DOCTOR OF PHILOSOPHY WITH A MAJOR IN MACHINE LEARNING

The Doctor of Philosophy with a major in Machine Learning program has the following principal objectives, each of which supports an aspect of the Institute's mission:

1. Create students that are able to advance the state of knowledge and practice in machine learning through innovative research contributions.
2. Create students who are able to integrate and apply principles from computing, statistics, optimization, engineering, mathematics and science to innovate, and create machine learning models and apply them to solve important real-world data intensive problems.
3. Create students who are able to participate in multidisciplinary teams that include individuals whose primary background is in statistics, optimization, engineering, mathematics and science.
4. Provide a high quality education that prepares individuals for careers in industry, government (e.g., national laboratories), and academia, both in terms of knowledge, computational (e.g., software development) skills, and mathematical modeling skills.
5. Foster multidisciplinary collaboration among researchers and educators in areas such as computer science, statistics, optimization, engineering, social science, and computational biology.
6. Foster economic development in the state of Georgia.
7. Advance Georgia Tech's position of academic leadership by attracting high quality students who would not otherwise apply to Tech for graduate study.

The academic requirements for the PhD in Machine Learning consist of 10 courses, passing the qualifying examination, and successfully defending a PhD thesis. Five of the courses are designated as "core"; students are expected to take these courses in their first two years in the program. The five remaining courses are chosen from a long, diverse list of electives. The qualifying examination consists of a focused literature program. The five remaining courses are chosen from a long, diverse list of 10 courses, passing the qualifying examination, and successfully defending a PhD thesis. Five of the courses are designated as "core"; students are expected to take these courses in their first two years in the program. The five remaining courses are chosen from a long, diverse list of electives. The qualifying examination consists of a focused literature review that takes place over the course of a semester, for which the student receives course credit.

Summary of General Requirements for a PhD in Machine Learning

- Core curriculum (5 courses, 15 hours).
- Area electives (5 courses, 15 hours).
- Responsible Conduct of Research (RCR) (1 course, 1 hour, pass/fail). Georgia Tech requires that all PhD students complete an RCR requirement that consists of an online component and in-person training. The online component is completed during the student's first semester enrolled at Georgia Tech. The in-person training is satisfied by taking PHIL 6000 or their associated academic program's in-house RCR course.
- Qualifying examination (1 course, 3 hours). This consists of a one-semester independent literature review followed by an oral examination.
- Doctoral minor (3 courses, 9 hours).
- Research Proposal. The purpose of the proposal is to give the faculty an opportunity to give feedback on the student's research direction, and to make sure they are developing into able communicators.
- PhD Dissertation.

Almost all of the courses in both the core and elective categories are already taught regularly at Georgia Tech. However, two core courses (designated in the next section) are being developed specifically for this program. The proposed outlines for these courses can be found in the Appendix. Students who complete these required courses as part of a master's program will not need to repeat the courses if they are admitted to the ML PhD program.

Core Courses

Machine Learning PhD students will be required to complete courses in five different areas. With the exception of the Foundations course, each of these area requirements can be satisfied using existing courses from the College of Computing or Schools of ECE, ISyE, and Mathematics.

Mathematical Foundations of Machine Learning. This will be a new course cross-listed between the College of Computing (CS) and Schools of ECE and ISyE. This required course is the gateway into the program, and will cover the key subjects from applied mathematics needed for a rigorous graduate program in ML. Particular emphasis will be put on advanced concepts in linear algebra and probabilistic modeling. A formal course proposal has been submitted to the graduate committees in the schools listed above; the outline of the material from this proposal can be found in the Appendix. The new course should have a CS/CSE/ECE/ISYE 7740 designation.

Intermediate Statistics. The purpose of this requirement is to expose students to the main concepts in mathematical statistics. It can be met through any one of the three courses listed below. While these courses emphasize different material, they are all centered on mathematical analysis of fundamental problems in statistics.

- ISYE 6412, Theoretical Statistics
- ECE 7251, Signal Detection and Estimation
- MATH 6262, Statistical Estimation

Machine Learning: Theory and Methods. This course serves as an introduction to the foundational problems, algorithms, and modeling techniques in machine learning. Each of the courses listed below treats
roughly the same material using a mix of applied mathematics and computer science, and each has a different balance between the two.

