Phys 494/594: Special Topics in Physics: Introduction to Machine Learning

Spring 2021

THE UNIVERSITY OF TENNESSEE KNOXVILLE

DEPARTMENT OF PHYSICS & ASTRONOMY

Course Description & Syllabus

Faculty Contact Information

Prof.	Adrian Del Maestro
Email:	`adel+ml@utk.edu`
Web:	`http://delmaestro.org/adrian`
Phone:	865-974-7998
Office:	306 South College Hall

Meeting Time

Tuesday/Thursday 1:10 – 2:25 PM, online on Zoom (link on Canvas).

Office Hours

Friday 3:00 – 4:30 PM, virtual on Zoom (link on Canvas).

Course Description

Machine Learning is rapidly becoming one of the most exciting and useful areas of modern research with important applications across the sciences. This class will provide an introduction to the fundamental concepts and applied tools of machine learning while being aligned with the needs and experience of physicists. We will focus on deep neural networks that can trained to perform a wide variety of tasks including image recognition, pattern identification, and natural language processing and discuss how these basic techniques can be applied to problems in physics, ranging from the prediction of material properties, the analysis of high-dimensional data sets, and to the discovery of phase transitions.

An outline of topics that will be discussed include:

1. Basics of neural networks and deep learning
2. Supervised learning including feed forward and convolutional neural networks.
3. Clustering and data visualization in high-dimensional spaces
4. Generative models such as auto encoders and restricted Boltzman machines
5. Recurrent neural networks

6. Reinforcement learning
7. Advanced topics including the use of neural networks to encode quantum states and learn physical Hamiltonians from experimental data.

Prerequisites

To be successful in this course you will need an understanding of linear algebra and calculus, including matrix multiplication and the chain rule. Python or similar programming experience, while not essential, will be extremely useful. Students without any prior programming experience should expect to spend time outside of class learning basic skills. Statistical physics at an undergraduate level would also be useful in developing a deeper appreciation of the intended applications.

Student Learning Outcomes

This course aims to provide students with the skills needed to move from data to decisions. This includes (1) understanding data; (2) make predictions, including regression, classification, and neural networks; (3) make decisions under uncertainty; (4) determine causal inference; and (5) understand how to apply the tools of machine learning to classical and quantum physics.

Value Proposition

Understanding large complex data sets and being able to rapidly identify fundamental patterns and make inferences is an essential skill of modern science.

Learning Environment

This class will be delivered in a completely flipped mode where synchronous time on zoom will be spent discussing content consumed outside of class followed by hands-on team programming exercises using Jupyter notebooks. Students will learn to use modern machine learning frameworks (e.g. TensorFlow, PyTorch) implemented in python.

Canvas

All course details, assignments, lecture notes and announcements will be available on Canvas at `https://utk.instructure.com/`. You are required to be aware of anything posted to the course website.

Reference Materials

I will provide copies of my lecture notes and videos on Canvas. There is no specific textbook for the course and we will take material from a variety of sources including:

- P. Mehta, M. Bukov, C.-H. Wang, A. G. R. Day, C. Richardson, C. K. Fisher, and D. J. Schwab, A High-Bias, Low-Variance Introduction to Machine Learning for Physicists, Physics Reports **810**, 1 (2019).
  `https://arxiv.org/abs/1803.08823`.
- Michael Neilsen, *Neural Networks and Deep Learning* (2019).
  `http://neuralnetworksanddeeplearning.com/`.

- David J.C. MacKay, *Information Theory, Inference, and Learning Algorithms*, (2005). `http://www.inference.org.uk/mackay/itila/book.html`
- Giuseppe Carleo, Ignacio Cirac, Kyle Cranmer, Laurent Daudet, Maria Schuld, Naftali Tishby, Leslie Vogt-Maranto, and Lenka Zdeborová, Machine learning and the physical sciences, Rev. Mod. Phys. **91**, 045002, (2019). `https://arxiv.org/abs/1903.10563`

Grading & Policies

Participation	10%
In Class Quizzes	10%
4-5 Assignments	50%
Final Project & Presentation	30%

No late assignments will be accepted and there will be no make-up quizzes. The lowest assignment and quiz grade will be dropped at the end of the semester.

Important Dates

The final project will be due on our scheduled final exam date: Wednesday May 5, 2021, 6:00 PM.

Religious Holidays

Students have the right to practice the religion of their choice. If you need to miss class to observe a religious holiday, please submit the dates of your absence to me in writing via email by the end of the second full week of classes. You will be permitted to make up work within a mutually agreed-upon time.

