USC Viterbi
School of Engineering

Units: 4 (Two 110-minute lectures per week)
Location: THH 212
Time: Tu/Thu 8:00 - 9:50

Instructor: Renyuan Xu
Office: OHE 310K
Office Hours (in person): Tu 10:00-11:00
(Online OH upon request)
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Office: OHE 340
Office Hours (in person): Wed 8:30-9:30
Office Hours and Discussion Session (online): Mon 18:00-20:00
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ISE 537 Financial Analytics

Course Description

Modern Portfolio Theory. Optimal Decision-making Problems in Finance. Market Microstructure and High-frequency Trading. Machine Learning Models for Quantitative Finance.

Course Overview

This course aims to prepare students with the basic knowledge of modern portfolio management, time-series analysis, market microstructure, and optimal execution. Various statistical methods and machine learning techniques will be introduced given their flexibility and computational power in analyzing financial data. This course also features advanced topics in machine learning for finance such as trading with reinforcement learning, market prediction with neural networks, and market simulator construction via generative adversarial networks.

Learning Objectives

By the end of this course the students will be able to

- Identify the basic structure of capital asset markets
- Identify the main investment vehicles and investment strategy categories
- Assess the basic performance metrics for securities and portfolios
- Describe the concepts of risk premia investing
- Build and test machine learning models using real data
- Interpret the market microstructure and high-frequency trading
- Work with real financial data at different frequency (low, middle, and high)
- Discuss (multi-period) decision-making problems in financial markets

- Calculate advanced statistical methods and machine learning techniques to real finance data sets.

Prerequisite(s): None

Recommended Preparation: Engineering statistics on the level of ISE 225; working knowledge of a programming language on the level of ISE 150.

Course Notes
The course materials are available on Blackboard.

Technological Proficiency and Hardware/Software
A programming language (Python is recommended).

Required Textbook None

Supplementary Materials (for reference)

- David Ruppert and David S. Matteson, *Statistics and Data Analysis for Financial Engineering with R examples,* ISBN 978-1-4939-2613-8
- Grinold, Kahn. *Active Portfolio Management*, 2nd Edition, ISBN 978-0070248823
- Dixon, Matthew F., Igor Halperin, and Paul Bilokon. *Machine Learning in Finance*. Springer International Publishing, 2020 ISBN 978-3030410674
- Jansen, Stefan. Machine Learning for Algorithmic Trading: Predictive models to extract signals from market and alternative data for systematic trading strategies with Python. Packt Publishing Ltd, 2020.
- Cartea, Álvaro, Sebastian Jaimungal, and José Penalva. *Algorithmic and High-frequency Trading.* Cambridge University Press, 2015. ISBN: 978-1107091146
- Lehalle, Charles-Albert, and Sophie Laruelle. *Market Microstructure in Practice*. World Scientific, 2018. ISBN: 978-9813231122
- Goodfellow, Ian, Yoshua Bengio, and Aaron Courville. *Deep Learning*. MIT press, 2016. ISBN: 978-0262035613
- Papers:
    - Avellaneda, Marco, and Jeong-Hyun Lee. *Statistical Arbitrage in the US Equities Market*. Quantitative Finance 10.7 (2010): 761-782.
    - Cont, Rama. *Empirical Properties of Asset Returns: Stylized Facts and Statistical Issues*. Quantitative Finance 1.2 (2001): 223.
    - Cont, Rama. *Statistical Modeling of High-frequency Financial Data*. IEEE Signal Processing Magazine 28.5 (2011): 16-25.
    - Almgren, Robert, and Neil Chriss. Optimal Execution of Portfolio Transactions. Journal of Risk 3 (2001): 5-40.
    - Gudelek, Boluk, and Ozbayoglu. *A Deep Learning Based Stock Trading Model with 2-D CNN Trend Detection.* 2017 IEEE Symposium Series on Computational Intelligence (SSCI). IEEE, 2017

- Hambly, Ben, Renyuan Xu, and Huining Yang. *Recent advances in reinforcement learning in finance.* Mathematical Finance 33.3 (2023): 437-503.
- Thomas Spooner, John Fearnley, Rahul Savani, Andreas Koukorinis. *Market Making via Reinforcement Learning.* 17th Int. Conf. on Autonomous Agents and Multi-Agent Systems (AAMAS).

