Yuan (Friedrich) Qiu

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Undergraduate School: Williams College
Graduation Date: June. 2024
Major: Mathematics, Computer Science
Major GPA: 3.81/4.0 ; Cum. GPA: 3.58/4.0
Research Interests: Number Theory, Analysis, Combinatorics, Theoretical Computer Science, Algorithms, Computational Complexity Theory, Quantum Computing, Quantum Algorithms

List of Mathematics Courses, with Grades:

MATH -- Independent Research in Analytic Number Theory: In Progress (Spring 2025, Study Abroad at the Math in Moscow Program /HSE University, Remote)
MATH -- Independent Research on Omega-Theorems for Sums of Multiplicative Functions, Part II: A+ (Fall 2024, Summer 2024, Study Abroad at the Math in Moscow Program /HSE University, Remote)
MATH -- Independent Research on Omega-Theorems for Sums of Multiplicative Functions, Part I: A+ (Summer 2024, Study Abroad at the Math in Moscow Program /HSE University, Remote)
MATH -- Independent Research on Quadratic Forms in Analytic Number Theory: A (Fall 2023, Study Abroad at the Math in Moscow Program /HSE University, Remote)
MATH -- Modular Forms: In Progress (Spring 2025, Study Abroad at the Math in Moscow Program / HSE University, Remote)
MATH--Introduction to Commutative and Homological Algebra: In Progress (Spring 2025, Study Abroad at the Math in Moscow Program / HSE University, Remote)
MATH --Differential Geometry: In Progress (Spring 2025, Study Abroad at the Math in Moscow Program / HSE University, Remote)
MATH --Dynamical Systems: In Progress (Spring 2024, Study Abroad at the Math in Moscow Program / HSE University, Remote)
MATH -- Introduction to Homology and Cohomology: A (Fall 2024, Study Abroad at the Math in Moscow Program / HSE University, Remote)
MATH -- Basic Representation Theory: B+ (Fall 2023, Study Abroad at the Math in Moscow Program / HSE University, Remote)
MATH -- Advanced Linear Algebra (Included in Basic Representation Theory, Fall 2023, Study Abroad at the Math in Moscow Program / HSE University, Remote)

MATH 419 -- Algebraic Number Theory: A- (Fall 2023, Williams College)
MATH 413-- Algebraic Geometry: A- (Spring 2023, Williams College)
MATH 442 - Introduction to Descriptive Set Theory: B+ (Fall 2022, Williams College)
MATH 407 -- Dance of the Primes /Analytic Number Theory: A (Fall 2023, Williams College)
MATH 394 -- Galois Theory: A (Spring 2024, Williams College)
MATH 313-- Introduction to Number Theory: A (Spring 2023, Williams College)
MATH 355 -- Abstract Algebra: A (Spring 2021, Williams College)
MATH 350 -- Real Analysis: A- (Fall 2020, Williams College)
MATH 341-- Probability: A (Fall 2022, Williams College)
MATH 409-- The Little Questions (Problem Solving): A (Fall 2022, Williams College)
MATH 320-- Introduction to Topology: A (Spring 2022, Study Abroad at the Budapest Semesters in Mathematics Program)
MATH --Riemann Surfaces: Audit (Fall 2022, Study Abroad at the Math in Moscow Program / HSE University, Remote)
MATH 378-- Quantum Information and Quantum Computation (Quantum Logic and Quantum Probability): A- (Spring 2022, Study Abroad at the Budapest Semesters in Mathematics Program)
MATH 345-- Graduate Graph Theory: A- (Spring 2022, Study Abroad at the Budapest Semesters in Mathematics Program)
MATH 315 -- Functional Analysis: Audit (Spring 2022, Study Abroad at the Budapest Semesters in Mathematics Program)
MATH 128-- Numerical Analysis: A (Berkeley Summer Session 2022, University of California, Berkeley)
MATH 126-- Partial Differential Equations: A+ (Berkeley Summer Session 2022, University of California, Berkeley)
MATH 317-- Introduction to Operations Research: B (Fall 2022, Williams College)
MATH 309-- Differential Equations: P (Spring 2020, Pass/Fail for Credit S20 because of COVID-19)
MATH 200-- Discrete Math: A+ (Fall 2020, Williams College)
MATH 151-- Multivariable Calculus: A- (Fall 2019, Williams College)
MATH 12 -- Mathematics of LEGO: Pass (Winter 2023, only Pass/ Fail choice for Winter Study)
MATH -- Complex Analysis: 94% (on Coursera)

List of Computer Science Courses, with Grades:

CSCI 494-- Honors Research in Computer Science: A (Spring 2024, Williams College)

CSCI 493-- Honors Research in Computer Science: A (Fall 2023, Williams College)

CSCI 31-- Senior Thesis: Computer Science: P (Pass/ Fail choice for Winter Study 2024, Williams College)

CSCI 381-- Deep Learning: B+ (Spring 2024, Williams College)

CSCI 378-- Human-AI Interaction: A (Fall 2020, Williams College)

CSCI 375-- Natural Language Processing: A- (Spring 2023, Williams College)

CSCI 374-- Machine Learning: A (Fall 2023, Williams College)

CSCI 371-- Computer Graphics: A (Spring 2023, Williams College)

CSCI 361-- Theory of Computation: A (Fall 2022, Williams College)

CSCI 334-- Principles of Programming Lang: A- (Spring 2021, Williams College)

CSCI 333-- Storage System: A (Spring 2021, Williams College)

CSCI 256-- Algorithm Design and Analysis: Audit (Fall 2023, Williams College)

CSCI 237-- Computer Organization: P (Spring 2020, Pass/Fail for Credit S20 because of COVID-19)

CSCI 136--Data Structures & Advanced Prog: B+ (Fall 2019, Williams College)

Certificate (MIT) -- Applied Data Science Program (Spring 2023, MIT)

IPAM RIPS REU: Quantum Algorithms, Quantum Computing

List of Physics Courses, with Grades:

PHYS 210 -- Math Methods for Scientists: A (Spring 2024, Williams College)

PHYS 301 -- Quantum Physics: B+ (Fall 2023, Williams College)

PHY -- General Physics II: A (Summer 2020, Massachusetts College of Liberal Arts)

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List of Mathematics, Computer Science and Physics Coursework

Last Updated December, 2024

Mathematics Courses

In Progress | MATH - Introduction to Commutative and Homological Algebra | Spring 2025 |Study Abroad at the Math in Moscow Program / HSE (Remote)

Commutative and homological algebra studies algebraic structures, say, modules over commutative rings, in terms of their generators and relations. It provides the most powerful algebraic tools for applications in algebraic and differential geometry, number theory, algebraic topology, etc. This course gives a quick introduction to these techniques. It is designed as the starting point for those who intend to study algebraic geometry and related topics.

