Computational Neuroscience

PSYC 3803 | PSYC-8805 | NEUR-4803

This course introduces the foundational principles of computational neuroscience, focusing on how neurons and neural circuits process information. Through hands-on simulations, students will explore both biological and artificial neural networks, gaining practical experience with computational tools like MATLAB. No prior programming experience is required.

Instructors	Dr. N Apurva Ratan Murty (ratan@gatech.edu) Dr. Tansu Celikel (celikel@gatech.edu) Dr. Omar Zeid (ozeid3@gatech.edu)
Teaching Assistant(s)	Mayukh Deb (mayukh@gatech.edu)
Meeting times	Tue/Thu 9:30-10:45 am
Classroom	JS Coon 250
Credits	3
Office hours	Dr. Murty – Tue 3-4 PM JS Coon 131 or with an appointment Dr. Celikel -- anytime with a prior appointment Dr. Zeid – Tue/Thu after class preferred, or with appointment

Course Description: This course explores the principles of neural processing, communication, information processing, and neural network modeling, bridging biological and artificial systems. Students will learn about the quantitative analysis of neural signals, neural coding, dendritic integration, and computational models, from point neurons to complex networks. The course introduces key concepts such as Hebbian and spike-timing-dependent plasticity, neural manifolds, network science, and information theory as they apply to neural systems.

Hands-on sessions will involve using MATLAB and computational tools to model neural networks, analyze data, and explore concepts like efficient coding, network theory, and the functioning of artificial neural networks (ANNs). Group projects provide opportunities to apply these methods in research-oriented environments, focusing on formulating hypotheses and testing models of neural computation.

By the end of the course, students will have a solid foundation in both the theoretical and practical aspects of neural and artificial networks, enabling them to use computational tools to investigate neural phenomena and draw connections between biological and artificial intelligence.

Prerequisites: Introductory courses in neuroscience and computational methods are recommended but not required. Tutorials require some coding experience.

Textbook: There is no required textbook. All the materials will be provided via the class website. You might find the following open-source textbooks helpful:

Computational Cognitive Neuroscience (5th edition)
https://github.com/CompCogNeuro/book/releases/download/v5.0.1/ccnbook_ed5.pdf
Neuronal dynamics
https://neuronaldynamics.epfl.ch/online/index.html

Evaluation Methods and Gradings:

Assignment: 10%	Weekly quiz: 30%	Group work: 30%	Final exam: 30%	
A = 90-100%	**B = 80-89%**	**C = 70-79%**	**D = 60-69%**	**F = 0-59%**

Learning Objectives:

1. Develop a strong foundation in key theoretical frameworks of neuroscience.
2. Learn to approach problems across different scales of neural complexity: from single neurons to entire neural networks
3. Gain practical experience in modeling neural circuits and systems.
4. Cultivate critical thinking about how "information" is represented and measured in neural systems. Consider different coding schemes and mathematical frameworks of measurement.
5. Understanding the neurobiological roots of modern AI: foundational concepts of perceptrons and artificial neural networks
6. Collaborate effectively in research: Learn research skills across all phases of the research pipeline: ideation, implementation, and presentation.

Class Schedule:

1. January 7, 2025 (Tuesday)	Introduction	Ratan + Tansu
2. January 9, 2025 (Thursday)	**Signals in the Brain** **From electrons to photons:** Quantitative analysis of neural signals	**Tansu**
3. January 14, 2025 (Tuesday)	**Nature of electrical communication in neurons and networks**	
4. January 16, 2025 (Thursday)	**Dendritic integration and back-propagation**	
5. January 21, 2025 (Tuesday)	Tutorial #1: How to MATLAB	
6. January 23, 2025 (Thursday)	**Neural coding and its plasticity** **Computational models of neurons:** From point neurons to anatomically realistic ones	**Tansu**
7. January 28, 2025 (Tuesday)	**Neural coding strategies and their plasticity:** Where do rate, time, and space coding meet Hebbian, and Spike-timing Dependent Plasticity?	
8. January 30, 2025 (Thursday)	**Group project time** *Meet with your group members and decide on your research topic -- Submit your research topic to the GTA by the end of today!*	

