SCMP MSE Course Master List

Core Fundamentals Courses

CIS 515: Fundamentals of Linear Algebra and Optimization

Prerequisite(s): Undergraduate course in linear algebra, calculus.
This course provides firm foundations in linear algebra and basic optimization techniques. Emphasis is placed on teaching methods and tools that are widely used in various areas of computer science. Both theoretical and algorithmic aspects will be discussed.

ENM L/R 502: Numerical Methods & Modeling

Prerequisite(s): Knowledge of a computer language, MATH 240 and 241; ENM 510 is highly recommended; or their equivalents
Numerical modeling using effective algorithms with applications to problems in engineering, science, and mathematics, and is intended for graduate and advanced undergraduate students in these areas. Interpolation and curve fitting, numerical integration, solution of ordinary and partial differential equations by finite difference, and finite element methods. Includes use of representative numerical software packages such as MATLAB PDE Toolbox.

CIS 502: Analysis of Algorithms

Prerequisite(s): CIT 594 or equivalent
An investigation of paradigms for design and analysis of algorithms. The course will include dynamic programming, flows and combinatorial optimization algorithms, linear programming, randomization and a brief introduction to intractability and approximation algorithms. The course will include other advanced topics, time permitting.

CIS 450/550: Database and Information Systems

Prerequisite(s): CIT 594 and CIT 592 or equivalent
Introduction to the theory and practice of data management systems, including databases and data integration. The Entity-Relationship approach as a modeling tool. The relational model, algebra and calculus. Database design and relational normalization. Views and their role in security and integration. Physical data organization and indexing structures. Query execution and optimization. Updates and integrity: transaction management, concurrency control and recovery techniques. XML and database backed Web sites.

Core Methods Courses (choose at least 2 out of 3)

1. Molecular Simulation Methods

CBE 525: Molecular Modeling and Simulations

Prerequisite(s): CBE 231 OR 618 or equivalent background in physical chemistry
Students will explore current topics in thermodynamics through molecular simulations and molecular modeling. The requisite statistical mechanics will be conveyed as well as the essential simulation techniques (molecular dynamics, Monte Carlo, etc.). Various approaches for calculating experimentally measurable properties will be presented and used in student projects.

OR

MSE 561 (MEAM 553): Atomic Modeling in Materials Science

This course covers two major aspects of atomic level computer modeling in materials. 1. Methods: Molecular statics, Molecular dynamics, Monte Carlo, Kinetic Monte Carlo as well as methods of analysis such as correlations, radial distribution function, etc. 2. Semi-empirical descriptions of atomic interactions: pair potentials, embedded atom method, covalent bonding, ionic bonding, tight-binding. Basics of the density functional theory. Needed mechanics, condensed matter physics, thermodynamics and statistical mechanics are briefly explained.

2. Continuum Simulation Methods

MEAM 646: Computational Mechanics

Prerequisite(s): ENM 510 & ENM 511, and one graduate level introductory course in mechanics. FORTRAN or C programming experience is necessary
The course is divided into two parts. The course first introduces general numerical techniques for elliptical partial differential equations - finite difference method, finite element method and spectral method. The second part of the course introduces finite volume method. SIMPLER formulation for the Navier-Stokes equations will be fully described in the class. Students will be given chances to modify a program specially written for this course to solve some practical problems in heat transfer and fluid flows.

ENM 540: Topics in Computational Science and Engineering

Prerequisite(s): Background in ordinary and partial differential equations; proficiency in a programming language such as MATLAB, C, or Fortran.
This course is focused on techniques for numerical solutions of ordinary and partial differential equations. The content will include: algorithms and their analysis for ODEs; finite element analysis forelliptic, parabolic and hyperbolic PDEs; approximation theory and error estimates for FEM.

3. Machine Learning

CIS 519: Introduction to Machine Learning

Machine learning has been essential to the success of many recent technologies, including autonomous vehicles, search engines, genomics, automated medical diagnosis, image recognition, and social network analysis, among many others. This course will introduce the fundamental concepts and algorithms that enable computers to learn from experience, with an emphasis on their practical application to real problems. This course will introduce supervised learning (decision trees, logistic regression, support vector machines, Bayesian methods, neural networks and deep learning), unsupervised learning (clustering, dimensionality reduction), and reinforcement learning. Additionally, the course will discuss evaluation methodology and recent applications of machine learning, including large scale learning for big data and network analysis.

OR

CIS 520: Machine Learning

Prerequisite(s): Elementary probability, calculus, and linear algebra. Basic programming experience.

This course covers the foundations of statistical machine learning. The focus is on probabilistic and statistical methods for prediction and clustering in high dimensions. Topics covered include SVMs and logistic regression, PCA and dimensionality reduction, and EM and Hidden Markov Models.

Applications/Elective Courses

STAT 503 (STAT 470): Data Analytics and Statistical Computing

Prerequisite(s): Two courses at the statistics 400 or 500 level

This course will introduce a high-level programming language, called R, that is widely used for statistical data analysis. Using R, we will study and practice the following methodologies: data cleaning, feature extraction; web scrubbing, text analysis; data visualization; fitting statistical models; simulation of probability distributions and statistical models; statistical inference methods that use simulations (bootstrap, permutation tests).

STAT 953 (STAT 473): Bioinformatics

Prerequisite(s): Good background in probability and statistics at the approximate level of STAT 430 and STAT 431

The material will follow the class textbook, Ewens and Grant "Statistical Models in Bioinformatics", Springer, second edition, 2005. An introduction to the use of statistical methods in the increasingly important scientific areas of genomics and bioinformatics. The topics to be covered will be decided in detail after the initial class meeting, but will be taken from the following: background probability theory of one and many random variables and of events; background statistical inference theory, classical and Bayesian; Poisson processes and Markov chain; the analysis of one and many DNA sequences, in particular shotgun sequencing, pattern analysis and motifs; substitution matrices, general random walk theory, advanced statistical inference, the theory of BLAST, hidden Markov models, microarray analysis, evolutionary models.

