15.487 Algorithmic Trading and Quantitative Investment Strategies

Course Description. This course covers advanced financial analytics and their practical applications to algorithmic trading and quantitative investment strategies. To that end, all of the topics covered—stochastic processes, option pricing, investment strategies, backtest simulation, data and computational architecture, portfolio construction, trading implementation, and risk management—will be developed in the context of specific quantitative trading strategies. The course is designed to follow the natural sequence of research, development, testing, and implementation for a quantitative investment manager. The objective of the course is to provide students with a sense of industry practice as well as a broader understanding of the art and science of investment management. Mathematical and statistical techniques will be covered in some depth—along with their computational implementation in R—however, the emphasis will be on financial applications, not on methodology.

Pre-requisites. This course is geared toward M.Fin. students. Others may enroll with the pre-requisite of 15.401, or its equivalent, and the educational background of students in the M.Fin. program. 15.433, 15.437, 15.460, and 15.496 are recommended courses that are highly complementary to 15.487. Some basic programming skills will be necessary—projects will make extensive use of R and of financial market data, though no prior exposure to this language is necessary.

Course Requirements and Grading. Course requirements include: regular attendance and class preparation/participation in lectures and recitations (10 percent), four projects (60 percent), and a final examination (30 percent). The closed-book final examination will be given during the regular May exam period—please reserve this date as soon as it is published, and schedule your interviews and travel plans accordingly.

Course times and locations:

<table>
<thead>
<tr>
<th>Meeting</th>
<th>Lecture</th>
<th>Recitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>W 2:30-5pm</td>
<td>F 10-11am</td>
</tr>
<tr>
<td>Location</td>
<td>E62-262</td>
<td>E51-145</td>
</tr>
</tbody>
</table>

Course staff:

<table>
<thead>
<tr>
<th>Name</th>
<th>Role</th>
<th>E-mail</th>
<th>Phone</th>
<th>Office + hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paul Mende</td>
<td>Instructor</td>
<td><a href="mailto:mende@mit.edu">mende@mit.edu</a></td>
<td>(617) 715-4835</td>
<td>E62-612 W 10:30-12pm</td>
</tr>
<tr>
<td>Valère Fourel</td>
<td>TA</td>
<td><a href="mailto:vfourel@mit.edu">vfourel@mit.edu</a></td>
<td>(617) 230-7179</td>
<td>E62-384 TBA</td>
</tr>
<tr>
<td>Robert Kissinger</td>
<td>Admin. support</td>
<td><a href="mailto:rkissing@mit.edu">rkissing@mit.edu</a></td>
<td>(617) 253-7006</td>
<td>E62-671</td>
</tr>
</tbody>
</table>
Course Materials. Required and recommended readings will be indicated in class and on handouts. There is no printed course reader: research articles, papers, resources, and web links will be posted on Stellar. These textbooks and reference books for the course are available at the Coop (asterisk* indicates required text):

- ❥Narang, Inside the Black Box, Wiley, 2013 [978-1118362419]

Computing Resources. Computing and data resources will be introduced in lecture and in recitation. Students will make use of market and trading resources including the Sloan Remote Lab, the Bloomberg terminals, and MIT’s access to multiple data vendors. A dedicated set of data servers and a data warehouse are available for class projects, and students are encouraged to familiarize themselves with these tools: R (open sources), Excel, Access, Matlab (all available from IS&T). The more adventurous are encouraged to download Microsoft’s free SQL Server Express for its query and data management tools.

Class Preparation and Participation. Class preparation and participation are important components of this course. Students are expected to come to each class well prepared to discuss the materials assigned. In addition, there may be short assignments distributed in each class for discussion during the following class. Such assignments are to be treated like “case-study” assignments that require considerable advance preparation, and students should expect to be “cold-called” in class to present their analyses of these assignments.

