Wuppertal/Cologne, 2022
Lecture + Exercises, 4 SWS

Machine Learning for Quantitative Finance

The goal of this lecture is to provide a detailed overview of Statistical/Machine Learning techniques applied to Quantitative Finance. We offer insights into the latest techniques of using such methods. Tackling topics that arise in derivatives pricing, calibration and hedging but also from time series management.
This includes sophisticated modeling approaches for the Q-quant setting and nowcasting, imputation or anomaly detection for the P-quant.
We give a thorough theoretical introduction but illustrate the concepts with concrete examples. Live demonstrations of the computational methods round up this course.
We cover Artificial Neural Networks, Gaussian Process Regression, Gaussian Mixtures and kernel methods and their applications.

We also explain how to set up the methods in Python using various libraries such as Numpy, SciKit Learn, Keras, Tensorflow, or PyTorch. Our chosen examples are directly linked to relevant practical applications from Quantitative Finance and can be explored further after the course since all the material is available either as Python code or Jupyter notebooks.

This lecture covers the fundamentals and it illustrates the application of state-of-the-art machine learning applications for Mathematical and Quantitative Finance. We wish to bring you to the next level with our presented material.

To earn credits for this course attending the lecture **and** successfully working on a project is obligatory. The project can either be on a theoretical aspect, i.e. assessment of a topic and working out the mathematical details, or on a practical one, i.e. by implementing a topic/algorithm/method in Python. The project should be finished by end of August 2022.

Material

Kienitz, *Mathematics of Machine Learning*, Lecture Notes, Wuppertal, SoSe 2020
Dixon, Halperin, Bilokon, *Machine Learning in Finance*, Springer 2020

Further information can be found here:

https://finciraptor.de


https://de.linkedin.com/in/j%C3%B6rg-kienitz-8b160a

https://papers.ssrn.com/sol3/cf_dev/AbsByAuth.cfm?per_id=744396

Lecture Highlights

This workshop covers the latest techniques for mastering Statistical Learning and Machine Learning methods including Neural Networks or Gaussian Process Regression and apply those to Quantitative Finance and Time Series analysis. Theoretical underpinnings are giving and explained. The material is illustrated with many relevant examples from Quantitative Finance.

Especially we cover

- Overview of some Statistical Learning / Machine Learning techniques
- Implementation and examples from Quantitative Finance using Python/Jupyter
- Neural Networks – Architectures, Mechanics and Applications
- Generative Methods applied to Quantitative Finance
- Gaussian Process Regression in the context of pricing and time series analysis
- Gaussian Mixtures for Local Stochastic Volatility or Bermudans in multiple dimensions
- Pricing and calibration for (rough) Stochastic Volatility models such as SABR or Heston or rough models like the rough Bergomi model
- Term structure models and Bermudan/American options
- Time Series forecasting/nowcasting and imputation using Gaussian Process Regression

Course Methodology

Presentation (lecture) with examples (**Jupyter Notebooks, Python Code**), Theorectical or practical project conducted by delegates.

Location and Time

The lecture takes place in Cologne, ifb SE, Büro Köln, Zeppelinstraße 4-8, 50667 Köln
Wednesday, 30.3. and Thursday, 31.3. from 9 a.m. to 5 p.m.
Topic assignment: until 30.04.2022
Topic assessment hand in: at latest 31.08.2022

It is **necessary** to register by sending an email to joerg.kienitz@math.uni-wuppertal.de since we need to secure the venue complies with COVID 19 restrictions to be in place.
That may include changing the venue meaning it may take place at the University of Wuppertal. This will be accordingly.

Contents of Lecture

Machine Learning and Quantitative Finance – Overview
The first part of the course introduces the subject and lays the foundation for the use cases and the more advanced considerations of this course.

