Course Syllabus

Link to pdf version: **BIPN164_Sp23_Aljadeff_Benna_Syllabus.pdf (https://canvas.ucsd.edu/courses/44853/files/9397948?wrap=1)** ⬇ **(https://canvas.ucsd.edu/courses/44853/files/9397948/download?download_frd=1)**

BIPN 164: Computational Models and Theories in Neuroscience

(https://canvas.ucsd.edu/courses/44853/files/9397818?wrap=1)

Spring Quarter 2023

(https://canvas.ucsd.edu/courses/44853/files/9397818?wrap=1)

In-person lectures: Tata Hall, Room 3201, TuTh 5-6:20pm
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Instructors: Johnatan Aljadeff, PhD; Marcus Benna, PhD

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Email: **aljadeff@ucsd.edu (mailto:aljadeff@ucsd.edu)** ; **mbenna@ucsd.edu (mailto:mbenna@ucsd.edu)**

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Office Hours:

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Aljadeff, Mondays 3-4pm. CNCB 107 (Weeks 1-4, 9-10)

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Benna, TBD (Weeks 5-10)

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Course IAs:

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TA: Meg Robinson (Wednesday discussions); Chandramouli Rajagopalan (Friday discussions)

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Email: m5robinson@ucsd.edu (mailto:m5robinson@ucsd.edu) ; crajagopalan@ucsd.edu (mailto:crajagopalan@ucsd.edu)

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Office Hours:

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Robinson, Thursdays 3:30-4:30pm. FAH 2101 or https://ucsd.zoom.us/j/3688622604 (https://ucsd.zoom.us/j/3688622604)

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Rajagopalan, TBD

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Course Description:

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This course covers mathematical models of neurons, synapses, and neural networks. We will introduce theoretical frameworks of brain activity and function to understand neural computation and control of behavior. We will discuss network dynamics, synaptic plasticity, learning and memory. Students will apply modeling approaches to address scientific questions and make predictions for experiments.

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Course Outcomes:

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The goal of this course is to give students the necessary background and skills to understand how modeling approaches are applied to problems in neuroscience. Students will learn how to identify the type of model appropriate for specific scientific questions, neuronal systems and experimental datasets. The students will gain experience in how to extract experimentally testable predictions from computational models of neuronal systems at the single neuron and the network level.

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Course Requirements:

Readings:

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The following two books cover the course material:

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- Gerstner, W., Kistler, W. M., Naud, R., & Paninski, L. (2014). *Neuronal dynamics: From single neurons to networks and models of cognition*. Cambridge University Press.
  ebook link: https://neuronaldynamics.epfl.ch/online/index.html (https://neuronaldynamics.epfl.ch/online/index.html)
- Dayan, P., & Abbott, L. F. (2005). *Theoretical neuroscience: computational and mathematical modeling of neural systems*. MIT press.
  ebook link: https://boulderschool.yale.edu/sites/default/files/files/DayanAbbott.pdf (https://boulderschool.yale.edu/sites/default/files/files/DayanAbbott.pdf)

These books differ primarily in the mathematical level of the presentation. Overall Dayan & Abbott is easier to understand, while Gerstner et al. provide a more complete and up-to-date view of the field. Both books are available for free as ebooks via the library. The instructors will therefore assign reading from either book, on a topic-by-topic basis. When assigned, course readings must be completed before lecture. Lectures will draw heavily from the readings, so please come prepared to answer or ask questions about it.

Another useful resource are the materials of the Neuromatch Academy (academy.neuromatch.io (https://academy.neuromatch.io/)). Students are encouraged to consult these lecture materials and worked-out exercises, which will help with this course's homework assignments.

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Attendance:

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Attendance is highly encouraged at every lecture, as the homework and final exam will include materials covered in lecture that may not be explicitly mentioned in the readings. A significant

portion of the lecture will be given on the white-board (not on slides). The course will not be podcasted.

The most effective way of succeeding in this course is attending the lectures and taking notes. Importantly, the lectures will include materials that may not be contained in the readings, so it will be beneficial to be present and engage in active listening, note taking and participation.

Please note: It is the students' responsibility to attend all classes and to find out (from a peer) about material covered in any classes they may have missed.

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Course Website:

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Please check the course website on Canvas at least three times a week for updates, announcements, and ongoing class operations. **Checking updates is your responsibility.** Please make sure you are aware of the information available on Canvas when preparing for class or other parts of the course.

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Email Policy:

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Email is a vital way to communicate with your professors, the course IAs and classmates. We highly suggest you check your email at least three times a week, as we will be sending important reminders and announcements to your email. This is an easy way to ensure you do not miss anything. It is also a great way to get in contact with us or the IAs with any questions about information not already accessible (e.g., not included on the syllabus or Canvas Page). Please note that it may take up to 48 hours to receive a response. Always include BIPN 164 in the subject of your email.