STAT SM 957: Seminar in Data Analysis

Prerequisite(s): STAT 541, 551 & 552, 925, or equivalents; permission of instructor

Survey of methods for the analysis of large unstructured data sets: detection of outliers, Winsorizing, graphical techniques, robust estimators, multivariate problems.

BIO SM 537 (CIS 635, GCB 537): Advanced Computational Biology

Prerequisite(s): BIOL 437 or permission of instructor

Discussion of special research topics.

BIO L/R 527 (BIOL 221, GCB 527): Genetics for Computational Biology

Prerequisite(s): BIOL 101 or 121. Permission of instructor required

This course will survey the discipline of molecular genetics. Two broad areas will be considered: 1) Molecular biology: DNA replication, transcription, translation, and the regulation of gene expression in both prokaryotic and eukaryotic systems and genomics and 2) Genetics: basic Mendelian & molecular genetics.

MATH 575: Mathematical Theory of Computation

Prerequisite(s): Math 574 or with the permission of the instructor
Continuation of Math 574.

MATH 582 (AMCS 701): Applied Mathematics and Computation

Prerequisite(s): Math 240-241, MATH 312 & MATH 360. Knowledge of Math 412 and Math 508 is recommended
This course offers first-hand experience of coupling mathematics with computing and applications. Topics include: Random walks, randomized algorithms, information theory, coding theory, cryptography, combinatorial optimization, linear programming, permutation networks and parallel computing. Lectures will be supplemented by informal talks by guest speakers from industry about examples and their experience of using mathematics in the real world.

MATH 583: Applied Mathematics and Computation

Prerequisite(s): Math 582 or with the permission of the instructor
Continuation of Math 582.

MATH 692: Numerical Analysis

Prerequisite(s): Math 320/321
A study of numerical methods for matrix problems, ordinary and partial differential equations, quadrature and the solution of algebraic or transcendental equations. Emphasis will be on the analysis of those methods, which are particularly suited to automatic high-speed computation.

AMCS 567 (BE 567): Mathematical and Computational Modeling of Biological Systems

Prerequisite(s): BE 324 and BE 350
This is an introductory course in mathematical biology. The emphasis will be on the use of mathematical and computational tools for modeling physical phenomena which arise in the study biological systems. Possible topics include random walk models of polymers, membrane elasticity, electrodiffusion and excitable systems, single-molecule kinetics, and stochastic models of biochemical networks.

CIS 460/560: Interactive Computer Graphics

Prerequisites: CIS 120. CIS 121 and CIS 240 are useful pre- or co-requisites.
This course is focused on programming the essential geometric and mathematical concepts underlying modern computer graphics. Using both 2D and 3D implementations, it covers fundamental topics in graphical user interfaces, computational geometry, 3D modeling and graphics algorithms.

CIS 610 (MATH 676): Advanced Geometric Methods in Computer Science

Prerequisite(s): CIS 510 or coverage of equivalent material

The purpose of this course is to present some of the advanced geometric methods used in geometric modeling, computer graphics, computer vision, etc. The topics may vary from year to year, and will be selected among the following subjects (nonexhaustive list): Introduction to projective geometry with applications to rational curves and surfaces, control points for rational curves, rectangular and triangular rational patches, drawing closed rational curves and surfaces; Differential geometry of curves (curvature, torsion, osculating planes, the Frenet frame, osculating circles, osculating spheres); Differential geometry of surfaces (first fundamental form, normal curvature, second fundamental form, geodesic curvature, Christoffel symbols, principal curvatures, Gaussian curvature, mean curvature, the Gauss map and its derivative dN, the Dupin indicatrix, the Theorema Egregium equations of Codazzi-Mainadi, Bonnet's theorem, lines of curvatures, geodesic torsion, asymptotic lines, geodesic lines, local Gauss-Bonnet theorem).

CIS 563: Physically Based Animation

Prerequisite(s): Students should have a good knowledge of object-oriented programming (C++) and basic familiarity with linear algebra and physics. Some background in computer graphics is helpful

This course introduces students to common physically based simulation techniques for animation of fluids and gases, rigid and deformable solids, cloth, explosions, fire, smoke, virtual characters, and other systems. Physically based simulation techniques allow for creation of extremely realistic special effects for movies, video games and surgical simulation systems. We will learn state-of-the-art techniques that are commonly used in current special effects and animation studios and in video games community. To gain hands-on experience, students will implement basic simulators for several systems. The topics will include: Particle Systems, Mass spring systems, Deformable Solids & Fracture, Cloth, Explosions & Fire, Smoke, Fluids, Deformable active characters, Simulation and control of rigid bodies, Rigid body dynamics, Collision detection and handling, Simulation of articulated characters, Simulated characters in games. The course is appropriate for both upper level undergraduate and graduate students.

CIS 562 (CIS 462): Computer Animation

Prerequisite(s): Previous exposure to major concepts in linear algebra (i.e. vector matrix math), curves and surfaces, dynamical systems (e.g. 2nd order mass-spring-damper systems) and 3D computer graphics has also been assumed in the preparation of the course materials

This course covers core subject matter common to the fields of robotics, character animation and embodied intelligent agents. The intent of the course is to provide the student with a solid technical foundation for developing, animating and controlling articulated systems used in interactive computer games, virtual reality simulations and high-end animation applications. The course balances theory with practice by "looking under the hood" of current animation systems and authoring tools and exams the technologies and techniques used from both a computer science and engineering perspective. Topics covered include: geometric coordinate systems and transformations; quaternions; parametric curves and surfaces; forward and inverse kinematics; dynamic systems and control; computer simulation; keyframe, motion capture and procedural animation; behavior-based animation and control; facial animation; smart characters and intelligent agents.

CIS 554: Programming Paradigms

Prerequisite(s): CIS 121 or CIT 594 or equivalent

Achieving mastery in a new programming language requires more than just learning a new syntax; rather, different languages support different ways to think about solving problems. Not all programming languages are inherently procedural or object-oriented. The intent of this course is to provide a basic understanding of a wide variety of programming paradigms, such as logic programming, functional programming, concurrent programming, rule-based programming, and others.

