UNITED STATES AIR FORCE ACADEMY

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

ECE 495 Syllabus - Fall 2024

Introduction to Neuromorphic Engineering

Course description

ECE 495 is a special topics course that will provide foundational knowledge in the specialized field of neuromorphic engineering. This course will introduce cadets to an alternate computing paradigm, specifically neuromorphic computing (i.e. brain-inspired computing). This course will cover topics including but not limited to neuroscience, state of the art neuromorphic architectures, and computational neuron programming methods. This course will challenge your current programming mindset and prepare you to continue exploring alternate computing methods.

Instructors

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Course Goals

Cadets completing ECE 495 will be able to independently formulate a work plan for and execute a neuromorphic engineering research project and analyze results in a technical document.

Course Prerequisites

- Introductory understanding of Python

Course Text

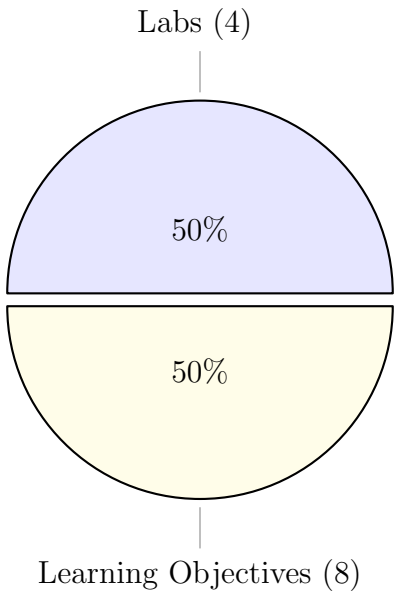
N/A

Course Communication

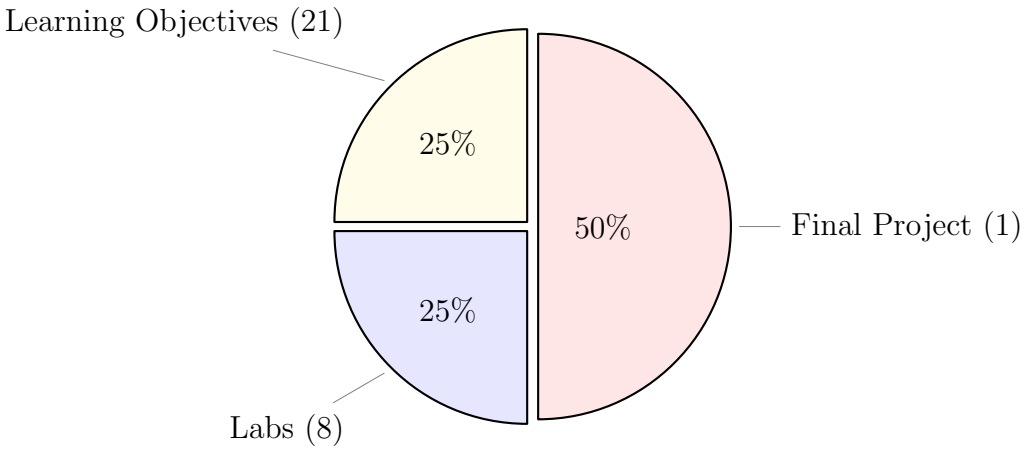
- **Gradescope** Cadets will be enrolled in the course on Gradescope. All Quizzes, Labs, and the Final Project will be submitted, graded, and returned through Gradescope.
- **Teams** Most communications regarding the course will be through Teams, including any due dates and schedule changes.
- **Email** Communications that require formal documentation should be submitted via email such as SCAs and notifications of bedrest.

The grade breakdown for the course at Prog and for your final grade are shown below. A number in parentheses indicates the number of items for that graded event.