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Course Assessments:

Homework Assignments:

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The Homework Assignments are aimed at assessing your understanding of the course material to date, your ability to apply the material you learned, and to present it in a professional and clear

way. You are encouraged to consult with online resources, including the Neuromatch Academy mentioned above, and with your classmates when working on the assignments. Homework will be assigned to groups of 2-4 students, to accommodate complementary backgrounds in biology, mathematics and programming.

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We will ask you to fill out a questionnaire on your background at the beginning of the course, to make these pairings effective and productive. It is important to be honest in filling out these questionnaires. Your responses will not affect your grade in any way. Misrepresentation of your background will make it extremely difficult to form effective teams for the homework assignments. **However, even when work on the assignments is done in pairs/groups, each student must write up and submit their own homework, which they will be graded on.** Homework solutions will be covered in the discussion section by the IAs in the following weeks, to ensure all course concepts are thoroughly understood.

Quizzes:

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Quizzes consisting of questions related to the lecture material will be assigned in between homework problems sets. They should be done individually.

Final Exam:

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The final is designed to evaluate your mastery of the course concepts and material. It will largely be based on a short answer and problem-solving format, drawing from lectures (including possible guest lectures), homework, and course readings. **You should not consult with your peers, the internet, course slides, readings, or your lecture notes while taking the exam**. You will be allowed to use one page of notes in the exam.

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The exam will be given in person and will be timed. You will only be allowed one attempt to take the final. The final will be given on 6/15/2023 from 7pm-10pm.

Section/Review Sessions:

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An optional section led by the IAs will be held each week. We encourage you to attend these sections to go over any questions or concerns you may have. While the section is intended to help

you with homework assignments and preparation for the exam, you will need to come with questions or points for clarification. It will not be a lecture that summarizes each week's material.

Grading/Re-grading Policy:

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For the course assessments, we will ensure that grading is as consistent and fair as possible, and if any grading errors should occur we will do our best to correct them. However, please do not ask for something to be regraded simply because you feel you deserve a higher grade, without a clear description of where you think there was an error. You are responsible for earning an A in this class. Earning an A will require: 1) attending lectures 2) actively participating in and taking notes on lectures and readings 3) submitting homework assignments on time 4) coming to office hours if you do not understand the material and 5) preparing for your exams (studying).

Late Assignment Policy:

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Deadlines are an integral part of professional and academic life, and there are deadlines for every assignment in this course. Assignments will lose 10% of the available points for each day they are late.

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Grading Breakdown:

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Assessment	**Grade Percentage**
4 homework assignments	15% x 4 = 60%
4 take-home short quizzes	4% x 4 = 16%
Final Exam	24%
Extra credit opportunities	1-3%

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Grade Scale:

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Letter Grade	Percentage
A+	97-100%
A	93-96.99%
A-	90-92.99%
B+	87-89.99%
B	83-86.99%
B-	80-82.99%
C+	77-79.99%
C	73-76.99%
C- (pass grade)	70-72.99%
D (fail grade)	60-69.99%
F (fail grade)	0-59.99%

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Accommodations:

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Students requesting accommodations for this course due to a disability must provide a current Authorization for Accommodation (AFA) letter issued by the Office for Students with Disabilities (OSD, https://osd.ucsd.edu/ (https://osd.ucsd.edu/)). Students should present their AFA letters to

the instructors and to the OSD Liaison at the Division of Biological Sciences in advance so that accommodations may be arranged.

If you will need to reschedule exams due to academic or sports exceptions, please provide the letter to the Instructors and the Teaching Assistant as soon as possible (preferably before the end of Week 3).

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Classroom Environment:

Professionalism Policy:

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Please adhere to all university policy and proper classroom etiquette. Those who are not following these guidelines will be asked to leave, in order to maintain the learning environment for other students. Please arrive on time, be attentive, and respectful to your instructor, guest lecturers, IAs, and fellow classmates. Be mindful of how much time and space you are occupying. Try not to interrupt others when they have the floor. Do not expect to feel comfortable with the material at all times. Expect this course to challenge you. UCSD recognizes the inherent dignity of all individuals and promotes respect for all people. **Hostility toward other students will not be tolerated. Free speech does not permit harassment, intimidation, threats, or other behaviors that impede the learning of other students or the work of instructors, guest lecturers, and IAs.**

You may use your laptop or tablets to take notes during lectures. However, this is strictly for note taking or class activities. If we notice that you are using it for anything other than class-related activities, we may ask you to put it away. Cell phones should be silenced before class and not used at all during lecture.