Projects. There are four projects that will provide students with additional opportunities to apply the methods covered in the lectures. Each project covers a specific aspect of the quantitative trading strategy around which the course is organized. Students will be assigned to project groups based on computer skills, industry experience, etc. so that each group will have a good balance of quantitative expertise and institutional background. The four projects and their distribution and due dates are tentatively planned to be as follows:

<table>
<thead>
<tr>
<th>Project</th>
<th>Topic</th>
<th>Distributed</th>
<th>Due</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Introduction to a Mean Reversion Strategy</td>
<td>February 8</td>
<td>February 22</td>
</tr>
<tr>
<td>B</td>
<td>Development of a Quantitative Strategy</td>
<td>February 22</td>
<td>March 15</td>
</tr>
<tr>
<td>C</td>
<td>Implementation of a Quantitative Strategy</td>
<td>March 15</td>
<td>April 19</td>
</tr>
<tr>
<td>D</td>
<td>Risk Management and Performance Attribution</td>
<td>April 19</td>
<td>May 5</td>
</tr>
</tbody>
</table>

Projects are due at 1:00pm on the due date. Projects submitted after deadline will be subject to a 25% grade-deduction for each 24-hour period they are late.
Classroom Values@MIT Sloan. Throughout this class, we plan to adhere to the policies and procedures outlined in the “Classroom Values@MIT Sloan” document that is included at the end of this syllabus for your convenience. Please make sure you read it and understand how it applies to this class.

15.487 Reserve List

Additional books are on reserve at Dewey Library (❖ indicates library e-book link available on Stellar)

- Dacorogna et. al., An Introduction to High-Frequency Finance, Elsevier, 2001
- Grinold and Kahn, Active Portfolio Management, McGraw-Hill, 1999
- Kissell and Glantz, Optimal Trading Strategies, AMACOM, 2003
- Lo, Hedge Funds: An Analytic Perspective, Princeton, 2010
- Qian, Hua, and Sorensen, Quantitative Equity Portfolio Management, CRC Press, 2007
- ❖ Rebonato, Volatility and Correlation, Wiley, 2004
15.487 List of Topics

The course will draw from the list of topics below. Note that not all will necessarily be covered.

1. Mathematical and Statistical Preliminaries
   a. Course overview, and the role of mathematics and statistics in financial analysis
   b. Classical vs. Bayesian statistical inference
   c. Common estimation methods (MLE, GMM)
   d. Basics of probability theory
   e. Review of stochastic processes and financial time series

2. Theory of Risk and Derivative Pricing
   a. Risk, uncertainty, and volatility
   b. Stochastic processes and stochastic calculus
   c. Derivative pricing under no-arbitrage
   d. Real-world limits to stochastic models
   e. Derivative pricing in incomplete markets
   f. Hedging in riskless and in risky markets
   g. Small fluctuations and the greeks
   h. Large fluctuations, jumps, rare events, and regime shifts
   i. Volatility modeling and volatility surface dynamics

3. Market Efficiency, Behavioral Finance, and Practice
   a. Classical and modern notions of market efficiency
   b. Tests of efficiency and rationality
   c. Behavioral finance
   d. Evolutionary psychology, sociobiology, and neuroeconomics
   e. The Adaptive Markets Hypothesis

4. Hedge Funds, Proprietary Trading, and Investment Management
   a. Industry overview and introduction to quantitative strategies
   b. Matching investment objectives to risk/reward profiles
   c. Mean reversion, momentum, and other dynamic trading strategies
   d. Anatomy of an equity market-neutral trading strategy
   e. Anatomy of a volatility trading strategy
   f. Degrees of “arbitrage” and their limits

5. The Econometrics of Backtest Simulations
   a. Definitions of “backtesting”
   b. Look-ahead, overfitting, and other data-snooping biases
   c. Bayesian decision theory and sequential analysis
   d. Monte Carlo simulation
   e. Rejecting the Random Walk Hypothesis
6. Forecasting Risk and Return
   a. Properties of risk and return distributions
   b. Forecast quality, forecast horizons, and scaling
   c. Estimating linear factor models and covariance matrices
   d. Estimating nonlinear and nonparametric factor models
   e. Estimating stochastic volatility and GARCH models

7. Data Architecture and Strategy Design
   a. Data sources, data vendors, and data quality
   b. Introduction to data architecture
   c. Data and computational architecture of a quantitative strategy
   d. Data domains: market, model, portfolio
   e. Tick data, trading technology, and beyond

8. Portfolio Construction
   a. Portfolio objectives, constraints, and optimization
   b. Trade-selection and trading-sizing algorithms
   c. Risk models and market models
   d. Limits to diversification
   e. Optimal trading rules, turnover, trade frequency, and calculational complexity

9. Trading Implementation
   a. Overview of market microstructure, market-making, and high-frequency trading
   b. Econometric models of market microstructure and trading costs
   c. Calibration, stress testing, and testability of trading algorithms
   d. Steady-state performance and transients, failure mode design, stability of parameters
   e. Control, tracking, and performance attribution for live and shadow portfolios