CIS 534 (CIS 434): Multicore Programming and Architecture

Prerequisite(s): CIS 371 or CIS 501, and significant programming experience

This course is a pragmatic examination of multicore programming and the hardware architecture of modern multicore processors. Unlike the sequential single-core processors of the past, utilizing a multicore processor requires programmers to identify parallelism and write explicitly parallel code. Topics covered include: the relevant architectural trends and aspects of multicores, approaches for writing multicore software by extracting data parallelism (vectors and SIMD), thread-level parallelism, and task-based parallelism, efficient synchronization, and program profiling and performance tuning. The course focuses primarily on mainstream shared-memory multicores with some coverage of graphics processing units (GPUs). Cluster-based supercomputing is not a focus of this course. Several programming assignments and a course project will provide students first-hand experience with programming, experimentally analyzing, and tuning multicore software. Students are expected to have a solid understanding of computer architecture and strong programming skills (including experience with C/C++).

CIS 535 (BIOL535, GCB 535): Introduction to Bioinformatics

The course covers methods used in computational biology, including the statistical models and algorithms used and the biological problems which they address. Students will learn how tools such as BLAST work, and will use them to address real problems. The course will focus on sequence analysis problems such as exon, motif and gene finding, and on comparative methods but will also cover gene expression and proteomics.

CIS 519 (CIS 419): Introduction to Machine Learning

Machine learning has been essential to the success of many recent technologies, including autonomous vehicles, search engines, genomics, automated medical diagnosis, image recognition, and social network analysis, among many others. This course will introduce the fundamental concepts and algorithms that enable computers to learn from experience, with an emphasis on their practical application to real problems. This course will introduce supervised learning (decision trees, logistic regression, support vector machines, Bayesian methods, neural networks and deep learning), unsupervised learning (clustering, dimensionality reduction), and reinforcement learning. Additionally, the course will discuss evaluation methodology and recent applications of machine learning, including large scale learning for big data and network analysis.

CIS L/R 502: Analysis of Algorithms

Prerequisite(s): CIT 594 or equivalent

An investigation of paradigms for design and analysis of algorithms. The course will include dynamic programming, flows and combinatorial optimization algorithms, linear programming, randomization and a brief introduction to intractability and approximation algorithms. The course will include other advanced topics, time permitting. 505. Software Systems. (C) Prerequisite(s): Undergraduate-level knowledge of Operating Systems and Networking, programming experience (CIT 594 or equivalent). This course provides an introduction to fundamental concepts of distributed systems, and the design principles for building large scale computational systems. Topics covered include communication, concurrency, programming paradigms, naming, managing shared state, caching, synchronization, reaching agreement, fault tolerance, security, middleware, and distributed applications. This course is appropriate as an upper-level undergraduate CIS elective.

CIS 500: Software Foundations

Prerequisite(s): CIS 121, 160, and 262 (or equivalents); plus substantial mathematical maturity (at least two additional undergraduate courses in math or theoretical CS). Undergraduate-level coursework in programming languages, compilers, functional programming, or logic is helpful but not required

This course introduces basic concepts and techniques in the foundational study of programming languages. The central theme is the view of programs and programming languages as mathematical objects for which precise claims may be made and proved. Particular topics include operational techniques for formal definition of language features, type systems and type safety properties, polymorphism, constructive logic, and the Coq proof assistant. This course is appropriate as an upperlevel undergraduate CIS elective. Undergraduates who have satisfied the prerequisites are welcome to enroll. No permission from the instructor is needed.

MSE 460: Computational Materials Science

Prerequisite(s): Junior or Senior Standing. Ability to write simple computer codes would be an advantage

This course will cover fundamentals of atomic level modeling of the structure and properties of materials. Specifically it will cover metals, semiconductors, oxides and other ionic crystals. First, the description of atomic interactions will be introduced. This will include both basics of the density functional theory and approximations in terms of pair potentials, embedded atom method and tightbinding. The methods of computer modeling include molecular statics, molecular dynamics, Monte Carlo and lattice dynamics (phonons). Interpretations of results of such modeling in terms of structures, for example using the radial distribution function, thermodynamic and statistical physics analyses will be an important component of the course.

MSE 561 (MEAM 553): Atomic Modeling in Materials Science

This course covers two major aspects of atomic level computer modeling in materials. 1. Methods: Molecular statics, Molecular dynamics, Monte Carlo, Kinetic Monte Carlo as well as methods of analysis such as correlations, radial distribution function, etc. 2. Semi-empirical descriptions of atomic interactions: pair potentials, embedded atom method, covalent bonding, ionic bonding, tight-binding. Basics of the density functional theory. Needed mechanics, condensed matter physics, thermodynamics and statistical mechanics are briefly explained.

MSE 637 (MEAM 637): Mesoscale Modeling and Simulation

This course is targeted at engineering, physical science, computational and mathematics Ph.D. students

The course focuses on techniques for the simulation/modeling of materials on a time and/or length scale that is large compared with atomistic/molecular but with structure that is fine on the scale of typical (homogenized) continuum theory. The course explores kinetic models, defect dynamics, and statistical mechanics models and their implementation in computer simulation.

CBE 525: Molecular Modeling and Simulations

Prerequisite(s): CBE 231 or 618 or equivalent background in physical chemistry
Students will explore current topics in thermodynamics through molecular simulations and molecular modeling. The requisite statistical mechanics will be conveyed as well as the essential simulation techniques (molecular dynamics, Monte Carlo, etc.). Various approaches for calculating experimentally measurable properties will be presented and used in student projects.

CBE 520: Modeling, Simulations, and Optimization of Chemical Processes

Nonlinear systems: numerical solutions of nonlinear algebraic equations; sparse matrix manipulations. Nonlinear programming and optimization; unconstrained and constrained systems. Lumped parameter systems: numerical integration of stiff systems. Distributed parameter systems: methods of discretization. Examples from analysis and design of chemical and biochemical processes involving thermodynamics and transport phenomena.