Curriculum:

Polynomial ideals and algebraic varieties. Noetherian rings. Hilbert base theorem. Integer ring extensions. Gauss-Kronecker-Dedekind lemma. Finitely generated algebras over a field. Noether's normalization theorem. Hilbert's Nullstellensatz. Geometry of ring homorphisms: category of affine schemes. Category of modules. Generators and relations. Exact sequences. Grothendieck group. Categories and functors. Representable functors. Natural transformations. Adjoint functors. The Hom-functor and tensor products. Projective, flat and injective modules. Frobenius duality. Linear, additive and Abelian categories. Complexes and homology. Canonical resolvents, bar-construction, classical derived functors; Ext and Tor. Composition of derived functors, spectral sequences. Koszul complex. Hilbert's syzygies theorem. duality. Category of sheaves. Cech cohomology. Leray spectral sequence. Sheaves of modules on algebraic varieties. Locally free resolvents. Ext-functors. Serre duality. Category of coherent sheaves on projective space. Serre theorem. Beilinson theorem.

If time allows: Resultants and determinants of multidimensional format, the ideal of a canonical curve and the Green problem, moduli of coherent sheaves on projective spaces

Textbooks: M. F. Atiyah, I. G. McDonald, Introduction to commutative algebra, Addison-Wesley, 1969. S. I. Gelfand, Yu. I. Manin, Methods of homological algebra, I. D.Eisenbud, Commutative Algebra: With a View Toward Algebraic Geometry, Springer, 1995.

In Progress | MATH - Differential Geometry| Spring 2025 |Study Abroad at the Math in Moscow Program / HSE (Remote)

In this course we present the basic concepts of differential geometry (metric, curvature, connection, etc.). The main goal of our study is a deeper understanding of the geometrical meaning of all notions and theorems.

Curriculum: Plane and space curves. Curvature, torsion, Frenet frame. Curves in pseudo-Euclidean spaces. Surfaces in 3-space. Metrics and the second quadratic form. Curvature. `Theorema egregium' of Gauss. Parallel translations. Gauss-Bonnet formulas. Fibrations. Topological connections as parallel translations. Curvature of a topological connection. Frobenius criterion.Vector bundle. Tangent,

cotangent, and tensor bundles. Sections. Differential forms on manifolds. Integrals of differential forms. Stokes' theorem. Connections as covariant derivatives. Curvature and torsion tensors. Riemannian manifolds. Symmetries of the curvature tensor. Geodesics. Extremal properties of geodesics. Sard's lemma. Transversality theorem. Applications.
Textbooks: Monfredo Do Carmo, Differential Geometry of Curves and Surfaces.

In Progress | MATH - Dynamical Systems | Spring 2025 |Study Abroad at the Math in Moscow Program / HSE (Remote)
The Theory of Dynamical Systems is a branch of mathematics, based on the idea of iterated functions. Concepts of contraction, ergodicity, structural stability, and others may be helpful for the investigations related to the theory of Differential Equations, and (to some extent) the Number Theory, the Mathematical Physics and the Probability Theory. Substantial contributions here were made by mathematicians of the Moscow school, e.g. Kolmogorov, Arnold, Alekseev, Anosov, Sinai, and others. The proposed course is an introduction to the subject. It contains a survey of the field; the basic theorems are proved; the key ideas are presented.
Curriculum: Introduction. Philosophy of general position. Generic dynamical systems in the plane. Limit behavior of solutions; Andronov-Pontryagin criterion of structural stability; Poincare-Bendixson theorem. Elements of hyperbolic theory. Hadamard – Perron theorem; Smale horseshoe; elements of symbolic dynamics; Anosov diffeomorphisms of a torus and their structural stability; Grobman-Hartman theorem; normal hyperbolicity and persistence of invariant manifolds; structurally stable DS are not dense. Attractors. Lyapunov stability of equilibrium points and periodic orbits; maximal attractors and their fractal dimension; strange attractors; Smale-Williams solenoid. Dynamical systems in low dimension. Diffeomorphisms of a circle; rotation number, periodic orbits; conjugacy to rigid rotation; flows on a torus; density; uniform distribution. Elements of ergodic theory. Survey of measure theory; invariant measures of dynamical systems; Krylov-Bogolyubov theorem; Birkhoff-Khinchin ergodic theorem; ergodicity of nonresonant shifts and Anosov diffeomorphisms of a torus; geodesic flows; mixing.
Textbooks: V. I. Arnold, Geometric theory of ordinary differential equations.
B. Hasselblat, A. Katok, Introduction to the modern theory of dynamical systems, Cambridge Univ. Press.

In Progress | MATH - Modular Forms | Spring 2025 |Vladimir Sergeevich Zhgoon |Study Abroad at the Math in Moscow Program / HSE (Remote)
The topics covered include
elliptic curves as complex tori and as algebraic curves, modular curves as Riemann surfaces and as algebraic curves, Hecke operators and Atkin–Lehner theory, Hecke eigenforms and their arithmetic properties, the Jacobians of modular curves and the Abelian varieties associated to Hecke eigenforms, elliptic and modular curves modulo p and the Eichler–Shimura Relation, the Galois representations associated to elliptic curves and to Hecke eigenforms.
Textbooks: A First Course in Modular Forms, by Fred Diamond, Jerry Shurman, Springer 2005

A | MATH - Introduction to Homology and Cohomology | Fall 2024 | Vladimir Sergeevich Zhgoon | Study Abroad at the Math in Moscow Program / HSE (Remote)

The emphasis of the course is on the interconnections of modern topology with other branches of mathematics and on concrete topological spaces (manifolds, vector bundles) rather than the most general abstract categories.

