Computational Neuroscience

SYDE 552 / BIOL 487

University of Waterloo, Winter 2025

Instructor
Terrence C. Stewart (he/him)
tcstewar@uwaterloo.ca

M 16:30 – 18:20
W 16:30 – 17:20
W 17:30 – 18:20 (discussion)

Course Page: https://learn.uwaterloo.ca/d2l/home/999135

Prerequisites: At least 3B Systems Design Engineering OR at least 3B in the Faculty of Science and one of CS (115, 135, 200) and a 200-level STAT course.

Course Objectives: There are far more topics in computational neuroscience than can be covered in a single course. We will focus our studies on neuron models, as well as brain areas including the visual system, the hippocampus, the basal ganglia, and current research topics. Throughout the course, we will emphasize the relationship between computational models and biological structure. By the end of the course, you should be able to:

- simulate and manipulate a variety of neuron models, from LIF to Hodgkin-Huxley
- describe the organization of the primate visual system and compare it to convolutional networks
- describe the organization of the hippocampus and its role in cognition
- describe the organization of the basal ganglia and compare it to modern reinforcement learning techniques

Teaching Approach: The course will be delivered in-person. In the unlikely event that there will be a disruption to in-person teaching we will deliver interactive sessions through the Learn Virtual Classroom. Any online sessions will be at the normal class time (16:30-18:20 Monday and Wednesday), run through the Virtual Classroom in Learn. It should be noted that the last hour of the Wednesday session is meant to be a Tutorial.

Pre-recorded Videos: In addition to the in-person sessions, there are also pre-recorded videos for the entire course available right now on YouTube. These videos were made for the course when it was taught in Winter 2021 by the same two instructors and but do not cover the hippocampus and basal ganglia sections.

Required Texts: None (readings will be posted on `Learn`, including selections from the following)

Kandel et al. (2000) Principles of Neural Science, 5th edition. McGraw-Hill.

Gerstner et al. (2014) Neuronal dynamics. Cambridge University Press.

Sutton and Barto (2020) Reinforcement Learning. The MIT Press

Goodfellow et al. (2016) Deep Learning. The MIT Press

Schedule

Introduction ..... Jan 6th – Jan 8th

1. Course Overview and Logistics
2. Neurons and the Central Nervous System

Neuron Models ..... Jan 13th – Jan 22nd

3. Simple Neuron Models
4. Hodgkin-Huxley Models
5. Compartmental Models
6. Synapses

Primate Visual System ..... Jan 27th – Feb 5th

7. Low-level Visual Processing
8. Perceptrons and Regression
9. Intermediate and High-level Visual Processing
10. Backpropagation and Convolutional Neural Networks

Hippocampus (HC) ..... Feb 10th – Feb 24th

11. Role in cognition and associated signalling
12. Modelling memory
13. Modelling spatial navigation

Basal Ganglia (BG) ..... Feb 26th – Mar 5th

14. Role in Cognition and Associated Signalling
15. Models of BG - Functional
16. Models of BG - Anatomical
17. Reinforcement Learning

Motor Control ..... Mar 10th – Mar 12th

18. The Motor Cortex
19. The Cerebellum

Ongoing Research Topics ..... Mar 17th – Apr 2nd

- The Neural Engineering Framework (?)
- Numerical Cognition (?)
- Fear Conditioning in Amygdala (?)
- Recurrent Networks and Working Memory (?)
- Biophysics of Drugs and Disorders (?)
- Higher-level Cognition (?)

Evaluation

Important Dates:

Assignment #1: Neuron Models ..... 15% (Jan 29th)
Assignment #2: Primate Visual System ..... 15% (Feb 12th)
Assignment #3: Hippocampus ..... 15% (Mar 5th)
Assignment #4: Basal Ganglia ..... 15% (Mar 19th)
Project Proposal ..... (Mar 19th)
Final Project Report: ..... 40% (Apr 23rd)

Project: Students may undertake the project in groups of at most 2. A list of potential topics will be available on `Learn`; these sug gestions will be updated as the lectures progress. Project groups and topics should be emailed to the instructors for approval by March 13th. Evaluation will be based on a final report consisting of an abstract, introduction (including literature review), methods (model details), results (simulations and data), and discussion. Marks will be assigned according to the content and clarity of these sections.