ESE 630: Elements of Neural Computation, Complexity, and Learning

Prerequisite(s): A semester course in probability or equivalent exposure to probability (e.g. ESE 530)
Non-linear elements and networks: linear and polynomial threshold elements, sigmoidal units, radial basis functions. Finite (Boolean) problems: acyclic networks; Fourier analysis and efficient computation; projection pursuit; low frequency functions. Network capacity: Feedforward networks; Vapnik-Chervnenkis dimension. Learning theory: Valiant's learning model; the sample complexity of learning. Learning algorithms: Perception training, gradient descent algorithms, stochastic approximation. Learning complexity: the intractability of learning; model selection.

ESE 603: Simulation Modeling and Analysis

Prerequisite(s): Probability (undergraduate level) and one computer language

This course provides a study of discrete-event systems simulation. Some areas of application include: queuing systems, inventory systems, reliability systems Markov Chains, Random-Walks and MonteCarlo systems. The course examines many of the discrete and continuous probability distributions used in simulation studies as well as the Poisson process. Long-run measurements of performances of queuing systems, steady-state behavior of infinite and finite-population queuing systems and network of queues are also examined. Fundamental to most simulation studies is the ability to generate reliable random numbers. The course investigates the basic properties of random numbers and techniques used for the generation of pseudo-random numbers. In addition, the course examines techniques used to test pseudo-random numbers for uniformity and independence. These include the Kolmogorov-Smirnov and chi-squared tests, runs tests, gap tests, and poker tests. Random numbers are used to generate random samples and the course examines the inverse-transform, convolution, composition and acceptance/rejection methods for the generation of random samples for many different types of probability distributions. Finally, since most inputs to simulation are probabilistic instead of deterministic in nature, the course examines some techniques used for identifying the probabilistic nature of input data. These include identifying distributional families with sample data, then using maximum-likelihood methods for parameter estimating within a given family and then testing the final choice of distribution using chisquared goodness-of-fit tests.

CIS SM 620: Advanced Topics in Artificial Intelligence

Prerequisite(s): CIS 520 or equivalent

Discussion of problems and techniques in Artificial Intelligence (AI): Knowledge Representation, Natural Language Processing, Constraint Systems, Machine Learning; Applications of AI.

Prerequisites

CIT L/R 592: Mathematical Foundations of Computer Science
Required for CIS 450/550
Foundations: Sets, Functions, Summations, and Sequences. Introduction to algorithms. Counting techniques: The pigeonhole principle, permutations and combinations. Discrete probability. Selected topics from Number theory and/or Graph theory.

CIT 594: Programming Languages & Techniques II
Required for CIS 502, CIS 450/550
Prerequisite(s): Unknown

CBE L/R 231: Thermodynamics of Fluids
Potentially required for CBE 525
Prerequisite(s): CBE 230
Students will understand, evaluate, and apply different equations of state relating pressure, temperature, and volume for both ideal and non-ideal systems. The course will focus on calculating and applying residual properties and departure functions for thermodynamic analysis of non-ideal gases. Students will apply and describe simple models of vapor-liquid equilibrium in multi-component systems (e.g. Raoult's Law, modified Raoult's Law, Henry's Law). Additionally, the class will analyze and describe properties of non-ideal mixtures and their component species. We will also model and predict reaction equilibria (including non-ideal fluid systems), as well as solve problems related to complex phase equilibria of multi-component systems (find equilibrium compositions for non-ideal phases).

CBE L/R 230: Material and Energy Balances of Chemical Processes
Required for CBE L/R 231
Prerequisite(s): CBE 160
Analysis of processes used in the chemical and pharmaceutical industries. Mass and energy balances, properties of pure fluids, equations of state. Heat effects accompanying phase changes and chemical reactions.

CBE 160: Introduction to Chemical Engineering

Required for CBE L/R 230

Students will learn to read and understand a process flow sheet. There is a focus on drawing a process flow sheet, and formulating and solving the material balances for the chemical processes involving chemical reactions (some with recycle streams, some with purge streams, and some with bypass streams). Additionally, students will understand the limits of the ideal gas law, and have a working knowledge of the cubic equations of state and the concept of a compressibility factor. The class will study the basic concepts of gas-liquid phase equilibrium and apply Raoult's Law to solve phase equilibrium problems. A final objective is to design flow sheets and solve material balances for simple chemical processes using ASPEN (chemical engineering simulation program).

CBE L/R 618 (BE 662, MEAM 662): Advanced Molecular Thermodynamics

Potentially required for CBE 525

Review of classical thermodynamics. Phase and chemical equilibrium for multicomponent systems. Prediction of thermodynamic functions from molecular properties. Concepts in applied statistical mechanics. Modern theories of liquid mixtures.

ENM 510: Foundations of Engineering Mathematics I

Required for MEAM 646 & ESE 646 & ENM 511; Recommended for ENM 502

Prerequisite(s): MATH 240, MATH 241 (see p. 19) or equivalent

This is the first course of a two semester sequence, but each course is self contained. Over the two semesters topics are drawn from various branches of applied mathematics that are relevant to engineering and applied science. These include: Linear Algebra and Vector Spaces, Hilbert spaces, Higher-Dimensional Calculus, Vector Analysis, Differential Geometry, Tensor Analysis, Optimization and Variational Calculus, Ordinary and Partial Differential Equations, Initial-Value and Boundary-Value Problems, Green's Functions, Special Functions, Fourier Analysis, Integral Transforms and Numerical Analysis. The fall course emphasizes the study of Hilbert spaces, ordinary and partial differential equations, the initial-value, boundary-value problem, and related topics.

