Deep Learning in Finance

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Course Description

This course consists of seven sessions, each lasting 2.5 hours, and follows the format of an advanced topics seminar. It provides an in-depth exploration of advanced deep learning techniques with applications to financial time series data.

Prior familiarity with deep neural networks and backpropagation derivation is required. The course begins with an overview of the theoretical foundations that justify deep learning models. It then delves into topics such as Transformers, Neural ODEs, GANs, Diffusion Models, and Graph Neural Networks (GNNs), culminating in a discussion on an end-to-end deep learning-based solution for asset pricing.

Evaluation

- **Home works**: 50%
- **Final Project**: 50%

Materials

- **Lecture slides**
- **Companion GitHub Repository**: Python/PyTorch

Textbooks

Primary Text

Chris Bishop, Hugh Bishop (2023) *Deep Learning*, The MIT Press.

Optional Texts

- Aston Zhang, Zachary C. Lipton, Mu Li, Alexander J. Smola (2023), *Dive into Deep Learning*, Cambridge University Press.

- Simon Prince, (2023) *Understanding Deep Learning*, The MIT Press
- Jakub M. Tomczak (2022) *Deep Generative Modeling* , Springer
- Ovidiu Calin, (2020) *Deep Learning Architectures*, Springer
- Daniel A. Roberts, Sho Yaida, Boris Hanin(2022) *The Principles of Deep Learning Theory: An Effective Theory Approach to Understanding Neural Networks* , Cambridge University Press
- Jong Chul Ye (2022) *Geometry of Deep Learning: A Signal Processing Perspective*, Springer

Lectures

- **Lecture 1: Deep Learning - Theoretical Justifications**
  - **Scope:** This lecture provides a high-level theoretical perspective on why deep learning works, focusing on approximation, optimization, and generalization. Topics include the universal approximation theorem, double descent regimes, and overparameterization. The lecture emphasizes the current limitations in theoretical understanding that explain the empirical success of deep learning models. We also explore semi-empirical and practical methodology to check the generalizability of deep learning models.
  - **Readings:**
    * Belkin, M., Hsu, D., Ma, S., and Mandal, S. (2019) Reconciling Modern Machine Learning and the Bias-Variance Tradeoff. Proceedings of the National Academy of Sciences (PNAS), 116(32), 15849–15854.
    * Tomaso Poggio, Andrzej Banburski, Qianli Liao (2019) Theoretical Issues in Deep Networks: Approximation, Optimization and Generalization Proceedings of the National Academy of Sciences (PNAS), 117 (48) 30039-30045.
    * Yasaman Bahria, Ethan Dyera, Jared Kaplanb, Jaehoon , (2024) Explaining neural scaling laws Proceedings of the National Academy of Sciences (PNAS), 117 (48) 30039-30045.
    * Charles Martin and Michael Mahoney (2021), Implicit self-regularization in deep neural networks
    * Oualid Missaoui (2025), Inductive Triplet Fine Tuning for Small Language Models
- **Lecture 2: Transformers for Financial Time Series Forecasting**
  - **Scope:** This lecture introduces the Transformers architecture and discusses its advantages over recurrent based sequence to sequence architectures. It also illustrates its application to financial time series forecasting.

- **Readings:**
    - Chapter 12, Transformers, from the primary textbook.
    - Vaswani et al, (2017) Attention is All you Need NIPS.
    - Edmond Lezmi, Jiali Xu, (2023) Time Series Forecasting with Transformer Models and Application to Asset Management , Amundi Institute.

- **Lecture 3: Neural Ordinary Differential Equations (NODE) for Financial Time Series Forecasting**
  - **Scope:** This lecture introduces Neural ODEs and its formulation and how they extend the concept of ResNets to continuous layers. It also provides and explanation of the architecture and implementation of NODEs in practice. Finally, it illustrates its application to financial time series forecasting.
  - **Readings:**
    - Chapter 1 and 2 from the PhD dissertatin of Patrick Kidger, On Neural Differential Equations , 2022.
    - Ricky T.Q. Chen, Yulia Rubanova, Jesse Bettencourt, David Duvenaud, (2018) Neural Ordinary Differential Equations, NIPS
    - Jingsui Li; Wei Zhu; Zhang Chen; Chao Pei (2023) Financial Time Series Prediction via Neural Ordinary Differential Equations Approach International Annual Conference on Complex Systems and Intelligent Science

- **Lecture 4: Generative Adversarial Models (GANs) for financial synthetic data**
  - **Scope:** This lecture introduces GANs and presents an overview of its components and architecture. It also derives the underlying updating equations for its training. Finally, it illustrates the applications of GANs in financial synthetic data generation.
  - **Readings:**
    - Chapter 17, Generative Adversarial Models, from the primary textbook.
    - Ian J. Goodfellow et al. (2014) Generative Adversarial Nets
    - Adil Rengim Cetingoz, and Charles Albert Lehalle, (2025) Synthetic Data for Portfolios: A Throw of the Dice Will Never Abolish ChancearXiv, arXiv:2501.03993

- **Lecture 5: Generative diffusion Modeling for Financial Synthetic Data**
  - **Scope:** This lecture introduces the generative diffusion models, provides and overview of its primary components and typical architecture, and derive the underlying equations for training. In addition, it illustrates its application to synthetic financial data generation.

- **Readings:**
  - Chapter 20, Diffusion Models, from the primary textbook.
  - Stanley Chan , (2025) Tutorial on Diffusion Models for Imaging and Vision
  - Andrew Lesniewski and Giulio Trigila (2025) Beyond Monte Carlo: Harnessing Diffusion Models to Simulate Financial Market Dynamics
  - Oualid Missaoui (2025) Deep Generative Modeling for Covariance Denoising in Finance
  - Zhuohan Wang, Carmine Ventre (2024) A Financial Time Series Denoiser Based on Diffusion Models, ICAIF

- **Lecture 6: Graph Neural Networks for Financial Data**
  - **Scope:** This lecture will introduce Graph Neural Networks (GNNs) and explain GNN architecture as well as graph embeddings. It will also illustrate how can GNN be potentially leveraged to model interconnected assets or networks of trading relationships.
  - **Readings:**
    - Chapter 13, Graph Neural Networks, from the primary textbook.
    - Franco Scarselli; Marco Gori; Ah Chung Tsoi; Markus Hagenbuchner; Gabriele Monfardini (2009), The Graph Neural Network Model IEEE Transactions on Neural Networks
    - Gregoire Pacreau, Edmond Lezmi, Jiali Xu, (2022) Graph Neural Networks for Asset Management

- **Lecture 7: The Virtue of Complexity in Finance**
  - **Scope:** This lecture discusses the virtue of complexity in finance based on Bryan Kelly et al work. The lecture will also review some of the recent publications on the application of deep learning to asset pricing and (latent) factor modeling.
  - **Readings:**
    - Bryan Kelly et al. (2023) The Virtue of Complexity in Return Prediction
    - Bryan Kelly et al. (2025) Understanding The Virtue of Complexity
    - Bryan Kelly et al. (2024) Large (and Deep) Factor Models
    - Guanhao Feng et al. (2023) Deep Learning in Characteristics-Sorted Factor Models
    - Jorge Guijarro-Ordonez et al. (2022), Deep Learning Statistical Arbitrage
    - Luyang Chen et al. (2021) Deep Learning in Asset Pricing
    - Guanhao Feng et al. (2018) Deep Learning Factor Alpha