**“Digital Intelligence”: A New Undergraduate Certificate Track**

**Introduction:**
The Digital Intelligence Certificate is an undergraduate, interdisciplinary course of study that equips students to develop foundational knowledge in computational technologies and their relationship to society. The interdisciplinary curriculum will guide students through a robust, thoughtful, and critical course of study of technology and its implications for individuals and society. In earning the proposed Certificate, students will gain a foundational understanding of contemporary and emerging computational thinking, which will be customized for different pathways to suit individual students’ interests, and may include topics such as artificial intelligence, cybersecurity, web/mobile technologies, databases, and software engineering. They will also study the ethical, legal, social and policy frameworks needed to understand the complex ways in which these technologies impact society. Students who complete the Digital Intelligence Certificate will be prepared to thoughtfully and ethically create, deploy, manage and critique emerging computational technologies in their chosen field of work.

**Program Details:**
The certificate is open to all Duke students. Students must take six courses to complete the certificate: the core course (“Computing and Ethics”, SciSoc 256), a capstone course (“Digital Intelligence Capstone,” SciSoc 498S), and four elective courses.

Elective courses are selected from four elective areas, one from each area. The four areas are:

1. **Computational Thinking**: courses that cover key concepts of computational thinking such as algorithms, computer programming, machine learning, artificial intelligence, and computer vision
2. **Ethics and Policy**: courses that examine the social, ethical and policy implications of emerging computer science and other digital technology
3. **Communication**: courses that teach and analyze how science & technology is communicated and how to communicate science and technology in the digital age.
4. **Computation in Practice**: courses that apply advances in computational thinking and data science to a variety of applied contexts, from biology to political science.

Together, the core and electives will provide students with a broad understanding of emerging computational and data technology as well as the policy and ethical issues they raise. The capstone course offers students a way to come back together as a cohort to integrate what they have learned across the different core and elective areas, with a culminating project and a course that helps them learn to present the findings in a compelling and accessible way. In this way, the students will have the potential to have a real-world impact with their projects, and training on how to present their work to their peers and a broader audience.
Before enrolling in the Capstone course, students must participate in a substantial, summer-long, or semester-long experiential research project. This can be accomplished either through participation in existing Duke programs such as Data+, DOmath, Code+, CS+, or the Huang Fellows program, or through a substantial independent project, equivalent to a semester in length, developed in consultation with Certificate faculty and supervised by a faculty mentor.

Below we summarize the program, and in the Appendix more details are provided on the classes.

Core Class:
- **Computation, Ethics, and Policy (SCISOC 256-02):** This Digital Intelligence core course examines a range of impactful emerging technologies through an applied ethical lens. In a flipped-classroom format, students will watch videos on a weekly basis featuring Duke faculty introducing and interviewing leading technology, ethics, and policy experts as they discuss relevant and timely topics. Fundamental concepts in the development and research of Computer Science concepts enabling these technologies will also be shared. Students will meet in small discussion groups to collectively engage with essential themes presented in the video and related literature. The core course must be taken by the end of the junior year, but preferably by the end of sophomore year.

Elective Area 1: Computational Thinking
- Courses that cover key concepts of computational thinking such as algorithms, computer programming, machine learning, artificial intelligence, and computer vision. Courses listed in this area fall into one of 3 categories:
  - for students with little or no prior programming experience or computational background
  - for students with some programming experience and computational background (which can be obtained from the courses in the first category or through co-curricular offerings)
  - for students in traditional computing majors (Computer Science or ECE) and majors with a close relationship to computing (such as Math or Statistics), this elective can be satisfied by any course with a significant programming component that is used to satisfy their major requirement. Such students are encouraged to take courses that focus on emerging computing technologies, such as Introduction to Artificial Intelligence (COMPSCI 370), Elements of Machine Learning (COMPSCI 371D) or Introduction to Computer Vision (COMPSCI 527).

Elective Area 2: Ethics and Policy
- Courses that examine the social, ethical and policy implications of emerging computer science and other digital technology

Elective Area 3: Representations, Translations & Communications
- Courses that teach and analyze how science and technology is communicated in the digital age

Elective Area 4: Computation in Practice
- Courses that apply advances in computational thinking and data science to a variety of applied
contexts, from biology to political science. This elective requirement may be fulfilled in one of two ways:
  o Option A – fulfilled through a traditional course
  o Option B - completing 100 hours of co-curricular learning activities, completed through the enrollment of a new course, Computation in Practice, which students can enroll in once 2/3 of their hours are complete to supervise the completion of 100 hours of co-curricular learning activities. See detailed description below under Elective Area 4: Computation in Practice – Co-Curricular Learning

Capstone Course:
  • Digital Intelligence Capstone (SCISOC 498S-02): This required capstone course will be taken during certificate students’ junior or senior year, following the completion of their Capstone Project (see below). SciSoc 498S-02 will bring students back together as a cohort to discuss their research projects with their peers, and learn the skills required to develop a robust presentation of their research findings. These include presentation skills, data visualization and/or science communication skills, public speaking fluency, and the ability to translate complex scientific or technical concepts to a broader audience. Students will develop and deliver a final presentation on their research projects for their peers and a broader public audience.

Capstone Project Requirement:
  • A substantial, summer or semester-long experiential project. This can be accomplished either through participation in existing programs such as Data+, CS+, Code+ and DOMath, Huang Fellows, or through a substantial independent project, equivalent to a semester in length, developed in consultation with Certificate faculty and supervised by a faculty mentor.
Elective Area 4: Computation in Practice – Co-Curricular Learning

- To be completed between sophomore and senior years.
- Offered across campus, including OIT’s Co-Lab, CCT’s +DataScience, or the Center for Data and Visualization Sciences.
  - Short-form co-curricular coursework can be completed outside of normal class schedules, and allows students to gain proficiency in basic and advanced computer programming, machine learning and AI techniques, and data curation and data visualization methods.
- Students interested in this option must declare their intention to pursue the 100 hours of co-curricular offerings and enroll in Computation in Practice when they enroll in the Certificate, and by no later than the fall of their junior year.
- When students declare their intention to enroll in Computation in Practice, they must meet with the Certificate Directors (Sarah Rispin Sedlak and/or David Carlson) or their designee (currently Shelley Rusincovitch at CCT and Esko Brummel at Science & Society), who will assist them in setting up an online portfolio for tracking their co-curricular hours.
  - Faculty and instructors who offer approved co-curricular options are given a “completion code” or the equivalent to provide to students to verify the students’ successful completion of the activity.
  - Students will be required to keep their online portfolio updated with their completed co-curricular activities.
  - Students will be required to meet at least annually with the Certificate Director and/or their designee to review their online portfolio to ensure that they are on track for the completion of 100 hours.
  - The Certificate Director or their designee will communicate these students’ progress with the faculty member supervising a Computation in Practice course that they will enroll in once they have completed two-thirds of their 100 hours, to enable the faculty member to confer a pass or fail for that course.
- Student may select from a curated and circulated list of approved co-curricular options, including lectures, workshops, and other extra-curricular opportunities (this list will be regularly updated by staff at Science & Society and CCT).
  - List of Co-Curriculars: pre-approved opportunities will be identified for and communicated with Certificate students at least 2 times per semester.
- Students may request permission in advance from the Certificate Directors to participate in co-curricular activities that are not on the pre-approved list.
  - Additionally, program directors can, at their discretion, approve a second elective from Elective Areas 2 or 3 in lieu of a course from the Elective Area 4 list.
- In their senior year, or once they have completed at least 2/3 of their co-curricular hours, students will be permitted to register for the class “Computation in Practice” and will be required to complete the balance of their 100 hours for successful completion of that class.
- The course will be graded on a pass/fail basis.
Appendix 1: Full Elective Course Listing

