Introduction to Neural and Cognitive Modelling

Final Project

Due:16/11/2024

1 Instructions

Groups of up to **2 students** can sign up for the Final Project. Inform the topic and group members' names by **6/10/2024** by initiating a group dialogue in **Project Forum** on Moodle.
Submit your elaborated Project Proposal ($\leq$ 2 page PDF) by **15/10/2024** to the Project Proposal Forum. The course Faculty and TA will inform their opinion on your project idea.
Mid Evaluation – 29/10/2024: Submit progress within max 1-Page
Final Report - 16/11/2024 You need to submit a report ($\leq$ 4 page PDF) and the code for the project in zipped format, the file named with both roll nos. The report shall have the following:

1. **Aim** of the modeling exercise.
2. **Introduction and Motivation** section explaining what variations have been introduced in the proposed model and how the variations differ from what we studied in the class. What experimental or empirical reasons motivated the proposal of the model?
3. **Methods** section needs to describe the model equations clearly and the types of experiments you plan to conduct with all the details of parameters chosen, parameter variations you considered for simulation experiments.
4. **Results** section needs to present the results of all the experiments (figures, plots etc) and a brief description of the observations from the plots.
5. **Discussion and Conclusion** section needs to highlight major observations from the project and what new knowledge you gained by doing this mini-project.
6. **References** section lists all the references and resources used in the project.

Apart from the submission of Final Report+code+data on 15/11/2024, project evaluation would also include demo and viva / video / in-person presentation during the Final Evaluation Week.

2 Project Topics List

1. Izhikevich neuron model
2. Kuramoto Oscillator model
3. Spiking neuron models
4. Any other reduced neuron models [Morris-Lecar Model, Rate-coded neural models, etc.]
5. Coincidence detectors, spike-response model (SRM), sigma-pi neuron model, McCulloch-Pitts Binary Neuron model
6. HH with human cortical pyramidal neuron parameters [one can look at ModelDB for parameter sets]
7. HH with various channels [one can look at ModelDB for parameter sets `https://modeldb.science/`; INAPK (persistent sodium and potassium channel) Model, etc.]
8. HH or other neuron models with Synaptic dynamics, shunting (divisive) inhibition
9. Plasticity: Spike time dependent plasticity (STDP), Long term potentiation (LTP), Long term depression (LTD), Hebbian learning
10. Use of complex models using packages such as Brian, GENESIS, NEURON, etc to implement morphological parameters (compartments, cable properties, etc) to make point-neuron models more sophisticated
11. Hebbian Learning and Plasticity – LTD, LTP, BCM Learning Rule
12. Unsupervised learning (Kohonen's SOM, Winner-take-all strategy), Decorrelation [See Horace Barlow's work: Barlow and Foldiak (1989)]
13. Applications On-Centre Off Surround framework / lateral inhibition [See for example, Sengupta, Surampudi, Melcher (2014) Brain Research, Sirosh and Miikkulainen, 1994]
14. Continuous Attractor Neural Networks (CANN) and applications [See Deco, Pollato, Zihl (2004)]
15. Dynamic Field Theory of cognition [Gregor Schöner, University of Bochum]
16. PsychRNN and Cognitive Tasks: `https://github.com/murraylab/PsychRNN`
17. Applications of RL for Cognitive Maps, Cognitive tasks, etc.
18. Decision-making models (Attractor Models, Drift Diffusion Model, Bayesian Models, etc.)

19. Abstract Models of Perception, Attention, Motor control, Emotions, Decision Making, etc (based on Hopfield Networks, Multilayer Perceptron, Recurrent Neural Networks, etc.)

20. Learning cortical representations through perturbed and adversarial dreaming (`https://elifesciences.org/articles/76384`)

21. Datasets that you might use: `https://crcns.org/data-sets`

22. Any other project idea with these themes, with the prior permission of the instructor. For example, look at G. Bard Ermentrout's page for more ideas on other projects: `http://www.pitt.edu/~phase/`

23. Modeling hippocampal spatial cells in rodents navigating in 3D environments

24. The flip-flop neuron: a memory efficient alternative for solving challenging sequence processing and decision-making problems.

25. A Basal Ganglia model for understanding working memory functions in healthy and Parkinson's conditions

26. The Striatal Beat Frequency (SBF) model is a neurobiological model that explains how the brain codes time using neural oscillators and spiny neurons in the basal ganglia. One instance, of such models can be found in Oscillatory multiplexing of neural population codes for interval timing and working memory.

3 Resources

1. 10 Classics from Cognitive Science Journal

2. Computational Modeling of Cognition and Behavior

3. Computational Cognitive Neuroscience Book by Randall O'Reilly & Y. Munakata

4. Connectionist Models of Cognition:Gary Cottrell, UCSD Cognitive Science

5. Janet Wiles, The University of Queensland, Australia

6. Michael Mozer's Cognitive Modeling course in UC Boulder

7. Language Models (Bayesian) Chris Lucas, University of Endinburgh, UK

8. Models of Memory

9. Thomas Trappenberg Computational Neuroscience Projects, Dalhousie University, Canada

10. Neuronal Dynamics by Wulfram Gerstner et al EPFL, Switzerland
11. Encyclopedia: Computational Neuroscience Curated by Eugene M. Izhikevich, Editor-in-Chief of Scholarpedia
12. Whole brain computational models: The Virtual Brain TVB (Victor Jirsa,tvbRS, France)

4 Courses

1. **MIT:**
   (a) Neural Circuits for Cognition, Fall
   (b) Computational Cognitive Science — Brain and Cognitive Sciences — MIT OpenCourseWare
2. **Stanford:**
   (a) Neural Network Models of Cognition (Jay McClelland)
3. **Harvard:**
   (a) Computational Cognitive Neuroscience: Building Models of the Brain
   (b) Computational Neuroscience