- Introduction to the subject – Basics of Statistical Learning / Machine Learning
  This introduces the concept of statistical learning/machine learning and discusses applications as well as fundamental notions and introduce some of the ML slang.
    - Supervised Learning for Classification, Regression
    - Unsupervised Learning
    - Selfsupervised Learning
    - Reinforcement Learning
    - Overfitting / Underfitting
    - Train, validate, test
    - Hyperparameters
- Bayesian vs Frequentist View
  We consider two views on statistics and highlight the differences.
- Linear and Logistic Regression as our guiding examples
  Before learning about some state-of-the-art techniques in statistical learning/machine learning we focus on an illustrative example and discuss different angles of the problem by focusing on an introductory example. This serves also as a guide for what we wish to achieve in this course. As an example, we consider the least squares Monte Carlo method
- Quantitative Finance
  We consider applications from Quantitative Finance, especially we focus on the following models as examples: Black-Scholes, Heston, SABR, rough Bergomi, Hull-White Term Structure Model. This is an overview and not a deep mathematical analysis of the models. We consider:
    - Pricing and calibration
    - Hedging
    - Time Series Analysis (prediction, imputation, outliers/anomalies)

Introduction to Machine Learning Methods and their Implementation – An Overview
We give an overview of ML methods with some illustrations in Python. We discuss some available packages that are necessary to work on topics in Quantitative Finance.

- Clustering (k-means and Gaussian Mean Mixture) – the E-M algorithm
- Support Vector Machines
- Lasso and Ridge Regression
- Ensemble Learning - bagging, boosting, decision trees and random forrests
- Python packages
    - Numpy and Scikit Learn
    - Pandas
    - Tensorflow, PyTorch, Keras
- Some examples:
    - Prcing and Greeking (Black-Scholes and SABR)
    - Monte Carlo (Bermudan Swaption Hull-White)
    - Stochastic Local Volatility Models
    - Xlwings – interacting with Excel

Artificial Neural Networks in Finance – introduction and examples

A hot topic is the application of Artificial Neural Networks to practical problems. We illustrate the theory and show different architectures that can be applied in practice. Finally, we show applications to option pricing, calibration and hedging. Furthermore, we give advice for further optimizing the methods by using e.g. feature engineering.

- Intro to Artificial Neural Networks (ANN)
  This introduces the architecure of Neural Networks and their implementation. You'll learn the math used by Tensorflow/PyTorch and we give a visual proof that an ANN can virtually learn any function.
  - Construction of ANNs
  - ANN at work
  - Math recap - (Backpropagation and Optimization, ie. stochastic gradient descent methods)
  - Learning functions – some visual experiments
- Learning pricing functions
  „learning to smile" – application to volatility modelling
- It's only an approximation! - We discuss interpolation and extrapolation
- Shallow vs Deep Learning and Preprocessing/Feature engineering – The CV method
- Different Types of Networks, their implementation and applications
  - FNN - Feed Forward
  - CNN - Convolutional
  - RNN - Recursive
  - LSTM – Long Short Term Memory
- Examples:
  - Deep Pricing and calibration - ANN and CNN
  - Deep Hedging – LSTM

Generative Modelling in Quantitative Finance – Introduction and Examples

Generative Modelling becomes increasingly popular. Many applications are known in image or video processing. VAE and GAN and suggest some applications for practical application.

- Differential Machine Learning – The CV method revisted
  We show how we could use the combination of two neural networks to enhance the standard learning by incorporating derivatives (Greeks) into the learning process
- VAE – Variational Autoencoder
  - Illustration of the Network Architecture
  - Convolutional Layers, Pooling Layers and how they work
  - Tuning the network architecture
  - Applications: Implied Volatility Surface Generation, Anomaly Detection, Nowcasting
- GAN - Generative Adversarial Neural Networks
  - Basic architecture of GANs
  - The Generator and the Discriminator
  - Linking the Generator and the Discriminator
  - Stabilizing the training
  - Applications: CorrGAN, QuantGAN

Gaussian Methods in Quantitative Finance

- **Kernel Density Estimation**
  - Kernel density estimation and its application
  - Local linear and Nadarya-Watson
  - Basic examples
- **Gaussian Mixture Models**
  - Mixture Models in finance – dos and donts
  - GMM as a kernel density estimator
  - GMM-DCKE
  - Conditional expectation and pricing – American/Bermudan Options
  - Stochastic Local Volatility – a new approach to calibration
  - GMM as a generative method
  - xVA/exposure
- **Gaussian Process Regression and Kernel Methods (GPR)**
  Based on Bayesian statistics GPR is successfully applied in science. We show how it can be used and optimized for Quantitative Finance applications.
  - Multi-dimensional Gaussian distribution (marginal, conditional distribution, etc.)
  - Intro to GPR and regression - how does it work?
  - Covariance functions and kernels – The kernel trick
  - Choosing kernels

Time Series Analysis

- Introduction
- Point estimates and distributional estimates
- Anomaly detection and Forecasting for time series
- Conditional expectation and pricing – American/Bermudan Options