	Small networks **Tansu**
10. February 4, 2025 (Tuesday)	Guest lecture: Cell-type specific information processing in the nervous system - Fleur Zeldenrust
11. February 6, 2025 (Thursday)	**Network theory:** From Erdős–Rényi model to small-world and scale-free networks; from structure to function
12. February 11, 2025 (Tuesday)	**Group project time** *Develop a hypothesis and a plan of approach -- Submit them to the GTA by the end of today!*
13. February 13, 2025 (Thursday)	Tutorial #2: From spiking neurons to neuromimetic multi-layer networks
14. February 18, 2025 (Tuesday)	**Networks as graphs** From networks in the brain to your Facebook
15. February 20, 2025 (Thursday)	**Group project time** *Hands-on data analysis and computational modeling*
	Measuring information in networks **Ratan**
16. February 25, 2025 (Tuesday)	**Information Theory in Neuroscience** Shannon's entropy, mutual information (connection with rate/temporal codes, from Tansu's part)
17. February 27, 2025 (Thursday)	**Group project time** *Hands-on data analysis and computational modeling*
18. March 4, 2025 (Tuesday)	Tutorial #3: Calculating information content
19. March 6, 2025 (Thursday)	**Efficient Coding Hypothesis** Global versus local efficiency, vulnerability, tradeoff between efficiency and robustness
20. March 11, 2025 (Tuesday)	**Manifolds of neural computation** Neural state spaces, dimensionality, communication subspaces
21. March 13, 2025 (Thursday)	**Group project time** *Hands-on data analysis and computational modeling*
22. March 18, 2025 (Tuesday)	No class (Spring Break)
23. March 20, 2025 (Thursday)	No class (Spring Break)
	Perceptrons to neural networks **Ratan**
24. March 25, 2025 (Tuesday)	**Perceptrons** Layers and hierarchical organization, modularity

	Basic perceptron, Biological Inspiration, and basic formulation	
25. March 27, 2025 (Thursday)	**Connectionist models today** Artificial Neural Network models of Human Cognition	
26. April 1, 2025 (Tuesday)	Tutorial #5: Training your own neural network models	
27. April 3, 2025 (Thursday)	**Group project time** *Summarize results and prepare presentations*	
28. April 8, 2025 (Tuesday)	**Neuromodulation using ANNs** ANNs as tools to study neural network function	
29. April 10, 2025 (Thursday)	**Neural networks as normative models of the brain** Feedforward, feedback, attention in neural networks and brains	
30. April 15, 2025 (Tuesday)	**Project Presentations and submission of the final product.**	
31. April 17, 2025 (Thursday)	Review lecture	Ratan + Tansu

Academic Integrity:
All students are assumed to have read the Code of Student Conduct and consented to be bound by it: https://policylibrary.gatech.edu/student-life/student-code-conduct. Violations of these rules of conduct are taken extremely seriously and will result in a failing grade for the course. Specific violations include (but are not limited to):

- Use or provision of prohibited assistance during quizzes or exams
- Sharing of outside assignments such as research reports or papers
- Plagiarism- This includes both the use of the words and ideas without attribution (e.g., by presenting online materials as if they were your own work)

Policy on Use of Generative AI (Artificial Intelligence) for class work:
In this class, we treat AI-based assistance, such as ChatGPT, the same way we treat collaboration with other people: for both individual and team-based assignments, you are welcome to discuss your ideas and work with other people, both inside and outside the class, as well as with AI-based assistants.

However, all work you submit must be your own. You should never include in your assignment anything that was not written directly by you without proper citation (including quotation marks and in-line citation for direct quotes).

Including anything you did not write in your assignment without proper citation will be treated as an academic misconduct case. If you are unsure where the line is between collaborating with AI and copying AI, we recommend the following heuristics:

Heuristic 1: Never hit "Copy" within your conversation with an AI assistant. You can copy your own work

into your own conversation but do not copy anything from the conversation back into your assignment.

Instead, use your interaction with the AI assistant as a learning experience, then let your assignment reflect your improved understanding.

Heuristic 2: Do not have your assignment and the AI agent open at the same time. Similar to the above, use your conversation with the AI as a learning experience, then close the interaction down, open your assignment, and let your assignment reflect your revised knowledge.

This heuristic includes avoiding using AI directly integrated into your composition environment: just as you should not let a classmate write content or code directly into your submission, so you should also avoid using tools that directly add content to your submission.

Deviating from these heuristics does not automatically qualify as academic misconduct; however, following these heuristics essentially guarantees your collaboration will not cross the line into misconduct.

Disability Services Accommodations Procedures for Students:
Georgia Tech complies with the regulations of the Americans with Disabilities Act of 1990 and offers accommodations to students with disabilities. If you need classroom accommodation, please make an appointment with the Office of Disability Services to discuss the appropriate procedures. Their website is www.disabilityservices.gatech.edu

Technology:
Cell phones should be kept on vibrate or silent. If you anticipate a phone call, let us know before class. There may be various times we use cell phones for class participation (in-class quizzes, texting polls, etc.). We welcome new technology and look forward to incorporating it into our classroom environment, but not at the cost of your learning.

