Course Name: Machine Learning and Pattern Recognition (AI 3011)
Course Website: https://ai3011.plaksha.edu.in
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Course Description

This course deals with the design, analysis, and methodology of algorithms used to recognize patterns in real-world data of any sort (images, audio, videos, text, financial, speech, biosensing, medical, etc.). This is the foundational course in Artificial Intelligence which has transformed the world around us in innumerable ways such as online search (ChatGPT), voice recognition ("Hey Google!"), facial recognition applications (iPhone screen lock), and medical diagnosis (DeepMind). Today, Machine Learning is perhaps the most-vibrant area of engineering research and is witnessing the most lucrative careers due to its sheer number of applications in every other field of research. It is the one field which has truly become interdisciplinary because of its capability to be useful in analyzing data from other branches of knowledge, from physics to psychology, medicine to meteorology, and politics to philosophy. Since Machine Learning and Pattern Recognition encompasses hundreds of algorithms and mathematical concepts, the goal of this course is not to give an overview of each one of them. Rather, it is to impart to students a strong fundamental background on these topics (such as feature clustering, dimensionality reduction, classification, and neural networks) with the ability to undertake real-world projects and build an end-to-end application. Overall, the students will gain a working knowledge of using these tools and algorithms and get a tangible idea of using them to solve real-world problems around them.

Course Overview

The first module of the course (Week 1-9) delves into the tools required to generate real-world datasets, recognize, and utilize patterns in them (such as feature extraction, clustering, dimensionality reduction, and classification), and how such algorithms could be deployed on real-world problems. These are the fundamentals of machine learning that are useful on any kind of datasets. The second module of the course (Week 10-12) goes deeper into a particular type of machine learning algorithms (Neural Networks) that have proven to be highly successful in recognizing patterns and be deployed on real-world applications. Finally, the last module (Week 13-15) is a bonus module on specific data visualization techniques like t-SNE and machine learning approaches like Reinforcement Learning and Genetic Algorithms that are used for specific applications. Additionally, "deep" machine learning models like CNNs, GANs, etc. will be introduced in this module only as black boxes so that students can get an overview of using them for different applications before studying them in-depth in the Deep Learning course next semester.

Learning Objectives (Statements that are not measurable but suitable for assessment) | To be used when faculty do not want to grade or give marks. This component is to be included in the Course outline being submitted to Academic office, the student version will only include learning outcomes.

By the end of this course, each student will have had the opportunity to:

Understand the basic concepts of Machine Learning and remember the holistic picture to connect the dots between the concepts.

Apply the above concepts to real-world problems outside those discussed in the class.

Analyze the world around them to search for problems that could utilize machine learning to solve.

Synthesize the knowledge from their hands-on experiences to gain confidence and willingness to tinker with and create working machine learning prototypes. This would be the ultimate evaluation of the learning from the course.

Learning Outcomes (Statements starting with measurable verbs suitable for evaluation) | To be used when faculty want to give grades and marks.

By the end of this course, each student will have had the opportunity to:

1. Engage in hands-on working with real-world data from images, audio, text, etc. to find statistical patterns.
2. Explore pattern recognition methods on the data for extracting features and work with them towards cleaning, clustering, classifying, etc. i.e., analyzing the statistical patterns in the data.
3. Demonstrate the ability to find real-world problems where they could use the above methods to build robust solutions.
4. Apply the above statistical techniques to build real-world applications.
5. Evaluate the efficacy of the developed solutions to make them more robust and scalable.
6. Create a prototype that utilizes machine learning to solve a real-world problem.
7. Articulate the characteristics and efficiency of their prototype as to how it works better than previously-existing solutions.

Required Texts and Online Resources

1. Hands-On Machine Learning with Scikit-Learn, Keras, and TensorFlow, 2nd Edition by Aurélien Géron Released September 2019 Publisher(s): O'Reilly Media, Inc. ISBN: 9781492032649
2. Machine Learning course videos by Andrew Ng (https://www.youtube.com/playlist?list=PLoROMvodv4rMiGQp3WXShtMGgzqpfVfbU)

Additional Resources

1. Pattern Classification by Richard O. Duda, Peter E. Hart, David G. Stork, 1974
2. https://medium.com/machine-learning-in-practice/my-curated-list-of-ai-and-machine-learning-resources-from-around-the-web-9a97823b8524
3. Pattern Recognition and Machine Learning by Christopher M. Bishop, 2006

Class Schedule

Week	Topics
Week 1	What is Machine Learning (ML)? How is it different from traditional programming? Why use ML? Types of ML systems Feature Selection and Extraction on multimodal data
Week 2	Feature Preprocessing (cleaning, handling missing values, one-hot encoding), dividing dataset into train/validation/test sets Basic Pattern Recognition Tools on Extracted Features (Template-based Matching, Correlation, Covariance, HOG features)
Week 3	Features Clustering