ENM 511: Foundations of Engineering Mathematics II

Required for MEAM 646 & ESE 646
Prerequisite(s): ENM 510 or equivalent
Vector Analysis: space curves, Frenet - Serret formulae, vector theorems, reciprocal systems, co and contra variant components, orthogonal curvilinear systems. Matrix theory: Gauss-Jordan elimination, eigen values and eigen vectors, quadratic and canonical forms, vector spaces, linear independence, Triangle and Schwarz inequalities, n-tuple space.Variational calculus: Euler-Lagrange equation, Finite elements, Weak formulation, Galerkin technique, FEMLAB. Tensors: Einstein summation, tensors of arbitrary order, dyads and polyads, outer and inner products, quotient law, metric tensor, Euclidean and Riemannian spaces, physical components, covariant differentiation, detailed evaluation of Christoffel symbols, Ricci's theorem, intrinsic differentiation, generalized acceleration, Geodesics.

STAT 430 (STAT 510): Probability

Recommended for STAT 953; Potentially required for STAT 530 & ESE 530
Prerequisite(s): MATH 114 or equivalent
Discrete and continuous sample spaces and probability; random variables, distributions, independence; expectation and generating functions; Markov chains and recurrence theory.

STAT 431: Statistical Inference

Recommended for STAT 953
Prerequisite(s): STAT 430
Graphical displays; one- and two-sample confidence intervals; one- and two-sample hypothesis tests; one- and two-way ANOVA; simple and multiple linear least-squares regression; nonlinear regression; variable selection; logistic regression; categorical data analysis; goodness-of-fit tests. A methodology course. This course does not have business applications but has significant overlap with STAT 101 and 102.

STAT 541: Statistical Methodology

Required for STAT SM 957
Prerequisite(s): STAT 431 OR 520 or equivalent; a solid course in linear algebra and a programming language
This is a course that prepares 1st year PhD students in statistics for a research career. This is not an applied statistics course. Topics covered include: linear models and their high-dimensional geometry, statistical inference illustrated with linear models, diagnostics for linear models, bootstrap and permutation inference, principal component analysis, smoothing and cross-validation.

STAT 551: Introduction to Linear Statistical Models

Required for STAT SM 957
Prerequisite(s): STAT 550
Theory of the Gaussian Linear Model, with applications to illustrate and complement the theory. Distribution theory of standard tests and estimates in multiple regression and ANOVA models. Model selection and its consequences. Random effects, Bayes, empirical Bayes and minimax estimation for such models. Generalized (Log-linear) models for specific non-Gaussian settings.

STAT 550: Mathematical Statistics

Required for STAT 551, STAT 925
Prerequisite(s): STAT 431 or 520 or equivalent; comfort with mathematical proofs (e.g., MATH 360)
Decision theory and statistical optimality criteria, sufficiency, point estimation and hypothesis testing methods and theory.

STAT 520: Applied Econometrics I

Potentially required for STAT 550
Prerequisite(s): MATH 114 and MATH 312) or equivalents, and an undergraduate introduction to probability and statistics.
This is a course in econometrics for graduate students. The goal is to prepare students for empirical research by studying econometric methodology and its theoretical foundations. Students taking the course should be familiar with elementary statistical methodology and basic linear algebra, and should have some programming experience. Topics include conditional expectation and linear projection, asymptotic statistical theory, ordinary least squares estimation, the bootstrap and jackknife, instrumental variables and two-stage least squares, specification tests, systems of equations, generalized least squares, and introduction to use of linear panel data models.

STAT 552 (BSTA 820): Advanced Topics in Mathematical Statistics

Required for STAT SM 957, STAT 925
Prerequisite(s): STAT 550 and 551
A continuation of STAT 550.

STAT 925: Multivariate Analysis: Theory

Potentially required for STAT SM 957
Prerequisite(s): STAT 530, STAT 550 & 552, or permission of instructor
This is a course that prepares PhD students in statistics for research in multivariate statistics and high dimensional statistical inference. Topics from classical multivariate statistics include the multivariate normal distribution and the Wishart distribution; estimation and hypothesis testing of mean vectors and covariance matrices; principal component analysis, canonical correlation analysis and discriminant analysis; etc. Topics from modern multivariate statistics include the Marcenko-Pastur law, the Tracy-Widom law, nonparametric estimation and hypothesis testing of high-dimensional covariance matrices, high-dimensional principal component analysis, etc.

STAT 530 (MATH 546): Probability

Required for STAT 925
Prerequisite(s): STAT 430 or STAT 510 or equivalent
Measure theory and foundations of Probability theory. Zero-one Laws. Probability inequalities. Weak and strong laws of large numbers. Central limit theorems and the use of characteristic functions. Rates of convergence. Introduction to Martingales and random walk.

MATH 114: Calculus, Part II

Required for STAT 925; Required for MATH 240; Required for PHYS 141; Required for PHYS 151; Required for ESE 301
Prerequisite(s): MATH 104
Functions of several variables, vector-valued functions, partial derivatives and applications, double and triple integrals, conic sections, polar coordinates, vectors and vector calculus, first order ordinary differential equations. Applications to physical sciences. Use of symbolic manipulation and graphics software in calculus.

MATH 104: Calculus, Part I

Potentially required for STAT 925; Required for BIOL 437; Required for PHYS 140; Required for PHYS 150
Brief review of High School calculus, applications of integrals, transcendental functions, methods of integration, infinite series, Taylor's theorem, and first order ordinary differential equations. Use of symbolic manipulation and graphics software in calculus.

STAT 510 (STAT 430): Probability

Potentially required for STAT 925; Potentially Required for STAT 530
Prerequisite(s): A one year course in Calculus
Elements of matrix algebra. Discrete and continuous random variables and their distributions. Moments and moment generating functions. Joint distributions. Functions and transformations of random variables. Law of large numbers and the central limit theorem. Point estimation: sufficiency, maximum likelihood, minimum variance. Confidence intervals.

BIOL 437: Introduction to Computational Biology & Biological Modeling

Potentially required for BIO SM 537
Prerequisite(s): Intermediate level biology, MATH 104; BIOL 446 or equivalent
This goal of this course is to develop a deep understsanding of techniques and concepts used in Computational Biology. The course will strive to focus on a small set of approaches to gain both theoretical issues such as algorithm design, statistical data analysis, theory of algorithms and statistics. Topics to be discussed include theory of computing, probability theory, multivariate statistics, molecular evolution, and network models. Grading is primarily based on 3 project reports.