Elective Area 1: Computational Thinking

For students with little or no prior programming experience or computational background, the Elective Area 1 can be satisfied with:

- **Programming and Problem Solving (COMPSCI 94)**
  Programming and problem solving in a specific domain such as robotics, virtual worlds, web programming, biology, genomics, or computer science. Students learn the basics of programming by studying problems in one application area. Not open to students who have taken Computer Science 101, 102, 116, Engineering 103 or Computer Science 201.

- **Introduction to Computer Science (COMPSCI 101L)**
  Introduction to the practices and principles of computer science and programming and their impact on and potential to change the world. Algorithmic, problem-solving, and programming techniques in domains such as art, data visualization, mathematics, natural and social sciences. Programming using high-level languages and design techniques emphasizing abstraction, encapsulation, and problem decomposition. Design, implementation, testing, and analysis of algorithms and programs. No previous programming experience required. Not open to students who have taken Computer Science 102, 116, Engineering 103 or Computer Science 201.

- **Interdisciplinary Introduction to Computer Science (COMPSCI 102L/NEURO 104L)**
  Introduction to the practices and principles of computer science and programming and their impact on and potential to change the world motivated by problems drawn from natural science, social science, engineering, and humanities. Programming using Python, appropriate libraries, and APIs to process, analyze, and visualize data. Design, implementation, and analysis emphasizing abstraction, encapsulation, and problem decomposition. No previous programming experience required.

- **Foundations of Data Science (COMPSCI 116)**
  Introduction to computer programming and statistical inference in the process of conducting analysis of real-world datasets, including economic data, document collections, geographical data, and social networks. Exploration of data via visualization and descriptive statistics. Creating predictions with techniques from machine learning and optimization. Testing hypotheses and making statistical inferences. Learn basic Python programming skills to organize and manipulate data in tables, and to visualize data effectively. Discussion of social issues surrounding data analysis such as privacy and bias. No prior programming experience or statistics is required.

- **Computational Methods in Engineering (EGR 103L)**
  Introduction to computer methods and algorithms for analysis and solution of engineering problems using numerical methods in a workstation environment. Topics include: numerical integration, roots of equations, simultaneous equation solving, finite difference methods, matrix analysis, linear programming, dynamic programming, and heuristic solutions used in engineering practice. This course does not require any prior knowledge of computer programming.

- **AI for Everyone (EGR 190.06)**
  Study arranged on special engineering topics in which the faculty have particular interest and competence because of research or professional activities. Consent of instructor(s) required.

- **Focus Program: Mathematics of Data Science (MATH 163FS) †**
  Introduction to the mathematics and algorithms that are central to a variety of data science applications. Basic mathematical concepts underlying popular data science algorithms will be introduced and students will write code implementing these algorithms. We will discuss the impact of these algorithms on society and ethical implications. Algorithms examined include: Google's pagerank, principal component analysis for visualizing high dimensional data, hidden
Markov models for speech recognition, and classifiers detecting spam emails. Linear algebra and basic probability will be the mathematical focus and there will be a programming component to this class using the R programming language. Open only to students in the Focus Program.

- **Introduction to Applied Mathematics: Modeling, Equations and Proofs (MATH 240)**
  The course will consist of 3 or 4 concrete applications, for which precise mathematical questions will be formulated, and a mathematical framework developed that will make it possible to answer these questions. In doing so, we will encounter and explore portions of real analysis, probability, linear algebra, convex analysis, information theory and maybe others. We will also learn how to construct watertight mathematical arguments and explore different proof techniques.
  Prerequisites: none, beyond high school calculus.

- **Logic (PHIL 150)**
  The conditions of effective thinking and clear communication. Examination of the basic principles of deductive reasoning.

- **Introduction to Data Science and Statistical Thinking (STA 199)**
  Intro to data science and statistical thinking. Learn to explore, visualize, and analyze data to understand natural phenomena, investigate patterns, model outcomes, and make predictions, and do so in a reproducible and shareable manner. Gain experience in data wrangling and munging, exploratory data analysis, predictive modeling, and data visualization, and effective communication of results. Work on problems and case studies inspired by and based on real-world questions and data. The course will focus on the R statistical computing language. No statistical or computing background is necessary. Not open to students who have taken a 100-level Statistical Science course, Statistical Science 210, or a Statistical Science course numbered 300 or above.

For students with some programming experience and computational background (which can be obtained from the courses above or through co-curricular offerings):

- **Data Structures and Algorithms (COMPSCI 201)**
  Analysis, use, and design of data structures and algorithms using an object-oriented language like Java to solve computational problems. Emphasis on abstraction including interfaces and abstract data types for lists, trees, sets, tables/maps, and graphs. Implementation and evaluation of programming techniques including recursion. Intuitive and rigorous analysis of algorithms.
  Prerequisite: Computer Science 101, 102, or 116, or Engineering 103L, or equivalent.

- **Everything Data (COMPSCI 216)**
  Study of data and its acquisition, integration, querying, analysis, and visualization. Concepts and computational tools for working with unstructured, semi-structured, and structured data and databases. Interdisciplinary perspectives of data and its impact crossing science, humanities, policy, and social science. Culminating team project applied to real datasets. Prerequisite: 200-level computer science OR 100-level Statistics OR 200-level Math course, or permission of instructor.

- **Python Programming in Mathematics (MATH 260)**
  Introductory programming course in Python providing a foundational background for programming in a mathematical setting. Students will learn the basics of object orientated programming: memory storage and variable scoping, recursion, objects and classes, and basic data structures. A variety of numerical methods will be introduced, with a focus on their practical implementation, through a series of practice modules covering subjects that may include: linear algebra, machine learning, operations research, and genetics. Recommended prerequisite: linear algebra (Mathematics 216, 218, or 221). No programming background is required. Not open to students who have taken Computer Science 201.

- **Fundamentals of Data Analysis and Decision Science (EGR/MATH 238L)**
  This course provides a mathematically rigorous and broad foundation for key concepts in probability and statistics, as well as the application of probability and statistics to the mathematical modeling of non-deterministic systems. The main motivation of the course is to show how these concepts are fundamental to a variety of current data analysis techniques, and to
demonstrate applications of these techniques in situations relevant to all engineering majors. Prerequisite: (Mathematics 216, 218, or 221) and (Engineering 103L, Computer Science 101L, Computer Science 201, or Mathematics 218L.)

