50.039 Theory and Practice of Deep Learning – Syllabus (2025)

Matthieu DE MARI, last update: 20th January 2025

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.

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Qun Song is an Assistant Professor in the Information Systems Technology and Design (ISTD) Pillar of the Singapore University of Technology and Design (SUTD). She received Ph.D. from Nanyang Technological University, Singapore. Her research interests include Artificial Intelligence of Things (AIoT), Cyber-physical system (CPS) robustness and resilience, and autonomous driving security and safety. She is the recipient of the 2023 MobiCom Best Community Contribution Award, the 2022 SenSys Best Paper Award Finalist, and the 2021 IPSN Best Artifact Award Runner-up.

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Yuan Jiayi (TA)

Yuan Jiayi is currently pursuing her Ph.D. degree in ISTD at SUTD, starting in 2024. Her research focuses on deep learning and computer vision, with a particular interest in depth map super-resolution and scene graph generation.

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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.

Python kernel and libraries required for this course

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.

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.

Weeks	Session 1	Session2	Session 3
	Introduction to course and Machine Learning Reminders		
1	Introduction to course, technical pre-requisites, ML jargon, ML problems, Linear Regression in Numpy and Scikit Learn, Gradient Descent	Polynomial Regresion, Overfitting vs. Underfitting, Train-Test Split, Regularization and Ridge/Lasso Regression	Logistic Regression, Neural Networks in Biology, Implementation of a Shallow Neural Network in Numpy, with manual Forward and Backward pass
	Advanced implementations in Neural Networks		
2	Initializers, Symmetry in Neural Networks, Exploding and Vanishing Gradients Problems, Activation functions and the Universal Approximation Theorem	A deep dive into Gradient Descent, Advanced Optimizers (AdaGrad, RMSProp, Adam), Mini-batch Stochastic Gradient Descent and the No Free Lunch Theorem	Binary Classification with Shallow Neural Networks, Good Practices for Neural Networks, Train-Test-Validation Split, Early Stopping, Savers and Loaders, and other questions
	Introduction to the PyTorch Framework		
3	The PyTorch Framework and its benefits compared to Numpy, the PyToch tensor object and its uses, converting our Shallow Neural Network from Numpy to PyTorch	Converting our Shallow Neural Network from Numpy to PyTorch (part 2 and end), AutoGrad and BackPropagation in PyTorch, GPU Acceleration	DataSets and DataLoader objects, from Binary to MultiClass Classification, Softmax and CrossEntropy functions, Deep Neural Networks
	From Linear to Convolutional Neural Networks		
4	The image datatype, from Linear to Convolutional layers, Conv2D implementation in details with its variations	Using the Conv2D layer to make CNNs, Dropout, BachNorm and LayerNorm, Pooling	Data Augmentation, Milestone models in CV (from AlexNet, ResNet, EfficientNet), Residual connections, Transfer Learning and Fine-Tuning

5	**Introduction to Adversarial Machine Learning**		
	Introduction to Adversarial Machine Learning, Noising Attacks, lessons learned from Adversarial Machine Learning about the limits of Neural Networks	Different types of Attacks, Gradient-based attacks and their effects, Ethical Implications of Adversarial Machine Learning	Advanced Attacks methods and Defense methods for Neural Networks
6	**Introduction to Sequential Neural Networks**		
	Introduction to Time Series and first attempts at making a Recurrent Neural Network	Limitations of our Recurrent Neural Networks, implementations of LSTMs and GRUs models	The Encoder-Decoder Architecture, the Seq2Seq models and their uses in Sequential Neural Networks
7	**Recess Week**		
8	**The Embedding Problem, and how it led to Transformers**		
	Introduction to the Embedding Problem, why it is so difficult to address it in the case of Language, a first attempt with CBoW	From CBoW to SkipGram, FastText and ELMO, lesson learned along the way	The need for attention and Transformers, contemporary uses of transformers, evaluating an embedding
9	**Introduction to Graph Convolutional Neural Networks and Transformers**		
	Introduction to Vision Transformers, reusing intuitions from the previous weeks (4&8) to build advanced networks	Introduction to Graph Datasets, the Graph Convolutional layers and implementation of our first Graph Convolutional Models	Advanced uses for Graph Convolutional models, GraphSAGE and attention in Graph Models
10	**Onwards, to Generative AI!**		
	Introduction to AutoEncoders and Generative AI problems	From AutoEncoders to Variational AutoEncoders and Generative Adversarial Networks	A brief overview of advanced Implementations of GANs: Wasserstein GANs, Progressive GANs, Conditional GANs, Style GANs and CycleGANs