Statement on Civility & Community

The Department of Physics & Astronomy at the University of Tennessee is committed to creating an environment that welcomes all people, regardless of their identities. We value the diversity that enriches our department. We understand the importance of free and open dialogue that includes the free exchange of ideas. We do not tolerate uncivil speech or any form of discourse that infringes on others' rights to express themselves, or has a negative impact on their education, or work environment. We actively promote an environment of collegiality and an atmosphere of mutual respect and civility. We understand that respect includes being considerate of others' feelings, circumstances, and their individuality. We recognize the necessity of a civil community in realizing the potential of individuals in teaching, learning, research, and service. We believe these values extend beyond the department into our work within physics regionally, nationally, and internationally, as well as work and studies in the university, and the broader community. We encourage all members of the department to intervene and report any incidents involving bigotry, or that violate the university code of conduct.
`http://www.phys.utk.edu/about/civility-community.html`

COVID-19

`https://teaching.utk.edu/wp-content/uploads/sites/78/2020/11/COVID-19-Syllabus.pdf`

1 Campus Syllabus

1.1 University Civility Statement

"Civility is genuine respect and regard for others: politeness, consideration, tact, good manners, gracious-ness, cordiality, affability, amiability and courteous-ness. Civility enhances academic freedom and integrity and is a prerequisite to the free exchange of ideas and knowledge in the learning community. Our community consists of students, faculty, staff, alumni, and campus visitors. Community members affect each other's well-being and have a shared interest in creating and sustaining an environment where all community members and their points of view are valued and respected. Affirming the value of each member of the university community, the campus asks that all its members adhere to the principles of civility and community adopted by the campus."
`https://civility.utk.edu/`

1.2 Emergency Alert System

The University of Tennessee is committed to providing a safe environment to learn and work. When you are alerted to an emergency, please take appropriate action. Learn more about what to do in an emergency and sign up for UT Alerts. Check the emergency posters near exits and elevators for building specific information. In the event of an emergency, the course schedule and assignments may be subject to change. If changes to graded activities are required, reasonable adjustments will be made, and you will be responsible for meeting revised deadlines.
`https://safety.utk.edu/`

1.3 Academic Integrity

Each student is responsible for his/her personal integrity in academic life and for adhering to UT's Honor Statement. The Honor Statement reads: "An essential feature of the University of Tennessee, Knoxville is a commitment to maintaining an atmosphere of intellectual integrity and academic honesty. As a student of the university, I pledge that I will neither knowingly give nor receive any inappropriate assistance in academic work, thus affirming my own personal commitment to honor and integrity."

1.4 Your Role in Improving This Course Through Assessment

At UT, it is our collective responsibility to improve the state of teaching and learning. During the semester you may be requested to assess aspects of this course either during class or at the completion of the class. You are encouraged to respond to these various forms of assessment as a means of continuing to improve the quality of the UT learning experience.

1.5 Students with Disabilities

Any student who feels they may need an accommodation based on the impact of a disability should contact Student Disabilities Services in Dunford Hall, at 865-974-6087, or by video relay at, 865-622-6566, to coordinate reasonable academic accommodations.
`https://sds.utk.edu`

1.6 Accessibility Policy & Training

`https://accessibility.utk.edu`

1.7 Wellness

The Student Counseling Center is the university's primary facility for personal counseling, psychotherapy, and psychological outreach and consultation services. The Center for Health Education and Wellness manages 974-HELP, the distressed student protocol, case management, the Sexual Assault Response Team, and the Threat Assessment Task Force.
`https://counselingcenter.utk.edu/` and `https://wellness.utk.edu/`

1.8 Social Distancing & COVID-19 Procedures

Students are required to wear face masks at all times and maintain social distancing (6 feet between individuals in traditional classrooms, or, in instructional laboratories and similar settings, only a few minutes in closer proximity when absolutely necessary to achieve learning objectives). Students who are feeling ill or experiencing symptoms such as sneezing, coughing, or a higher than normal temperature will be excused from class and should stay at home. Instructors have the right to ask those who are not complying with these requirements to leave class in the interest of everyone's health and safety. In the event that a student refuses to comply with these requirements, the instructor has the right to cancel class. Additionally, following other simple practices will promote good health in and out of the classroom, such as frequent and thorough hand washing, wiping down desks and seats with disinfectant wipes whenever possible, not sharing personal items such as pens and cell phones, and avoiding crowded hallways and other enclosed spaces.

The Volunteer Creed reminds us that we bear the torch in order to give light to others. As Volunteers, we commit to caring for one another and for the members of the communities in which we live, work, and learn. This semester, the University asks that we all demonstrate the Volunteer spirit by following these and other health guidelines and requirements.