Students with more advanced computational backgrounds will be able to take more advanced computational thinking electives, including:

- **Introduction to Computer Systems (COMPSCI 210D)**
  This course provides a programmer’s view of how computer systems execute programs and store information. It examines key computational abstraction levels below modern high-level languages; introduction to C, number and data representations, computer memory, assembly language, memory management, the operating-system process model, high-level machine architecture including the memory hierarchy, and introduction to concurrency. Prerequisite: Computer Science 201. Not open to students who have taken Computer Science 250D.

- **Computer Architecture (COMPSCI/ECE 250D)**
  Computer structure, assembly language, instruction execution, addressing techniques, and digital representation of data. Computer system organization, logic design, microprogramming, cache and memory systems, and input/output interfaces. Prerequisite: Computer Science 201.

- **Software Design and Implementation (COMPSCI 307/308)**
  Techniques for design and construction of reliable, maintainable, and useful software systems development in teams. Programming paradigms and tools for small to medium projects: revision control, GUI, software engineering, testing, documentation. Prerequisite: Computer Science 201.

- **Introduction to Operating Systems (COMPSCI 310/ECE 353)**
  Basic concepts and principles of multiprogrammed operating systems. Processes, interprocess communication, CPU scheduling, mutual exclusion, deadlocks, memory management, I/O devices, file systems, protection mechanisms. Prerequisites: Computer Science 201 and Computer Science / Electrical and Computer Engineering 250D.

- **Introduction to Database Systems (COMPSCI 316)**
  Databases and relational database management systems. Data modeling, database design theory, data definition and manipulation languages, storing and indexing techniques, query processing and optimization, concurrency control and recovery, database programming interfaces. Current research issues including XML, web data management, data integration and dissemination, data mining. Hands-on programming projects and a term project. Prerequisite: Computer Science 201.

- **Introduction to the Design and Analysis of Algorithms (COMPSCI 330)**
  Design and analysis of efficient algorithms including sorting, searching, dynamic programming, graph algorithms, fast multiplication, and others; nondeterministic algorithms and computationally hard problems. Prerequisites: Computer Science 201 and 230.

- **Mathematical Foundations of Computer Science (COMPSCI 334)**
  An introduction to theoretical computer science including studies of abstract machines, the language hierarchy from regular sets to recursively enumerable sets, noncomputability, and complexity theory. Prerequisites: Computer Science 201 and 230.

- **Computer Network Architecture (COMPSCI 356)**
  Introduces students to the fundamentals of computer networks. Focus on layered architecture of the network protocol stack. Case studies drawn from the Internet, combined with practical programming exercises. Concepts include the Internet architecture, HTTP, DNS, P2P, Sockets, TCP/IP, BGP, routing protocols, and wireless/mobile networking and their applications such as how to achieve reliable/secure communications over channels, how to find a good path through a network, how to share network resources among competing entities, how to find an object in the network, and how to build network applications. Prerequisite: CompSci/ECE 250D or CompSci 210D.

- **Introduction to Artificial Intelligence (COMPSCI 370)**
  Algorithms and representations used in artificial intelligence. Introduction and implementation of algorithms for search, planning, decision, theory, logic, Bayesian networks, robotics, and machine
learning. Prerequisite: Computer Science 201 and one of the following: Computer Science 230, 200-level Mathematics course, or 200-level Statistical Science course.

- **Elements of Machine Learning (COMPSCI 371D)**
  Fundamental concepts of supervised machine learning, with sample algorithms and applications. Focuses on how to think about machine learning problems and solutions, rather than on a systematic coverage of techniques. Serves as an introduction to the methods of machine learning. Prerequisite: Mathematics 221, 218, or 216; Mathematics 212; Mathematics 230 or Statistical Science 230; and Computer Science 201.

- **Introduction to Computer Vision (COMPSCI 527)**
  Image formation and analysis; feature computation and tracking; image, object, and activity recognition and retrieval; 3D reconstruction from images. Prerequisites: Mathematics 221, 218 or 216; Mathematics 212; Mathematics 230 or Statistical Science 230; Computer Science 101; Computer Science 230.

- **Introduction to Algorithms (COMPSCI 531D)**
  Applications include dynamic data structures, graph algorithms, randomized algorithms. Intractability and NP completeness. Prerequisite: Computer Science 201 and 230, or equivalent.

- **Design and Analysis of Algorithms (COMPSCI 532)**
  Design and analysis of efficient algorithms. Algorithmic paradigms. Applications include sorting, searching, dynamic structures, graph algorithms, randomized algorithms. Computationally hard problems. NP completeness. Prerequisites: Computer Science 201 and 330 or equivalent.

- **Artificial Intelligence (COMPSCI 570)**
  Design and analysis of algorithms and representations for artificial intelligence problems. Formal analysis of techniques used for search, planning, decision theory, logic, Bayesian networks, robotics, and machine learning. Prerequisite: Computer Science 201 and Computer Science 330.

- **Theory and Algorithms for Machine Learning (COMPSCI 671)**
  This is an introductory overview course at an advanced level. Covers standard techniques, such as the perceptron algorithm, decision trees, random forests, boosting, support vector machines and reproducing kernel Hilbert spaces, regression, K-means, Gaussian mixture models and EM, neural networks, and multi-armed bandits. Covers introductory statistical learning theory. Recommended prerequisite: linear algebra, probability, analysis or equivalent.

- **Statistical Computing (STA 323D)**
  A practical introduction to statistical programming focusing on the R programming language. Students will engage with the programming challenges inherent in the various stages of modern statistical analyses including everything from data collection/aggregation/cleaning to visualization and exploratory analysis to statistical model building and evaluation. This course places an emphasis on modern approaches/best practices for programming including source control, collaborative coding, literate and reproducible programming, and distributed and multicore computing. Prerequisite: Statistical Science 210 and Statistical Science 240L or 230.

- **Machine Learning and Data Mining (STA 325)**
  The rapid growth of digitalized data and the computer power available to analyze it has created immense opportunities for both machine learning and data mining. This course introduces machine learning and data mining methods. Topics covered include information retrieval, clustering, classification, modern regression, cross validation, boosting and bagging. Course emphasizes selection of appropriate methods and justification of choice, use of programming for implementation of the method, and evaluation and effective communication of results in data analysis reports. Prerequisite: Prerequisite: Statistical Science 210 and (Statistical Science 240L or 230 or 231).

- **Introduction to Statistical Decision Analysis (STA 340)**
  Quantitative methods for decision making under uncertainty. Probability theory, personal probabilities and utilities, decision trees, ROC curves, sensitivity analysis, dominant strategies, Bayesian networks and influence diagrams, Markov models and time discounting, cost-
effectiveness analysis, multi-agent decision making, game theory. Prerequisite: Statistical Science 230 or 231.