Description and Assessment of Assignments

- **Midterm Exam:** in person
- **Final Project:** a take-home data analysis project.
- **Homework assignments**
  - The assignments are exercises related to the topics discussed in class.
  - Students should submit all of them to the Blackboard before the class on Tuesday
  - (unless otherwise indicated). They will be graded and returned in the following week.
  - No late homework will be accepted.
  - For homework questions related to coding and data analysis, please type up your
  - solutions.
  - For homework questions related to calculations and proofs, hand-written solutions are also acceptable.

Grading Breakdown

- Homework 40%
- Midterm exam 30%
- Final Project 30%

Assignment Submission Policy
Assignments should be submitted on Blackboard. No late assignment is considered unless under emergencies. No makeup exams are considered.

Course Schedule: A Weekly Breakdown

Week	Topics/Daily Activities	Homework	Reference
1 (8/21-8/27)	Course Introduction and Logistics Introduction to Electronic Markets, Algorithmic Trading and Asset Returns Review of Basic Concepts in Probability		Ruppert & Matteson Ch 2-4
2 (8/28-	Risk and (One Period) Modern Portfolio Theory (One Period) Mean-Variance Optimization	HW1 available	Ruppert & Matteson

Week	Topics/Daily Activities	Homework	Reference
9/3)	Capital Asset Pricing Model (CAPM)		Ch 16-17
3 (9/4-9/10)	Arbitrage Pricing Theory (APT) Linear Regression (LR) Application of LR: Factor Models	HW1 due	
4 (9/11-9/17)	Principal Component Analysis (PCA) Application of PCA: Statistical Arbitrage	HW2 available	Ruppert & Matteson Ch 18 Avellaneda & Lee (2010)
5 (9/18-9/24)	Time Series Analysis I: Autocorrelation, Partial Autocorrelation, Stationarity	HW2 due	Ruppert & Matteson Ch 12
6 (9/25-10/1)	Time Series Analysis II: ARIMA Models and Forecasting Application: Stock Price Modeling	HW3 available	Ruppert & Matteson Ch 13
7 (10/2-10/8)	(Multi-period) Optimal Execution of Portfolio with Transaction Cost		Almgren & Chriss (2001)
8 (10/9-10/15)	Review Session (Tuesday) Fall Recess (Thursday)	HW3 due	
9 10/16-10/22	TBD (Tuesday) Midterm Exam (Thursday): **in person (no make-up)**		Stefan Ch 1 & 6
10 10/23-10/29	Introduction to Neural Network (NN) and Deep Learning (DL) Stochastic Gradient Descent, Backpropagation, Test and Validation	HW4 available	Goodfellow, Bengio & Courville Ch 6 & 8 Dixon, Halperin, and Bilokon Ch 4 & 8
11 10/30-11/5	NN Architectures: CNN, RNN, LSTM DL Application 1: Time Series Prediction (Bitcoin price and High-frequency trading data)		Goodfellow, Bengio & Courville Ch 6 & 8 Dixon, Halperin, and Bilokon Ch 4 & 8

Week	Topics/Daily Activities	Homework	Reference
12 11/6- 11/12	DL Application 2: Fraud Detection Reinforcement Learning Basics: Markov Decision Peocess and Bellman Equation	HW4 due	Dixon, Halperin, and Bilokon Ch 9
13 11/13	Reinforcement Learning Algorithms: Policy Evaluation, Q-learning Policy-gradient Method	HW5 available	Hambly, Xu and Yang
14 11/20- 11/26	RL Application I: Optimal Execution (revisited) Thanksgiving Holiday (Thursday)		Dixon, Halperin, and Bilokon Ch 9 Hambly, Xu and Yang
15 11/27- 12-3	RL Application II: Market Making (with a brief introduction on market microstructure and limit order books)	HW5 due	Hambly, Xu and Yang Spooner, Fearnley, Savani, and Koukorinis
Final	Final project will be released in roughly Week 12 and is due at the time the university would normally reserve for a final exam; please refer to the final exam schedule in the USC *Schedule of Classes* at classes.usc.edu.		

