UNIVERSITY OF WATERLOO | FACULTY OF MATHEMATICS DAVID R. CHERITON SCHOOL OF COMPUTER SCIENCE

Neural Networks

CS 489/698: Topics in Computer Science (Winter 2020)

Description

This course surveys how networks of neurons can perform computation. We will cover a variety of methods for designing and training neural networks. We will study some state-of-the-art methods for artificial neural networks, as well as some approaches that are guided by the biological constraints of the brain. We will look at both supervised and unsupervised learning. Other topics include population coding.

Instructional Team

Instructor:

Jeff Orchard (online schedule)
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Teaching Assistants:

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Online Access:

Public Web Page	cs.uwaterloo.ca/~jorchard/CS_489_Neural_Networks
Piazza	piazza.com/uwaterloo.ca/winter2020/cs489698/home
Desire2Learn	

Lecture Schedule

- MWF 11:30-12:20, STC 0060

Suggested Prerequisites

One of (CS 370, CS 371), one of (STAT 206, STAT 231, STAT 241)

Goals

By the end of the course, students will be able to:

- Write a program to simulation the activity of a network of neurons
- Formulate a neural learning method as gradient-based optimization
- Derive a neural learning method based on energy minimization
- Encode and decode data from the activity of a population of neurons
- Identify some commonalities between artificial neural networks and the brain

Textbooks

- *Theoretical Neuroscience*, Dayan and Abbott, 2001 (UW library link)
- *Neural Networks and Deep Learning*, Nielsen, 2017 (link)
- *Deep Learning*, Goodfellow, Bengio and Courville, 2016 (link)
- *Neural Engineering*, Eliasmith and Anderson, 2003: MIT Press.

Evaluation

The course will have several assignments, a midterm, and final exam. Assignments will involve programming in Python. The approximate grade breakdown is:

- 50% Assignments
- 15% Midterm Exam(s)
- 35% Final Exam for those taking **CS 489**, or Project for those taking **CS 698**

Graduate students registered in CS 698 will do a project instead of writing the final exam. Its grading will be based on a project report submitted during the final exam period.

Topics

1. Background (4 hours)
    - Neuron models, spiking vs. firing-rate
    - Activation curves
    - Synapses
    - Networks of neurons
    - The Brain: vision, memory, motor control
    - Overview of Learning: Supervised/Unsupervised/Reinforcement
2. Supervised learning (9 hours)
    - Perceptron
    - Training, Validation, Testing
    - Universal Approximation Theorem
    - Cost functions
    - Gradient descent using finite-difference approx of gradient
    - Error Backpropagation
    - Vanishing/Exploding Gradients
    - Stochastic Gradient Descent (SGD)
    - Regularization, Momentum, Dropout
3. Unsupervised learning (6 hours)
    - Autoencoders
    - Network Energy
    - Restricted Boltzmann Machines (RBM)
    - Self Organizing Maps (SOM)
    - Variational Autoencoders
4. Population coding (7 hours)
    - Optimal Linear Decoding
    - Transformations and Dynamics
    - Neural integrators as working memory
    - Prescribed Error Sensitivity learning
5. Convolutional Neural Networks (2 hours)
6. Recurrent Neural Networks (3 hours)
    - Backprop Through Time (BPTT)
    - Long Short-Term Memories (LSTM)
7. Additional Topics (5 hours)
    - Software Packages
    - Adversarial Inputs
    - Predictive Coding
    - Equilibrium Propagation
    - Vector Embeddings (word2vec)

Course Work Policies

Assignment Submission

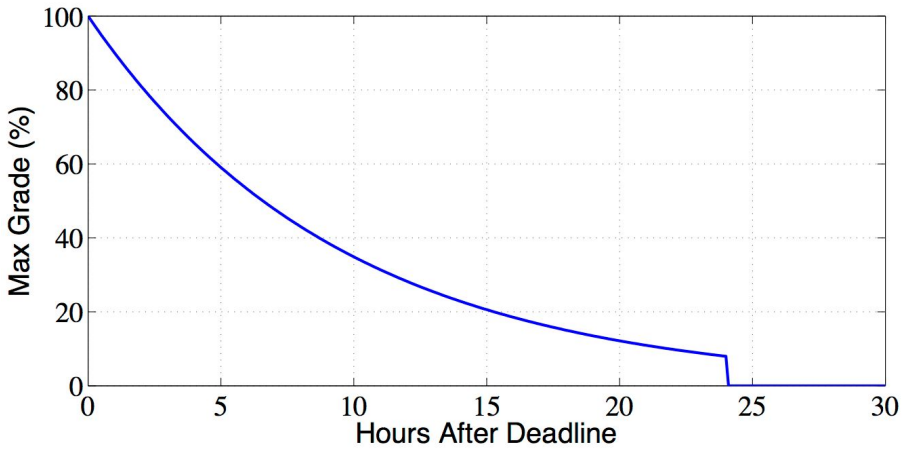
Assignments are submitted through Crowdmark in electronic form only. For each programming question, you will submit a PDF of a **jupyter notebook**, containing both code and output. We will use Python (version 3.6). For each non-programming question, you will submit a PDF, either of handwritten solutions (scanned or photographed), or typeset (eg. using Microsoft Word, or LATEX). If a photo of handwritten work is submitted, it is your responsibility to ensure that it is legible. Solutions that are not legible may be assessed a penalty.

Missed or Late Work

Late Policy: Your assignment solutions should be submitted online before the deadline. When multiple files are submitted, your official assignment submission time will be determined by your last submission. For example, if you hand in questions 1 and 2 on time, but hand in question 3 late, then the whole assignment will be counted as late. Also, if you submit solutions for a particular question more than once, only your most recent submission will be graded.

