राष्ट्रीय प्रौद्योगिकी संस्थान पटना / NATIONAL INSTITUTE OF TECHNOLOGY PATNA
(शिक्षा मंत्रालय, भारत सरकार के अधीन एक राष्ट्रीय महत्व का संस्थान / An Institute of National Importance under Ministry of Education, Gov. of India)
संगणक विज्ञान एवं अभियांत्रिकी विभाग / DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING
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CSXX0259: **Theoretical and Computational Neuroscience**
L-T-P-Cr: 3-0-0-3

Pre-requisites: Fundamental knowledge of basic Linear Algebra and Calculus, basics of Neuroscience or Biology (recommended), and Programming in Python or MATLAB.

Course Objectives:

1. Introduce fundamental concepts in neuroscience relevant to computation.
2. Explore mathematical models of neurons and neural circuits.
3. Understand neural coding, plasticity, and dynamics.
4. Apply computational techniques to simulate and analyse brain function.
5. Discuss the implications of models in neuroscience and cognitive science.

Course Outcomes – After completing this course, students should be able to:
CO-1. *Describe* and *understanding* the basic structure and function of the nervous system and computational models.
CO-2. *Analyse* mathematical models of neurons, such as integrate-and-fire and Hodgkin-Huxley models.
CO-3. Applying and ssimulate neural responses using coding models like rate coding, population coding, etc.
CO-4. *Evaluate* learning mechanisms in networks, including Hebbian learning and spike-timing rules.
CO-5. *Discuss* recent advances and ethical implications of brain modelling and brain-machine interfaces.

Course Outcomes–Cognitive Levels–Program Outcomes Matrix –
[H: High relation (3); M: Moderate relation (2); L: Low relation (1)]

Course Outcomes	Program Outcomes											
	PO-1 (Engineering knowledge)	PO-2 (Problem analysis)	PO-3 (Design/development of solutions)	PO-4 (Conduct investigation of complex problems)	PO-5 (Modern tool usage)	PO-6 (The engineer and society)	PO-7 Environment and sustainability	PO-8 (Ethics)	PO-9 (Individual and team work)	PO-10 Communication)	PO-11 (Project management and finance)	PO-12 (Life-long learning)
CO-1	3	3	3	3	3	3			3	3	1	3
CO-2	3	3	3	3	3	3		1	3	3	1	3
CO-3	3	3	3	3	3	3			3	3	1	3
CO-4	3	3	3	3	3	2			3	3	1	3
CO-5	3	3	3	3	3	3	2	1	3	3	1	3

UNIT 1 Introduction to Neuroscience: **Lectures: 4**

Neurons, synapses, brain organization, signal transmission, Neural Modelling Basics: Membrane potential, ion channels, Hodgkin-Huxley, LIF models, Neurons and conductance-based models, Integrate-and-fire neurons and population models.

UNIT 2 Neural Coding and Decoding: Lectures: 6

Neural Encoding I: Firing Rates and Spike Statistics Rate coding, spike coding, population coding, tuning curves, Neural Encoding II: Reverse Correlation and Visual Receptive Fields, Neural Decoding, Information Theory,

UNIT 3 Neural Networks and Dynamics: Lectures: 9

Model Neurons I: Neuroelectronics, Model Neurons II: Conductances and Morphology, Feedforward networks, attractor dynamics, recurrent networks, Network Models, Feature maps and competitive population coding, Recurrent associative networks and episodic memory, **Dynamical Systems Theory in Neuroscience:** Phase portraits, fixed points, limit cycles, bifurcations, Stability analysis, Application to single neuron dynamics and network oscillations, **Recurrent Neural Networks, Models of Oscillations and Rhythms:** Mechanisms of rhythm generation (pacemaker cells, network oscillations), Synchronization in neural populations, Examples: Central Pattern Generators (CPGs), brain rhythms (alpha, gamma), **Learning and Memory in Networks:** Hopfield networks (associative memory), Perceptrons and basic supervised learning, Unsupervised learning (e.g., Hebbian learning, competitive learning).

UNIT 4 Adaptation and Learning: Lectures: 7

Plasticity and Learning: Synaptic Plasticity Rules, Unsupervised Learning, Supervised Learning, Classical Conditioning and Reinforcement Learning: Classical Conditioning, Static Action Choice, Sequential Action Choice, Representational Learning: Density Estimation, Causal Models for Density Estimation

UNIT 5 System-level Models:
Lectures: 8
Modular networks and complementary systems: Modular mapping networks, Coupled attractor networks, Sequence learning, Complementary memory systems, Motor Control and Reinforcement Learning: Motor learning and control, Classical conditioning and reinforcement learning, Formalization of reinforcement learning, Deep reinforcement learning, The cognitive brain: Attentive vision, An interconnecting workspace hypothesis, Complementary decision systems, Probabilistic reasoning: causal models and Bayesian networks, Structural causal models and learning causality.

UNIT 5 Higher-Level Brain Functions and Advanced Topics: Lectures: 6

Models of Sensory Processing: Visual cortex models (e.g., orientation selectivity, visual hierarchies), Auditory processing models, **Models of Decision Making:** Drift-diffusion models, Bayesian inference in the brain, **Brain-Computer Interfaces:** Computational challenges and opportunities, **Deep Learning and Neuroscience:** Connections between artificial neural networks and biological brains, Using deep learning for neural data analysis.

References

1. Dayan, P., & Abbott, L. F. (2001). *Theoretical Neuroscience*. MIT Press.
2. Gerstner, W., & Kistler, W. M. (2002). *Spiking Neuron Models*. Cambridge University Press.
3. Trappenberg, T. P. (2010). *Fundamentals of Computational Neuroscience*. Oxford University Press.

Rolls, E. T., & Deco, G. (2010). *The Noisy Brain: Stochastic Dynamics as a Principle of Brain Function*.