4.453 Creative Machine Learning for Design

Spring 2023

*Design generated by Renaud Danhaive*

This research seminar focuses on applications of machine learning (ML) for creative expression, algorithmic design, and data-informed design exploration, with an emphasis on visual and 3D generative systems. Throughout the semester, we will explore how recent advances in artificial intelligence, and specifically machine learning, can offer humans more natural, performance-driven design processes. The class covers a wide range of machine learning algorithms and their applications to design, with topics including neural networks, generative adversarial networks, variational autoencoders, dimensionality reduction, transformers, and other ML techniques. It includes an open-ended applied research or design project demonstrating an original, creative use of machine learning for design, architecture, engineering, or art. Enrollment is limited to 20 students.

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| **Instructors**Renaud DanhaiveCaitlin MuellerOus Abou Ras (TA)Tasha Hirt (TA) | **Meetings**W 2-5pmMIT room 4-265 | **Class Websites**[Canvas](https://www.google.com/url?q=https://canvas.mit.edu/courses/13601&sa=D&source=editors&ust=1675872434462623&usg=AOvVaw3c_HbiaY0iBBAnnMcKHMBz)[Slack](https://www.google.com/url?q=https://mit-4453-sp22.slack.com/&sa=D&source=editors&ust=1675872434463260&usg=AOvVaw2uxG0v6k4wjuuniiHlFtg7)[Zoom](https://www.google.com/url?q=https://mit.zoom.us/j/99734201920&sa=D&source=editors&ust=1675872434463798&usg=AOvVaw18Pc6DysYq1UIBWycgYflg) (backup only) |
| **Level**G + Advanced undergraduates | **Units**3-0-9 | **Textbook + Readings**Readings will be assigned in class on a weekly basis |

**Contact and assistance with course content**

For questions and course-related posts, please use our Slack workspace instead of email unless absolutely necessary.  The teaching style of the class will rely heavily on peer discussion on Slack to help foster increasing independence and student competence with tools, skills, and basic debugging over the semester.  Questions with answers that are easily found in assignment prompts or coding notebooks may not be answered directly or thoroughly.

**Prerequisites**

Programming experience in Python (e.g. 6.100A or similar). The seminar focuses on applications of machine learning for design. Therefore, we will not cover the theoretical underpinnings of machine learning in detail, but we will instead focus on an intuitive understanding of the most common algorithms developed through a combination of high-level theory, case studies, and hands-on experimentation. If you have already taken an applied machine learning class, this class will teach you ways to apply your machine learning knowledge to creative design applications. If you have never taken an ML class before, we will provide the necessary help and support.  We will not spend time in class teaching programming fundamentals or Python syntax, and we assume familiarity with both.  We will use Google Colab notebooks for Python programming, which we have found to offer a good balance of ease of getting started and flexibility.

**Limited enrollment and listener policy**

Due to the space limits of our classroom and time limits of our teaching staff, the course enrollment will be limited to 40 registered students.  A small number of listeners may be permitted if space in the classroom allows.  Students may apply to enroll in the class by completing a short HW 0 that will be distributed at the end of the first lecture.  Decisions on enrollment will be communicated by teaching staff by 5pm on Friday, February 10.

**Intended learning outcomes**

At the end of 4.453, you’ll be able to:

* Understand the basic mathematical and probabilistic principles behind modern ML algorithms
* Critically apply existing ML algorithms to architectural and structural design applications
* Prototype ideas by combining off-the-shelf libraries with visual and 3D content generation software
* Generate and gather design data using sampling algorithms
* Create compelling, interactive visualizations of high-dimensional design spaces using dimensionality reduction
* Use ML to explore design spaces with an emphasis on performance
* Generate design content, including images, drawings, and 3D geometries, with ML-based generative algorithms
* Evaluate the use of ML in creative contexts through an understanding of data sources, algorithmic concepts, authorial intent, and reproducibility

**Academic integrity and honesty**

MIT's expectations and policies regarding academic integrity should be read carefully and adhered to diligently: [http://integrity.mit.edu](https://www.google.com/url?q=http://integrity.mit.edu&sa=D&source=editors&ust=1675872434470233&usg=AOvVaw1GIBKsuZF4IkhWmBJiz1dk)

**Meeting structure**

All classes will meet in person in 4-265 on the MIT campus.  Video of lectures will be recorded as a backup for students who must miss classes due to health or other approved reasons but will not be provided by default.