Course Project: the purpose of the class project is for you to practice solving data analytic problems in finance.

Project Timeline: Given that the steps of each project are outlined in details, there is no presentation nor intermediate report required.

Tentative Topics (this is for reference ONLY; the final project requirement will be announced in early November):

1. Dynamic Trading Strategy Design:
    - Lecture Notes 6-9 and Jupyter Notebooks ("Lecture 8: Regression for Pair Trading.ipynb" are related to this project.
    - Design an improved version of the pairs trading strategy (introduced in class) by including more stocks in your strategy.
    - You can consider using the top 100 stocks (https://companiesmarketcap.com/) and their daily close price during the period of 2019 - 2020 [Note: you may not have access to all the stocks from Yahoo Finance during this period; please explain how you handle this issue].
    - Explain whether dimension reduction techniques are needed.
    - Please show the out-of-sample performance and explain what criterion you use for the out-of-sample test.
    - Show evidence that the strategy you develop is profitable.

- Compare the out-of-sample performance between your strategy and a pairs-trading strategy. Explain the results.

2. Price Prediction: Comparison between ARIMA Model and LSTM

- Lecture Notes 11-13 and 21-22 and Jupyter Notebooks ("Lec 10-11 Time Series," "Lec 12-13 Time Series.ipynb," "Lectures 21-22: Deep Learning," and "Lecture 22 Stock Price Prediction using LSTM") are related to this project.
- Choose two stocks as you wish for the prediction. Do predictions separately for each stock.
- Pick a period (explain why) and use the daily close price from Yahoo Finance for the prediction.
- Show evidence of convergence for the LSTM model and explain how you pick the lags for the ARIMA model.
- Compare the out-of-sample performance between the ARIMA Model and LSTM.
- Explain the pros and cons of both methods. Any difference between the performances of the two stocks you pick?

3. Reinforcement Learning for Optimal Execution

- Lecture Notes 14, 17-20 and the Jupyter Notebook "Lecture19-Reinforcement Learning for Optimal Execution" are related to this project.
- Train the Q-learning algorithm with the simulation environment provided in the Jupyter Notebook ("Lecture 21: Reinforcement Learning for Optimal Execution") on Blackboard.
- Show evidence of convergence.
- Use the Sharpe Ratio as the criterion and compare the performance of Q-learning to the following two strategies: (a) executing with a constant trading speed, (b) executing everything at time 0.
- Design a new simulation environment and repeat the above procedures. Explain your results.

Final Report Requirement: The final report is expected to contain the following components:

- Introduction to the dataset you use, the data format and the steps you perform for data pre-processing.
- Brief introduction to the models you use in the project.
- Detailed discussion for the model evaluation: proper choice of evaluation criterion (or loss function), out-of-sample test, comparison to benchmark models.
- Detailed explanation on how model parameters are selected.
- Detailed explanation of your results.
- Discussion on financial interpretation or economic insights of your model.
- A conclusion paragraph to summarize the methodology and your results.

- *Optional* If you explore some other related aspects of the project (of your own choice), extra credits will be granted based on the quality of the additional materials. If you decide to include some extra work, please clearly indicate what are additional in your report.

Grading: The final project of the report accounts for 30% of the semester grade.

Statement on Academic Conduct and Support Systems

Academic Integrity:
The University of Southern California is a learning community committed to developing successful scholars and researchers dedicated to the pursuit of knowledge and the dissemination of ideas. Academic misconduct, which includes any act of dishonesty in the production or submission of academic work, comprises the integrity of the person who commits the act and can impugn the perceived integrity of the entire university community. It stands in opposition to the university's mission to research, educate, and contribute productively to our community and the world.

All students are expected to submit assignments that represent their own original work, and that have been prepared specifically for the course or section for which they have been submitted. You may not submit work written by others or "recycle" work prepared for other courses without obtaining written permission from the instructor(s).