	K-Means, Finding optimal k (number of classes) for clustering GMM Clustering and DBScan Clustering methods
Week 4	Features Dimensionality Reduction Curse of Dimensionality, Principal Component Analysis (PCA), Independent Component Analysis (ICA) Linear Discriminant Analysis (LDA) [Quiz 1]
Week 5	Features Classification and Regression I Distance-based Classification, K-Nearest Neighbors Classification Performance Metrics (Confusion Matrix, ROC Curve, F1-score vs. Accuracy, Precision, Sensitivity, etc.) and Data Sampling
Week 6	Features Classification and Regression II SVMs, Kernels, Support Vector Regression, Voting Classifier Semi-supervised Learning
Week 7	Main challenges of ML Systems (insufficient data, overfitting, poor quality data, irrelevant features, noise in the dataset, etc.) Responsible AI: Fairness, Inclusion, and Ethics in ML (Biases and Examples)
Week 8	[Midterm Project Evaluation]
Week 9	Performing Computer Vision, Time-series, and NLP Analyses with above techniques on real-world data (applications in Computer Science, Finance, Biology, and Robotics) [Quiz 2]
Week 10	Introduction to Neural Networks (NNs) Biological NNs and parallels with Artificial NNs, Mathematical formalization of neurons (Perceptron), Perceptron Training Algorithm, Learning and linear separability in a Perceptron, XOR Problem

	Multilayer Neural Networks, Backpropagation and its training algorithm, solving the XOR problem, decision boundaries in hidden layers
Week 11	Hyperparameters Tuning in Neural Networks Learning Rate, Momentum, Adaptive Learning Rate, Accelerated Learning, Weights Initialization (vanishing and exploding gradients, and dead neurons) Regularization (L1, L2, and Dropout), Batch Normalization, Mini-batch
Week 12	Deep Learning (Visual Data) Convolutional Neural Networks (CNN), Common CNN Architectures Overview, Main Concepts: Weight-sharing, Convolution, Padding, Pooling CNN Spatial Dropout, BatchNorm, deeper dive into the common CNN Architectures (VGG-16, ResNets, NiN, GoogLeNet, Inception v3, etc.), Transfer Learning
Week 13	Recurrent Neural Networks Backpropagation through time, Long-short term memory (LSTM), Many-to-one word RNNs, Generating text with character RNNs Attention Mechanisms and Transformers
Week 14	Generative Adversarial Networks (GANs) Autoencoders, Fully-connected Autoencoders, Convolutional Autoencoders GANs loss function, applications and different types of GANs
Week 15	[Quiz 3] Genetic Algorithms, Reinforcement Learning
Week 16	[Final Project Evaluation]

Generative AI Policy

The use of Generative AI platforms like ChatGPT, Google Bard, GitHub Copilot, etc. is absolutely not permitted for any kind of code generation/debugging/evaluation/analysis for this course. Violation of this policy in any form by a student will make them ineligible to pass the course. However, such Generative AI platforms may be used for anything else that is not related to programming like referring to different sources, reading about the history of ML research, getting ideas about what problems could be solved using ML, examining which algorithms are apt to use for a particular problem, etc.

Class Demos

Each class will consist of about 50-60 minutes of lecture followed by demos inspired by real-world applications for the next 20 minutes. These demos will be shown by the instructor using MATLAB (and may also include some embedded systems for tangible "real-world" applications) so that the students can visualize the practical applications of the concepts taught in the class.

Labs

Each lab will be used for two purposes. First, the students will be given a programming assignment to implement one of the class demos using Python to get a "hands-on" learning experience. The output of this assignment and students' understanding of the related concept will be graded and will contribute towards the grading assessment component (see below) of the lab. Second, the lab will also serve as a time when the students will be able to discuss the progress (queries/questions/received feedback) on their semester project for the course with the TAs and the instructor.

Project

This class will involve a project which will serve several purposes. First, it will give you the opportunity to explore in-depth the multidimensional (pun intended) facets of the Machine Learning and Pattern Recognition course. Second, it will support the development of your critical thinking and hands-on application skills; in my opinion, this is one of the primary goals of university education.

The students will form groups of two or three (Remember: One is a maverick, two is a pair, three is a team, and four is a crowd) to undertake a project. The project must be inspired by a real-world problem (the instructor will help the students to identify the problem) and which could be potentially solved by developing a machine learning solution. The students are expected to work with the instructor in the first three weeks to identify a problem for each group, the hardware and/or software resources that would be needed, and the methodologies that may be required to work on it. Students are also encouraged to approach other faculty members to access data from their research for this project.

