CPE 490/590 ST: Machine Learning for Engineering Applications

Instructor: Rahul Bhadani

Day/Time: Mon/Wed 6:00 PM - 7:20 PM
Location: ENG 240

Instructor	Rahul Bhadani
Office	ENG 217-H
Office Hours	M/W 4:45 PM - 5:45 PM
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Reference(s)	Required *Python for Probability, Statistics, and Machine Learning*. José Unpingco. Springer, 3rd Edition, 2022. ISBN-10: 3031046471, ISBN-13: 978-3031046476 Required *Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow*. Aurélien Géron. O'Reilly Media, 2nd Edition, 2019. ISBN-10: 1492032646, ISBN-13: 978-1492032649
Prerquisites	(i) EE 385 or ISE 390 or equivalent; (ii) and MA 244 or equivalent

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Course Description

> Machine learning deals with the automated classification, identification, and/or characterization of an unknown system and its parameters. There are an overwhelming number of application-driven fields that can benefit from machine learning techniques. For example, machine learning can be used to design and optimize wind turbines, secure and authenticate wireless communications, interface and control robotic systems, analyze and predict weather patterns, and monitor and diagnose mechanical faults. This course will introduce you to the fundamentals of machine learning and develop core principles that allow you to determine which algorithm to use, or design a novel approach to solving the engineering task at hand. This course will also use software technology to supplement the theory learned in the class with applications using real-world data.

Catalogue Description

This course provides fundamental knowledge of machine learning. Students will learn concepts and techniques of machine learning, including mathematical preliminaries, scientific Python, optimization, supervised and unsupervised learning, and deep learning. Through hands-on projects and real-world examples, students will gain practical experience in applying machine learning to solve complex engineering problems.

Course Learning Outcome

For CPE 490

- Apply fundamental concepts of probability, statistics, and machine learning using Python.
- Use machine learning libraries such as Scikit-Learn, TensorFlow, and PyTorch, for building and evaluating models for accuracy, precision, and recall.
- Implement and analyze machine learning algorithms for classification, regression, clustering, and dimensionality reduction by coding them from scratch and using popular Python libraries such as sci-kit-learn and PyTorch.
- Apply machine learning techniques to real-world datasets, interpreting the results through visualization methods such as loss curves, boxplots, histograms, and more.

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- Implement and analyze machine learning algorithms for classification, regression, clustering, and dimensionality reduction by coding them from scratch and using popular Python libraries such as sci-kit-learn and PyTorch.
- Apply machine learning techniques to real-world datasets, interpreting the results through visualization methods such as loss curves, boxplots, histograms, and more; identify areas for improvement, and extend to other applications.
- Apply and adapt existing machine learning methods to solve complex engineering problems, with a measurable performance improvement (e.g. 10% increase in accuracy or F1-score).

Academic Topics

The set of topics and areas covered by this course, and upon which you may be tested, include:

- Course Introduction, Mathematical Preliminaries: Linear Algebra, Probability and Statistics,
- Scientific Python Numpy, Scikit-learn, IPython & Jupyter Notebook, Matplotlib, Pandas, Matrix Algebra with Python, Root-finding using Newton Raphson Method, Probability and Statistics with Python, PyTorch for Linear Algebra
- Optimization and Gradient Descent Continuous Optimization, Optimization Using Gradient Descent, Univariate Optimization, Multivariate Optimization, Constrained Optimization and Lagrange Multipliers, Convex Optimization, Methods of Least Square, Implementation in Pandas, Scipy and Pytorch
- Supervised Learning – Regression Simple Linear Regression, Variance Estimation, Goodness of Fit, Confidence-band, Matrix approach to Regression, Multiple Linear Regression, Polynomial Regression, Locally Weighted Regression, Kernel Methods for Regression, Implementation in Scipy and PyTorch
- Supervised Learning – Logistics Regression Classification Problem, Logistics Function, Model Assessment
- Overfitting and Regularization Overfitting, Underfitting, Bias-Variance Tradeoff, Regularization, Ridge-Regression, LASSO, Elastic-Net
- Dimensionality Reduction and Feature Selections Maximum Variance Perspective, Projection Perspective, Eigenvector Computation and Low-Rank Approximations, Principal Component Analysis, Latent Variable Perspective, Feature Selection, Data Transforms, Implementation using Scikit-learn, Pandas, and Pytorch
- Supervised Learning – Support Vector Machine (SVM) Linear Classifier, Concept of Hyperplane, Hard Margin SVM, Soft-Margin SVM, Kernel-based SVM, Implementation using Scipy

