Math 801: Topics in Applied Mathematics

Mathematical Introduction to Machine Learning

Fall 2021

Department of Mathematical Sciences, UWM

Lecture Time and Place

5:00 PM - 6:15 PM, Monday and Wednesday.

Instructor

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Office Hours: 3:00 - 4:00 PM, Monday and Wednesday.

Computer Lab Place

EMS Building, Room E424A.

Textbook

Lectures are given in Instructor's teaching notes based on the current literature on machine learning and deep learning. None of textbooks are required but students are recommended to read the following reference books:

- ***Deep Learning***, *by Ian Goodfellow, Yoshua Bengio, and Aaron Courville, MIT Press, 2016.* The book is available for reading on the website https://www.deeplearningbook.org/.
- ***Deep Learning with PyTorch***, *by Eli Stevens, Luca Antiga, and Thomas Viehmann, Manning, ISBN 9781617295263, 2020.*
  A copy of the book in the pdf format can be downloaded via the link
  https://pytorch.org/assets/deep-learning/Deep-Learning-with-PyTorch.pdf

Required Software

Computer work will be done in the computer script programming language *Python* based on a deep learning software library, PyTorch, which is maintained on the website https://pytorch.org.

You can install *Jupyter Notebook* from the website *https://jupyter.org/*. You then can get a tutorial lesson on the deep learning with PyTorch on the website
https://pytorch.org/tutorials/beginner/deep_learning_60min_blitz.html

Goals and Learning Outcomes

Students who successfully complete this course will be able to:

1. Understand the basic concepts and mathematical foundation of deep learning algorithms.

2. Implement basic neural networks and deep learning algorithms based on the library PyTorch.
3. Develop and analyze deep learning algorithms for solving real-world application problems.

Prerequisites

Graduate standing; At least one of Math 313/315 (P), Math 413(P), Math 417(P), Math 521(P), Math 621(P), Math 617 (P), and Math 715 (P); or consent of instructor.

Course Description

This course introduces basic mathematical techniques for data classification, dimensionality reduction, regression, and neural network parameter estimation. These techniques lay the mathematical foundation for understanding and developing machine learning algorithms.

Topics Covered

- **Machine learning basics:** Main problems to be solved by machine learning such as classification, regression, machine translation, anomaly detection, density estimation, etc..
- **Deep learning algorithms:** Deep neural networks, loss functions, regularization strategies, maximum likelihood algorithms, optimization algorithms for minimizing a loss function.
- **Dimensionality reduction techniques:** Singular value decomposition (SVD) and principal components analysis (PCA).
- **Probability and regression techniques:** Review of basic probability theory and statistic techniques, linear and nonlinear regression for deep learning, and Monte Carlo methods.
- **Optimization techniques for training deep learning models:** Stochastic gradient descent (SGD), SGE with adaptive moment (Adam) learning rates, nonlinear conjugate gradient method, BFGS algorithm, and batch normalization strategies.

Tentative Schedule

Week 1	Introduction (Chapter 1); basics of Python notebook and PyTorch; build and solve a deep learning model for a data classification problem by using PyTorch. *(First class meets on September 6, 2021.)*
Week 2	Build and solve a deep learning model for a MNIST data set from http://yann.lecun.com/exdb/mnist/ by using PyTorch. See the tutorial on *https://github.com/hadam1993/MNIST_Tutorial*. HW1.
Weeks 3, 4	Deep neural networks; loss functions; learning rates; and learning conditional distributions with maximum likelihood; part 1 of HW2
Weeks 5, 6	Regularization strategies for reducing the test error of deep learning, part 2 of HW2.
Weeks 7, 8, 9	Optimization techniques for training deep learning models; HW3.
Weeks 10, 11	Convolutional networks; Deep recursive neural networks; HW4.

Weeks 12 to 15	Discussion of current research topics on deep learning theory and applications; selected papers are assigned to students for their course projects.
Final Exam	Present course projects on Dec 22, 7:30-9:30AM

Assignments and Grading

- Four homework evaluations: 50 %. HW1 and HW2 for 15% each and HW3 and HW4 for 10 % each.
- Attendance: 10 %
- Discussion: 10 %
- Final Project: 30 %
- Grading scale: A (93-100), A- (88-92), B+ (83-87), B (78-82), C+ (73-77), C (65-72), D (55-64), F (below 55)

Credit hour policy and time allocation

The expected workload for this 3-credit course is 148 hours: 35 hours in the classroom (including lecture attendance and in-class midterm), 2 hours for the final exam, and 111 hours of homework and exam preparation (at 3 hours per class hour).

Class attendance

Attendance is required. Attendance will be taken after the second week. Each class missing is resulted in one point reduction. There is no provision for absences, missing examination, and missing homework due to vacations, family outings, social activities, or other special plans and appointments, etc. Absences due to illness require medical excuse on Physician's letterhead, signed by a physician.

Homework policies

Late homework will not be accepted. Collaboration among students is allowed but each student must submit his/her own work.

Project policies

Students can select project topics themselves. They can also select the topics that are discussed in the course discussion session. Collaboration among students is allowed but each student must submit his/her own work. The final project report is required to be written in Latex or MS word format. It includes title, abstract, and references. The main body of the report consists of introduction, method, results, discussion, and conclusion.

Discussion

Homework discussions will be held on selected problems. Each student needs at least two presentations on his/her work to earn the discussion points.

Make-up policies

No make-up is given for the final exam, but an incomplete grade can be given to eligible students (see link below).

University policies

1. Students with disabilities. http://uwm.edu/arc/
2. Religious observances. https://apps.uwm.edu/secu-policies/storage/other/SAAP%201-2.%20Accommodation%20of%20Religious%20Beliefs.pdf
3. Students called to active military duty. http://uwm.edu/active-duty-military/
4. A notation of "incomplete" may be given in lieu of a final grade to a student who has carried a subject successfully until the end of a semester but who, because of illness or other unusual and substantiated cause beyond the student's control, has been unable to take or complete the final examination or to complete some limited amount of term work. https://apps.uwm.edu/secupolicies/storage/other/SAAP%201-13.%20Incomplete%20Grades.pdf
5. Discriminatory conduct. https://apps.uwm.edu/secu-policies/storage/other/SAAP%205-1.%20Discriminatory%20Conduct%20Policy.pdf
6. Title IX/Sexual Violence. https://uwm.edu/sexual-assault/.
7. Academic misconduct. https://uwm.edu/deanofstudents/conduct/academic-misconduct/
8. Complaint procedures. https://apps.uwm.edu/secu-policies/storage/other/SAAP%205-1.%20Discriminatory%20Conduct%20Policy.pdf
9. Grade appeal procedures. https://apps.uwm.edu/secu-policies/storage/other/SAAP%201-10.%20Grade%20Appeals%20by%20Students.pdf
10. LGBT+ resources. Faculty and staff can find resources to support inclusivity of students who identify as LGBT+ in the learning environment. http://uwm.edu/lgbtrc/
11. Smoke and Tobacco-Free campus. UWM prohibits smoking and the use of tobacco on all campus property. https://apps.uwm.edu/secu-policies/storage/other/SAAP%2010-8.%20Smoke%20and%20Tobacco-Free%20Campus%20Policy.pdf
12. Final Examinations. https://apps.uwm.edu/secu-policies/storage/other/SAAP%201-9.%20Final%20Examinations.pdf

Note

The instructor reserves the right to make changes to the syllabus as needed as the course progresses.