50.039 - Theory and Practice of Deep Learning (2024)

About the instructors and teaching assistants

Prof. Matthieu (Matt) De Mari

Matthieu De Mari received the PhD degree in Mathematics and Computer Science from CentraleSupelec, France, in July 2015. He was involved with several research projects using various tools from statistics, simulation, optimization, and machine learning theories, to analyse the performance of the future generation of wireless networks. More specifically, his research and teaching interests revolve around game theory, mean field game theory, deep learning, and reinforcement learning.

Email: matthieu_demari@sutd.edu.sg

Office and office hours: 2.401-07, email this professor first to arrange a meeting, in person or online.

ISTD page: https://istd.sutd.edu.sg/people/faculty/matthieu-de-mari/

Prof. Ngai-Man (Man) Cheung

Ngai-Man (Man) Cheung’s research interests are image and signal processing, computer vision and AI. His research has resulted in 14U.S. patents grantedand more than 100 research papers including top publications such as NeurIPS, CVPR,etc. Two of his inventions have been licensed to companies. One of his research results has led to a SUTD spinoff on AI for wound care. His research has also been featured in the National Artificial Intelligence Strategy. He has received several research recognitions, including the Best Paper Finalist at the IEEE Conference on Computer Vision and Pattern Recognition (CVPR) 2019, the Finalist of Super AI Leader (SAIL) Award at the World AI Conference (WAIC) 2019at Shanghai, China.

Email: ngaiman_cheung@sutd.edu.sg

Office and office hours: 2.401-26, email this professor first to arrange a meeting, in person or online.

ISTD page: https://istd.sutd.edu.sg/people/faculty/ngai-man-man-cheung/

Nirmalendu Prakash (TA)

Nirmalendu received his B.Eng. degree in Mechanical Engineering from Pune University, India, in 2010. From 2010 to 2019 he worked as a software engineer in India. He moved to Singapore in 2019, to do MTech in Intelligent Systems at NUS. After that, he worked as a Research Assistant at SMU and SUTD. Currently, he is working towards the Ph.D. degree in ISTD at SUTD. His research focus is analysis and mitigation of social biases in language models.

Email: nirmalendu_prakash@mymail.sutd.edu.sg

Telegram: nirmal05

Phone: +65 9128 1484

Hazel Hee Zhenrui (TA)

Hazel Hee, SUTD ISTD Alumni 2022 graduate. Currently working as a Research Assistant. Has TA various subjects for ISTD since 2020.

Email: hazel_hee@sutd.edu.sg

Telegram: hahahazel

Course description

The detailed course description (aims of this course, learning objectives and measurable outcomes) can be found on the course page, online, at https://istd.sutd.edu.sg/undergraduate/courses/50-039-theory-and-practice-of-deep-learning.

Pre-requisites for this course

Below is a list of pre-requisites for the course.

We strongly advise students to revise such topics before the beginning of the term.

✓ Python programming (Term 1 CTD and Term 3 DDW courses).

✓ Freshmore Mathematics courses on probabilities, statistics, calculus, and linear algebra.

✓ More specifically, you must know about matrix operations, be able to compute a derivative for functions of many variables and understand the logic behind the gradient descent algorithm (these notions have been covered in Freshmore Mathematics classes).

✓ Knowledge of 50.007 Machine Learning would be a great plus, although not required.

List of topics (week-by-week)

Below is a week-by-week schedule. Note that it may be adjusted, at your professors' discretion, depending on the students' pace and needs.

Lectures and weeks will be split between Prof. Matt and Prof. Man

- **Week 1 (Matt):** Introduction to course, some ML jargon reminders, linear and polynomial regression, generalization, ridge regression and regularization, overfitting/underfitting, logistic regression, neural networks and how they relate to biology. Building our own custom class of shallow neural networks, along with gradient descent, training and testing procedure.
- **Week 2 (Matt):** Introduction to PyTorch framework, tensors and dataloaders objects. Implementing a shallow neural network in PyTorch, backpropagation in PyTorch with AutoGrad, advanced optimizers, multi-label classification with shallow neural networks. Finally, moving from shallow to deep neural networks.
- **Week 3 (Matt):** Guided project and good practices for Deep Learning projects (train/test/dev, bias/variance, advanced regularization, dropout, normalizing inputs/outputs/layers, trainer functions, savers/loader functions for reproducibility and transfer learning).
- **Week 4 (Man):** The image data type, image processing techniques and typical computer vision operations, the convolution operation and layers, Convolutional Neural Networks, advanced CNNs and SotA. Preparing transition to the 50.035 Computer Vision course. Adversarial machine learning, attacking a Neural Network with basic gradient-based attacks, fundamental limits of

Neural Networks, defence mechanisms and state-of-the-art of some advanced attacks techniques.

