1 COURSE DESCRIPTION

1.1 Overview

Despite the abundance of fast accumulating knowledge from Brain research, Neuroscientists see molecules, spikes and synapses, and therefore fail to grasp the computing essence of neural processes; Computational scientists can appreciate Brain as a multiscale complex recurrent network of heterogeneous elements that is self-organized and performs computations, and leverage this knowledge to create intelligent algorithms.

1.2 Syllabus

Weeks 01 – 03: [NeuroScience] Biophysics of Brain Computation
Weeks 04 – 07: [Computational Modeling] Neurons as Spike Processing Machines
Weeks 08 – 15: [Neuroinspired AI] Integrating Neurons into Recursive Networks

WEEK 01 Introduction to Neuro-inspired Computing: Overview of Brain Computation (Computational Abstraction, Compensation mechanisms for intrinsic limitations of the brain, Neurons and Biological Neural Circuits).

WEEK 02 Brain Computation at the Macro-Scale: Vision, Movement, Memory, Learning and Cognition (Marr's model of early visual information processing, reinforcement learning in the basal ganglia, sensory-motor computation, decision making).

WEEK 03 Brain Computation at the Micro– and Meso– Scales: Biological Neurons and Networks (information encoding, dendritic computation, axonal growth, neuron homeostasis, types of neurons, Drosophila and human connectomics)

ASSIGNMENT 1 [How to build a spiking neuron model.]

WEEK 04 Elements of Neuronal Dynamics in Biophysically realistic Neuron Models (Hodgkin-Huxley model, type I and II neuron models).

WEEK 05 Dimensionality reduction and phase plane analysis: Integrate & Fire, Izhikevich, Spike Response Models, nonlinear neuron models (threshold effects, reduction to 2-D, phase plane analysis).

WEEK 06 Estimating Parameters of probabilistic neuron models (Parameter Optimization in Linear and Non–Linear models, Statistical Formulation of Encoding Models, Fit Evaluation)

ASSIGNMENT 2 [How to build a network of spiking neuron models]

WEEK 07 Evolving Neuronal Populations (direct encodings, duplication and differentiation, neuron homeostatis, modularity, exploratory growth).

WEEK 08 Brain as an optimization machine (Principles of efficient wiring, Learning as Design/Design of Learning).

WEEK 09 Learning via synaptic tuning (Hebb's rule, Hopfield networks, Hopfield search in the Brain, self-organizing maps, synaptic plasticity).

WEEK 10 Memory and Attractor Dynamics (Associations in memory, Hopfield model, memory networks with SNNs).

DRAFT PAPER [Development of a Spiking Neural Network.]

WEEKS 11–12 Students' Presentations.

WEEK 13 Building functional networks of spiking model neurons.

WEEK 14 Synaptic Plasticity and Learning in Spiking Neural Networks (Hebb's rule, Unsupervised Learning, Reward-based Learning in Spiking Neural Networks, Dynamics in 'Plastic' SNNs).

WEEK 15 Computational elements of decision making, emotions and consciousness (coding of decisions, somatic marker theory, being a model).

FINAL PAPER [Development of a Spiking Neural Network.]

1.3 Specific Goals

1. To explore how computation in the human brain can be effectively modeled across different levels of abstraction (from a single neuron to brain systems);
2. To introduce a computational formalization of brain function based on the model of neuron as a Spike Processing Machine – Spike Neural Networks (SNNs);
3. To employ SNNs and solve a CS problem in a term-wide project.

1.4 Structure

- 24 lectures (1 h 20 min, each);
- A term project;
- 2 assignments to prepare the students for the term project;
- A paper presentation (the most influential paper for your project)