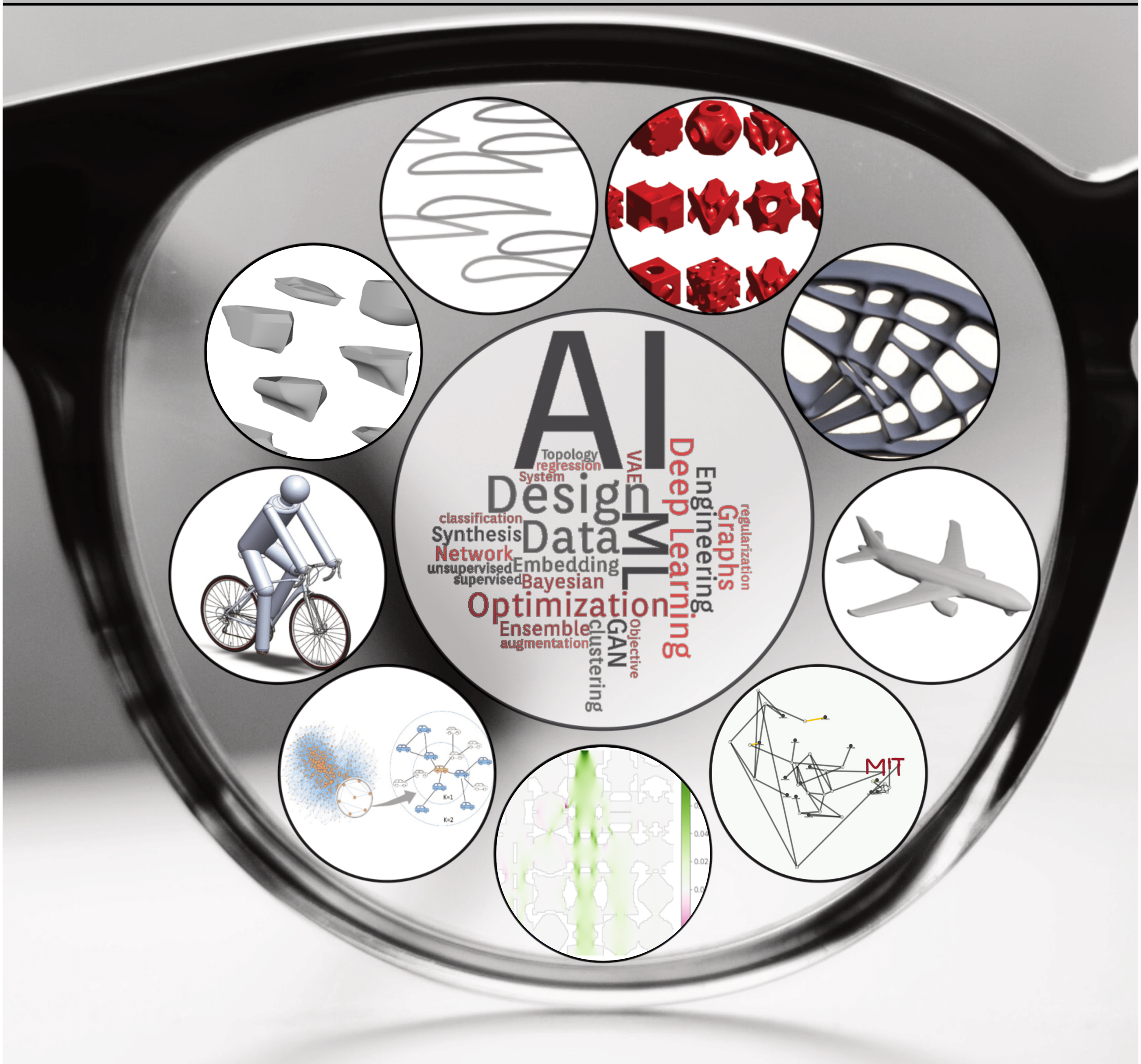
2.155: Artificial Intelligence and Machine Learning for Engineering Design



Learn to apply Artificial Intelligence and Machine Learning methods to design new products or systems and solve complex engineering problems. This project-based course will focus both on the theory and the practical implementation of machine learning and optimization techniques.

MIT 2.155/2.156 Fall 2023 Prof. Faez Ahmed (faez@mit.edu)

2.155/2.156 Artificial Intelligence and Machine Learning for Engineering Design

Instructor	Faez Ahmed faez@mit.edu Office hours: Monday noon - 1 pm in 3-435A
Class	MW 1:00 PM – 2:30 PM in 4-145
Subject	Undergraduate (2.155) Graduate (2.156) 12 units 3-0-9
Course Assistant	[TA] Lyle Regenwetter regenwet@mit.edu TA office hours: TBA
Description:	In this course, students will delve into the applications of Artificial Intelligence and Machine Learning in engineering design, focusing on the creation of new products and addressing engineering design challenges. Emphasis will be on the practical implementation of advanced machine learning and optimization strategies. Participants will be involved in a term project, employing these AI techniques to address complex problems of their choice. Additionally, there will be hands-on exercises in machine learning tailored to specific engineering issues, such as robotics, aircraft, structures, and metamaterials. The curriculum also incorporates discussions on research papers, facilitated by students. This course is designed for engineering students with preliminary knowledge in programming and machine learning, aiming to apply these tools across diverse engineering landscapes.
Prerequisites	2.086, 6.100A, or permission of instructor. The class does not expect you to have a background in machine learning. However, familiarity with programming skills is recommended.
List of topics	• Introduction to Python • Data Visualization • Single and Multi-objective Design Optimization • Similarity, Norms, and Feature Engineering • Supervised Learning: Classification Methods • Supervised Learning: Regression Methods

