PURDUE UNIVERSITY

WELDON SCHOOL OF
BIOMEDICAL ENGINEERING

Syllabus

Computational Neuroscience and Learning: basic

BME 495A, Spring 2014

Professor:
Eugenio Culurciello
Weldon School of Biomedical Engineering
Purdue University
206 S. Martin Jischke Drive, room 2031
West Lafayette, Indiana 47907
Web: http://engineering.purdue.edu/elab/

Meeting time and place:
Tue/Thur in MJIS 1083 from 1:30-2:45

Assistants:
Alfredo Canziani, acanzian@purdue.edu

Course Description and Objectives:
Learning objectives: this course sets the foundation of computational neuroscience: a branch of neuroscience that creates computable models of biological neural systems, in particular large scale neural networks for processing sensory information. This course builds on basic neural modeling, presents computable neuron models and extends to large networks of neurons. This course will teach how to use and write efficient software models of mammalian somatosensory systems, with focus on visual and auditory processing. The course studies the use of biologically-loyal models and application-oriented models, and how to trade one for the other when efficiency is needed in very large (> 1 Million) networks. The course is also deeply rooted in machine learning, and in particular supervised and unsupervised learning systems. The application is in synthetic and artificial vision and audition, perception, intelligence for robots and automatic system.
Lecture will include an overview of the state-of-the-art in the field, new opportunities and ideas for innovation and success with such systems. System-level lectures will be in the form of recent paper review and discussion.
Nature and purpose of the course: The course introduces student to the design and scaling issues of artificial brains and neural networks in both software and hardware implementations.
Main topics to be covered: The main topics are computational neuroscience, machine learning, deep-networks, artificial vision and auditory systems, physiology and neuroscience of mammalian perception, multi-sensory integration, real and artificial neural networks. Also computer vision, vision sub-blocks and vision areas.

Any special aspects of the format: The course will include a series of lecture by the instructor and will also feature selected presentation by the instructor from technical papers in the field of neuromorphic

systems design. In addition the class will feature final practical projects in neuromorphic systems. The projects will be tailored to real-life computer-vision (or speech-recognition or other sensing modalities), both provided by the instructor and/or suggested by the students themselves.
Learning outcomes: students will be able to understand, design and use bio-inspired deep-learning networks, and write algorithms to learn to segment, track, categorize, classify, objects of interest in a visual scene. Students will also be able to simulate large biological neural network with several million of neurons.

Course Schedule:

Week 1: Neuron and neural network models
Week 2: Deep neural networks
Week 3: Training neural networks: supervised techniques
Week 4: Training neural networks: unsupervised techniques
Week 5: Ventral pathways models: objects
Week 6: V1, V2 and object segmentation networks
Week 7: Visual attention: top-down, bottom-up
Week 8: Dorsal pathway models: visual motion
Week 9: Learning to predict motion and actions
Week 10: Full-scene understanding
Week 11: An entire vision system, part I
Week 12: Final project **proposal** presentations
Week 13: An entire vision system, part II
Week 14: Final project proposal discussion
Week 15: Final project reports and presentations

Prerequisites:
Basic knowledge of biology, real neurons, some foundation of the human nervous system is useful but not required.
Students should have basic knowledge of computers use and one or more programming languages.
No previous experience of knowledge in machine learning or neural networks is required.
You can ask permission of the instructor if you have taken similar courses elsewhere or wish to be advised

Strongly recommended related courses:
BME 301: Bioelectricity - or equivalent
ECE 301: Signals and Systems – or similar
BIOL 230: Biology of the Living Cell – or similar, nervous system focus
BIOL 302: Human Design: Anatomy and Physiology – or similar anatomy course, nervous system focus
CS 110: Introduction to Computers – or equivalent
CS 158, 159, ECE 264: C programming – or equivalent; this is an example programming course
CS 471 Introduction to Artificial Intelligence
You can ask permission of the instructor if you have taken similar courses elsewhere or wish to be advised

Attendance Policy:

No lecture is available in the textbooks or online in its complete form. In-class attendance is required because of the interactive nature of the course. If students miss a class, they will need to make an appointment with fellow students to review the missed material. Part of the course features some online lectures that can be enjoyed anytime, but class presence is still required for the full course.

Collaboration Policy:
Students are encouraged to talk to classmates about the homework problem sets, assignments, and final project. The write-up and coding work must be the student's own work.

Required Readings:
Each student is required to read an application article each week of the course. Also perform additional material search online and in books. The class online schedule will provide a weekly list of reading material.