**Assignments and project**

The central focus of this subject is a semester-long original research project, supported by 8 preliminary homework assignments, 1 group mini-project, weekly readings, and class discussions.  Work is to be completed individually unless specified otherwise.  Late assignments will result in a penalty of 20% of the total available grade for each day past the deadline, unless extreme circumstances warrant an extension (must be arranged with the teaching assistant via Slack 24 hours before the deadline).

**Evaluation criteria and grading breakdown**

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| 10% | Attendance and participation: students are expected to attend the full session of each class and to actively contribute to the intellectual atmosphere via discussions, in-class exercises, and general participation.  In addition, students are expected to help each other by answering questions on Slack.  Unexcused absences and/or non-participation will result in grade reduction. |
| 35% | 8 assignments (7 best scores are included in grade): each based on Python coding notebooks and some conceptual evaluation questions. |
| 15% | Mini-project: Students will work in teams to explore and explain well-known models/methods from ML that are relevant to the aspirations of our class via hands-on coding. |
| 5% | 1-page project abstract |
| 10% | Final project presentation: Students will each give a 7-minute research presentation highlighting the key contributions of their final projects.  Evaluation will consider both the content and the quality/clarity of the presentation. |
| 25% | Final project deliverable* The main deliverable for all projects is a research report (limited to five pages), which clearly and concisely presents the original research work completed during the course.  The paper should be written in the style of a scholarly, technical academic publication that could be presented at a conference or submitted to a journal. Evaluation will consider originality, scholarly quality, technical accuracy, and thoroughness of results.
* Students are also expected to submit a usable implementation of their work.
* Other final project deliverables will be discussed on an individual basis depending on the type of project of each student.
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**Late submissions**

You have 4 slack days, which you can use as you wish for assignments 1–8. Late submissions not covered by a slack day will incur a penalty of 20% of the total available grade for each day past the deadline. Any assignment submitted after solutions have been posted will be deemed missing.  Please note that assignments will be posted on Wednesday afternoons following lecture and will typically be due 8 days later on Thursday mornings.

**Course outline**

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| Week |  Date | Topic | Assignments |
| **01** | February 8  | **Introduction + Intro to optimization**Efficient design space exploration | HW 0 + HW 1 assignedHW 0 due | Feb 9 |
| **02** | February 15 | **Sampling + Clustering and dimensionality reduction**Building and visualizing design data setsSimplifying and visualizing high-dimensional design data | HW 2 assignedHW 1 [due](https://www.google.com/url?q=https://goo.gl/kbQbH6&sa=D&source=editors&ust=1675872434487372&usg=AOvVaw1mCsi8bB8I6rnqJ_qsD9aR) | Feb 16 |
| **03** | February 22 | **Intro to supervised learning and regression**Surrogate modeling for fast performance evaluation | HW 3 assignedHW 2 due | Feb 23 |
| **04** | March 1 | **Intro to neural networks**Multi-layer perceptrons and compositional pattern-producing networks | HW 4 assignedHW 3 due | March 2 |
| **05** | March 8 | **Convolutional neural networks**Simulation field prediction | HW 5 assignedProject assignedHW 4 due | March 9 |
| **06** | March 15 | **CNNs under the hood**Exploiting trained CNNs for inverse design, image generation, and stylization | Mini-project assignedHW 5 due | March 16 |
| **07** | March 22 | **Latent variable models Pt. 1**Generative models for design |  |
| **08** | April 5 | **Latent variable models Pt. 2**Fine-tuning pretrained models | HW 6 assigned1-page project abstract due |
| **09** | April 12 | **Mini-projects and final project feedback** | Mini-project due  in-class presentations) |
| **10** | April 19 | **Differentiable pipelines and modular neural networks**Combining models for design applications | HW 6 due | April 20 |
| **11** | April 26 | **Intro to RNN + Transformers Pt. 1** |  |
| **12** | May 3 | **Transformers Pt. 2** |  |
| **13** | May 10 | **Final project presentations** | Final report draft due |
| **14** | TBD | **Final project presentations** | Updated final report (optional) |

HW 0 - Simple coding and data manipulation/plotting

HW 1 - Image based classification

HW 2 - Optimization and sampling with lots of visualization and interactive widgets (Old 2 + 3)

HW 3 - Clustering/dim red (t-sne) and regression (RF) on midsole data (Old 6 + 4)

HW 4 - Old HW 5, neural networks, coral SDF

HW 5 - Old HW 7. Sneaker inverse design, GAN

HW 6 - Old HW 8, language model

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