- Cross-Validation
- Unsupervised Learning: Clustering Methods
- Dimensionality Reduction
- Neural Networks: MLPs and Convolutional Neural Nets
- Self-Supervised Learning
- Deep Generative Models: Generative Adversarial Networks
- Deep Generative Models: Diffusion Models
- Applications of Generative Models for Design Synthesis
- Computational Creativity and Novelty Detection
- AutoML
- Natural Language Processing Introduction
- Transformers: BERT, GPT
- Interpretability of Neural Networks
- Statistical Graph Learning for Complex Systems
- Graph Neural Networks
- Ethics in Machine Learning
- Challenges in Data-Driven Design Applications

Term project

Engage in a comprehensive term project, utilizing the skills and techniques learned throughout the course. Students are encouraged to tailor their projects around personal or research interests. Conclude the term by showcasing your work through an end-of-semester poster presentation.

Challenge problems

Join teams to tackle AI-centric design challenges. Engage with varied facets of machine learning and design through each problem, ranging from optimization to deep generative models. Submissions should include your solutions, relevant code, and a reflective report on your approach.

Research paper discussion

Some classes will start with a 30-minute chat led by a student about a design research paper. For these classes, you need to write a short review of a paper you pick. This review should have a summary and your thoughts about the paper, plus any questions you think would be good to talk about. Make sure to give this in before the class starts.

Grading

Grading will be based on projects, challenge problems, and paper presentations. The grading breakdown and milestones will be discussed in the first lecture. Students taking graduate version (2.156) complete additional assignments.

Programming

We will use the Python programming language for all assignments in this course. For students who have never used Python, introductory tutorials and starter code will be provided for most of the problems and demos. While other programming languages such as MATLAB, Julia, and R are permissible for assignments, primary support and resources will be provided for Python.

Recommended Text Books

There is no single textbook that covers all of the topics we will discuss in this course. The recommended books listed below may be useful for a deeper understanding of the topics.

- Ulrich, Karl T. & Eppinger, S. D. & Yang, M. Product design and development. Tata McGraw-Hill Education.
- Kevin Murphy, Machine Learning: A Probabilistic Perspective, MIT Press
- Aaron Courville, Ian Goodfellow, and Yoshua Bengio, Deep Learning, MIT Press
- Tom Mitchell, Machine Learning, McGraw Hill

Office hours

To improve students' familiarity with Python and its libraries, we will conduct weekly TA office hours to cover student needs for Python knowledge and machine learning libraries. These office hours will be used to explain the challenge problems when they first come out, answer any questions related to the problems, and provide an opportunity for open Q&A to any questions that were not addressed during lectures. Attendance is optional.

Previous Year Projects

The class was offered in Fall 2021 and Fall 2022 as 2.s997. The previous projects covered a diverse range of applications, from medical design to energy systems, with pioneering methods like generative adversarial networks and symbolic optimization. This showcases the course's extensive reach into contemporary engineering topics and innovative computational approaches.

List of projects from 2022:

- Learning Deformable Point Cloud Correspondences in Medical Ultrasound Data
- Motorsports Cooling Optimization
- Optimized Torsion Spring for Rehabilitative Exoskeleton

- Nozzle Constraints Aware Data-Driven Topology Optimization
- Predicting Loads on a Decentralized Grid
- Wind Farm Model and Wake Steering Optimization with PyWake
- Using Machine Learning to Optimize Black Box Simulations
- Latent Space Design Exploration of Complex Structures
- Temperature and Density Measurements Using Optical Spectroscopy and Machine Learning in Inhomogeneous Non-Optically Thin Plasmas
- Implementing Natural Language Processing to Assess the Design and Performance of the iPhone SE
- Machine Learning for Inverse Kinematics
- Classifying the Impact Performance of Truss-Based Lattices
- Efficient Meshing Scheme for the AMORE Mesh
- Data-Driven Modeling of McKibben Actuator Dynamics
- Bike Design Analysis and Classification Using AutoML

List of projects from 2021:

- Data-Driven Design of Customized Prosthetic Feet
- Multi-Objective Optimization of Ventricular Catheters Using Genetic Algorithm
- Symbolic Regression and Variational Autoencoder Generation of Metamaterial Unit Cells
- When Machine Learning Meets IC Engine: ML Application on Gas Flow Pattern in Piston Ring Pack System
- Evaluation Method on 3E+S for Energy Mix Options in Power Generation Market Using GA Algorithm
- Preliminary Benchmark Study of Algorithm Configuration, Selection, and Evaluation for Data-Driven Modeling of Experimentally-Derived Datasets
- Robot Exploration Initialization Optimization

- Using Segmented Images to Improve Bicycle Image Reconstruction with Variational Autoencoder
- Using Machine Learning Model to Optimize Peak Load and Heat Stress Under Heat Waves for Buildings in Various Dimensions by Adjusting Fan Speed and Thermostat Setpoint
- Multi-Objective Optimization for Strength-Ductility Tradeoff Using Deep Learning
- Topology Optimization Using CNN and Conditional GAN

Below are a few photos from the final poster presentations in 2022 (top) and 2021 (bottom).