BIOL 101: Introduction to Biology

Potentially required for BIO L/R 527
Biology majors and pre-medical students should take either BIOL 101 or 121. BIOL 101 is the companion course to BIOL 102, may be taken before or after BIOL 102. Lab fee $150.

BIOL L/R 121: Introduction to Biology – The Molecular Biology of Life

Potentially required for BIO L/R 527
Prerequisite(s): Solid high school biology and strong high school chemistry or CHEM 101; BIOL 123 is recommended
An intensive introductory lecture course covering the cell, molecular biology, biochemistry, and the genetics of animals, bacteria, and viruses. This course is comparable to Biology 101, but places greater emphasis on molecular mechanisms and experimental approaches. Particular attention is given to the ways in which modern cell biological and molecular genetic methods contribute to our understanding of evolutionary processes, the mechanistic basis of human disease, and recent biotechnological innovations. Students are encouraged to take BIOL 121 and 123 concurrently.

MATH 240: Calculus, Part III

Required for MATH 582, ENM 502, MATH 241, MATH 360,MATH 320, BE 324, & ENM 510
Prerequisite(s): MATH 114
Linear algebra: vectors, matrices, systems of linear equations, vector spaces, subspaces, spans, bases, and dimension, eigenvalues, and eigenvectors, maxtrix exponentials. Ordinary differential equations: higher-order homogeneous and inhomogeneous ODEs and linear systems of ODEs, phase plane analysis, non-linear systems.

MATH 241: Calculus, Part IV
Required for MATH 58, ENM 502, BE 350, ESE 540 & ENM 510
Prerequisite(s): MATH 240
Partial differential equations and their solutions, including solutions of the wave, heat and Laplace equations, and Sturm-Liouville problems. Introduction to Fourier series and Fourier transforms. Computation of solutions, modeling using PDE's, geometric intuition, and qualitative understanding of the evolution of systems according to the type of partial differential operator.

MATH 312 (MATH 412): Linear Algebra
Required for MATH 582
Prerequisite(s): MATH 240. Students who have already received credit for either Math 370, 371, 502, or 503 cannot receive further credit for MATH 312 or MATH 313/513.
Linear transformations, Gauss Jordan elimination, eigenvalues and eigenvectors, theory and applications. Mathematics majors are advised that MATH 312 cannot be taken to satisfy the major requirements.

MATH 361: Advanced Calculus
Potentially required for MATH 582
Prerequisite(s): MATH 360
Continuation of MATH 360.

MATH 360: Advanced Calculus
Required for MATH 582
Prerequisite(s): MATH 240
Syllabus for MATH 360-361: a study of the foundations of the differential and integral calculus, including the real numbers and elementary topology, continuous and differentiable functions, uniform convergence of series of functions, and inverse and implicit function theorems. MATH 508-509 is a masters level version of this course.

MATH 412: Linear Algebra
Recommended for MATH 582
Prerequisite(s): Unknown

MATH 508: Advanced Analysis
Recommended for MATH 582
Prerequisite(s): MATH 240/241. MATH 200/201 recommended
Construction of real numbers, the topology of the real line and the foundations of single variable calculus. Notions of convergence for sequences of functions. Basic approximation theorems for continuous functions and rigorous treatment of elementary transcendental functions. The course is intended to teach students how to read and construct rigorous formal proofs. A more theoretical course than Math 360.

MATH 202 (MATH 200): Proving Things – Analysis

Recommended for MATH 508
Prerequisite(s): MATH 104, MATH 114, or MATH 240
Taken concurrently with Calculus, this course gives an introduction to mathematical reasoning and is recommended to anyone with a serious interest in mathematics.

MATH 203 (MATH 201): Proving Things- Algebra

Recommended for MATH 508
Prerequisite(s): MATH 104, MATH 114, or MATH 240 (see p. 17 or p. 19)
Taken concurrently with Calculus, this course gives an introduction to mathematical reasoning and is recommended to anyone with a serious interest in mathematics.

MATH 320: Computer Methods in Mathematical Science I

Required for MATH 692; Required for MATH 321
Prerequisite(s): MATH 240 and ability to program a computer, or permission of instructor
Students will use symbolic manipulation software and write programs to solve problems in numerical quadrature, equation-solving, linear algebra and differential equations. Theoretical and computational aspects of the methods will be discussed along with error analysis and a critical comparison of methods.

MATH 321: Computer Methods in Mathematical Sciences II

Required for MATH 692
Prerequisite(s): MATH 320
Continuation of MATH 320.

BE L/R 324: Chemical Basis of Bioengineering II

Required for AMCS 567; Required for MSE 559
Prerequisite(s): PHYS 140, 141 or 150, 151; MATH 240, CHEM 101 and 102
Advanced topics in physical chemistry including solution and colloid chemistry, electrochemistry, surface phenomena, and macromolecules applied to biological systems.

PHYS 140: Principles of Physics I

Required for BE L/R 324; Required for PHYS 141; Potentially required for BE 350
Prerequisite(s): MATH 104
Classical laws of motions; interactions between particles; conservation laws and symmetry principles; particle and rigid body motion; gravitation, harmonic motion. Engineering students only.

PHYS 141: Principles of Physics II

Potentially required for BE L/R 324
Prerequisite(s): PHYS 140, MATH 114
Electric and magnetic fields; Coulomb's, Ampere's, and Faraday's laws; Maxwell's equations; emission, propagation, and absorption of electromagnetic radiation; interference, reflection, refraction, scattering, and diffraction phenomena. Engineering students only.