Other violations of academic integrity include, but are not limited to, cheating, plagiarism, fabrication (e.g., falsifying data), collusion, knowingly assisting others in acts of academic dishonesty, and any act that gains or is intended to gain an unfair academic advantage.

The impact of academic dishonesty is far-reaching and is considered a serious offense against the university. All incidences of academic misconduct will be reported to the Office of Academic Integrity and could result in outcomes such as failure on the assignment, failure in the course, suspension, or even expulsion from the university.

For more information about academic integrity see the student handbook or the Office of Academic Integrity's website, and university policies on Research and Scholarship Misconduct.

Please ask your instructor if you are unsure what constitutes unauthorized assistance on an exam or assignment, or what information requires citation and/or attribution.

Students and Disability Accommodations:

USC welcomes students with disabilities into all of the University's educational programs. The Office of Student Accessibility Services (OSAS) is responsible for the determination of appropriate accommodations for students who encounter disability-related barriers. Once a student has completed the OSAS process (registration, initial appointment, and submitted documentation) and accommodations are determined to be reasonable and appropriate, a Letter of Accommodation (LOA) will be available to generate for each course. The LOA must be given to each course instructor by the student and followed up with a discussion. This should be done as early in the semester as possible as accommodations are not retroactive. More information can be found at osas.usc.edu. You may contact OSAS at (213) 740-0776 or via email at osasfrontdesk@usc.edu.

Support Systems:

Counseling and Mental Health - (213) 740-9355 – 24/7 on call
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.

988 Suicide and Crisis Lifeline - 988 for both calls and text messages – 24/7 on call
The 988 Suicide and Crisis Lifeline (formerly known as the National Suicide Prevention Lifeline) provides free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week, across the United States. The Lifeline is comprised of a national network of over 200 local crisis centers, combining custom local care and resources with national standards and best practices. The new, shorter phone number makes it easier for people to remember and access mental health crisis services (though the previous 1 (800) 273-8255 number will continue to function indefinitely) and represents a continued commitment to those in crisis.

Relationship and Sexual Violence Prevention Services (RSVP) - (213) 740-9355(WELL) – 24/7 on call
Free and confidential therapy services, workshops, and training for situations related to gender- and power-based harm (including sexual assault, intimate partner violence, and stalking).

Office for Equity, Equal Opportunity, and Title IX (EEO-TIX) - (213) 740-5086
Information about how to get help or help someone affected by harassment or discrimination, rights of protected classes, reporting options, and additional resources for students, faculty, staff, visitors, and applicants.

Reporting Incidents of Bias or Harassment - (213) 740-5086 or (213) 821-8298
Avenue to report incidents of bias, hate crimes, and microaggressions to the Office for Equity, Equal Opportunity, and Title for appropriate investigation, supportive measures, and response.

The Office of Student Accessibility Services (OSAS) - (213) 740-0776
OSAS ensures equal access for students with disabilities through providing academic accommodations and auxiliary aids in accordance with federal laws and university policy.

USC Campus Support and Intervention - (213) 740-0411
Assists students and families in resolving complex personal, financial, and academic issues adversely affecting their success as a student.

Diversity, Equity and Inclusion - (213) 740-2101
Information on events, programs and training, the Provost's Diversity and Inclusion Council, Diversity Liaisons for each academic school, chronology, participation, and various resources for students.

USC Emergency - UPC: (213) 740-4321, HSC: (323) 442-1000 – 24/7 on call
Emergency assistance and avenue to report a crime. Latest updates regarding safety, including ways in which instruction will be continued if an officially declared emergency makes travel to campus infeasible.

USC Department of Public Safety - UPC: (213) 740-6000, HSC: (323) 442-1200 – 24/7 on call
Non-emergency assistance or information.

Office of the Ombuds - (213) 821-9556 (UPC) / (323-442-0382 (HSC)
A safe and confidential place to share your USC-related issues with a University Ombuds who will work with you to explore options or paths to manage your concern.

Occupational Therapy Faculty Practice - (323) 442-2850 or otfp@med.usc.edu

Confidential Lifestyle Redesign services for USC students to support health promoting habits and routines that enhance quality of life and academic performance.