If your assignment is late, your assignment grade will be multiplied by a lateness scaling factor. This factor decays continuously by 10% per hour, and then drops to zero after 24 hours. That is, if *t* is the number of hours after the deadline, then

$$\text{lateness scale factor} = \begin{cases} 0.9^t & \text{if } t \leq 24 \text{ hours} \\ 0 & \text{if } t > 24 \text{ hours} . \end{cases}$$



Missed Assignments: Assignments not submitted will be given a grade of zero. If the student offers a valid and well documented reason for the omission (eg. a Verification of Illness Forms (VIF), counselling letter, etc.), the weight of the assignment will be added to the final exam weight.

Missed Midterm: If the student cannot write the midterm exam for a valid and well documented reason, the weight of the exam (15%) will be added to the final exam, making the final exam worth 50% of their final grade.

Remarking Policy

If a student feels that their work was not graded properly, they may post a private message to the instructors on Piazza describing their concern. The message should be labelled with the “re-mark” tag. Such requests must be made within a week of receiving the result.

Group Work

Students are encouraged to discuss assignments with other individuals in the class. However, a student's submitted assignment should be their own work.

Other Important Information

Academic Integrity: You are allowed to discuss theoretical and computational assignment problems and your solution strategies with your classmates, and you are allowed to consult external material (for example, reference books and online sources), but you are not allowed to copy any material from a classmate or from an external source for your assignments: all assignment material that you submit (including written documents, program code and graphical output) should be strictly your own work. Compliance will be actively monitored. More generally, 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. (Check http://uwaterloo.ca/academic-integrity/ for more information.)

Grievance: A student who believes that a decision affecting some aspect of his/her university life has been unfair or unreasonable may have grounds for initiating a grievance. Read Policy 70, Student Petitions and Grievances, Section 4, http://www.adm.uwaterloo.ca/infosec/Policies/policy70.htm. 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 [check uwaterloo.ca/academic-integrity/] to avoid committing an academic offence, and to take responsibility for his/her actions. 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 graduate Associate Dean. For information on categories of offences and types of penalties, students should refer to Policy 71, Student Discipline, https://uwaterloo.ca/secretariat/policies-procedures-guidelines/policy-71. For typical penalties check Guidelines for the Assessment of Penalties, http://www.adm.uwaterloo.ca/infosec/guidelines/penaltyguidelines.htm.

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 he/she has a ground for an appeal should refer to Policy 72 (Student Appeals) http://www.adm.uwaterloo.ca/infosec/Policies/policy72.htm.

Note for students with disabilities: The 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. See http://uwaterloo.ca/disability-services/ for more information.

Mental Health: If you or anyone you know experiences any academic stress, difficult life events, or feelings like anxiety or depression, we strongly encourage you to seek support.

On-campus Resources

- Campus Wellness https://uwaterloo.ca/campus-wellness/

- Counselling Services: counselling.services@uwaterloo.ca / 519-888-4567 ext 32655 / Needles Hall North 2nd floor, (NH 2401)
- MATES: one-to-one peer support program offered by Federation of Students (FEDS) and Counselling Services: mates@uwaterloo.ca
- Health Services: located across the creek from Student Life Centre, 519-888-4096.

Off-campus Resources

- Good2Talk (24/7): Free confidential help line for post-secondary students. Phone: 1-866-925-5454
- Here 24/7: Mental Health and Crisis Service Team. Phone: 1-844-437-3247
- OK2BME: set of support services for lesbian, gay, bisexual, transgender or questioning teens in Waterloo. Phone: 519-884-0000 extension 213

Diversity: It is our intent that students from all diverse backgrounds and perspectives be well served by this course, and that students' learning needs be addressed both in and out of class. We recognize the immense value of the diversity in identities, perspectives, and contributions that students bring, and the benefit it has on our educational environment. Your suggestions are encouraged and appreciated. Please let us know ways to improve the effectiveness of the course for you personally or for other students or student groups. In particular:

- We will gladly honour your request to address you by an alternate/preferred name or gender pronoun. Please advise us of this preference early in the semester so we may make appropriate changes to our records.
- We will honour your religious holidays and celebrations. Please inform us of these at the start of the course.
- We will follow AccessAbility Services guidelines and protocols on how to best support students with different learning needs.

Intellectual Property: Students should be aware that this course contains the intellectual property of their instructor, TA, and/or the University of Waterloo. Intellectual property includes items such as:

- Lecture content, spoken and written (and any audio/video recording thereof);
- Lecture handouts, presentations, and other materials prepared for the course (e.g., PowerPoint slides);
- Questions or solution sets from various types of assessments (e.g., assignments, quizzes, tests, final exams); and
- Work protected by copyright (e.g., any work authored by the instructor or TA or used by the instructor or TA with permission of the copyright owner).

Course materials and the intellectual property contained therein, are used to enhance a student's educational experience. However, sharing this intellectual property without the intellectual property owner's permission is a violation of intellectual property rights. For this reason, it is necessary to ask the instructor, TA and/or the University of Waterloo for permission before uploading and sharing the intellectual property of others online (e.g., to an online repository).

Permission from an instructor, TA or the University is also necessary before sharing the intellectual property of others from completed courses with students taking the same/similar courses in subsequent terms/years. In many cases, instructors might be happy to allow distribution of certain materials. However, doing so without expressed permission is considered a violation of intellectual property rights.

Please alert the instructor if you become aware of intellectual property belonging to others (past or present) circulating, either through the student body or online. The intellectual property rights owner deserves to know (and may have already given their consent).

Please see Policy 73 for more information,
http://uwaterloo.ca/secretariat/policies-procedures-guidelines/policy-73-intellectual-property-rights