Curriculum:

Chain complexes, cycles, boundaries, and homology groups. Polyhedra, triangulations, and simplicial homology groups of topological spaces. Betti numbers and the Euler characteristic. Homology groups of classical surfaces: sphere, torus, Klein bottle, projective plane.

Cell spaces or CW-complexes. Cell chains, cycles, boundaries, and incidence coefficients. Cell homology groups and their coincidence with simplicial homology groups (without proof). Examples: multidimensional spheres, tori and projective spaces.

The long exact sequence associated with a short sequence of chain complexes. Relative homology groups. The exact sequence of a pair of topological spaces. Mayer−Vietoris exact sequence. Computing the homology groups of some topological spaces.

Main topological constructions: product, quotient space, cone, wedge, suspension, join, loop space and their homology groups.

Homotopy. Classification of mappings from a circle to itself and their degrees or rotation numbers. The index of an isolated singular point of a plane vector field. Poincaré index theorem: the sum of the indices of a vector field on a surface is equal to its Euler characteristic. Brushing a sphere. Brouwer fixed point theorem.

Singular homology groups of topological spaces. Homology groups of a point. Homotopy invariance of singular homology groups. Exact sequences of pairs and triples. Homology groups of spheres. The coincidence of singular, cell, and simplicial homology groups.

Intersection of submanifolds and cycles. Homological interpretation of the index of a vector field. Lefschetz fixed point theorem and its applications.

Cohomology groups and Poincaré duality. De Rham cohomology groups. Multiplication of cocycles and its applications.

Textbooks: S.Matveev, Lectures on Algebraic Topology, AMS, 1999.

A+ | MATH - Independent Research on Omega-Theorems for Sums of Multiplicative Functions | Fall 2024 | Alexander B. Kalmynin | Study Abroad at the Math in Moscow Program /HSE (Remote)

Work on the omega-theorem of the fractional sigma function. Utilize the functional equation, contour shifting integration, and the Mellin-Barnes integral formula to transform the problem into a linear combination of Bessel functions, which are approximated by asymptotic trigonometric functions. Apply Soundarajan's Lemma to produce precise bounds for these functions and uncover transitional points in the fractional sigma function.

Textbooks: Analytic Number Theory, by Henryk Iwaniec; Emmanuel Kowalski; Papers.

A+ | MATH - Independent Research on Omega-Theorems for Sums of Multiplicative Functions | Summer 2024 | Alexander B. Kalmynin | Study Abroad at the Math in Moscow Program /HSE (Remote)

Work on the omega-theorem of the fractional sigma function. Utilize the functional equation, contour shifting integration, and the Mellin-Barnes integral formula to transform the problem into a linear combination of Bessel functions, which are approximated by asymptotic trigonometric functions. Apply

Soundarajan's Lemma to produce precise bounds for these functions and uncover transitional points in the fractional sigma function.
Textbooks: Analytic Number Theory, by Henryk Iwaniec; Emmanuel Kowalski; Papers.

A | MATH - Independent Research on Quadratic Forms in Analytic Number Theory | Fall 2023 | Alexander B. Kalmynin | Study Abroad at the Math in Moscow Program /HSE (Remote)
Work on the fluctuations of the asymptotic formula for counting Pythagorean triples with the largest term less than a given magnitude x. Focus on some logarithmic improvements on the known bound of error term Ω(x^(1/3)) using Voronoi-type summation formulas and modern strategies of obtaining lower bounds for oscillating sums.
Textbooks: Richard Guy, Unsolved Problems in Number Theory; Papers.

Audit | MATH - Riemann Surfaces | Fall 2022 | Serge Lvosski | Study Abroad at the Math in Moscow Program / HSE (Remote)
The course is mainly devoted to the classical theory of Riemann surfaces and complex algebraic curves, founded by Riemann, Abel, Jacobi, Weierstrass, Hurwitz and others. This fundamental theory is the basis of algebraic geometry, the theory of complex manifolds and other important parts of contemporary mathematics. Lately the theory of Riemann surfaces has played a remarkable role in mathematical physics. Some of these applications will also be considered in the course.
Curriculum:
Riemann surfaces and Fuchsian groups.
Meromorphic functions and the Riemann-Hurwitz formula.
Holomorphic differentials and bilinear Riemann relations.
Meromorphic differentials.
Riemann-Roch theorem.
Weierstrass points.
Canonical embedding.
Elliptic curves and functions.
Jacobi manifolds.
Abel's theorem.
Riemann surfaces and algebraic curves.
Θ-functions.
Addition theorems for Θ-functions.
Abel's map.
The Riemann theorem on zeros.
Θ-divisor.
Θ-functions and integrable systems.
Textbooks:
G. Springer, Introduction to Riemann surfaces, Addison-Wesley Publishing Company, Inc., Reading, Massachusetts, USA, 1957.
H. D. Mumford, Tata Lectures on Theta I, Progress in Mathematics, vol. 28, Birkhauser, 1983.

A | MATH 320 - Introduction to Topology | Spring 2022 | Ágnes Szilard |Study Abroad at the Budapest Semesters in Mathematics Program

This is a standard introductory course the goal of which is to get acquainted with the basic notions of the field. Thus we start with point-set topology and the study of topological spaces, in particular metric spaces, continuity, connectedness, compactness. The machinery developed will allow us to consider one of the major theorems of topology: the classification of compact, connected surfaces. In the second half of the course we get a taste of algebraic topology - the notion of the fundamental group of a topological space will be introduced as well as several ways of computing it. Throughout the course we will study numerous examples and applications.

Topics:

Topological spaces, homeomorphism. First examples. The classification problem and the role of topological invariants.

Constructing new topologies from given ones: the subspace, quotient and product topologies.

Some topological invariants: the Hausdorff property, compactness, connectedness, path-connectedness.

Compact, connected surfaces. Euler characteristic and orientability. The classification theorem of compact connected surfaces.

The fundamental group. Intuitive examples.

Methods to calculate the fundamental group: covering spaces, retracts and deformation retracts.

If time permits: properly discontinuous group actions.

Textbooks: Handouts.

