

# PHY391 Machine Learning for Physics Research

Fall 2024

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Time: Tuesday and Thursday, 9:20-10:35 Eastern US time

Location: LL316

## Course Description

The course is addressed to undergraduate and graduate students familiar with data analysis methods as typically taught in science labs, but who have little or no familiarity with machine learning. It will provide an overview of machine learning methods as used in physics, and more broadly, science research. It is an introduction to the main concepts, methods, and python libraries for machine learning, emphasizing practical training through examples.

## Course Contents

1. Introduction. Types and Challenges of Machine Learning in Physics. Working with python, Jupyter Notebooks and Machine Learning Libraries.
2. Classification. Training of Models. Cost Functions. Gradient Descent. Regularization.
3. Logistic Regression. Support Vector Machines. Decision Trees.
4. Ensemble Learning. Random Forests.
5. Dimensionality Reduction. Principal Components Analysis. Unsupervised Learning.
6. Deep Learning Basics. Multilayer Perceptrons. Optimization of Parameters. Backpropagation.
7. Convolutional Neural Networks. Recurrent Neural Networks. Graph Networks. Hamiltonian Neural Networks. Physics-inspired Neural Networks.
8. Introspection. Uncertainty and Robustness. Design of Objective Functions.
9. Weakly-supervised Classification. Autoencoders. Generative Models. Reinforcement Learning.
10. Hardware Requirements for Large Network Training.

## Initial Competences

- Data analysis methods as typically practiced in undergraduate science labs
- Basic scientific programming concepts and skills.
- Some experience writing scripts or small programs, basic use of command line.

## Final Competences

- Ability to select machine learning method to analyze data.
- Ability use classical machine learning tools and libraries.
- Ability to select and train deep neural network models.
- Knowledge of strength and shortcomings of machine learning methods.

## Office Hours and Individual meetings

Office Hours to be determined during the first meeting. I will also be available for individual meetings (through zoom or in person).

## Slack and Course Site

We will use Slack for course announcements, questions, links, ideas, and group activities. Students are expected to check it regularly and submit any course-related communication to the instructor or to other students there. It's much easier to quickly answer questions or requests on Slack. Homework will be submitted and graded on Course Site.

## Textbooks

Aurélien Géron, “Hands-On Machine Learning with Scikit-Learn, Keras & TensorFlow,” third edition, O'Reilly, 2022

Martin Erdmann, Jonas Glombitza, Gregor Kasieczka, Uwe Klemradt, “Deep Learning for Physics Research,” World Scientific, 2021

Viviana Acquaviva, “Machine Learning for Physics and Astronomy,” Princeton, 2023

The first two textbooks are available as ebooks through Lehigh University libraries.

## Grading

The course grade will be based on:

- 1. Homework problems (50%).** The homework problems will be data analysis exercises using python. Since practical training is one of the main aims of the course, students will be expected to devote a significant amount of time on the homework every week. Students will receive at least 50% for effort on each problem.
- 2. Class Participation and Quizzes (10%).**
- 3. Final Project (40%).** The final project will be decided in coordination with the instructor and should involve application of methods introduced in the course to a data analysis problem in physics.

# University Policies

## **Accommodations for Students with Disabilities:**

Lehigh University is committed to maintaining an equitable and inclusive community and welcomes students with disabilities into all of the University's educational programs. In order to receive consideration for reasonable accommodations, a student with a disability must contact Disability Support Services (DSS), provide documentation, and participate in an interactive review process. If the documentation supports a request for reasonable accommodations, DSS will provide students with a Letter of Accommodations. Students who are approved for accommodations at Lehigh should share this letter and discuss their accommodations and learning needs with instructors as early in the semester as possible. For more information or to request services, please contact Disability Support Services in person in Williams Hall, Suite 301, via phone at 610-758-4152, via email at [indss@lehigh.edu](mailto:indss@lehigh.edu), or online at <https://studentaffairs.lehigh.edu/disabilities>.

## **Bias, Discrimination, Harassment, Retaliation, and Sexual Misconduct:**

Lehigh University upholds The Principles of Our Equitable Community and is committed to providing an educational, working, co-curricular, social, and living environment for all students that is free from harassment and discrimination on the basis of age, color, disability, gender identity or expression, genetic information, marital or familial status, national or ethnic origin, race, religion, sex, sexual orientation, or veteran status.

Harassment and discrimination, including sexual harassment and misconduct, not only disrupts this commitment and violates our principles, but may also violate University policy and applicable laws.

Lehigh University and its faculty are committed to providing an environment that is free from bias, discrimination, harassment, retaliation, and sexual misconduct (including sexual harassment, sexual assault, stalking, dating violence, domestic violence, and sexual exploitation). If you have experienced, witnessed, or become aware of any of these behaviors, you are strongly encouraged to report the incident to the Lehigh University Police Department (LUPD) at 610-758-4200 or to the Equal Opportunity Compliance Coordinator/Title IX Coordinator (EOCC) at 610-758-3535 or at [eocc@lehigh.edu](mailto:eocc@lehigh.edu).

If you would prefer to submit your report electronically, two online reporting forms are available and may be submitted to report the incident:

Gender Violence Incident Notification Form: <https://cf.lehigh.edu/gves/auth/gvreport/>

Discrimination, Harassment, Retaliation, or Bias Incident Reporting Form:

[https://cm.maxient.com/reportingform.php?LehighUniv&layout\\_id=30](https://cm.maxient.com/reportingform.php?LehighUniv&layout_id=30)

Please note that, while the University options to respond may be limited, the online reporting forms may be submitted anonymously. Every effort will be made to address concerns reported anonymously.

You can access support and resources even if you do not want to take any further action following the submission of a report.