PHYS 150: Principles of Physics I: Mechanics and Wave Motion

Potentially required for BE L/R 324; Potentially required for PHYS 151 & BE 350; Required for MEAM 210
Prerequisite(s): MATH 104
This calculus-based course is recommended for science majors and engineering students. Classical laws of motion; interactions between particles; conservation laws and symmetry principles; particle and rigid body motion; gravitation, harmonic motion. Credit is awarded for only one of the following courses: PHYS 008, PHYS 101, PHYS 150, or PHYS 170. Students with AP or Transfer Credit for PHYS 91 or PHYS 93 who complete PHYS 150 will thereby surrender the AP or Transfer Credit.

PHYS 151: Principles of Physics III: Thermal Physics and Waves

Required for BE L/R 324
Prerequisite(s): PHYS 150, MATH 114
The topics of this calculus-based course are electric and magnetic fields; Coulomb's, Ampere's, and Faraday's laws; Maxwell's equations; emission, propagation, and absorption of electromagnetic radiation; interference, reflection, refraction, scattering, and diffraction phenomena. Credit is awarded for only one of the following courses. PHYS 009, PHYS 102, PHYS 151, or PHYS 171. Students with AP or Transfer Credit for PHYS 92 or PHYS 94 who complete PHYS 151 will thereby surrender the AP or Transfer Credit.

CHEM L/R101: General Chemistry I

Required for BE L/R 324; Required for CHEM 102
Basic concepts and principles of chemistry and their applications in chemistry and closely-related fields. The first term emphasizes the understanding of chemical reactions through atomic and molecular structure. This is a university level course, treating the material in sufficient depth so that students can solve chemical problems and can understand the principles involved in their solution. It includes an introduction to condensed matter. This course is suitable for majors or non-majors and is recommended to satisfy either major or preprofessional requirements for general chemistry. This course is presented for students with high school chemistry and calculus. Students with a lesser background than this should take Chemistry 100.

CHEM L/R 102: General Chemistry II

Required for BE L/R 324
Prerequisite(s): CHEM 101
Continuation of Chemistry 101. The second term stresses the thermodynamic approach to chemical reactions, electrochemical processes, and reaction rates and mechanisms. It includes special topics in chemistry.

BE L/R 350: Transport Processes in Living Systems

Required for AMCS 567
Prerequisite(s): MATH 241 or equivalent, PHYS 140 or 150
Introduction to basic principles of fluid mechanics and of energy and mass transport with emphasis on applications to living systems and biomedical devices.

CIS 510 (CIS 410): Curves and Surfaces: Theory and Applications

Required for CIS 610
Prerequisite(s): Basic knowledge of linear algebra, calculus, and elementary geometry
The course is about mathematical and algorithmic techniques used for geometric modeling and geometric design, using curves and surfaces. There are many applications in computer graphics as well as in robotics, vision, and computational geometry. Such techniques are used in 2D and 3D drawing and plot, object silhouettes, animating positions, product design (cars, planes, buildings), topographic data, medical imagery, active surfaces of proteins, attribute maps (color, texture, roughness), weather data, art, etc. Three broad classes of problems will be considered: approximating curved shapes, using smooth curves or surfaces. Interpolating curved shapes, using smooth curves or surfaces. Rendering smooth curves or surfaces.

CIS L/R 121: Programming Languages and Techniques II: Data Structures in Java

Required for CIS 554; Required for CIS 500
Prerequisite(s): CIS 120 and 160
This is an introductory course about Basic Algorithms and Data Structures using the Java programming language. We introduce elementary concepts about the complexity of an algorithm and methods for analyzing the running time of software. We describe data structures like stacks, queues, lists, trees, priority queues, maps, hash tables and graphs, and we discuss how to implement them efficiently and how to use them in problems-solving software. A larger project introducing students to some of the challenges of software development concludes the course.

CIS L/R 120: Programming Languages and Techniques I

Required for CIS 121; Required for CIS 160

A fast-paced introduction to the fundamental concepts of programming and software design. This course assumes some previous programming experience, at the level of a high school computer science class or CIS110. (If you got at least 4 in the AP Computer Science A or AB exam, you will do great.) No specific programming language background is assumed: basic experience with any language (for instance Java, C, C++, VB, Python, Perl, or Scheme) is fine. If you have never programmed before, you should take CIS 110 first.

CIS L/R 160: Mathematical Foundations of Computer Science

Required for CIS 121; Required for CIS 500; Required for CIS 262
Prerequisite(s): CIS 120

What are the basic mathematical concepts and techniques needed in computer science? This course provides an introduction to proof principles and logics, functions and relations, induction principles, combinatorics and graph theory, as well as a rigorous grounding in writing and reading mathematical proofs.

CIS 371: Computer Organization and Design

Potentially required for CIS 534
Prerequisite(s): CIS 240

This is the second computer oganization course and focuses on computer hardware design. Topics covered are: (1) basic digital system design including finite state machines, (2) instruction set design and simple RISC assembly programming, (3) quantitative evaluation of computer performance, (4) circuits for integer and floating-point arithmatic, (5) datapath and control, (6) micro-programming, (7) pipeling, (8) storage hierarchy and virtual memory, (9) input/output, (10) different forms of parallelism including instruction level parallelism, data-level parallelism using both vectors and message-passing multi-processors, and thread-level parallelism using shared memory multiprocessors. Basic cache coherence and synchronization.

CIS 240: Introduction to Computer Architecture

Required for CIS 371
Prerequisite(s): CIS 110 or equivalent experience
You know how to program, but do you know how computers really work? How do millions of transistors come together to form a complete computing system? This bottom-up course begins with transistors and simple computer hardware structures, continues with low-level programming using primitive machine instructions, and finishes with an introduction to all aspects of computer systems architecture and serves as the foundation for subsequent computer systems courses, such as Digital Systems Organization and Design (CIS 371), Computer Operating Systems (CIS 380), and Compilers and Interpreters (CIS 341). The course will consider the SPARC architecture, boolean logic, number systems, and computer arithmetic; macro assembly language programming and subroutine linkages; the operating system interface and input/output; understanding the output of the C compiler; the use of the C programming language to generate specific assembly language instructions.