B+ | MATH - Basic Representation Theory | Fall 2023 | Vladimir Ivanov |Study Abroad at the Math in Moscow Program / HSE (Remote)

Representation Theory studies how a group or other algebraic objects may act in vector spaces. It is a fundamental tool for studying groups using Linear Algebra. Representations appear in various models in Mathematical Physics, Number Theory, Algebraic Combinatorics, and other areas of mathematics. The course aims to introduce basic concepts and results of the classical theory of complex representations of finite groups and simple examples of representations of Lie groups and Lie algebras. In this course we consider only finite-dimensional representations.

Program of the Course.

1. Examples of representations. Subrepresentations. Invariant subspaces. Irreducible representations.
2. Direct sum of representations. Complete reducibility. Maschke's theorem.
3. Tensor product of representations.
4. Morphisms of representations. Schur's lemma. Uniqueness of the decomposition of completely reducible representation into a sum of irreducible ones.
5. Characters of representations, their properties. Conjugacy classes. Group algebra. Central functions. Regular representation.
6. Orthogonality of complex matrix elements. Group algebra of a finite group as a product of matrix algebras, corresponding to irreducible representations.
7. Number of irreducible complex characters. Orthogonality relations.
8. Examples of complex character tables: abelian groups, dihedral group Dn, groups S3, S4, A4. Decomposition of tensor products of irreducible representations.
9. Examples of Lie groups. Definition of a matrix Lie group. Connected Lie groups.
10. Covering of SO(3,R) by SU(2).
11. Lie algebra is the tangent space of a Lie group at the identity element. Definition of an abstract Lie algebra.

12. Representations of the Lie algebra sl (2,C).
13. Connection between representations of Lie groups and Lie algebras. Polynomial representation of the Lie group sl(2,C).
14. Tensor product of representations of Lie algebras. Clebsch-Gordan decomposition for the Lie algebra sl(2,C).
15. Compact groups and their representations. Peter-Weyl theorem. 16. Highest weight sl(3,C)-modules. Recommended Textbooks. 1. W. Fulton, J. Harris, Representation Theory. A First Course. 2. E.B. Vinberg, Linear Representations of Groups. 3. G.James, M.Liebeck, Representations and Characters of Groups. (for items 1-5 of the program) 4. B.C. Hall, Lie Groups, Lie Algebras, and Representations. (for items 6-10 of the program)

Textbooks:

Representation Theory.

W. Fulton, J. Harris, Representation theory. A first course. (Sections 1, 2, 4, 7, 8, 11, 12)

E.B. Vinberg, Linear Representations of Groups.

G.James, M.Liebeck, Representations and Characters of Groups. (For the first half of the course, Sections 1-20)

B. Hall, Lie Groups, Lie Algebras, and Representations. An Elementary Introduction (For the second half of the course, Chapters 1-4) Revising Linear Algebra.

S. Freidberg, A. Insel, L. Spence, Linear Algebra. (The sections without an asterisk)

S. Axler, Linear Algebra Done Right.

S. Roman, Advanced Linear Algebra (Chapters 1-3, 7-11, 14, 18).

Revising Group Theory.

C.Pinter, A book of abstract algebra. (Chapters 1-16)

J.Fraleigh, A first course in abstract algebra. (Sections 1-14)

Revising Multivariable Calculus and introductory Differentiable Manifolds notions (for the second half of the course).

W.Boothby, An Introduction to Differentiable Manifolds and Riemannian Geometry (Chapters 1-3)

J.Lee, Introduction to Smooth Manifolds (for a deeper and more general picture, Chapters 1-3)

L.Nicolaescu, Lectures on the Geometry of Manifolds, https://www3.nd.edu/~lnicolae/Lectures.pdf (for a deeper and more general picture, Sections 1.1, 1.2, 2.1)

Additional resources.

A | MATH 394 - Galois Theory | Spring 2024 | Leo Goldmakher|Williams College

Some equations–such as x^5-1=0–are easy to solve. Others–such as x^5-x-1=0–are very hard, if not impossible (using finite combinations of standard mathematical operations). Galois discovered a deep connection between field theory and group theory that led to a criterion for checking whether or not a given polynomial can be easily solved. His discovery also led to many other breakthroughs, for example proving the impossibility of squaring the circle or trisecting a typical angle using compass and straightedge. From these not-so-humble beginnings, Galois theory has become a fundamental concept in modern mathematics, from topology to number theory. In this course we will develop the theory and explore its applications to other areas of math.

Textbooks: Galois Theory, 2nd edition, by David Cox.

A- | MATH 419 - Algebraic Number Theory | Fall 2023 | Allison Pacelli|Williams College

We all know that integers can be factored into prime numbers and that this factorization is essentially unique. In more general settings, it often still makes sense to factor numbers into "primes," but the factorization is not necessarily unique! This surprising fact was the downfall of Lame's attempted proof of Fermat's Last Theorem in 1847. Although a valid proof was not discovered until over 150 years later, this error gave rise to a new branch of mathematics: algebraic number theory. In this course, we will study factorization and other number-theoretic notions in more abstract algebraic settings, and we will see a beautiful interplay between groups, rings, and fields.
Textbooks: Stewart and D. Tall, Algebraic Number Theory and Fermat's Last Theorem.

A | MATH 407 - Dance of the Primes / Analytic Number Theory | Fall 2023 | Thomas A. Garrity|Williams College
Prime numbers are the building blocks for all numbers and hence for most of mathematics. Though there are an infinite number of them, how they are spread out among the integers is still quite a mystery. Even more mysterious and surprising is that the current tools for investigating prime numbers involve the study of infinite series. Function theory tells us about the primes. We will be studying one of the most amazing functions known: the Riemann Zeta Function. Finding where this function is equal to zero is the Riemann Hypothesis and is one of the great, if not greatest, open problems in mathematics. Somehow where these zeros occur is linked to the distribution of primes. We will be concerned with why anyone would care about this conjecture. More crassly, why should solving the Riemann Hypothesis be worth one million dollars? (Which is what you will get if you solve it, beyond the eternal fame and glory).
Textbooks: J. Stopple, A Primer of Analytic Number Theory; T. M. Apostol, Introduction to Analytic Number Theory.