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Principles of Community:

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UCSD is dedicated to learning, teaching, and serving society through education, research, and public service. Students are encouraged to be creative and are rewarded for individual as well as collaborative achievements. To foster the best possible working and learning environment, UC San Diego strives to maintain a climate of fairness, cooperation, and professionalism. UCSD students are expected to practice these basic principles as individuals and in groups. Please review and abide by the UCSD Principles of Community: **https://ucsd.edu/about/principles.html**

(https://ucsd.edu/about/principles.html) . These specifically include 1) fostering inclusiveness, respect, and a welcoming environment and 2) promoting collaborative attitudes and actions.

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We support the education and social advancement of all students, regardless of their immigration status, religion, race, ethnicity, gender identity, or any other social factors that could be used to limit their life opportunities. We are here to help you succeed, and we will do what we can to make that happen.

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Schedule:

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Week and Weekly Focus		Daily Topic	Readings
Week 1 (Aljadeff): Single neuron models	Tue (4/4)	Introductions, Syllabus Review, Course Expectations, Questionnaire; Why is modeling important for understanding the brain? What kind of models will be (and will not be) discussed in this course?	No readings
	Thu (4/6)	Hodgkin and Huxley: ion channels and nonlinear conductance equations	D&A Chapter II 5 GKN&P Chapter 2

Week 2 (Aljadeff): Single neuron models	Tue (4/11)	From the Hodgkin-Huxley equations to spiking activity (oscillations). The neuron's input-output relationship	D&A Chapter II 5 GKN&P Chapter 4
	Thu (4/13): Deadline to add the course	Mathematical primer on dimensionality reduction (principal component analysis) From Hodgkin-Huxley oscillations to simplified models.	
Week 3 (Aljadeff): Single synapse models	Tue (4/18)	Viewing each synapse as a dynamical system: Models of resource depletion, facilitation, adaptation, and short term plasticity	D&A Chapter II 5.8 (partially covers material) Tsodyks, M., Pawelzik, K., & Markram, H. (1998). Neural networks with dynamic synapses. Neural computation, 10(4), 821-835.
	Thu (4/20)	Approaches for studying neural network activity: what is a mean-field theory?	https://doi.org/10.1162/089976698300017502 (https://doi.org/10.1162/089976698300017502) (Challenging but highly recommended reading)
Week 4 (Aljadeff): Network connectivity	Tue (4/25)	Connectivity motifs Connectivity degree distributions	

	Thu (4/27):	Connectomics in neuroscience:	
	Deadline to Drop without a “W”	What have we learned from extracting the wiring diagram of a neural circuit?	
Week 5 (Benna): Network dynamics	Tue (5/2)	Firing rate models, feedforward vs. recurrent networks.	Background material: GKN&P Chapters 12 & 15
	Thu (5/4):	Continuously labeled networks, selective amplification, input integration, gain modulation.	D&A Chapter 7.1-7.3 Mathematical Appendix A.3
Week 6 (Benna): Network dynamics	Tue (5/9)	Excitation/inhibition balance, network stability, attractors.	D&A Chapter 7.4-7.9
	Thu (5/11):	Perception, learned behavior and cognition: perceptual decision making and cortical field models.	GKN&P Chapters 16 & 18
Week 7 (Benna): Synaptic plasticity	Tue (5/16)	Autoassociative memory and Hopfield networks.	GKN&P Chapter 17
	Thu (5/18)	Single synapse dynamics, Hebbian & covariance learning, Oja’s rule.	D&A Chapter 8.1-8.2

Week 8 (Benna): Synaptic plasticity	Tue (5/23)	Unsupervised learning at the network level, mutual inhibition, PCA. (Similarity matching?)	D&A Chapter 8.3 GKN&P Chapter 19
	Thu (5/25)	Supervised learning and the perceptron.	D&A Chapter 8.4-8.7
Week 9 (Benna): Advanced topics	Tue (5/30)	Supervised learning using backpropagation and biologically plausible approximations.	TBD
	Thu (6/1)	If time permits: reinforcement learning, or complex synapses for efficient long-term memory.	D&A Chapter 9.1-9.3, or https://arxiv.org/pdf/1706.04946.pdf
Week 10 (Aljadeff): Advanced topics and exam review	Tue (6/6)	From a steady state view of neural activity to transient dynamics.	
	Thu (6/8)	Transient brain dynamics and final exam review	
Final Exam	Thu (6/15)	7-10pm, location TBD	

Course Summary:

Date	Details	Due
Fri Apr 21, 2023	**Homework Assignment 1: (https://canvas.ucsd.edu/courses/44853/assignments/636775)**	due by 8pm
Tue Apr 25, 2023	**Quiz 1, lectures 1-6 (https://canvas.ucsd.edu/courses/44853/assignments/646375)**	due by 11:59pm
Fri May 5, 2023	**Homework Assignment 2: (https://canvas.ucsd.edu/courses/44853/assignments/636776)**	due by 8pm