Recommended online course to deepen knowledge:
- https://www.coursera.org/ courses on Machine Learning (Andrew Ng and Jeffrey Hinton)

Suggested book titles to read during the course to deepen knowledge:
- "Scaling Up Machine Learning" Cambridge University Press book, edited by Ron Bekkerman, Misha Bilenko, and John Langford
- Pattern Recognition and Machine Learning, Christopher M. Bishop, Springer, ISBN-10: 0387310738
- From Neuron to Brain,
http://www.amazon.com/Neuron-Brain-Cellular-Molecular-Approach/dp/0878934391/ref=sr_1_1?s=books&ie=UTF8&qid=1318871105&sr=1-1

Software for homework and projects:
This course requires the use and basic knowledge of programming languages. We will provide tools for students to improve their coding skills, but students are required to learn the tools quickly in order to take this course for credit.
- **Lua and Torch** - open source software for algorithm prototyping with neural networks
http://www.torch.ch/
Programming work can be performed on a personal machine or any of the university computers. The BME MJIS laboratory can be used for this purpose.

Projects:
The final project will consist on the design of a complete neuromorphic system. We use project in this course because it is the best way to stimulate class discussions and also problem-solving abilities, and to understand the theoretical concepts. Projects will require the use of a laptop / PC workstation for groups of 2-4 students. The project can be collaborative within a group, but a final report is required for each individual student. The students will run the software specified above to perform the tasks assigned. Note that software installation, syntax learning and compilation problems are typical with beginner students, so start your projects early to avoid problem. Projects are the final component of this course and require significant amount of time (~6 weeks or more) and also reflect in a large portion of the grade (see: Evaluation).

Homework:
The weekly homework will be several coding exercises of neural network model in software. The homework requires basic knowledge of computers, elementary programming skills, use of operating systems.
Please note that no late assignments will be accepted (less extenuating circumstances discussed in advanced with the teaching crew). Note that software installation, syntax learning and compilation problems are typical with beginner students, so start your homework early to avoid problem. Instructors are not able to help you on those issues.

Handouts:
Several handouts will be distributed during the course of the semester to provide additional material and explanatory notes. All handouts will be distributed in class and will be made available through the course web-page. Left-over paper copies that are not picked up in class will be left in folders outside the instructor's office.

Evaluation:
Class participation: 30%
Homework: 30%
Project: 40%, of which:
- 10% problem analysis and initial system design
- 15% software implementation
- 10% simulation results and demonstrations
- 5% coding practices and scalability of implementation

Students with special needs:
If you have a disability of any kind that could affect your work for the course, please contact me by email or in person as soon as possible, so that we can arrange appropriate accommodations in consultation with Purdue's Disability Resource Center.

Academic Integrity:
This course is designed at an introductory level for senior undergraduates. Both are required to show engagement and reading material well above the basic one provided in the course.
It is important to cite carefully ideas and information that you have obtained by any means other than your own engagement with primary reading (i.e. papers/texts/materials) or from class lectures/discussion. I encourage you to share and discuss your work with your peers in the course, but if you receive help from anyone, it's important to provide a detailed acknowledgment of that help when you turn in your assignment.
See http://www.purdue.edu/odos/osrr/integrity.htm for guidelines on academic integrity. If you are caught cheating in any way you will receive an F for the course.

What do letter grades mean in this class?
A 'B' grade means doing just what was asked of you, a 'C' grade means doing very nearly what was asked, and an 'A' grade means doing a really good job and showing creativity. Creativity doesn't mean making an observation that nobody has ever expressed, but it does mean thinking independently and working steadily so as to sustain your independent thought and design, within the context of the course.

In your final portfolio, it's important that you show that you have seriously engaged with novel design aspects and with the questions/ideas at stake in the course, and that you have done your best to explain your responses clearly and persuasively to your peers and instructors.

A: You have shown strong command of the course material and skills involved, showing knowledge, understanding, and independent thought. We expect that you will have very little difficulty in extending these skills in other contexts.

B: You have shown satisfactory command of the course material and skills involved. We expect that you will be able to use and extend the knowledge and skills acquired, and we see potential for development if you pursue this subject and/or continue to develop the skills involved.

C: You have shown some command of the course material. We see some potential for development if you wish to increase your command of the material and analytical skills involved in the course, but there is much room for improvement.

D: You have shown a barely adequate command of the material and skills. We fear that you are unlikely to be able to apply this knowledge at any level or continue studies in this direction unless you drastically change your study techniques.

F: You have not shown enough command of the material to be given credit for learning.

+ and – signs adjust grades within this overall pattern (e.g. a B+ often reflects promising and substantial command of the course materials, but without the independent thought needed for an A- or an A; alternatively a B+ can indicate that the student has shown signs of creativity and understanding, but without the solid basis in knowledge that would result in an A- or A; a B- suggests that there is clear promise for development, but that there are significant areas of weakness that need to be addressed in order to show a solid command of the course material/skills.) An A+ doesn't affect GPA, but it will be used to honor exceptional work.

There is no grading curve in this class. Everyone in the class could potentially achieve at least an A-, if everyone works steadily on their reading week by week (achieving good quiz, homework and project grades and participating thoughtfully in class discussion), and if everyone puts detailed thought into their papers, presentations and project final documents.