B+ | MATH 442 - Introduction to Descriptive Set Theory | Fall 2022 | Jenna Zomback|Williams College
Descriptive set theory (DST) combines techniques from analysis, topology, set theory, combinatorics, and other areas of mathematics to study definable (typically Borel) subsets of Polish spaces. The first part of this course will cover the topics necessary to understand the main objects of study in DST: we will develop comfort with point-set topology (enough to juggle with Polish spaces and Borel sets), and set theory (just well-orderings and cardinality). The second part of the course will feature selected topics in descriptive set theory: for example, trees, the perfect set property, Baire category, and infinite games.
Textbooks: A. Tserunyan, Introduction to Descriptive Set Theory.

A- | MATH 413 - Algebraic Geometry| Spring 2023 | Ralph E. Morrison|Williams College
Algebraic geometry is the study of shapes described by polynomial equations. It has been a major part of mathematics for at least the past two hundred years, and has influenced a tremendous amount of modern mathematics, ranging from number theory to robotics. In this course, we will develop the Ideal-Variety Correspondence that ties geometric shapes to abstract algebra, and will use computational tools to explore this theory in a very explicit way.
Text: D. A. Cox, J. Little, and D. O'Shea, Ideals, Varieties, and Algorithms.

A | MATH 313 - Introduction to Number Theory | Spring 2023 | Susan R. Loepp|Williams College

The study of numbers dates back thousands of years, and is fundamental in mathematics. In this course, we will investigate both classical and modern questions about numbers. In particular, we will explore the integers, and examine issues involving primes, divisibility, and congruences. We will also look at the ideas of numbers and primes in more general settings, and consider fascinating questions that are simple to understand, but can be quite difficult to answer.
Textbooks: Harold M. Stark, An Introduction to Number Theory.

A | MATH 355 - Abstract Algebra | Spring 2021 | Susan R. Loepp|Williams College
Algebra gives us tools to solve equations. The integers, the rationals, and the real numbers have special properties which make algebra work according to the circumstances. In this course, we generalize algebraic processes and the sets upon which they operate in order to better understand, theoretically, when equations can and cannot be solved. We define and study abstract algebraic structures such as groups, rings, and fields, as well as the concepts of factor group, quotient ring, homomorphism, isomorphism, and various types of field extensions. This course introduces students to abstract rigorous mathematics.
Textbooks: Joseph A. Gallian, Comtemporary Abstract Algebra.

A- | MATH 350 - Real Analysis | Fall 2020 | Leo Goldmakher|Williams College
Why is the product of two negative numbers positive? Why do we depict the real numbers as a line? Why is this line continuous, and what do we mean when we say that? Perhaps most fundamentally, what is a real number? Real analysis addresses such questions, delving into the structure of real numbers and functions of them. Along the way we'll discuss sequences and limits, series, completeness, compactness, derivatives and integrals, and metric spaces. Results covered will include the Cantor-Schroeder-Bernstein theorem, the monotone convergence theorem, the Bolzano-Weierstrass theorem, the Cauchy criterion, Dirichlet's and Riemann's rearrangement theorem, the Heine-Borel theorem, the intermediate value theorem, and many others. This course is excellent preparation for graduate studies in mathematics, statistics, and economics
Textbooks: Richard Johnsonbaugh and W.E.Pfaffenberger, Foundations of Mathematical Analysis.

A- | MATH 345 - Graph Theory |Spring 2022 | Gabor Simonyi | Study Abroad at the Budapest Semesters in Mathematics Program
A brief overview of the basic concepts of graph theory will be followed by an in-depth discussion of some classical chapters of graph theory as well as some aspects of a current area: information theoretic graph theory.
Topics:
Basics: Graphs, degrees, paths and cycles, independent sets, cliques, isomorphism, subgraphs, complement of a graph, trees, Euler tours.
Hamilton cycles: sufficient conditions for Hamiltonicity, theorems of Dirac, Ore, Pósa, and Chvatál, the optimality of Chvatál's theorem.
Matchings: matchings in bipartite graphs, Hall's theorem and K ?onig's theorem, Tutte's theorem, stable matchings, Gale-Shapley theorem.
Colorings: The concept of chromatic number, its relation to the clique number, Mycielsky's construction, coloring edges, Vizing's theorem, list coloring, choice number, its relation to the chromatic number, list coloring conjecture, Galvin's theorem.

Planarity: Euler’s formula, Kuratowski’s theorem, coloring of planar graphs, list coloring of planar graphs.
Basics of extremal graph theory: Tur ´an’s theorem and related results, graph Ramsey theorems.
Perfect graphs: Basic examples, perfectness of comparability graphs, the Perfect Graph Theorem, the Strong Perfect Graph Theorem.
More advanced topics on colorings: Fractional chromatic number, the chromatic number of Kneser graphs and Schrijver graphs.
Capacities of graphs: Products of graphs, Shannon capacity and its bounds, connection to Ramsey numbers, Sperner capacity and other related concepts originated in information theory.
Textbooks: R. Diestel, Graph Theory (available as a digital edition, too) + handouts.

A-| MATH 378 - Quantum Information and Quantum Computation (Quantum Probability and Quantum Logic)| Spring 2022 | Mihaly Weiner | Study Abroad at the Budapest Semesters in Mathematics Program

The course is about the non-classical calculus of probability which is behind Quantum Physics. (Read this short summary written in a "Q&A" form about the essence of Quantum Physics.) The emphasis will be on the mathematical, information-theoretical and philosophycal aspects (but not directly on physics). In the first part of the course the neccessary mathematical tools are introduced, while in the second part some simple physicial systems as well as quantum computers and some "paradoxes" (such as the "EPR" paradox) are discussed.
Topics:
1st part (the mathematical tools): finite dimensional Hilbert spaces, orthogonal projections, operator norms, normal operators, self-adjoint operators, unitary operators, spectral resolution, operator-calculus, positive operators, tensorial products ortho-lattices and probability laws, distributive and non-distributive probability spaces, dispersion free and pure states, measurable quantites the ortho-lattice of projections, Gleason's theory (without proof), operations between measurable quantites.
2nd part (applications): spin systems, the "EPR" paradox, quantum cryptography (the protocol of Bennett and Brassard), state changes, symmetries operations and Wigner's theorem, dense coding, no-clone theorem, quantum bits and quantum computers, complexity and quantum complexity, an example of an algorithm for a quantum computer (either Grover's search algorithm or Shor's algorithm for factorizing numbers)
Textbooks: handouts and Chapter VIII and IX of T. Matolcsi: A Concept of Mathematical Physics, Models in Mechanics.