- **Bayesian Inference and Modern Statistical Methods (STA 360L)**
  Principles of data analysis and advanced statistical modeling. Bayesian inference, prior and posterior distributions, multi-level models, model checking and selection, stochastic simulation by Markov Chain Monte Carlo. Prerequisite: Statistical Science 210 and (Statistical Science 230, 231, or 240L) and (Mathematics 202, 202D, 212, or 222) and (Computer Science 101L, Computer Science 201, or Engineering 103L) and (Mathematics 216, 218, or 221).

- **Predictive Modeling and Statistical Learning (STA 521L)**
  An introduction to statistical learning methods for prediction and inference. Topics include exploratory data analysis and visualization, linear and generalized linear models, model selection, penalized estimation and shrinkage methods including Lasso, ridge regression and Bayesian regression, regression and classification based on decision trees, Bayesian Model Averaging and ensemble methods, and time permitting, smoothing splines, support vector machines, neural nets, or other advanced topics. The R programming language and applications used throughout. Instructor consent required. Corequisite: Statistical Science 323D or 523L and Statistical Science 360, 601, or 602L.

- **Bayesian Statistical Modeling and Data Analysis (STA 601L)**
  Principles of data analysis and modern statistical modeling. Exploratory data analysis. Introduction to Bayesian inference, prior and posterior distributions, predictive distributions, hierarchical models, model checking and selection, missing data, introduction to stochastic simulation by Markov chain Monte Carlo using a higher-level statistical language such as R or Matlab. Applications drawn from various disciplines. Not recommended for students with credit for Statistical Science 360. Prerequisites for undergrads: Statistical Science 210 and one of 240 or 432.

- **Numerical Analysis (STA 612)**
  Error analysis, interpolation and spline approximation, numerical differentiation and integration, solutions of linear systems, nonlinear equations, and ordinary differential equations. Prerequisites: knowledge of an algorithmic programming language, intermediate calculus including some differential equations, and Mathematics 221.

- **Mathematical Numerical Analysis (MATH 361S)**
  Development of numerical techniques for accurate, efficient solution of problems in science, engineering, and mathematics through the use of computers. Linear systems, nonlinear equations, optimization, numerical integration, differential equations, simulation of dynamical systems, error analysis. Research project and paper required. Not open to students who have had Computer Science 220 or 520. Prerequisites: Mathematics 212 and 221 and basic knowledge of a programming language (at the level of Computer Science 101), or consent of instructor.

- **Statistical Learning and Inference (STA 432/MATH 343)**
  Estimators and properties (efficiency, consistency, sufficiency); loss functions. Fisher information, asymptotic properties, and distributions of estimators. Exponential families. Point and interval estimation, delta method. Neyman-Pearson lemma; likelihood ratio tests; multiple testing; design and the analysis of variance (ANOVA). High-dimensional data; statistical regularization and sparsity; penalty and prior formulations; model selection. Resampling methods; principal component analysis, mixture models. Prerequisite: (Statistical Science 240L, 230, or 231) and (Mathematics 202, 212, 219, or 222). Not open to students with credit for STA 250. Recommended prerequisite: Statistical Science 210, 360, and (Mathematics 221, 218, or 216).

- **Introduction to Linear Programming and Game Theory (MATH 375)**
  Fundamental properties of linear programs; linear inequalities and convex sets; primal simplex method, duality; integer programming; two-person and matrix games. Prerequisite: Mathematics 221 or equivalence.

- **Advanced Linear Algebra (MATH 403)**
  Topics in linear algebra beyond those in a first course. For example: principal component analysis and other decompositions (singular value, Cholesky, etc.); Perron-Frobenius theory; positive semi-
definite matrices; linear programming and more general convexity and optimization; basic simplicial topology; Gerschgorin theory; classical matrix groups. Applications to computer science, statistics, image processing, economics, or other fields of mathematics and science. Prerequisite: Mathematics 212 or 222 and Mathematics 218 or 221.

- **Topological Data Analysis (MATH 412)**
  Introduction to topology from a computational viewpoint, with a focus on applications. Themes include basic notions of point-set topology, persistent homology, finding multi-scale topological structure in point cloud data. Algorithmic considerations emphasized. Prerequisite: Mathematics 221 or equivalent.

- **Introduction to High Dimensional Data Analysis (MATH 465/COMPSCI 445)**

- **Mathematics of Machine Learning (MATH 466)**
  The course will explore mathematics underlying the practice and theory of various machine learning concepts and algorithms. Kernel methods, deep learning, reinforcement learning, generalization error, stochastic gradient descent, and dimension reduction or data embeddings will be introduced. The interplay between the mathematics and real applications will be a component of the course. Students can take both this course and Mathematics 465 for credit. Recommended prerequisite: Mathematics 230/340 and 218/216/221 and some familiarity with programming, preferably Python.

- **Theory and Practice of Algorithms (MATH 560)**
  The mathematical theory of algorithms and graphs and their practical implementations. Examines the foundational mathematical structures for the behavior and analysis of algorithms from a variety of domains, with a particular emphasis on graphs. Students tie theory to practice by writing code to implement algorithms and compare experimentally observed run-times to those predicted by the mathematical theory. Recommended prerequisite: Computer Science 201; or recommended corequisite: ECE 551; or equivalent.

- **Numerical Linear Algebra, Optimization and Monte Carlo Simulation (MATH 561)**
  Structured scientific programming in C/C++ and FORTRAN. Floating point arithmetic and interactive graphics for data visualization. Numerical linear algebra, direct and iterative methods for solving linear systems, matrix factorizations, least squares problems and eigenvalue problems. Iterative methods for nonlinear equations and nonlinear systems, Newton’s method. Prerequisite: Mathematics 212 and 221.

- **Applied Computational Analysis (MATH 563)**

- **Numerical Analysis (MATH 565)**
  Error analysis, interpolation and spline approximation, numerical differentiation and integration, solutions of linear systems, nonlinear equations, and ordinary differential equations. Prerequisites: knowledge of an algorithmic programming language, intermediate calculus including some differential equations, and Mathematics 221.

- **Applied Probability for Statistical Learning (ECE 480)**
  This course discusses topics in Bayesian probability and its application to foundations of statistical learning. The primary objectives of the course are to provide a mathematically rigorous foundation in Bayesian probability and inference, develop strong intuition for Bayesian constructs, provide a foundation in statistical learning, and to show how Bayesian methods are fundamental to a variety
of modern statistical learning techniques. Topics include probabilistic reasoning, Bayesian inference, linear models, mixture models, and model selection. Prerequisite: (Mathematics 216, 218, or 221) and (Statistical Science 130L, Statistical Science 240L, Mathematics 230, Mathematics 340, ECE 380, ECE 555, or EGR 238L) and (EGR 103L, Computer Science 101L, or Computer Science 201).

- **Fundamentals of Computer Systems and Engineering (ECE 550D)**
  Fundamentals of computer systems and engineering for master's students whose undergraduate background did not cover this material. Topics covered include: Digital logic, assembly programming, computer architecture, memory hierarchies and technologies, IO, hardware implementation in VHDL, operating systems, and networking. Undergraduates may not take this course and should take ECE 250D, 353, and/or 356 instead. Corequisite: ECE 551D.