10. Risk Management
    a. Leverage, liquidity, capacity, margin, cash management, and capital allocation
    b. Normal markets, extreme markets, and rare events
    c. Insurance, hedging, shaping the return profile
    d. Risk and human behavior
    e. Physics envy and an uncertainty checklist

11. Machine Learning and Algorithmic Trading
    a. Supervised and unsupervised learning
    b. Use and preparation of data
    c. Predictive modeling
    d. Reinforcement learning

12. Open Questions and Parting Thoughts
**15.487 Course Schedule**

Note: This is an *approximate* schedule for the course and meant to serve as a very rough guide to the pace of the course; some material may take longer or shorter to cover than the allotted time.

**Lectures:**

<table>
<thead>
<tr>
<th>Session</th>
<th>Date</th>
<th>Topic</th>
<th>Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Feb 8</td>
<td>Course overview and motivation. Mathematical and statistical preliminaries.</td>
<td>Project A posted</td>
</tr>
<tr>
<td>4</td>
<td>Mar 1</td>
<td>Hedge funds, proprietary trading, and investment management.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Mar 8</td>
<td>Portfolio construction. Data architecture and strategy design.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Mar 15</td>
<td>Forecasting risk and return.</td>
<td>Project B due, Project C posted</td>
</tr>
<tr>
<td>-</td>
<td>Mar 22</td>
<td><em>No class: SIP Week at Sloan</em></td>
<td></td>
</tr>
<tr>
<td>-</td>
<td>Mar 29</td>
<td><em>No class: Spring break</em></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Apr 5</td>
<td>Market microstructure. Trading implementation.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Apr 12</td>
<td>Risk measurement and risk management</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Apr 19</td>
<td>Risk measurement and risk management</td>
<td>Project C due, Project D posted</td>
</tr>
<tr>
<td>10</td>
<td>Apr 26</td>
<td>Theory of risk and derivative pricing. Arbitrage, no-arbitrage, and limits to arbitrage.</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>May 3</td>
<td>Volatility and correlation</td>
<td>Project D due 5/5</td>
</tr>
<tr>
<td>13</td>
<td>May 17</td>
<td>Open questions and parting thoughts</td>
<td></td>
</tr>
</tbody>
</table>
Classroom Values@MIT Sloan

The MIT Sloan Mission

The mission of the MIT Sloan School of Management is to develop principled, innovative leaders who improve the world and to generate ideas that advance management practice.

Values@MIT Sloan

The MIT Sloan Mission statement (above) provides the context for core values that express who we are at our best. These core values include integrity, respect, collaboration, innovation, and positive impact. We invite all members of our community – students, staff, faculty, alumni – to practice these values in all the ways we work together, both inside and outside of the classroom.

MIT Sloan Policy on Classroom Behavior

In order to create a productive learning environment and to ensure mutual respect it is essential that the norms and rules of classroom etiquette and behavior reflect the highest standards. It is also important that these norms be consistently enforced by the faculty across all classes. Although in the final analysis each faculty member is responsible for his or her own classroom, there are significant negative consequences for other faculty and for the School if rules are not consistent and are not enforced. Therefore it is the policy of the MIT Sloan School that:

- Students are expected to arrive promptly on time and to stay for the entire class.
- Faculty are expected to begin and end class on time.
- Laptops and e-readers not be open in the classroom except with explicit permission of the faculty (e.g., when used to deliver an e-course pack or otherwise used as part of the instructional program or when required by students because of physical or other challenges)
- Cellphones and PDAs are not to be used or permitted to ring in the classroom.
- Students are expected to attend all classes.

It is expected that faculty will articulate how these rules apply in their class as well as how the rules will be enforced.

MIT Sloan Career Development Office Recruiting Policy

Students are required to schedule campus interviews outside of scheduled class times and to make every attempt to schedule second round interviews and site visits outside of class times. Classes missed for such activities are not excused absences and may count against your participation grade.
ACADEMIC HONESTY – INTEGRITY IN PRACTICE

As a member of the MIT Sloan academic community, you are expected to uphold the highest standards of academic integrity. Violations of academic integrity include, but are not limited to, cheating, plagiarism, unauthorized collaboration, and facilitating academic dishonesty. Please see the document Academic Integrity at the Massachusetts Institute of Technology: A Handbook for Students for further discussion of this topic. These standards are also discussed below, specifically regarding plagiarism, individual work, and team work.