- Unsupervised Learning – Classification Clustering techniques, K-means, Hierarchical Clustering, Agglomerative Clustering, DBSCAN, Graph-based Clustering, Expectation Maximization Algorithms, Gaussian Mixture Model, Evaluating Cluster Qualities, Implementation using Scipy
- Introducing Deep Learning – Neural Networks Perceptron, Multi-layer Perceptron, Nonlinear Activation Functions, Backpropagation Algorithms, Vectorization and Batch Techniques, Neural Network Layers, Training Neural Networks, Learning Rates and Optimization Techniques in Neural Network, Implementation using PyTorch

Weekly Schedule

Week	Topics	Representative Homework Assignment (Subject to change based on how class progresses)
1	Course Introduction, Mathematical Preliminaries	HW1: Implement basic linear algebra operations using NumPy.
2	Scientific Python	HW2: Develop a Jupyter notebook demonstrating data manipulation with Pandas and visualization with Matplotlib. Domain-specific hw: traffic flow data using Pandas and Matplotlib.
3	Optimization and Gradient Descent (Part 1)	HW3: Implement gradient descent for univariate optimization using PyTorch.
4	Optimization and Gradient Descent (Part 2)	HW4: Solve a constrained optimization problem using Lagrange multipliers.
5	Supervised Learning - Regression (Part 1)	HW5: Implement and compare simple linear regression using Scipy and PyTorch.
6	Supervised Learning - Regression (Part 2)	HW6: Confidence Band, Uncertainty Quantification

Table 1: Course Schedule and Homework Assignments (Weeks 1-6)

Week	Topics	Homework Assignment
7	Supervised Learning - Regression (Part 3)	HW7: Implement kernel regression and compare its performance with linear regression. Example homework: Uses kernel regression for traffic density estimation.
8	Supervised Learning - Logistic Regression	HW8: Develop a logistic regression classifier for a binary classification problem. Example homework: Build a fault detection model for electronic circuits.
9	**Spring Break**	
10	Overfitting and Regularization	HW9: Implement Ridge and LASSO regression, comparing their performance on a dataset. Example homework: Applies regularization to traffic accident prediction models.
11	Dimensionality Reduction and Feature Selection	HW10: Perform PCA on a high-dimensional dataset and visualize the results. Example homework: Uses PCA for dimensionality reduction in autonomous vehicle sensor data.

Table 2: Course Schedule and Homework Assignments (Weeks 7-11)

Week	Topics	Homework Assignment
12	Supervised Learning - SVM	HW11: Implement a kernel-based SVM classifier using Scipy. Example homework: Implements SVM for anomaly detection in power systems.
13	Unsupervised Learning - Classification	HW12: Implement K-means clustering and evaluate cluster quality. Example homework: Applies clustering to IoT sensor data analysis.
14	Introducing Deep Learning - Neural Networks	HW13: Implement a multi-layer perceptron using PyTorch for a classification task. Example homework: Implements a neural network for traffic sign recognition.
15	Convolutional Neural Network, LSTM, and Transformers	HW14: Implement a CNN for license plate recognition in smart parking systems

Table 3: Course Schedule and Homework Assignments (Weeks 12-16)

Summary of your responsibilities as an active participant in this course

Commit to taking part in every single class meeting. Commit to being engaged by switching off your mobile devices. Commit to learning the material in advance by performing the reading assignments without distraction. Commit to starting your homework and quizzes early by reading the homework descriptions before you start working on the code. Commit to helping everyone in the class by actively engaging in all the in-class exercises — even if you don't understand the topic, and even if you understand the topic better than everyone (including the instructors).

Commit to being an engaged member of this class, and your reward will be a deeper understanding of your own abilities and a deeper appreciation of how you can succeed in your career through committing to do better.

Course Outline

The listing of weekly course lecture topics may be found on the course webpage and is subject to change without notice due to class progress. In the event of a class cancellation, advance notice *via email* will be given, but any homework due that day will still be due unless otherwise notified via email.