- CS 7616, Pattern Recognition
- CSE/ISYE 6740, Computational Data Analysis
- ECE 6254, Statistical Machine Learning
- ECE 6273, Methods of Pattern Recognition with Applications to Voice

**Probabilistic Graphical Models and ML in High Dimensions.** This will be a new course cross-listed between the College of Computing (CS) and schools of CSE and ECE. The course will provide students with an introduction to the theory and practice of graphical models, one of the most dominant frameworks in machine learning and artificial intelligence. Similar courses have been taught as special topics courses in the School of CSE, including CSE 8803ML (Machine Learning II: Advanced Topics) and CS 8803PGM (Introduction to Probabilistic Graphical Models). A formal course proposal has been submitted to the graduate committees in the schools listed above; the outline of the material from this proposal can be found in the Appendix. The course should be designated CS/CSE/ECE 7741.

**Optimization.** Optimization plays a crucial role in both developing new machine learning algorithms and analyzing their performance. The three courses below all provide a rigorous introduction to this topic; each emphasizes different material and provides a unique balance of mathematics and algorithms.

- ECE 8823, Convex Optimization: Theory, Algorithms, and Applications
- ISYE 6661, Linear Optimization
- ISYE 6663, Nonlinear Optimization
- ISYE 6669, Deterministic Optimization
- ISYE 7683, Advanced Nonlinear Programming

**Electives**

In addition to meeting the five core area requirements, each student is required to complete five elective courses. These courses are required for getting a complete breadth in ML. These courses must be chosen from at least two of the five subject areas listed below.

**i. Statistics and Applied Probability:** To build breadth and depth in the areas of statistics and probability as applied to ML.

- AE 6505, Kalman Filtering
- BMED 6700, Biostatistics
- ECE 6558, Stochastic Systems
- ECE 6601, Random Processes
- ECE 6605, Information Theory
- ISYE 6404, Nonparametric Data Analysis
- ISYE 6413, Design and Analysis of Experiments
- ISYE 6414, Regression Analysis
- ISYE 6416, Computational Statistics
- ISYE 6420, Bayesian Statistics
- ISYE 6761, Stochastic Processes I
- ISYE 6762, Stochastic Processes II
- ISYE 7400, Adv Design-Experiments
- ISYE 7401, Adv Statistical Modeling
- ISYE 7405, Multivariate Data Analysis
- MATH 6263, Testing Statistical Hypotheses
- MATH 6266, Statistical Linear Modeling
- MATH 6267, Multivariate Statistical Analysis
- MATH 7244, Stochastic Processes and Stochastic Calculus I
- MATH 7245, Stochastic Processes and Stochastic Calculus II

**ii. Advanced Theory:** To build a deeper understanding of foundations of ML.

- CS 7280, Network Science
- CS 7510, Graph Algorithms
- CS 7520, Approximation Algorithms
- CS 7530, Randomized Algorithms
- CS 7535, Markov Chain Monte Carlo Algorithms
- CS 7540, Spectral Algorithms
- CS 7545, Machine Learning Theory
- ECE 6283, Harmonic Analysis and Signal Processing
- ECE 6555, Linear Estimation
- ISYE 7682, Convexity
- MATH 6112, Advanced Linear Algebra
- MATH 6221, Advanced Classical Probability Theory
- MATH 6580, Introduction to Hilbert Space
- MATH 7338, Functional Analysis
- MATH 7586, Tensor Analysis
- MATH 88XX, Special Topics: Mathematical Foundations of Learning Theory
- MATH 88XX, Special Topics: High Dimensional Probability and Statistics

**iii. Applications:** To develop a breadth and depth in variety of applications domains impacted by/with ML.

- AE 6373, Advanced Design Methods
- AE 8803, Machine Learning for Control Systems
- AE 8803, Nonlinear Stochastic Optimal Control
- BMED 6780, Medical Image Processing
- BMED 8813BHI, Biomedical and Health Informatics
- BMED 8813MHI, mHealth Informatics
- BMED 8813MLB, Machine Learning in Biomedicine
- BMED 8823ALG, OMICS Data and Bioinformatics Algorithms
- CS 6440, Introduction to Health Informatics
- CS 6465, Computational Journalism
- CS 6474, Social Computing
- CS 6475, Computational Photography
- CS 6476, Computer Vision
- CS 6601, Artificial Intelligence
- CS 7450, Information Visualization
- CS 7476, Advanced Computer Vision
- CS 7630, Autonomous Robots
- CS 7636, Computational Perception
- CS 7646, Machine Learning for Trading
- CS 7650, Natural Language Processing
- CSE 6141, Massive Graph Analysis
- CSE 6240, Web Search and Text Mining
- CSE 6242, Data and Visual Analytics
- CSE 6301, Algorithms in Bioinformatics and Computational Biology
- ECE 4580, Computational Computer Vision
to their current research. Subsequently, the student will have a closed oral exam with the three members of the committee. The exam will be interactive, with the student and the committee discussing and criticizing each work and posing questions related to the student’s current research to determine the breadth of student’s knowledge in that specific area.