Student Well-Being
It is important for us to promote health/wellness and belonging in this course, as well as remove barriers to well-being. We are aware that you may experience stressors that impact your academic experience. We do not want hunger or thirst to affect your ability to stay focused and engaged in this course, therefore, you are welcome to bring snacks/meals into this classroom. We encourage you to stay hydrated, so you are welcome to bring a water bottle and fill/refill it. If you need to take a break that requires you to leave the classroom briefly, that is fine but please try to limit the break to 4-5 minutes maximum. Otherwise, a break of 5 minutes is integrated into the class schedule for every 45 min of class time.

Campus Resources for Students

There is a myriad of resources at Georgia Tech to support you. If you are experiencing concerns, seeking help is a courageous thing to do for yourself and those who care about you. Below you will find some resources to support you both as a student and as a person.

Academic support

Center for Academic Success http://success.gatech.edu

Tutoring & Academic Support https://tutoring.gatech.edu/

Peer-Led Undergraduate Study (PLUS) http://success.gatech.edu/tutoring/plus

Academic coaching http://success.gatech.edu/coaching

Residence Life's Learning Assistance Program https://housing.gatech.edu/learning-assistance-program

Academic advisors for your major http://advising.gatech.edu/

Personal Support

Georgia Tech Resources

The Office of the Dean of Students: https://studentlife.gatech.edu/ **404-894-6367**; Smithgall Student Services Building 2nd floor. You also may request assistance at https://gatech-advocate.symplicity.com/care_report/index.php/pid423974?

Center for Mental Health Care & Resources provides crisis intervention, testing and assessment, short-term individual counseling, group counseling, couples counseling, and referrals to on and off campus resources. To schedule an appointment, you can call the Center at **404-894-2575** or walk into the office, Suite 238, Smithgall Student Services "Flag" Building to schedule an appointment. Services include short-term individual counseling, group counseling, couples counseling, testing and assessment, referral services, and crisis intervention. *Students in crisis during the day can walk into the assessment suite (8am-4pm, Monday through Friday). To reach the on call after hours (after 5:00 pm on weekends and during the weekends) call 404-894-2575 and follow the prompts.*

Students' Temporary Assistance and Resources (STAR): https://star.studentlife.gatech.edu/. STAR services include Campus Closet, Financial Assistance, Housing, and Klemis Kitchen

Stamps Health Services: https://health.gatech.edu; 404-894-1420. Primary care, pharmacy, women's health, psychiatry (referrals to psychiatry start in the Center for Mental Health Care & Resources), immunization and allergy, health promotion, and nutrition

Wellness Empowerment Center: wellnesscenter.gatech.edu/ 404-894-9980.WE Center provides upstream, innovative, and relevant programs, services, and initiatives to help students and employees thrive.

VOICE Victim-Survivor Support: https://healthinitiatives.gatech.edu/support-services/advocacy

Women's Resource Center: http://www.womenscenter.gatech.edu; 404-385-0230

LGBTQIA Resource Center: http://lgbtqia.gatech.edu/; 404-385-2679

Veteran's Resource Center: http://veterans.gatech.edu/; 404-385-2067

OMED: Educational Services: http://www.omed.gatech.edu; 404-894-3959

Georgia Tech Police: https://police.gatech.edu/ 404-894-2500

Statement of Intent for Inclusivity: As a member of the Georgia Tech community, we are committed to creating a learning environment in which all our students feel safe and included. Because we all are individuals with varying needs, we are reliant on your feedback to achieve this goal. To that end, we invite you to enter into dialogue with us about the things we can stop, start, and continue doing to make my classroom an environment in which every student feels valued and can engage actively in our learning community.

To be removed from syllabus later

- Resources (some are relevant): https://neural-reckoning.org/comp-neuro-resources.html
- Open course text-book https://neuronaldynamics.epfl.ch/online/index.html
- Including recorded lectures https://humaninformationprocessing.com/teaching/
- Open Comp-Neuro resources https://github.com/asoplata/open-computational-neuroscience-resources?tab=readme-ov-file#simulation-software
- Dan Goodman's resources https://neural-reckoning.org/comp-neuro-resources.html
- Neuromatch Academy https://compneuro.neuromatch.io/tutorials/intro.html