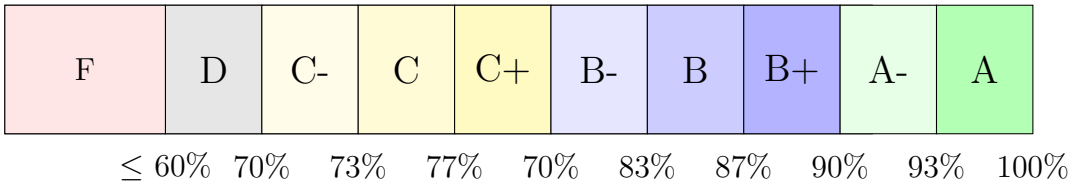
Prog Grade Weighting



Final Grade Weighting



Grade Scale



This course will utilize an alternative grading format. The intent is that your grades will be fairer, more accurate, and more meaningful. This grading format should also improve your learning and retention of concepts taught throughout the semester.

Learning Objective Quizzes

Learning objectives are key concepts required to succeed in this course and retain knowledge for future academic and professional endeavors. The Learning Objectives section of this syllabus details all learning objectives for this course. Your mastery (i.e. understanding) of a learning objective will be assessed using weekly quizzes. Key things to know:

- Each quiz will contain questions for at least two learning objectives.
- Each learning objective will span *two* separate quizzes to aid in your learning retention.
- To demonstrate mastery of an objective, you will be required to complete *all* questions regarding that objective with perfect accuracy. Whether or not you demonstrate mastery directly impacts your final grade for the course.
  - For each quiz question, you will receive a 1 (entirely correct) or 0 (incorrect).
  - If you receive a 0 on a question, you will be provided meaningful feedback on how to improve your understanding of that learning objective. The correct answer will not be provided.
  - You will have the opportunity to retake that quiz question once during the next quiz.
  - Retake questions will be similar but not identical to the original for which you received a 0.
  - If you do not complete a submission by the deadline for an assessment or you clearly did not put effort into your submission, you can earn your retake by reading a scientific publication chosen by your instructor, giving a 3-5 minute summary of the paper to the class, and answering questions in real time from your instructor and/or classmates regarding the paper. *Please, put in effort and submit your quiz answers on time!* Also take special note of the absences policy and adhere to due dates!
  - Two questions for an objective with scores of 1 demonstrate mastery of that objective, in which case you will earn a *total score* of 1 for that objective. For any objectives with one or more 0s, you will earn a *total score* of 0 for that objective.
  - The total scores for each objective determine your final learning objectives grade for the course. Example: you show mastery of 18 objectives out of 21 for the semester. Your learning objectives grade for the course is therefore $\frac{18}{21} = 86\%$
- Quizzes will be individual effort and completed outside of class and submitted, graded, and returned via Gradescope. You will have three hours to complete your quiz once it has been opened.

- You may only use class resources as well as Nengo documentation (nengo.ai and Nengo forum) to complete your quiz. Search engines, ChatGPT, or other AI assistants are not allowed during quizzes.
- Quizzes will be due each Sunday at 2359 unless otherwise directed by your instructor. Check Gradescope for official deadlines.

Labs

Labs are challenging programming assignments that will solidify your understanding of one or more learning objectives through application. Key things to know about labs:

- Labs will be given in the form of Jupyter notebooks. You can find the required Jupyter notebooks for the course here. You will be required to fill in the blanks within pre-written code or write portions of code from scratch within the notebooks.
- The Jupyter notebooks will also contain all instructions required for the lab, detailed notes with useful references, and tips for programming correctly. *Thoroughly reading the notes is critical to doing well on your labs.*
- Labs will be scored similar to quizzes, where you will receive a score of 1 (entirely correct) or 0 (incorrect).
- To earn a 1, all items listed in the instructions must be completed correctly as laid out in your Jupyter notebook.
- If you receive a 0, you have the opportunity to improve your score within one week of the original due date *if and only if* you have submitted your lab with clear effort by the original due date.
- To change your score from a 0 to a 1, you must demonstrate full understanding of the concepts covered in the lab by making changes to correct your code and scheduling EI with your instructor to talk through where you went wrong and how you fixed it.
- Labs will be graded individually, however working together is encouraged as noted in the Collaboration policy.
- There will be a dedicated work day during lecture periods for each lab (excluding the setup lab); however, work outside of class will be required to complete the labs.
- Labs will be submitted, graded, and returned via Gradescope.
- There are no restrictions regarding resources used to complete your labs. Be cautious that ChatGPT is known to provide incorrect code for programming assignments in this class - be sure to use generative AI tools responsibly (i.e. as a learning tool, not as a way to complete your lab).