- **Week 5 (Man):** Continuation of Week 4.
- **Week 6 (Matt):** Sequential data (times series, text, etc.), vanilla Recurrent Neural Networks, Gated Recurrent Units, Long-Short Term Memory cells, advanced RNN networks, mixing models for advanced architectures.
  Mid-Term Exam (based on content from W1-5).
- **Week 7 (NA):** Recess week.
- **Week 8 (Matt):** The embedding problem, more advanced concepts on RNNs, introduction to Natural Language Processing (NLP) and Word Embeddings for NLP, brief state-of-the-art on NLP, attention and transformers architectures.
  Preparing transition to the 50.040 Natural Language Processing course.
- **Week 9 (Man):** Quick introduction to Graph Theory and typical graph datasets and problems, basics of Graph Convolutional Networks, brief state-of-the-art of advanced Graph Convolutional Networks.
- **Week 10 (Man):** Generative Models, Autoencoders and Variational Autoencoders, Generative Adversarial Networks (GANs), Advanced concepts on Generative Adversarial Networks, Practice on GANs.
- **Week 11 (Man):** Topics for curiosity. Introduction to Physics-Informed Neural Networks. Introduction to diffusion models. Introduction to Explainability/Interpretability and open questions in research about Neural Networks. What will be the next revolution in AI? (a word on ChatGPT, Dall-E, etc.).
- **Week 12 (Matt):** Brief introduction to reinforcement learning, and state-action-rewards systems, multi-armed bandit problem and the exploration/exploitation trade-off, Q-learning and Deep Q-Learning. Brief state-of-the-art discussion about further works in Reinforcement Learning and the recent uses of Reinforcement Learning with Human Feedback.
- **Week 13 (Man and Matt):** Recap. Closing and future directions for studying Deep Learning. Project presentations and guest conferences (TBA).
- **Week 14 (NA):** Final exam (based on content from W1-13).

Some video recordings from the previous years might be uploaded, but content of the video lectures might not be up to date. We strongly encourage students to come to class and use video recordings for revision purposes.

Textbooks for advanced concepts

Shall the students require extra reading beyond what is provided in the course, the books below are considered some of the most important ones in Deep Learning.

✓ Michael A. Nielsen, "Neural networks and deep learning", 2015.
(http://neuralnetworksanddeeplearning.com/).

✓ Ian Goodfellow and Yoshua Bengio and Aaron Courville, "Deep learning", 2016.
(https://www.deeplearningbook.org/)

✓ Yaser S. Abu-Mostafa and Malik Magdon-Ismail and Hsuan-Tien Lin. "Learning from data", 2012.
(https://work.caltech.edu/library/textbook.html)

The course also attempts to present the most recent concepts and scientific papers in Artificial Intelligence/Machine Learning/Neural Networks. Arxiv links to the paper PDFs will often be provided, and demo codes might be shown in class. Students are also encouraged to refer to the PapersWithCode website.

We invite the curious reader to refer to the textbooks, scientific papers and demo codes.

Python kernel and libraries

For this course, you will need to install Python 3, and the following libraries.
Please note that this is a non-exhaustive list.

✓ Numpy and Pandas,

✓ Scipy and Scikit-Learn,

✓ PyTorch and TorchVision,

✓ Matplotlib and Seaborn,

✓ H5PY, Networkx and Gym,

✓ Possibly more libraries.

There is no need to get familiar with PyTorch before the course, as it will be covered in class. Getting familiar with it beforehand, however, will never hurt. Professors will often refer to the PyTorch documentation and tutorials for demos (https://pytorch.org/tutorials/).

You may use any IDE of your choice but expect some Jupyter Notebooks for in-class demos from your professors.

Course assessment

The assessment for this course is described below.

Homeworks (20%)

- Homeworks will be given every two weeks or so.
- Homework instructions and deadlines will be posted on eDimension.
- One extension request per term is allowed, **as long as you email instructors to ask for such an extension before the deadline.**

Midterm (20%)

- Date: 13 March 2024, 2.30-4.30pm
- Venue to be announced.
- Notions from Weeks 1-6 will be tested.

Final exam (25%)

- Date: 24 April 2024, 9-11am
- Venue to be announced.
- Notions from Weeks 1-13 will be tested.

Project (31%)

- More details about the project will be given around Week 3 in class and on eDimension.
- Submission expected by Week 13.
- Problem statement can be freely decided by students, submit your project proposal.
- If you feel uninspired for this project, your professors will suggest a project idea.
- **No extensions will be given for projects.**

Participation (2%)

- To your instructurs' discretion.

Survey and course feedback (2%)

- This is a university requirement and 2% is awarded if you complete the mid-term and end-of-course student feedback surveys.