Late Policy: Completed work should be submitted via `Learn` by midnight on the due date. Late work may be submitted via email for reduced credit. The reduction will be 0-100% based on lateness and the reason for the delay, at the discretion of the instructors.

Fair Contingencies for Emergency Remote Teaching: We are facing unusual and challenging times. To provide contingency for unforeseen circumstances, the instructor reserves the right to modify course topics and/or assessments and/or weight and/or deadlines with due notice to students. In the event of further challenges, the instructor will work with the Department/Faculty to find reasonable and fair solutions that respect rights and workloads of students, staff, and faculty.

Online Academic Integrity: Other than the final project (which can optionally be done in groups of two), all students are expected to work individually and submit their own original work. Under Policy 71, the instructor may have follow-up conversations with individual students to ensure that the work submitted was completed on their own. Any follow up will be conducted remotely (e.g., MS Teams, Skype, phone), as the University of Waterloo has suspended all in-person meetings until further notice.

Policy on the Use of Generative AI Generative artificial intelligence (GenAI) trained using large language models (LLM) or other methods to produce text, images, music, or code, like Chat GPT, DALL-E, or GitHub CoPilot, may be used for assignments in this class with proper documentation, citation, and acknowledgement. Recommendations for how to cite GenAI in student work at the University of Waterloo may be found through the Library: https://subjectguides.uwaterloo.ca/chatgpt_generative_ai. Please be aware that generative AI is known to falsify references to other work and may fabricate facts and inaccurately express ideas. GenAI generates content based on the input of other human authors and may therefore contain inaccuracies or reflect biases.

In addition, you should be aware that the legal/copyright status of generative AI inputs and outputs is unclear. Exercise caution when using large portions of content from AI sources, especially images. More information is available from the Copyright Advisory Committee: https://uwaterloo.ca/copyright-at-waterloo/teaching/generative-artificial-intelligence

You are accountable for the content and accuracy of all work you submit in this class, including any supported by generative AI.

Wellness Support and Contact Information: University can be a challenging environment and it is normal to need support. Campus Wellness services are available to students through counselling and health

services. If you are struggling or need someone to talk to you, please reach out. To book an appointment or learn more about the services, call 519-888-4567 x32655 or explore www.uwaterloo.ca/campus-wellness. If you're experiencing a crisis and feel unable to cope and Campus Wellness is closed, contact any of these after-hours supports: EmpowerMe (1-833-628-5589), Good2Talk (1-866-925-5454) or Here 24/7 (1-844-437-3247). They are available at any time of the day or night to help.

Academic Integrity: In order to maintain a culture of academic integrity, members of the University of Waterloo community are expected to promote honesty, trust, fairness, respect and responsibility. Refer to the Office of Academic Integrity for more information.
Grievance: A student who believes that a decision affecting some aspect of their university life has been unfair or unreasonable may have grounds for initiating a grievance. Read Policy 70, Student Petitions and Grievances, Section 4. When in doubt, please be certain to contact the department's administrative assistant who will provide further assistance.
Discipline: A student is expected to know what constitutes academic integrity to avoid committing an academic offence, and to take responsibility for their actions. [Check the Office of Academic Integrity for more information.] A student who is unsure whether an action constitutes an offence, or who needs help in learning how to avoid offences (e.g., plagiarism, cheating) or about "rules" for group work/collaboration should seek guidance from the course instructor, academic advisor, or the undergraduate associate dean. For information on categories of offences and types of penalties, students should refer to Policy 71, Student Discipline. For typical penalties, check Guidelines for the Assessment of Penalties.
Appeals: A decision made or penalty imposed under Policy 70, Student Petitions and Grievances (other than a petition) or Policy 71, Student Discipline may be appealed if there is a ground. A student who believes they have a ground for an appeal should refer to Policy 72, Student Appeals.
Note for students with disabilities: AccessAbility Services, located in Needles Hall, Room 1401, collaborates with all academic departments to arrange appropriate accommodations for students with disabilities without compromising the academic integrity of the curriculum. If you require academic accommodations to lessen the impact of your disability, please register with AccessAbility Services at the beginning of each academic term.