- Labs will generally be due prior to the start of the next lecture (following a lab workday). Check Gradescope for official deadlines.

Final Project

Your final project is a culmination of your learning in this course. Key things to know about your final project:

- The final project will consist of four submissions: a literature survey utilized to select an algorithm to implement using Nengo and a detailed path forward to do so, two coding checkpoints determined in the aforementioned detailed path forward, and completed Python code with a scientific paper detailing methods used and analysis of results.
- Final project submissions are fast-paced given the amount of required work for each submission. As such, there will be no retakes offered.
- Each submission will receive one of the following scores:
  - 1: Submission meets or exceeds expectations of the assignment. Understanding of concepts is evident. There are no nontrivial errors. Communication (i.e. code comments and adjusted work plans) is clear and complete.
  - .75: Submission meets expectations of the assignment. Understanding of concepts is evident. Some revision or expansion is needed but no significant gaps or errors are present. Communication (i.e. code comments and adjusted work plans) is clear and complete.
  - .5: Partial understanding of concepts is evident but significant gaps remain. Improved communication (i.e. code comments and adjusted work plans) and/or significant revisions are needed.
  - .25: Not enough information is present to determine whether there is understanding of concepts. Work is fragmentary, contains significant omissions, or too many errors exist to easily correct. Improved communication (i.e. code comments and adjusted work plans) and/or significant revisions are needed.
  - 0: Either there was no submission or minimal effort was given on submission.
- There will be dedicated workdays during lecture periods; however, these workdays are meant to serve as dedicated time to discuss and work through programming challenges with your instructor and classmates (*i.e you are expected to have identified challenges prior to attending the workday period*). Therefore, work outside of class will be required to complete the Final Project.
- You final project will be graded individually and submitted, graded, and returned via Gradescope. Check Gradescope for official deadlines.
- Working together is encouraged as noted in the Collaboration policy; however, each student will select a different topic.

Obj	Description	Quiz
O1	I can describe why certain inputs elicit larger responses from a biological neuron.	Q1, Q3
O2	I understand how synaptic connections play a role in the propagation of information between biological neurons.	Q2, Q3
O3	I can discuss the benefits of using the brain as inspiration for computing technologies.	Q2, Q4
O4	I can recall the basic design of neuromorphic computing architectures.	Q2, Q4
O5	I understand the functionality and parameters of different neural network layers.	Q3, Q5
O6	I can explain why datasets are split into training data, test data, and sometimes validation data.	Q3, Q5
O7	I can contrast testing and training methods of traditional DNNs built for GPUs vs SNNs built for neuromorphic platforms.	Q4, Q6
O8	I can analyze the performance of a neural network based on the outputs of the network.	Q4, Q6
O9	I can design a Nengo neuron ensemble with appropriate intercepts and encoders to best represent data.	Q5, Q8
O10	I can recall why more neurons within a Nengo ensemble better represent my data.	Q5, Q8
O11	I understand the functionality of the synapse argument in Nengo.	Q5, Q9
O12	I can analyze Nengo decoder values (for both representation and transformations).	Q6, Q10
O13	I can select the appropriate radii of a Nengo neuron ensemble for a given problem.	Q6, Q11
O14	I understand the use cases for a multi-dimensional Nengo neuron ensemble and can build one when necessary.	Q6, Q11
O15	I can build a Nengo connection using the function argument.	Q7, Q12
O16	I can build a Nengo connection using the transform argument.	Q7, Q12
O17	I can choose when to use the function argument versus transform argument in a Nengo connection.	Q7, Q13
O18	I can explain why to use f' and g' functions to implement dynamics using Nengo neurons.	Q7, Q13
O19	I can design f' and g' functions to implement dynamics using Nengo neurons for a given problem.	Q7, Q14
O20	I can create a Python class and use it in conjunction with a Nengo node to perform complicated mathematical functions within a Nengo model.	Q9, Q14
O21	I can generate an Address Event Representation table from neuron spiking outputs.	Q10, Q15