Audit | MATH 315 - Functional Analysis | Spring 2022 | Dávid Kunszenti-Kovács | Study Abroad at the Budapest Semesters in Mathematics Program

Topics covered:
Normed spaces, Banach spaces: standard examples of function spaces, bounded linear operators, linear functionals, dual spaces and weak topologies.
Hilbert spaces: inner products, orthogonal complements, representation of linear functionals, adjoint operator, self-adjoint, unitary and normal operators.
Fundamental theorems of functional analysis: Hahn-Banach theorem, Uniform Boundedness Theorem, Open Mapping Theorem, Closed Graph Theorem. Spectral theory: resolvent and spectrum, bounded self-adjoint operators, compact operators. Unbounded linear operators and applications to PDE theory.

Textbooks: A Course in Functional Analysis, by John Conway, Springer 2007

A | MATH 341 - Probability | Fall 2022 | Mihai Stoiciu|Williams College

The historical roots of probability lie in the study of games of chance. Modern probability, however, is a mathematical discipline that has wide applications in a myriad of other mathematical and physical sciences. Drawing on classical gaming examples for motivation, this course will present axiomatic and mathematical aspects of probability. Included will be discussions of random variables (both discrete and continuous), distribution and expectation, independence, laws of large numbers, and the well-known Central Limit Theorem. Many interesting and important applications will also be presented, including some from classical Poisson processes, random walks and Markov Chains.

Textbooks: G. Grimmett and D. Stirzaker, Probability and Random Processes.

A+ | MATH 200 - Discrete Math | Fall 2020 | Chad M. Topaz | Williams College

In contrast to calculus, which is the study of continuous processes, this course examines the structure and properties of finite sets. Topics to be covered include mathematical logic, elementary number theory, mathematical induction, set theory, functions, relations, elementary combinatorics and probability, and graphs. Emphasis will be given on the methods and styles of mathematical proofs, in order to prepare the students for more advanced math courses.

Textbooks: Susanna S. Epp, Discrete Mathematics with Applications.

A | MATH 409 - The Little Questions | Fall 2022 | Steven J. Miller | Williams College

Using math competitions such as the Putnam Exam as a springboard, in this class we follow the dictum of the Ross Program and "think deeply of simple things". The two main goals of this course are to prepare students for competitive math competitions, and to get a sense of the mathematical landscape encompassing elementary number theory, combinatorics, graph theory, and group theory (among others). While elementary frequently is not synonymous with easy, we will see many beautiful proofs and "a-ha" moments in the course of our investigations. Students will be encouraged to explore these topics at levels compatible with their backgrounds.

Textbooks: Miodrag S. Petkovic, Famous Puzzles of Great Mathematicians.

B | MATH 317 - Introduction to Operations Research | Fall 2022 | Steven J. Miller | Williams College

In the first N math classes of your career, you can be misled as to what the world is truly like. How? You're given exact problems and told to find exact solutions.The real world is sadly far more complicated. Frequently we cannot exactly solve problems; moreover, the problems we try to solve are themselves merely approximations to the world! We are forced to develop techniques to approximate not just solutions, but even the statement of the problem. Additionally, we often need the solutions quickly. Operations Research, which was born as a discipline during the tumultuous events of World War II, deals with efficiently finding optimal solutions. In this course we build analytic and programming techniques to efficiently tackle many problems. We will review many algorithms from earlier in your mathematical or CS career, with special attention now given to analyzing their run-time and seeing how they can be improved. The culmination of the course is a development of linear programming and an exploration of what it can do and what are its limitations. For those wishing to take this as a Stats course, the final project must have a substantial stats component approved by the instructor.

Textbooks: Joel N Franklin, Methods of Mathematical Economics: Linear and Nonlinear Programming, Fixed-Point Theorems; Notes on linear programming and on random matrix theory.

A+ | MATH 126 - Partial Differential Equations | Summer 2022 | Nima Moini | Berkeley Summer Session 2022

Waves and diffusion, initial value problems for hyperbolic and parabolic equations, boundary value problems for elliptic equations, Green's functions, maximum principles, a priori bounds, Fourier transform.

Textbooks: Walter Strauss, Partial Differential Equations: An Introduction.

A | MATH 128 - Numerical Analysis | Summer 2022 | Per-Olof Sigfred Persson | Berkeley Summer Session 2022

Programming for numerical calculations, round-off error, approximation and interpolation, numerical quadrature, and solution of ordinary differential equations. Practice on the computer.

Textbooks: Richard Burden and J. Douglas Faires, Numerical Analysis.

P | MATH 309 - Differential Equations | Spring 2020 (Pass/Fail for Credit S20 because of COVID-19) | Julie C. Blackwood | Williams College

Historically, much beautiful mathematics has arisen from attempts to explain physical, chemical, biological and economic processes. A few ingenious techniques solve a surprisingly large fraction of the associated ordinary and partial differential equations, and geometric methods give insight to many more. The mystical Pythagorean fascination with ratios and harmonics is vindicated and applied in Fourier series and integrals. We will explore the methods, abstract structures, and modeling applications of ordinary and partial differential equations and Fourier analysis.

Textbooks: Steven H. Strogatz, Nonlinear Gynamics and Chaos.

A- | MATH 151 - Multivariable Calculus | Fall 2019 | Colin C. Adams | Williams College

Applications of calculus in mathematics, science, economics, psychology, the social sciences, involve several variables. This course extends calculus to several variables: vectors, partial derivatives, multiple integrals. There is also a unit on infinite series, sometimes with applications to differential equations.

Textbooks: John Rogawski, Colin Adams, Multivariable Calculus.

94% | MATH - Complex Analysis | Summer 2022 | Coursera Certificate 2022 (Online)

This course provides an introduction to complex analysis which is the theory of complex functions of a complex variable. We will start by introducing the complex plane, along with the algebra and geometry of complex numbers, and then we will make our way via differentiation, integration, complex dynamics, power series representation and Laurent series into territories at the edge of what is known today. Each module consists of five video lectures with embedded quizzes, followed by an electronically graded homework assignment. Additionally, modules 1, 3, and 5 also contain a peer assessment.