- **Mobile Application Development (ECE 564)**
  Explores the world of mobile application development with focus on needs of engineers. Centered on Apple environment, with the development environment being on OS X and the target environment being an iOS device- iPad, iPhone, iPod Touch or Apple Watch. Real world context focused on the common programming patterns for engineers in academia or business- standalone apps, apps connected to other systems, apps connected to the cloud. Covers fundamentals essential to understanding all aspects of app development. Taught in a team environment. Students required to present their project proposals and deliver an app as a final project. Prerequisite: CompSci 307D or CompSci 308 or ECE 551D or ECE 751D.

- **Introduction to Machine Learning (ECE 580)**
  Introduction to core concepts in machine learning and statistical pattern recognition, with a focus on discriminative and generative classifiers (nearest-neighbors, Bayes, logistic regression, linear discriminant, support vector machine, and relevance vector machine). Dimensionality reduction and feature selection. Classifier performance evaluation, bias-variance tradeoff, and cross-validation. Prerequisite: (Mathematics 216, Mathematics 218, Mathematics 221, or ECE 586) and (Computer Science 201 or ECE 551D) and (ECE 480 or ECE 581). Not open to students who have taken Computer Science 671D.

- **Deep Learning (ECE 685D)**
  Provides an introduction to the machine learning technique called deep learning or deep neural networks. A focus will be the mathematical formulations of deep networks and an explanation of how these networks can be structured and "learned" from big data. Discussion section covers practical applications, programming, and modern implementation practices. Example code and assignments will be given in Python with heavy utilization of PyTorch (or Tensorflow) package. The course and a project will cover various applications including image classification, text analysis, object detection, etc. Prerequisite: ECE 580, ECE 681, ECE 682D, Statistical Science 561D, or Computer Science 571D.

**Elective Area 2: Ethics and Policy**

- **Ethics of Emerging Technology (SCISOC 585-01)**
  The Digital Intelligence course helps students navigate and understand and analyze the ethical and social impact of emerging technologies through an applied ethical lens. In a flipped-classroom format, students will watch asynchronous videos on a weekly basis featuring leading technology, ethics, and policy experts as they discuss relevant and timely topics such as algorithmic bias, the impact of social media on democracy, and privacy in the digital age. Students will meet weekly in small discussion groups to work through case studies and to critically engage with a practical ethics approach to the topics presented in the video and additional assigned material.

- **Introduction to Digital Feminism (COMPSCI 112S/SOCIOL 217S)**
  The aim of this course is to critically analyze digital culture from a feminist and gender studies perspective. We will address topics related to digital innovation and its history, unpacking, and
questioning them through the insights offered by genders studies analytical tools. Subjects such as the rise of the Silicon Valley, gaming culture, social media, algorithms, Artificial Intelligence, extraction of data applied to biotechnology, macroeconomic development of IT platforms and the impact of technology on ecology will be discussed starting from a current event or debate, to which we will give a historical, ethical, sociological, theoretical, literary, or cinematographic perspective.

- **Race, Gender, Class, & Computing (COMPSCI 240)**
  This course explores the diversity, equity, and inclusion (DEI) challenges in computing through an introduction to and analysis of identity as a social construct, its impact on computing departments and organizations, and the resulting impact of technology on various identities.

- **Technical and Social Analysis of Information and the Internet (COMPSCI 342)**
  The development of technical and social standards governing the Internet and information technology in general. The role of software as it relates to law, patents, intellectual property, and IETF (Internet Engineering Task Force) standards. Written analysis of issues from a technical perspective with an emphasis on the role of software and on how standards relate to social and ethical issues. Current events as a driver for writing in traditional and online formats related to technology and policy. Open only to students with declared Computer Science major. Prerequisite: Computer Science 201.

- **Race, Genomics and Society (CULANTH 261D)**
  The field of genetics has been at the forefront of discourse concerning the concept of “race” in humans. This course explores human origins, human variation, human identity, and human health through a broad range of enduring and emerging themes and challenging questions related to race and genetics (and now, genomics) on a global scale. Students will acquire knowledge and skills required for integrative analyses of the relevant scientific, ethical, legal, societal, cultural, and psychosocial issues. Open to students at all levels from any discipline in the arts, humanities, and sciences (natural, social, formal, and applied).

- **Amazon.com and the Cybereconomy (CULANTH 273)**
  This course will introduce students to the complexities and controversies around the meteoric growth of the digital economy, with a focus on the biggest company of them all, Amazon. We will examine questions that range from labor conditions and consumerism to data harvesting, algorithmic marketing, and monopoly concerns. By drawing on insights from cultural anthropology, economics, history, and other disciplines, the course will give students a new understanding of how e-commerce is changing the structure of our economy, society, and everyday lives. Students will do an individual research project on some aspect of Amazon for a final project.

- **Global Apple: Life and Death and the Digital Revolution (CULANTH 360S)**
  Examination of the Apple Corporation’s development from a Silicon Valley garage operation to a company with unprecedented global reach; the Cult of Steve Jobs, the Apple Launch and use the design and development of the Apple Store; labor and environmental struggles over Apple supply chain and production processes, from cobalt mining in Africa to Foxconn factories in China; migrant worker suicide and poetry as forms of protest in China; e-waste villages and digital rubbish; everyday uses of Apple technology and the ethics of consuming Apple products.

- **The Googlization of Knowledge: Information, Ethics and Technology (ISS 112)**
  Google has altered the way we see the world and ourselves. Its biases, valuing popularity over accuracy, affect how we value information and navigate news and ideas. This course examines information from different angles within the context of social justice, open access to information, and how the Internet and Google affect our lives. Themes include knowledge as a public good, Internet policies, data and visual literacies, social media, and artificial intelligence. Hands-on work researching how technology affects the access, understanding, and reliability of information in students’ lives. Analysis, discussions, and reflection assignments with ongoing application to team-based projects.
• **Social Movements and Social Media (ISS 323S/VMS 323S)**
Examines uses and abuses of social media by social movements. Interested in a broader historical study of mediating technologies and oppositional public sphere, course considers the uses of cameras, phones, cassette players, radio, and social media platforms, but also books, bodies, art, fashion, and automobiles as oppositional technologies. Studies political and ethical uses of technologies in social unrest. Investigates impact of technologies on social movements and social transformations in contemporary history. Student driven case studies will highlight contemporary engagement with social media by networked social movements.

• **Cyber Law: Law, Language and Computers (LINGUIST 498)**
Cyber law refers to the legal principles that govern the creation, use of computers, software, and computer networks, or that relate to the transfer, use, and storage of electronic information. In this course we will analyze the key legal principles concerning: ownership of the designs of integrated circuits and computer software; crimes involving the use of computers; protection of electronic data, with particular concern for the protection of privacy interests; freedom of expression on the internet. There will be several over-arching meta-themes in this course, and other related themes. This course is designed for students with little or no familiarity with the American legal system.