Grade Policy

As your instructor, I do not "give" grades: I assign the grade that you earn—based on your individual performance. You will not be competing with other students for your grade for all assignments in this course: your grade is solely based on the points you earn, in the below-weighted categories:

For CPE 486 students

Homework	70%
Quizzes	20%
Attendance/In-Class Participation	10%

For CPE 586 students

Homework	60%
Quizzes	20%
Attendance/In-Class Participation	10%
Reproducing Result from an Existing ML Paper	10%

Grading Scale	
Percentage	**Grade**
90% - 100%	A
75% - 89%	B
60% - 74%	C
45% - 64%	D
0% - 44%	F

The percent score will be rounded to the nearest integer before assigning the final grade.

Students with Disabilities

The University of Alabama in Huntsville will make reasonable accommodations for students with documented disabilities. If you need support or assistance due to a disability, you may be eligible for academic accommodations. Apply here or contact Disability Support Services (256.824.1997 or Wilson Hall 128) as soon as possible to coordinate accommodations.

Technology Statement

This course will use UAH's learning management system, Canvas, as well as other technology tools. Students will be expected to have access to a computer with internet capabilities in order to fully participate in this course.

Course Websites

Main Website http://uah.instructure.com/

Homework Submission Policy

You must submit all of the code, data, and pdf files in a zip folder (i.e., not rar, 7z, etc) on Canvas. If the submission requires only a single file, it doesn't need to be zipped. Assignments must be submitted as a zip file with code and a pdf document with your solutions! You must include a single PDF file (not doc, docx, or multiple JPEG figures of the pages from your homework) with the solutions. Failure to follow any/all of these policies leaves the instructor the option not to grade the homework based on a failure to follow the homework submission policy. Your zip and pdf should be named as follows LastFirst-HW-X.zip and LastFirst-HW-X.pdf, where Last is your last name as it appears on Canvas, First is your first name as it appears on Canvas and X is the homework number.

Missed Assignments/Make-Ups/Extra Credit

No late homework assignments or quizzes will be accepted. Students are expected to start working on their assignments as soon as it is posted. There will not be extra credit assignments.

Attendance, Participation, and Quizzes

Attendance is mandatory. Although the class roll will be taken every day, pop quizzes or class handouts *may* be given without notice. Pop quizzes may not be made up, though a certain number may be dropped. In-class exercises will serve as objective measures of your participation and attendance, and may not be made up. Expected absences for valid reasons (e.g., travel to a conference) *must be cleared in advance* to avoid penalty for missing participation.

Attendance Policy

All students are expected to arrive on time and attend lectures. If there are extenuating circumstances, please email the instructor. If you are absent, you are responsible for learning the material covered in class. If you are absent when an assignment is due, you must have submitted the assignment before the due date to receive credit. Please contact your instructor if you have specific questions or concerns.

Class Disruptions

Please silence your cell phone, and do not use it during the class. The use of a phone in class will adversely affect your attendance grade[*].

Academic Integrity

Students are expected to do all work by themselves, except when specified by the instructor in writing. All exceptions will be plainly marked in the requirements for that exercise or project. Any violations of this policy will be dealt with to the full extent permitted by the University of Alabama in Huntsville, and *may result in suspension or expulsion from the university, in addition to a failing grade*. Please familiarize yourself with the Code of Academic Integrity if you have any questions.

Communication & Instructional Continuity

In this class, the official mode of communication is through the Slack channel. During the week, students can expect a response from the instructor within a 24-48 hour timeframe. Messages sent during the weekend may not be answered until the following week. On occasion, response times may vary due to domestic and international travel for conferences or meetings.

[*]Uh, um, unless you are programming it as part of an in-class exercise. But please no talking or texting. Unless, uh, that is part of the class exercise too.

In the event a regularly scheduled course is unexpectedly interrupted, course requirements, due dates, and grading policy are subject to change when necessitated by revised course delivery, semester calendar, or other instances. Information about changes in this course can be obtained from the Canvas course webpage or by contacting me. If, under these circumstances, I do not respond within 72 hours, please contact my department at ece@uah.edu.