Below are the project evaluation criteria:

1. Problem Statement

   The problem that students are trying to solve must be related to a difficulty that they face in their lives. For reference, projects undertaken by the UG 2021-25 are here: https://ai3011.plaksha.edu.in/projects.html. This time, the scope of the projects has been widened so that students can also work on projects that solve research problems in collaboration with other faculty members as well. The idea here is that students envision solving a problem that traditional programming cannot solve and that there is merit in solving it utilizing machine learning by collecting/utilizing data from the past.
2. Background and Significance

   Students will be asked to do a thorough background survey to see what related solutions are already available for the identified problem, their merits and limitations, and what are the possible strategies to overcome those limitations. The students will then choose exactly what contribution they want to make to the identified problem and what would be its significance.

3. Data Collection
   Students are expected to collect data themselves for the project rather than using an existing dataset unless the kind of data collection they are planning to pursue is not possible at Plaksha. In the latter case, students will be evaluated on their understanding of the niches of the dataset being used by them and preprocessing the dataset.

4. Development of the ML Solution
   The students will be expected to utilize the ML concepts discussed in the class (or related concepts) to program a solution and then validate its efficiency (empirically, please provide numbers) against other solutions presently used by others.

5. Understanding of fundamental concepts
   Students' understanding of the fundamental ML concepts utilized in solving the problem and why the choices to use those models/techniques were made.

6. Deployability of the Solution
   The efficacy of the developed solution and its deployability at Plaksha University. Students are expected to show the feasibility.

The students can also submit a video (maximum duration 2 minutes) during the final evaluation explaining the various components of the project.

Students must also submit their software code for the entire project to check for plagiarism. Any violation of the institute's policy on plagiarism will make the students ineligible to pass the course.

Grading

Quiz 1 (week 5): 10%

Project (midterm evaluation i.e., week 8): 20%

Quiz 2 (week 9): 10%

Quiz 3 (week 15): 10%

Project (final evaluation i.e., week 16): 30%

Lab Evaluation: 15%

Attendance: 5%

Participation

Participation is not mere attendance in the class! In order to effectively participate in the course, it is critical that each member of the team read the course assignments and participate in class discussions and simulations and in group work. The participation grade will be based on your participation both in the class as a whole and in small groups. This grade is a "value added" assessment; in other words, sheer frequency or volume of verbal activity is not necessarily the goal of class participation. The grade is derived from meaningful dialogue based on reading and thinking reflectively.

To participate in class more fully, you might consider, for example, commenting on specific issues raised in the class readings; illustrating specific issues from the readings with examples from your personal experience; raising questions not covered in the readings; comparing or contrasting ideas of various theorists from the readings; or supporting or debating the insight or conclusions of a classmate (or the instructor!) by referencing concepts, experiences or logical reasoning.

Part of participation also includes setting the tone of collegiality, whether that is through contributing to a snack table, engaging in conversation with classmates during breaks, or making fellow students feel welcome. Participation is not merely an intellectual exercise; it is also a community building experience.

Attendance

Regular attendance is expected in this course in order to achieve maximum learning for all participants. Unforeseen circumstances do sometimes arise, so periodic absences may occur. If you find that you must miss or be late to a class meeting, please contact the instructor's teaching fellow prior to the start of class. **Students are expected to maintain at least 70% attendance in both lectures and labs, failure to do so would make them score zero towards the attendance grade (5% of the course grade).**

Incompletes

An "Incomplete" grade will be awarded in case a student does not complete any assessment or evaluation exercise as a result of which they do not meet the passing criterion. This is only for medical/social emergencies beyond the control of students or cases of pending disciplinary investigation and must be approved by the Dean, Academic Affairs.

Scholastic Dishonesty | Academic Integrity

Situations involving academic integrity are governed by the UG academic policy. Here are the specifics: the instructor shall report case to the Academic Integrity Committee, which, after taking into due consideration the nature of the evaluation component and the intensity of the offence, as well as the number of times the student has committed prior offenses, will prescribe the appropriate corrective action.

Advising

My goal is to be as available as possible to meet your needs during the semester. To reach me:

- E-mail me at siddharth.s@plaksha.edu.in; this is the best way to contact me. I check e-mail frequently and, unless I am out of town, I will usually respond to your e-mail within 24 hours.

- In Person: Although I will try to make myself available to you if you "drop by", please do not expect a substantive conversation; I may have other commitments. However, I will be available every week during office hours, Monday 5-6 PM, Office No. 2411.

To make a phone or in-person appointment, please contact my teaching fellow Mr. Pushpinder Singh (pushpinder.singh@plaksha.edu.in) and Ms. Poonam Adhikari (poonam.adhikari@plaksha.edu.in).