• **Cryptography and Society (MATH 165FS) †**
Introduction to topics in mathematical cryptography, and the role of cryptography within society, in both historic and modern contexts. Cryptographic systems studied will include: early historical ciphers; the Enigma machines of WWII; modern public channel cryptography. Students will learn: to encode/decode using each system; to quantify the complexity, strength, and weaknesses of each system; to use elementary techniques from combinatorics, graph theory, abstract algebra, and number theory; about the role cryptography plays in human society. Open only to students in the Focus Program. Department consent required.

• **Business Ethics: The Debate Over Corporate Social Responsibility (PHIL 270)**

• **Cybersecurity and National Security Law and Policy (PUBPOL 551)**
Course examines issues of cybersecurity and privacy. Focuses on roles that different government organizations play in protecting cybersecurity. Course also examines the issues raised by the government's acquisition and storage of information in the interests of national security. Examines the intersection between commercial privacy and cybersecurity, business planning and government surveillance in the global economy, focusing on the US and the EU, with particular attention to the tensions that have arisen in the aftermath of the Snowden revelations of NSA surveillance activity, various large scale cybersecurity breaches and questions as to the trustworthiness of technology.

• **Technology Policy (PUBPOL 680S)**
An overview of current issues in technology policy, such as content moderation, antitrust, data sharing, and encryption. The course will approach these issues from a practitioner's perspective, exploring the costs and benefits of existing and potential policy frameworks and the relationship between public policy and technology product design.

• **From Siri to Skynet: Our Complex Relationships with Technology (SCISOC 197FS) †**
From mobile phones to driverless cars, modern high-tech devices have human-facing elements that shape our relationships with technology. Some integrate seamlessly into our daily lives, others frustrate us, and some simply captivate us. Students will investigate the intersection between people and technology to better understand how design can influence performance, safety, and user satisfaction. Topics include design principles; user experience concepts; and an overview of human strengths and limitations influencing interactions with technology. Case studies will include various technologies, including emerging systems such as brain-computer
Elective Area 3: Communications

- **Science Fiction Film (ARTHIST 238)**
  Science fiction film from the 1950s to the present. From talking apes to mind control, forbidden planets to genetic dystopias, alien invasions to travel in time and space, an exploration of classic films in the genre with attention to how the films imagine the relationships among science, politics, and society over time. Attention to visual as well as literary story telling.

- **Science & the Media (BIOETHIC 510S-01)**
  Those who write about science, health and related policy must make complex, nuanced ideas understandable to the nonscientist in ways that are engaging and entertaining, even if the topic is far outside the reader's frame of reference. Course examines different modes of science writing, the demands of each and considers different outlets for publication and their editorial parameters. Students interview practitioners of the craft. Written assignments include annotations of readings and original narratives about science and scientists. Course considers ways in which narrative writing can inform and affect policy. Prerequisites: a 200-level science course and/or permission of the instructor.

- **Global Stories, Local Issues (CULANTH 223S)**
  What stories are there to tell about often overlooked objects and people and places? How can we research and share those stories with generosity and integrity? In every corner of our lives—the stickers on our computers, the plates at a local restaurant, the wood in our guitars—there is a story to be told that connects our individual experiences to broader, often global, phenomena. Participants will learn and use methods of ethnography and archival research to connect their experiences and their observations about a place, community, or thing to larger stories about culture and society, and they will practice writing about their research in engaging and broadly accessible ways.

- **Games and Culture (CULANTH 440S)**
  Examines analog and computer games from a cultural perspective. Explores how prevailing culture and values affect game design, popularity, and experience. how games affect those areas of culture, such as imagining disaster, utopia, and dystopia. Explores role-playing and identity, ethics, group behavior, competition, politics, gender, race, and aesthetics.

- **Documentary and Policy: How Documentary Influences Policy (DOCST 272S)**
  Examines documentaries as catalysts for change in local, state, and federal laws and regulations, with special attention to relationships between film and organizations with political influence. Looks at how documentaries have altered public sentiment and political outcomes. Uses case studies of documentary films (essay-style, journalistic, information-driven films; narrative, story-driven films; propaganda; art films; and hybrids of all the above). Explores the question of how a film achieves influence: for example, with a high-profile theatrical and/or television release, by utilization as an educational tool, or by 'going viral' to become part of a public conversation.

- **Science and the Modern World (HISTORY 106)**
  This course surveys the history of science from the sixteenth century through the present day. It addresses science not just as a body of knowledge and methods but as a cultural activity that has shaped and been shaped by modern global history. Topics will range across physical sciences, life sciences, earth and environmental sciences, and social sciences. This course takes a global perspective, with emphasis on parallels, differences, and interconnections among ways of knowing nature in different places and times, as well as the role of specific materials, environments, technologies, and practical problems in the development of modern science.

- **News as a Moral Battleground (PUBPOL 371)**
  Ethical inquiry into journalism and its effect on public discourse. Issues include accuracy,
transparency, conflicts of interest and fairness. Topics include coverage of national security, government secrecy, plagiarism/fabrication, and trade-offs of anonymous sourcing.

- **Social Marketing: From Literary Celebrities to Instagram Influencers (ENGLISH 253)**
  Typical Duke students spend hours each day using social media. You’ve surely heard the platforms described as “revolutionary,” and you’ve also heard them described as “time wasters.” What you probably haven’t thought about is how similar they are to previous “revolutionary” communications technologies like novels, newspapers, and even language itself. This course explores ways in which studying the masters of previous “social” media technologies—the Shakespeares, Whitmans, and Eliots of the world—can help us understand how influencers on digital social media leverage the same platforms you use every day to market themselves, build their brands, and grow their audiences.

- **Fundamentals of Web-Based Multimedia Communications (ISS 240S)**
  Multimedia information systems, including presentation media, hypermedia, graphics, animation, sound, video, and integrated authoring techniques; underlying technologies that make them possible. Practice in the design innovation, programming, and assessment of web-based digital multimedia information systems. Intended for students in non-technical disciplines. Engineering or Computer Science students should take Engineering 206 or Computer Science 408.

- **Alt-Science; Bad Science: The Policy, Politics and Ethics of Misinformation on Science, Tech, Health (SCISOC 611S)†**
  This course will explore the origins, effects, and solutions to mis- and disinformation about science, technology, and health. It will investigate the social and technical forces that motivate, facilitate, amplify, and sustain misinformation about technical topics through a series of historical and contemporary cases. Drawing on ethical and policy frameworks, we will ask both what is just and what is expedient in how we approach and mitigate false and problematic content.

- **Visualizing Society (SOCIOL 179FS) †**
  This class will teach you how to use modern, widely used tools to create insightful, beautiful, reproducible visualizations of social science data. We will also put the theory and practice of visualization into context throughout the semester. By that I mean that we will think about different ways of looking at social science data, about where data comes from in the first place, and the implications of choosing to represent it in different ways. Open only to students in the Focus Program. Department consent required.