If our regular scheduled class meeting is interrupted or the campus should unexpectedly close, students should immediately log onto Canvas and read any course announcements. Students are encouraged to continue the readings and other assignments as outlined on the course syllabus until otherwise advised. Any student who does not could fall behind in the course.

Course Conduct

All students must treat others with civility and respect and conduct themselves in a way that does not unreasonably interfere with the opportunity of other students to learn. All communication between student/instructor and between student/student should be respectful and professional.

Academic Honesty

Your written assignments and examinations must be your own work. Academic misconduct will not be tolerated. Examples of unacceptable behavior include plagiarism/use of prior work/use of Chegg and other online problem-solving sites/etc. To ensure that you are aware of what is considered academic misconduct, you should review carefully the definitions and examples provided in the Student Handbook. If you have questions in this regard, please contact me without delay.

Course Artificial Intelligence (AI) Policy

You are allowed to use a generative model-based AI tool for your assignment. However, you must submit an accompanied reflection report on how you use the AI tool, what was the query for the tool and how it improved your understanding of the subject. You must also add your thoughts on how you would tackle the assignment if there was no such tool available. Failure to provide a reflection report for every single assignment where an AI tool was used may result in a penalty and subsequent actions will be taken in line with plagiarism policy.

Safety Instructions

The frequent operation of a computer, such as will be required in this course, may have long-term disabling effects if you do not appropriately consider your ergonomic interaction with the computer, desk, chair, and light sources. Poorly designed workstations/practices can lead to musculoskeletal disorders and may result in chronic pain, inability to sleep, or expensive surgery decades from today. The habits you form in your university years may well impact your future performance, and it is highly recommended that you consult with the office risk management and compliance https://www.uah.edu/rmi.

Disability Statement

The University of Alabama in Huntsville will make reasonable accommodations for students with documented disabilities. If you need support or assistance due to a disability, you may be eligible for academic accommodations. Apply here or contact Disability Support Services (256.824.1997 or Wilson Hall 128) as soon as possible to coordinate accommodations.

Mental Health Statement

As a student you may experience a range of issues that can cause barriers to learning, such as strained relationships, increased anxiety, alcohol/drug problems, feeling down, difficulty concentrating and/or lack of motivation. These mental health concerns or stressful events may lead to diminished academic performance or reduce a student's ability to participate in daily activities.

The University of Alabama in Huntsville offers services to assist you with addressing these and other concerns you may be experiencing. If you or someone you know are suffering from any of the aforementioned conditions, you can learn more about the broad range of confidential mental health services available on campus via the Department of Student Affairs located under the Health and Wellness or the UAH Counseling Center by calling 256.824.6203.

24-hour emergency help is also available through the 24/7 National Suicide Prevention Hotline at 1.800.273.TALK or at suicidepreventionlifeline.org or a student who lives on-campus can reach out to the UAH PD dispatch to contact an on-call counselor by calling 256.824.6596. If you find yourself in a mental health emergency, call 6911 on-campus or 911 off-campus.

Pertinent UAH Policies & Guidelines

- UAH Student Handbook
- Academic Misconduct Policy

- Complete listing of UAH Policies and Procedures
- AI and the Classroom

Campus Resources

The University of Alabama in Huntsville offers a range of student services to enhance the experience of students.

- Academic Support Services – ASAP, Student Success Center, Tutoring, PASS, Academic Support Centers by College
- Student Support Services – Counseling Center, Disability Support Services, Student Health Services, Office of International Services, Multicultural Affairs, etc.
- UAlert—Sign up for UAH's emergency notification system to receive urgent messages from the university
- Registrar's Office – Academic Calendars, Course Registration, Student Records, Commencement
- M. Louis Salmon Library – Printed and Online Resources, Reference Services, Group Study Rooms, AV Resources, Printing
- Canvas Support – Call 844-219-5802 to report an issue with Canvas.
- OIT Help Desk – For technical support, contact the OIT Help Desk (helpdesk@uah.edu; 256.824.3333)

NOTE: When submitting a support ticket include your name, your class, the element/assignment being affected, and a detailed description of the issue. Providing a screenshot is often very helpful in diagnosing an issue.

Important Dates

Review the semester dates and deadlines and the academic calendar.

Subject to Change

Every effort is made to follow the guidelines in the syllabus; however, if needed, the syllabus will be amended. You will be notified if changes are made.

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