11	**Introduction to Reinforcement Learning**		
	Introduction to Reinforcement Learning, Exploration vs. Exploitation Trade-Off in Multi-Arm Bandit Problems	The V and Q functions, Bellman Equations and introduction to Q-Learning and the need for Deep-Q-Learning	From Q-Learning to Deep-Q-Learning, brief overview of advanced topics in RL, Reinforcement Learning with Human Feedback and its uses for fine-tuning
12	**A pot-pourri of curiosity topics in Deep Learning**		
	Introduction to Physics-Informed Neural Networks and their possible uses	Introduction to Diffusion Models, Stable Diffusion and how it led to the Midjourney and DALL-E models	On the need of Explainable AI, and attempts to make AI models explainable.
13	**Introduction to course and Machine Learning Reminders**		
	Project Presentations	Project Presentations	Avengers, Assemble: understanding ChatGPT and how it was made. Recap and End of course.
14	**Exam Week**		

Note that the colour code is used to indicate lectures in class (blue), lectures to be conducted online due to public holidays (green), project presentations in class (orange/brown) and exam (red).

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 only.

Conference

There are ongoing discussions regarding a possible conference on Week 13, Wednesday evening. The tentative date for this conference would be 23rd Apr 2025, 6pm, right after the SSNLP event (organized by Prof. Soujanya Poria), on 23rd Apr 2025, 9am-6pm.

We would like to <u>strongly</u> encourage students to attend both events. Participation to these events could affect your participation score. More details on both events will follow closer to the date.

An important note on public holidays and CNY classes

This year, there are many public holidays that have effects on some of the scheduled lectures. The following lectures will be cancelled and will be replaced by video recordings to be uploaded on eDimension. **The students will be responsible for self-studying the materials.**

- Wednesday 29th January 2025, 9-10.30am
- Thursday 30th January 2025, 1.30-3pm
- Thursday 30th January 2025, 3.30-5.30pm
- Friday 31st January 2025, 11.30am-1.30pm
- Monday 31st March 2025, 10.30am-noon
- Friday 18th April 2025, 11.30am-1.30pm

Please enjoy CNY, but please remember to do your self-study.

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.

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. Penalties for late submissions will be at our discretion.**

Midterm (20%)

- Date: 5th March 2025, 6-7.30pm, confirmed.
- Venue: TT 2 (1.309), TT 3 (1.310) & TT 4 (1.312).
- Paper exam, no coding. Notions from Weeks 1-5 will be tested.
- As is university policy, a single A4, double-sided, handwritten (not printed, pen and paper only!) cheatsheet is allowed for exams. This is university policy and not my decision.

Final exam (25%)

- Date: 2nd May 2025, 9-11am, confirmed.
- Venue: 2.408 for class 1 and 2.306 for class 2.
- Paper exam, no coding. Notions from Weeks 1-12 will be tested.
- As is university policy, a single A4, double-sided, handwritten (not printed, pen and paper only!) cheatsheet is allowed for exams. This is university policy and not my decision.

Project (31%)

- More details about the project will be given around Week 2-3 in class and on eDimension.
- Submission expected by End of Week 12.
- 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%)

- Graded up to your instructors' discretion, will include attendance to classes/seminars among many other components.

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.