membrane | Dayan & Abbott |

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| 2 lectures | Constructing a biophysical model of an axon | Hodgkin-Huxley model of squid's giant axon - voltage gates channels, Activation & inactivation gates; kinetic equation of gates;<br><br>Response of HH neuron to steady current & single pulse – spike trains | Dayan & Abbott |
| 2 lectures | Modeling spatial & temporal distribution of membrane potential along an axon / dendrite | Cable equation | Dayan & Abbott |
| | Action potential as a wave along an axon | Traveling wave solution for cable equation + HH model for ionic currents | Notes |
| 2 lectures | Models of dendrites | Solutions of cable equations for passive currents – infinite cables, finite & semi-finite cables (qualitative understanding) ; Branching & equivalent cylinder - Rall Model ; Dendrites with active processes ; Dendritic function in cognition. | Dayan & Abbott ; notes |
| 3 lectures | Synapses | Models of synapses | Dayan & Abbott |
| 3 lectures | Conductance based models (based on HH model) to explain various firing patterns of neurons | Range of spike patterns & responses of neurons; Class-1 and class-2 neurons<br><br>Morris Lecar model ; A-current; h-current; Connor-Steven's model,<br><br>Models of bursting | Izhikevich |
| 2 lectures | Dynamical systems – brief introduction | Introduction to dynamical systems - Fixed points, stability of nonlinear ODE's; Bifurcations - Saddle node bifurcation, saddle node on invariant circle bifurcation, Hopf bifurcations | Izhikevich |
| 3 lectures | Dynamical systems approach for understanding neuron response | Change in HH dynamics by parameter change; bifurcation diagram of HH neuron;<br><br>Class-1 and class-2 neurons – meaning & phase plane analysis | Izhikevich |
| **Neural encoding & decoding (20 lectures)** | | | |

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| 5 lectures | Stochastic nature of spike trains in response of stimuli – experiments & mathematical description | Spike trains & firing rates; Tuning curves; Spike triggered average; Spike train statistics; Neural code | Dayan & Abbott / Spikes |
| 2 lecture | Stimulus-response description of systems | Estimating firing rates – Weiner-Volterra method expansion, static nonlinearities; | Dayan & Abbott / Spikes |
| 7 lectures | Descriptive models of neurons & prediction of their response to a given stimuli | Reverse correlation methods : Simple cells, Spatial receptive fields, Temporal receptive fields, Response of a simple cell to counterphase grating, Space-time receptive fields, Non-separable receptive fields | Dayan & Abbott / Spikes |
| 2 lectures | Descriptive models of neurons & prediction of their response to a given stimuli | Static nonlinearities : Complex cells; Receptive fields in the Retina & LGN; V1 Receptive fields | Dayan & Abbott |
| 4 lectures | Build techniques for decoding experimental data. | Bayes theorem; Discrimination , ROC curves, ROC analysis for motion discrimination, Likelihood ratio test | Dayan & Abbott |
| **Advanced Topics in Theoretical Neuroscience (6 Lectures)** | | | |
| 1 Lecture | Neural Circuit Dynamics | Investigation into the dynamics of neural circuits to understand how patterns of activity encode information and give rise to specific behaviors or cognitive functions. | Research Articles |
| 2 Lecture | Connectomics and Structural Network Analysis | Advancements in mapping the connectome, the comprehensive map of neural connections in the brain, and analyzing the structural properties of neural networks. | Research Articles |
| 1 Lecture | Synaptic Plasticity and Learning | Research on the mechanisms underlying synaptic plasticity and learning, exploring how neural connections change over time in response to experiences | Research Articles |
| 1 Lecture | Neuro-informatics and Computational Models | Development and refinement of computational models that simulate neural processes, aiding in the understanding of complex brain functions. | Research Articles |

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| 1 Lecture | Neural Correlates of Consciousness | Investigation into the neural basis of consciousness, exploring the relationships between neural activity patterns and subjective experiences. | Research Articles |

## 5. Evaluation Scheme

| EC No. | Evaluation component | Duration | Weightage | Date, time and venue | Nature of component |
|---|---|---|---|---|---|
| 1 | Midsem test | 90 minutes | 25% | 13-March-2019 | Closed book |
| 3 | Comprehensive Exam | 3 hour | 50% | 6-May-2019 | Closed book |
| 4 | Assignments + Test covering computational part of assignments + Paper presentation | continuous | 25% | continuous | Open Book |

## 6. Chamber consultation Hours

To be announced in the class

## 7. Notices

To be displayed on Moodle LMS

## 8. Make-up policy

Only on a case-to-case basis on medical grounds, or pressing and urgent personal matters.