CIS L/R 110: Introduction to Computer Programming

Required for CIS 240
Introduction to Computer Programming is the first course in our series introducing students to computer science. In this class you will learn the fundamentals of computer programming in Java, with emphasis on applications in science and engineering. You will also learn about the broader field of computer science and algorithmic thinking, the fundamental approach that computer scientists take to solving problems.

CIS L/R 501: Computer Architecture

Potentially required for CIS 534
Prerequisite(s): Knowledge of computer organization and basic programming skills.
This course is an introductory graduate course on computer architecture with an emphasis on aquantitative approach to cost/performance design tradeoffs. The course covers the fundamentals ofclassical and modern uniprocessor design: performance and cost issues, instruction sets, pipelining,superscalar, out-of-order, and speculative execution mechanisms, caches, physical memory, virtualmemory, and I/O. Other topics include: static scheduling, VLIW and EPIC, software speculation, long(SIMD) and short (multimedia) vector execution, multithreading, and an introduction to shared memory multiprocessors.

CIS L/R 262: Automata, Computability, and Complexity

Required for CIS 500
Prerequisite(s): CIS 160
This course explores questions fundamental to computer science such as which problems cannot be solved by computers, can we formalize computing as a mathematical concept without relying upon the specifics of programming languages and computing platforms, and which problems can be solved efficiently. The topics include finite automata and regular languages, context-free grammars and pushdown automata, Turing machines and undecidability, tractability and NP-completeness. The course emphasizes rigorous mathematical reasoning as well as connections to practical computing problems such as test processing, parsing, XML query languages, and program verification.

MEAM L/R 210: Statistics and Strength of Materials

Required for ESE 540
Prerequisite: MEAM 110/147 or PHYS 150. MATH 240 and MEAM 247 strongly recommended
This course is primarily intended for students in mechanical engineering, but may also be of interest to students in materials science and other fields. It continues the treatment of statics of rigid bodies begun in MEAM 110/PHYS 150 and progresses to the treatment of deformable bodies and their response to loads. The concepts of stress, strain, and linearly elastic response are introduced and applied to the behavior of rods, shafts, beams and other mechanical components. The failure and design of mechanical components are discussed.

MEAM L/R 110: Introduction to Mechanics

Required for MEAM L/R 210
Prerequisite: MATH 104
This lecture course and a companion laboratory course (MEAM 147) build upon the concepts of Newtonian (classical) mechanics and their application to engineered systems. This course introduces students to mechanical principles that are the foundation of upper-level engineering courses including MEAM 210 and 211. The three major parts of this course are: I. Vector Mechanics; II. Statics and Structures; and III. Kinematics and Dynamics. Topics include: vector analysis, statics of rigid bodies, introduction to deformable bodies, friction, kinematics of motion, work and energy, and dynamics of particles. Case studies will be introduced, and the role of Newtonian mechanics in emerging applications including bio- and nano- technologies will be discussed.

MEAM 147: Introduction to Mechanics Lab

Recommended for MEAM L/R 210

This half-credit laboratory class is a companion to the Introduction to Mechanics lecture course (MEAM 110). It investigates the concepts of Newtonian (classical) mechanics through weekly hands on experiments, emphasizing connections between theoretical principles and practical applications in engineering. In addition to furthering their understanding about the workings of the physical world, students will improve their skills at conducting experiments, obtaining reliable data, presenting numerical results, and extracting meaningful information from such numbers.

MEAM 247: Mechanical Engineering Laboratory

Should be taken with MEAM L/R 210

This is the first of a two semester sophomore level laboratory sequence that students complete over the fall and spring semesters. The course teaches the principles of experimentation and measurement as well as analysis and application to design. This fall semester course follows closely with MEAM 210, involving experiments to explore the principles of statics and strength of materials.

BIOL 446: Statistics for Biologists

Required for BIOL 437

Prerequisite(s): MATH 104 or equivalent, or permission of instructor.

Introductory probability theory. Principles of statistical methods. Problems of estimation andhypothesis testing in biology and related areas.

BIOL 123: Introductory Molecular Biology Laboratory

Should be taken with BIOL 121

An intensive introductory laboratory course emphasizing how molecular biology has revolutionized our understanding of cell and organism functions. BIOL 121 and 123 should be taken concurrently.

ESE 301: Engineering Probability

Potentially required for ESE 530

Prerequisite(s): MATH 114

Basic ideas of probability theory. Combinatorics. Random variables and functions of random variables. Means, moments and generating functions. Order statistics and special distributions. Inequalities and the central limit theorem.

ESE 530: Elements of Probability Theory

Potentially required for ESE 630

Prerequisite(s): A solid foundation in undergraduate probability at the level of STAT 430 or ESE 301 at Penn. Students are expected to have a sound calculus background as covered in the first two years of a typical undergraduate engineering curriculum.

This rapidly moving course provides a rigorous development of fundamental ideas in probability theory and random processes. This course is a prerequisitefor subsequent courses in communication theory and telecommunications such as ESE 576 and TCOM 501. The course is also suitable for students seeking a rigorous graduate level exposure to probabilistic ideas and principles with applications in diverse settings. We will focus on discrete and continuous probability spaces. The topics covered are drawn from: abstract probability spaces; combinatorial probabilities; conditional probability; Bayes's rule and the theorem of total probability; independence; connections with the theory of numbers, Borel's normal law; rare events, Poisson laws, and the Lovasz local lemma; arithmetic and lattice distributions arising from the Bernoulli scheme; limit laws and characterizations of the binomial and Poisson distributions; continuous distributions in one and more dimensions; the uniform, exponential, normal, and related distributions and their characterizations and applications; random variables, distribution functions; random number generation and statistical tests of randomness; measures of central tendency -- mean, median, mode; mathematical expectation and the Lebesgue theory; expectations of functions, key properties, moments, convolutions; operator methods and distributional convergence, the central limit theorem, selection principles; conditional expectation; tail inequalities, concentration; convergence in probability and almost surely, the law of large numbers, the law of the iterated logarithm; Poisson approximation, Janson's inequality, the SteinChen method; moment generating functions, renewal theory; characteristic functions.