The success of the examination will be determined by the committee’s qualitative assessment of the student’s understanding of the theory, methods, and ultimate impact of the assigned syllabus.

The student will be given a passing grade for meeting the requirements of the committee in both the written and the oral part. Unsatisfactory performance on either part will require the student to redo the entire qualifying exam in the following semester/year. Each student will be allowed only two attempts at the exam.

Students are expected to perform the review by the end of their second year in the program.

Doctoral Dissertation

The primary requirement of the PhD student is to do original and substantial research. This research is reported for review in the PhD dissertation, and presented at the final defense. As the first step towards completing a dissertation, the student must prepare and defend a Research Proposal. The proposal is a document of no more than 20 pages in length that carefully describes the topic of the dissertation, including references to prior work, and any preliminary results to date. The written proposal is submitted to a committee of three faculty members from the ML PhD program, and is presented in a public seminar shortly thereafter. The committee members provide feedback on the proposed research directions, comments on the strength of writing and oral presentation skills, and might suggest further courses to solidify the student’s background. Approval of the Research Proposal by the committee is required at least six months prior to the scheduling of the PhD defense. It is expected that the student complete this proposal requirement no later than their fourth year in the program.

The PhD thesis committee consists of five faculty members: the student’s advisor, three additional members from the ML PhD program, and one faculty member external to the ML program. The committee is charged with approving the written dissertation and administering the final defense. The defense consists of a public seminar followed by oral examination from the thesis committee.

Minor

The minor will follow the standard Georgia Tech requirement: 9 hours outside the student’s home unit, with a GPA in those courses of at least 3.0. These courses are in addition to the other core and elective requirements. The courses for the minor should form a cohesive program of study, outside the area of ML, that is approved by the Faculty Advisory Committee. Typical programs will consist of three courses from the same school (any school at the Institute) or three courses from the same elective area in the courses listed above. The courses should all be from the same School or from the same elective area in the courses listed above. Programs that do not meet this criteria cannot be approved by the Graduate Committee.

iv. Computing and Optimization: To provide more breadth and foundation in areas of math, optimization and computation for ML.

• CS 6505, Computability and Algorithms
• CS 6550, Design and Analysis of Algorithms
• CSE 6140, Computational Science and Engineering Algorithms
• CSE 6643, Numerical Linear Algebra
• CSE 6644, Iterative Methods for Systems of Equations
• CSE 6710, Numerical Methods I
• CSE 6711, Numerical Methods II
• ISYE 6645, Monte Carlo Methods
• ISYE 6662, Discrete Optimization
• ISYE 6664, Stochastic Optimization
• ISYE 6679, Computational methods for optimization
• ISYE 7656, Advanced Combinatorial Optimization
• ISYE 7687, Advanced Integer Programming

v. Platforms: To provide breadth and depth in computing platforms that support ML and Computation.

• CS 6421, Temporal, Spatial, and Active Databases
• CS 6430, Parallel and Distributed Databases
• CS 6290, High-Performance Computer Architecture
• CSE 6220, High Performance Computing
• CSE 6230, High Performance Parallel Computing

Qualifying Examination

The purpose of the Qualifying Examination is to judge the candidate’s potential as an independent researcher.

The Ph.D. qualifying exam consists of a focused literature review that will take place over the course of one semester. At the beginning of the second semester of their second year, a qualifying committee consisting of three members of the ML faculty will assign, in consultation with the student and the student’s advisor, a course of study consisting of influential papers, books, or other intellectual artifacts relevant to the student’s research interests. The student’s focus area and current research efforts (and related portfolio) will be considered in defining the course of study.

At the end of the semester, the student will submit a written summary of each artifact which highlights their understanding of the importance (and weaknesses) of the work in question and the relationship of this work