- **Public Speaking: Policy Advocacy and Communication (WRITING 384)**
  Theoretical and practical understanding of the elements of effective advocacy, especially as applied to policy issues. Focus on oral communication (both formal public speaking and interactive exchange), written exposition, and presentation skills. Emphasis on the human dimensions of the communication process-voice and body behavior, audience evaluation, focus, control, and self-awareness. Identifies techniques for minimizing communication distraction, developing confidence in presentation situations, and analyzing informational requirements. Does not apply toward public policy studies major. This course is open to students in their junior or senior year.

**Elective Area 4: Computation in Practice**

- **Population Genetics (BIOLOGY 460)**
  Use of genetic sequence analysis to examine aspects of natural populations of humans and other organisms in the past and present. Topics include molecular phylogenetics; the origin, maintenance, and loss of major features of evolution; the evolutionary process at the molecular level; reconstruction of human origins and paleohistory; and genetic information in forensic studies. Not open to students who have taken Biology 250.

- **Introduction to the Finite Element Method (CEE 530)**
  Investigation of the finite element method as a numerical technique for solving linear ordinary and partial differential equations, using rod and beam theory, heat conduction, elastostatics and
dynamics, and advective/diffusive transport as sample systems. Emphasis placed on formulation and programming of finite element models, along with critical evaluation of results. Topics include: Galerkin and weighted residual approaches, virtual work principles, discretization, element design and evaluation, mixed formulations, and transient analysis. Prerequisites: a working knowledge of ordinary and partial differential equations, numerical methods, and programming in FORTRAN or MATLAB.

- **Introduction to Computational Genomics (COMPSCI 260)**
  A computational perspective on the analysis of genomic and genome-scale information. Focus on exploration and analysis of large genomic sequences, but also attention to issues in structural and functional genomics. Topics include genome sequence assembly, local and global alignment, gene, and motif finding, protein threading and folding, and the clustering and classification of genes and tissues using gene expression data. Students to learn computational approaches to genomics as well as to develop practical experience with handling, analyzing, and visualizing information at a genome-scale.

- **Algorithms in the Real World (COMPSCI 333)**
  Design and implementation of modern algorithms. Stresses application and project-based development of algorithmic techniques. Emphasis on algorithmic ideas that have had substantial impact in the real world, including approximation, randomization, hashing, streaming, spectral techniques, optimization, and search. Project-driven: Several homework assignments as well as a larger student-driven course project researching, designing, and implementing algorithms for a substantive problem with real world applications. Prerequisite: Computer Science 201 and Computer Science 230 or equivalent.

- **Computer Security (COMPSCI 351)**
  Cryptographic primitives including private key cryptography, and public key cryptography. Software security including buffer overflows, SQL injection, Web-based attacks, and viruses. Network security including TCP and DNS. Topics in applied cryptography including digital currency, searchable encryption, secure multiparty computation, secret sharing, homomorphic encryption, Zero knowledge proofs. Anonymity. Prerequisite: Computer Science 250D.

- **Security Incident Detection, Response, and Resilience (CYBERSEC 510)**
  Current and emerging technologies and processes to monitor, detect and respond to security incidents in systems, networks, and clouds will be covered including automation and analytics. Best practices for developing effective incident response plans, including regulatory and legal considerations, will be studied. Also studied is how to build resilience into development, manufacturing, or other business processes in the case of an incident.

- **Applying Machine Learning to Advance Cybersecurity (CYBERSEC 520)**
  The use of machine learning and AI is becoming more prevalent for collecting and analyzing data as its consolidation increases in value. Cyberattacks seek to steal, deny access, misrepresent (such as deepfakes), or compromise the privacy of information. Students will explore the power of machine learning and AI’s use in enhancing Cybersecurity tools across the NIST Framework and in detecting and exploiting vulnerabilities in timeframes and ways heretofore unthinkable.

- **The Human Element in Cybersecurity (CYBERSEC 531)**
  This course will examine the challenges associated with humans using, managing, and manipulating socio-technical systems with cybersecurity vulnerabilities. Technology and policy defenses and mitigations will be explored as well as societal, ethical, and legal implications of cybersecurity interventions.

- **Econometrics and Data Science (ECON 204D)**
  This course builds on the foundation laid in 104. Develops skills necessary to analyze and interpret real world data using modern data science methods to provide a toolkit to be sophisticated consumers and producers of empirical research in econ as well as other fields in the social, health and life sciences. Mastery of the material provides knowledge of econometric and data science methods to think critically about the quality of evidence about how individuals behave, markets work, firms make money or societies operate. Prerequisite: (Economics 21 and 22, 23 and 24, 101,
(101D, or 201D) and (Economics 104D, Statistical Science 111 or Statistical Science 432/Mathematics 343).

- **Secure Software Development (FINTECH 514)**
  This course is about minimizing risk when creating software and will focus on the fundamental structure of a Secure Development Life Cycle (SDLC), the advantages and challenges of cryptography, then explore automated testing solutions. Students will learn to effectively manage risk in the process of creating software. Hands-on experience with specific technologies prepares students to make informed decisions about the design, architecture, and implementation of software. Assignments use automated vulnerability hunting tools. Students will learn the risk profile of the target software project, and an understanding of how these tools add value to the overall secure development life cycle.

  Robo-Advice brings investment services to a wider audience at lower costs compared to human advisors. Students will construct a very basic advisor using the Python programming language. This will be a short experiential case study with an open-source Python code. Student teams will develop a comprehensive venture capital investment memorandum for a real-world Robo-Advising startup. Teams will analyze the Robo-Advisor's market environment, including the financial services industry, wealth management segments, competitors, and channels; and, internal company characteristics, such as business strategy, asset allocation and portfolio composition, cost of customer acquisition, and financials.

- **Introduction to Global Health Data Science (GLHLTH 298L)**
  Rigorous introduction to health data science using current applications in biomedical research, epidemiology, and health policy. Use modern statistical software to conduct reproducible data exploration, visualization, and analysis. Interpret and translate results for interdisciplinary researchers. Critically evaluate data-based claims, decisions, and policies. Includes exploratory data analysis, visualization, basics of probability and inference, predictive modeling, and classification. This course focuses on the R computing language. No statistical or computing background is necessary. Not open to students who have taken a 100-level Statistical Science course, Statistical Science 210, or a Statistical Science course numbered 300 or above.

- **Experimental Interface Design (ISS 198)**
  Class explores issues surrounding embodied approaches to interface design. Articulates methodology for generating new forms of human/computer interface; includes workshops, discussions, student presentations, critiques and group brainstorming sessions. Content related to biomimetics; haptic body knowledge; multi-modal sensing; physical computing; physical | digital relationships; networked relations; the potentials of virtual space and different qualities of space, both visual and sonic. Database potentials discussed and explored in service of developing new approaches to interface. Instructor consent required.

- **Humanities Text Mining and Meaning (ISS 255)**
  The digital text has led to new forms of research and is receiving increasing attention from artificial intelligence (AI). The application of machine learning to text, known as text mining, presents unique intellectual challenges that require major contributions from the humanities. This course introduces students to the interdisciplinary domain of text mining through a humanities-based media-theoretic framework. Students will first learn text data prep skills and practices fundamental to meaningful analysis. The semester will later introduce unsupervised machine learning and topic modeling and culminate in a group project. Not recommended for advanced CS students.