The homework assignments will require time to think through and practice the concepts discussed in the lectures. In fact, a significant amount of your learning will happen while completing the homework assignments. These assignments are not meant to be completed quickly; rather you'll need paper and

pen with you to work through the questions. In total, we expect that the course will take 6-12 hours of work per module, depending on your background.
Textbooks: Handouts.

Computer Science Courses

A | CSCI 493 - Honors Thesis in Computer Science | Fall 2023 | Aaron Williams | Williams College
Computer Science thesis. This is part of a full-year thesis (493-494). This course provides highly-motivated students an opportunity to work independently with faculty on research topics chosen by individual faculty. Students are generally expected to perform a literature review, identify areas of potential contribution, and explore extensions to existing results. The course culminates in a concise, well-written report describing a problem, its background history, any independent results achieved, and directions for future research.
Textbooks: KNUTH, D.E. Art of Computer Programming, Volume 4A, Fascicle 4, The: Generating All Trees-History of Combinatorial Generation, Addison-Wesley Profcssional, 2013; OXLEY, J.G. Matroid theory, vol. 3. Oxford University Press, USA, 2006; Papers.

A | CSCI 494 - Honors Thesis in Computer Science | Spring 2024 | Aaron Williams | Williams College
Computer Science thesis. This is part of a full-year thesis (493-494). This course provides highly-motivated students an opportunity to work independently with faculty on research topics chosen by individual faculty. Students are generally expected to perform a literature review, identify areas of potential contribution, and explore extensions to existing results. The course culminates in a concise, well-written report describing a problem, its background history, any independent results achieved, and directions for future research.
Textbooks: KNUTH, D.E. Art of Computer Programming, Volume 4A, Fascicle 4, The: Generating All Trees-History of Combinatorial Generation, Addison-Wesley Profcssional, 2013; OXLEY, J.G. Matroid theory, vol. 3. Oxford University Press, USA, 2006; Papers.

P | CSCI 31 - Honor Senior Thesis in Computer Science | Winter 2024 (Pass/ Fail choice for Winter Study) | Aaron Williams | Williams College
Computer Science thesis. This course provides highly-motivated students an opportunity to work independently with faculty on research topics chosen by individual faculty. Students are generally expected to perform a literature review, identify areas of potential contribution, and explore extensions to existing results. The course culminates in a concise, well-written report describing a problem, its background history, any independent results achieved, and directions for future research.
Textbooks: KNUTH, D.E. Art of Computer Programming, Volume 4A, Fascicle 4, The: Generating All Trees-History of Combinatorial Generation, Addison-Wesley Profcssional, 2013; OXLEY, J.G. Matroid theory, vol. 3. Oxford University Press, USA, 2006; Papers.

B+ | CSCI 381 - Deep Learning | Spring 2024 | Mark Hopkins | Williams College
This course is an introduction to deep neural networks and how to train them. Beginning with the fundamentals of regression and optimization, the course then surveys a variety of neural network

architectures, which may include multilayer feedforward neural networks, convolutional neural networks, recurrent neural networks, and transformer networks. Students will also learn how to use deep learning software such as PyTorch or Tensorflow.

This course teaches you the fundamentals required to be an informed practitioner of deep learning. It will proceed through three temporal zones:

Twilight Zone: In which we learn/review the fundamental background for deep learning, including gradient descent, simple regression models, important probability distributions, regularization, and matrix manipulation (with the Python torch package).

Midnight Zone: In which we learn about mainstream deep learning architectures, including multilayer feed forward networks, convolutional neural networks, and recurrent neural networks.

Abyssal Zone: In which we dive into the cutting edge, examining advanced architectures and important applications.

Learning objectives for this course include (but are not limited to) the following:

Given access to reference documentation for PyTorch, a student will be able to transform an input tensor into a specified goal tensor, while preserving automatic differentiation.

Given a computation graph, a student will be able to compute an arbitrary partial derivative using repeated applications of the Chain Rule of Partial Derivatives.

A student should be able to derive maximum likelihood estimates for ordinary linear regression and robust linear regression.

A student should be able to derive MAP estimates for ridge regression and lasso regresssion.

A student should be able to derive the gradient of the MLE loss function for logistic regression.

A student should be able to devise a dataset that cannot be modeled using logistic regression, and prove that it cannot be modeled. The student should be able to show that the dataset can be modeled using a two-layer feedforward neural network.

A student should be able to use backpropagation to compute the gradient of a loss function with respect to a particular parameter in a simple multilayer feedforward neural network.

Given an example classification/regression problem, a student should be able to design a sensible output layer for a neural network classifier.

A student should be able to define (from memory) the ReLU and softmax functions.

Given the kernel size, number of kernels, and stride, a student should be able to give the dimensions of the parameter tensors of a convolutional neural network.

A student should be able to apply a maxpool operation on an example tensor.

A student should be able to complete a partially drawn function graph for a convolutional neural network.

Given a particular padding and stride, a student should be able to manually convolve a (small) image with a kernel.

A student should be able to draw a function graph for an unraveled recurrent neural network, including giving the dimensions of the parameter tensors. The student should be able to compute partial derivatives using this graph and back propagation.

Textbooks: Handouts; Papers.

A | CSCI 378 - Human - AI Interaction | Fall 2020 | Iris Howley | Williams College

Artificial intelligence (AI) is already transforming society and every industry today. In order to ensure that AI serves the collective needs of humanity, we as computer scientists must guide AI so that it has a

positive impact on the human experience. This course is an introduction to harnessing the power of AI so that it benefits people and communities. We will cover a number of general topics such as: agency and initiative, AI and ethics, bias and transparency, confidence and errors, human augmentation and amplification, trust and explainability, and mixed-initiative systems. We explore these topics via readings and projects across the AI spectrum, including: dialog and speech-controlled systems, computer vision, data science, recommender systems, text summarization, and UI personalization, among others.
Textbooks: Handouts; Papers

A- | CSC I 375 - Natural Language Processing | Spring 2023 | Katie Keith | Williams College
Natural language processing (NLP) is a set of methods for making human language accessible to computers. NLP underlies many technologies we use on a daily basis including automatic machine translation, search engines, email spam detection, and automated personalized assistants. These methods draw from a combination of algorithms, linguistics and statistics. This course will provide a foundation in building NLP models to classify, generate, and learn from text data. Through this course, you can learn the foundational methods used in NLP from first principles in statistics, algorithms, and lingusitics, understand key facts about human language that motivate NLP methods, and critically disern what problems are possible to solve, implement, experiment with, evaluate, and improve NLP models, gaining practical skills for building natural language systems, learn about and navigate the process of an open-ended NLP research project and Reason about the ethical and social implications that arise from NLP systems.
Textbooks: D. Jurafsky and J. H. Martin, Speech and Language Processing. Papers.