	Lecture	Lab Workday	Notes
1	Course Overview		Setup Lab Released
2	Neuroscience		
3	Neuroscience		
4	Neuroscience		
5	Neuromorphic Engineering		
6	Neuromorphic Engineering		Setup Lab Due
7	Deep Neural Networks (DNNs)		
8		DNNs	
9		Spiking DNNs	
10	Neuron Basics - Representation		
11	Neuron Basics - Representation		
12	Neuron Basics - Transformation		
13	Neuron Basics - Transformation		
14		Neuron Basics	
15	Dynamics		
16	Dynamics		
17		Dynamics	
18	Bubble Sort		
19		Bubble Sort	
20	Path Planning		
21	Path Planning		
22		Path Planning	
23	Event-based Data		
24		Event-based Data	
25	Spiking Algorithm Brainstorm		Final Project (FP) Released
26	Advanced Neuron Functions		
27		Advanced Neuron Functions	FP Lit Survey & Work Plan Due
28		Final Project	
29		Final Project	
30		Final Project	
31		Final Project	FP Ckpt1 Due
32		Final Project	
33		Final Project	
34		Final Project	
35		Final Project	FP Ckpt2 Due
36		Final Project	
37		Final Project	
38		Final Project	
39		Final Project	
40		Final Project	FP Final Submission Due

1. **Instructor Philosophy**

   Communication is critical. This includes questions, concerns, requests, and challenges you may have as we work through this course together. And yes, we will be working through this course together. A large portion of the course will be spent working topics of interest specifically to you *selected by you* that have never been completed otherwise. This will require a significant amount of independent effort on your part. If you show up having put in the work, I will put in the work alongside you to ensure you succeed in this course and walk away with critical thinking skills and research experience that will prepare you for future academic and professional endeavors.

2. **Academic Honor**
   Your honor is extremely important. The course's academic security policies are designed to help you succeed in meeting academic requirements while practicing the honorable behavior our country rightfully demands of its military. Do not compromise your integrity by violating academic security or by taking unfair advantage of your classmates.

3. **Extra Instruction**
   EI is one of the best and easiest ways to succeed in this class; EI is recommended and welcomed early and often.

4. **Absences**
   In the event of an absence, communicate with your instructor **beforehand.** Please expect all quizzes, labs, and final project submissions to be due as scheduled, regardless of absence type. Should you have extenuating circumstances such as no internet while on approved travel or too ill to complete work while on bedrest, you must communicate an alternate plan with your instructor and ensure that your instructor has approved the alternate plan **before** the deadline for quizzes, labs, or final project submissions have occurred. If the original deadline passes and you have not submitted your assessment or challenge problem without an approved extension from your instructor, you will receive a 0 and you will not receive any retake opportunities.

5. **Collaboration**
   Collaboration (not copying) is highly encouraged unless your instructor provides direction otherwise. A good litmus test to distinguish between copying and collaboration is as follows: students must be able to explain every step indicated on their submitted work to be considered collaboration and not copying. All help received on work submitted for grading must be documented in accordance with the course documentation policy below.

6. **Generative AI**
   Your instructor is pro-AI unless noted otherwise (example: quiz grading details); however, I expect you to use generative AI platforms (ChatGPT, etc) as a tool rather than to complete your assignments for you. Similar to the collaboration policy: a good litmus test is that you must be able to explain every step indicated on your submitted work to be considered responsible use of generative AI. It will become clear quickly if you are using AI irresponsibly: ChatGPT often generates incorrect code for programming assignments in this course. If you utilize generative AI on any assignment, include a documentation statement as outlined in the Documentation Policy.

7. **Documentation**
   In accordance with the Dean's policy for documentation, all ECE assignments must have a documentation statement. The documentation statement should be clearly identified with the word "Documentation." If you did not collaborate, then the statement "Documentation: None," is appropriate. In the instance that you utilize a generative AI platform to assist you on your assignment, your documentation statement should contain the platform you utilized and *how* you used it. Example "Documentation: ChatGPT to write a for loop in python." Assignments without a documentation statement or with a clearly incomplete documentation statement will receive a 0 with retake policies as described in the Grading section.