*It is your responsibility to make yourself aware of MIT’s rules of academic integrity and to adhere to them.* When students are found to have violated academic standards, disciplinary action will result. Possible consequences include grade reduction, an F grade, a transcript notation, delay of graduation, or expulsion from MIT.

This discussion of academic integrity below is not exhaustive, and there may be areas that remain unclear to you. *If you are unsure whether some particular course of action is proper, it is your responsibility to consult with your professor and/or teaching assistant for clarification.*

**Plagiarism**

Plagiarism occurs when you use another’s intellectual property (words or ideas) and do not acknowledge that you have done so. Plagiarism is a very serious offense. If it is found that you have plagiarized -- deliberately or inadvertently -- you will face serious consequences, as indicated above.

The best way to avoid plagiarism is to cite your sources - both within the body of your assignment and in a bibliography of sources you used at the end of your document.

Materials gathered through research via the Internet must be cited in the same manner as more traditionally published material. Lack of such citation constitutes plagiarism.

To review rules of citation: [http://libguides.mit.edu/content.php?pid=80743&sid=598642](http://libguides.mit.edu/content.php?pid=80743&sid=598642)

**Individual Assignments**

Many assignments in MIT Sloan courses are expected to be done individually. The information below outlines what is meant by “individual” work. These rules should be observed unless otherwise defined by the instructor.

When you are asked to do *individual* work, you are expected to adhere to the following standards:

- Do not copy all or part of another student’s work (with or without "permission").
- Do not allow another student to copy your work.
- Do not ask another person to write all or part of an assignment for you.
- Do not work together with another student in order to answer a question, or solve a problem, or write a computer program jointly.
- Do not consult or submit work (in whole or in part) that has been completed by other students in this or previous years for the same or substantially the same assignment.
- Do not use print or internet materials directly related to a case/problem set unless explicitly authorized by the instructor.
- Do not use print or internet materials without explicit quotation and/or citation.
- Do not submit the same, or similar, piece of work for two or more subjects without the explicit approval of the two or more instructors involved.
Please note that many classes will require a combination of team work and individual work. *Be sure that you follow all the guidelines for individual work when a faculty member identifies an assignment as an individual one.*

**Team Assignments**

When you are asked to *work in teams*, there is a broad spectrum of faculty expectations. Three general types of appropriate collaboration on team assignments are described below. The instructor will indicate in the syllabus what his/her expectations are. If there is any uncertainty, it is the student’s responsibility to clarify with the professor or TA the type of team work that is expected.

**Type 1 collaboration:**
The professor states that collaboration is allowed, but the final product must be individual. An example of this might be a problem set.

- You are allowed to discuss the assignment with other team members and work through the problems together.
- What you turn in, however, must be your own product, written in your own handwriting, or in a computer file of which you are the sole author.
- Copying another’s work or electronic file is not acceptable.

**Type 2 collaboration:**
The professor states that collaboration is encouraged but that each person’s contribution to a given deliverable does not have to be substantial (allowing groups to take a "divide and conquer" approach). An example of this might be a brief progress report that is part of a more extensive collaboration (as a whole, the more extensive collaboration may be Type 3).

- Each team member is encouraged to contribute substantially to the team assignment, however, the team may choose to assign one or more team members to prepare and submit the deliverable on behalf of the team.
- Regardless of how work is shared or responsibilities are divided among individual team members, each member of the team will be held accountable for the academic integrity of the entire assignment. If, for example, one member of the team submits plagiarized work on behalf of the team, the entire team will be subject to sanctions as appropriate.
- The team may not collaborate with other students outside of the team unless the professor explicitly permits such collaboration.

**Type 3 collaboration:**
The professor states that collaboration is expected and that each team member must contribute substantially to the deliverable. An example of this might be the 15.311 OP project.

- Each team member must make a substantial contribution to the assignment. It is not, for example, acceptable to divide the assignments amongst the team members (e.g., part of the team completes the OP Project while the rest of the team prepares a team case for DMD), though the team may divide the work of any one assignment to complete it as they deem appropriate.
- The team may not collaborate with other students outside of the team unless the professor explicitly permits such collaboration.

*If you are unsure whether some particular form of interaction is proper in individual or team work, it is your responsibility to consult the instructor and/or teaching assistant for clarification and guidance.*