- **Advanced Data Visualization (ISS 313L/STA 313L)**
  This course is all about the art and science of visualizing data. Learn about the what (types of visualizations, tools to produce them), the how (start with a design, pre-process the data, map it to graphical attributes, make strategic decisions about visual encoding, post-process for readability and visual appeal), and the why (the theory behind the grammar of graphics). Evaluate the clarity, effectiveness, and honesty of visualization choices and improve (your and others’) visualizations.
through an iterative design process. Discuss the role of statistical graphics in modeling and inference. Do it all in R, reproducibly, and using a variety of modern data visualization packages. Prerequisite: Prerequisite: Statistical Science 198L or (198L-1 and 198L-2) or 199L or (199L-1 and 199L-2) or 210L.

- **Mapping History with GIS (ISS 315)**
  Beginner/intermediate Geographic Information System (GIS) course designed to help students learn how to investigate history spatially. Emphasizes perspectives, procedures, and tools that are relevant to applications of GIS in Art History and Humanistic disciplines. Designed as a hybrid lecture/lab format in which direct instruction is supplemented by hands on learning labs using ArcGIS software and real-world spatial data. The main skills students will gain are: integration of spatial and tabular data, geoprocessing, data visualization, creating features, editing features, vector and raster integration, spatial analysis, georeferencing.

- **Mathematical and Interdisciplinary Modeling Seminar (MATH 282S)**
  Introduction to mathematical techniques and their applications to real world problems. Class meetings will start with an introduction to a mathematical tool (and often its implementation), with the remainder of the class devoted to working in teams on modeling strategies for a given problem. Practice problems will be drawn from the COMAP Mathematical or Interdisciplinary Contest for Modeling, and students may have the opportunity to participate in the contest in February. Students will learn about a range of tools useful for modeling and write reports describing models and results. Prerequisite: Math 111 (or 121) and 112 (or 122). Some programming experience is useful but not required.

- **Mathematical Finance (MATH 581)**
  An introduction to the basic concepts of mathematical finance. Topics include modeling security price behavior, Brownian and geometric Brownian motion, mean variance analysis and the efficient frontier, expected utility maximization, Itô's formula and stochastic differential equations, the Black-Scholes equation and option pricing formula. Prerequisites: Mathematics 212 (or 222), 221, and 230 (or 340), or consent of instructor.

- **Financial Derivatives (MATH 582)**
  A rigorous introduction to financial derivatives with applications. Topics include: binomial trees and geometric Brownian motion; European options, American options, forwards, and futures; put-call parity; the Black-Scholes-Merton pricing formula and its derivations; Delta and Gamma hedging; implied volatility; Merton jump-diffusion model; Heston model; GARCH(1,1) model. Prerequisites: Math 212 (or 222) and Math 230 (or 340) or consent of instructor.

- **Current Technologies in Genomics and Precision Medicine (MGM 325)**
  Comprehensive overview of genome science technologies, analytical tools, clinical applications, and related issues. Exposure to a range of technologies currently used in research and some in clinical practice, as well as the tools to interrogate the large datasets generated by these technologies. Projects will explore the range of datasets publicly available and analysis of genomic datasets. Prerequisite: Biology 201L or 203L.

- **Journalism in the Age of Data (PJMS 375)**
  Teaches the tools and techniques used by investigative journalists to acquire and analyze data to discover story ideas and draw and evaluate conclusions about politicians, public policy, broader behavior of public institutions. Students should have basic familiarity with journalism concepts, but no specific technical or mathematical skills required.

- **Introduction to Machine Learning and Legislative Behavior (POLSCI 189FS) †**
  Our goal as social scientists is to build models of the world and provide advice to policy makers. Given that human actors are often strategic and the games they play are complex, building and testing these models is difficult and distinct from common examples of machine learning. A task that is often used to motivate introductions to machine learning is teaching a model to recognize hand-written characters using MNIST data (https://www.tensorflow.org/datasets/catalog/mnist). Our task is harder: we must build models that involve forecasting human behavior ranging from votes in a legislature to changes in stock prices.
• **Identity, Action and Emotion (SOCIOL 176FS) †**
  Uses mathematical models to describe how people import cultural meanings into social interactions. Explains how people maintain identities in role relationships and group interactions. Explores a theory of how people perform normal institutional roles, respond to odd situations, and try to feel good about themselves. Uses computer simulations to model self, identity, and emotional processes. Involves reading academic literature, collecting evidence, giving research presentations, and writing a research proposal. Teaches how to think scientifically about routine and unexpected parts of everyday life.

• **Data Science and Society (SOCIOL 367S)**
  Interdisciplinary field of computational social science, drawing from sociology, computer science, and related disciplines. Obtain skills to automate collection of social science data from new sources (Twitter, Facebook, Google, etc.), classify unstructured data into discrete variables, analyze them using a combination of techniques that includes screen-scraping, natural language processing and machine learning. Complex ethical and legal issues that arise when working with these novel sources of data. Students develop their imagination about new questions that can be asked with these new data sources. Reading and reproducing exemplary studies produced by computational social scientists.

• **Regression Analysis (STA 210L)**
  Extensive study of regression modeling. Multiple regression, weighted least squares, logistic regression, log-linear models, analysis of variance, model diagnostics and selection. Emphasis on applications. Examples drawn from a variety of fields. Prerequisite: 100-level Statistical Science course or Statistical Science 230 or Statistical Science 240L. Interested students with a different background should discuss and seek instructor consent.

• **Case Studies in the Practice of Statistics (STA 440L)**
  Students apply statistical analysis skills to in-depth data analysis projects ranging across diverse application areas including but not limited to energy, environmental sustainability, global health, information and culture, brain sciences, and social networks. Students practice cutting-edge statistical methods and communicate their results both technically and non-technically via presentations and written reports. Prerequisite: Statistical Science 360.

• **Introduction to Digital Humanities (VMS 203D)**
  Digital approaches to humanistic research and its expression, across disciplines and fields. Critical approaches to the digital turn in contemporary culture; theoretical approaches to digital creation and digital remediation of analog sources. Topics include aesthetics, cultural impact, opportunities for global circulation. Critical contextualization around access, authorship, diversity and inclusion, media effects, and evaluation. Exercises in text analysis, digital mapping, data visualization, databases, networks, online archives and exhibitions, immersive media, situated within broader cultural debates on digital cultures, and on best practices for interdisciplinary collaboration.

• **Constructing Immersive Virtual Worlds (VMS 270S)**
  Theory, practice, and creation of 3D virtual worlds. Hands-on design and development of online collaborative simulation environments. Introduction to graphics workflow for creating virtual world media assets. Critical exploration of state-of-the-art virtual world technologies; 3D graphics, chat, voice, video, and mixed reality systems. Topics include: history/culture of virtual worlds, identity and avatars; behavioral norms; self-organizing cultures; user-generated content, virtual world economies; architectural scalability.