A | CSCI 374 - Machine Learning | Fall 2023 | Rohit Bhattacharya | Williams College
Machine learning is a field that derives from artificial intelligence and statistics, and is concerned with the design and analysis of computer algorithms that "learn" automatically through the use of data. Computer algorithms are capable of discerning subtle patterns and structure in the data that would be practically impossible for a human to find. As a result, real-world decisions, such as treatment options and loan approvals, are being increasingly automated based on predictions or factual knowledge derived from such algorithms. This course explores topics in supervised learning (e.g., random forests and neural networks), unsupervised learning (e.g., k-means clustering and expectation maximization), and possibly reinforcement learning (e.g., Q-learning and temporal difference learning.) It will also introduce methods for the evaluation of learning algorithms (with an emphasis on analysis of generalizability and robustness of the algorithms to distribution/environmental shift), as well as topics in computational learning theory and ethics.
Textbooks: Daphne Koller and Nir Friedman, Probabilistic Graphical Models; Steffen L. Lauritzen, Graphical Models; Kevin Murphy, Machine Learning: A Probabilistic Perspective.

A | CSCI 371 - Computer Graphics | Fall 2023 | James Bern | Williams College
This course covers the fundamental mathematics and techniques behind computer graphics, and will teach students how to represent and draw 2D and 3D geometry for real-time and photorealistic applications. Students will write challenging implementations from the ground up in C/C++, OpenGL, and GLSL. Topics include transformations, rasterization, ray tracing, immediate mode GUI, forward and inverse kinematics, and physically-based animation. Examples are drawn from video games, movies, and robotics.

Textbooks: Steve Marschner, Peter Shirley, Fundamentals of Computer Graphics; Tomas Akenine-Moller, Eric Haines, Naty Hoffman, Real-Time Rendering; Papers.

A | CSCI 361 - Theory of Computation | Fall 2022 | Aaron Williams | Williams College

This course introduces a formal framework for investigating both the computability and complexity of problems. We study several models of computation including finite automata, regular languages, context-free grammars, and Turing machines. These models provide a mathematical basis for the study of computability theory–the examination of what problems can be solved and what problems cannot be solved–and the study of complexity theory–the examination of how efficiently problems can be solved. Topics include the halting problem and the P versus NP problem.

Textbooks: Sipser, Michael, Introduction to the Theory of Computation; R. Hearn and E. D. Demaine, Games, Puzzles, and Complexity.

A- | CSCI 334 - Principles of Programming Lang | Spring 2021 | Stephen N. Freund | Williams College

A programming language is a programmer's principle interface to the computer. As such, the choice of an appropriate language can make a large difference in a programmer's productivity. A major goal of this course is to present a comprehensive introduction to the principle features and overall design of both traditional and modern programming languages. You will examine language features both in isolation and in the context of more complete language descriptions. The material will enable you to:

Quickly learn programming languages, and how to apply them to effectively solve programming problems.

Rigorously specify, analyze, and reason about the behavior of a software system using a formally defined model of the system's behavior.

Realize a precisely specified model by correctly implementing it as a program, set of program components, or a programming language.

We will examine features of a large variety of languages, though we will not study many of languages themselves extensively. Like other CS courses, we will discuss alternate ways of solving problems, looking at the pros and cons. Because programming languages are so tied up (and motivated by) programming problems, we will not only investigate language features, but also the software engineering problems that spawned them.

At the end of this course you will have a more thorough understanding of why certain programming language features provide better support for the production of reliable programs, while others are fraught with ambiguity or other problems. Since programming languages mediate between the programmer and the raw machine, we will also gain a deeper understanding of how programming languages are compiled, what actually happens when a program is executed on a computer, and how the programming language design affects these issues. As an example, by the end of the course, you should be able to understand why Java has replaced C++ language of choice for many projects and to recognize where language design is likely to head in the future.

Textbooks: John C. Mitchell, Concepts In Programming Languages. Additional readings will be posted on the web site. The segments of the course that introduce new programming language paradigms will also feature some programming in languages representative of the functional and object-oriented paradigms (Lisp, ML, Scala, and possibly others).

A | CSCI 333 - Storage System | Spring 2021 | William Jannen | Williams College

This course will examine topics in the design, implementation, and evaluation of storage systems. Topics include the memory hierarchy; ways that data is organized (both logically and physically); storage hardware and its influence on storage software designs; data structures; performance models; and system measurement/evaluation. Readings will be taken from recent technical literature, and an emphasis will be placed on identifying and evaluating design trade-offs.

Textbooks: Operating Systems: Three Easy Pieces by Remzi H. Arpaci-Dusseau and Andrea C. Arpaci-Dusseau (version 1.0). The C Programming Language, 2nd edition by Brian Kernighan and Dennis Ritchie. Additional readings will be assigned from various sources, including conference proceedings, research journals, magazines, and textbook excerpts. You may also be required to search out and select resources on your own. Additional readings will be digitally accessible from the course website; they will be accessible while connected to the Williams network (or while off-campus using the library's proxy server).

Audit | CSCI 256 - Algorithms Design and Analysis | Fall 2023 | Aaron Williams | Williams College

This course investigates methods for designing efficient and reliable algorithms. By carefully analyzing the structure of a problem within a mathematical framework, it is often possible to dramatically decrease the computational resources needed to find a solution. In addition, analysis provides a method for verifying the correctness of an algorithm and accurately estimating its running time and space requirements. We will study several algorithm design strategies that build on data structures and programming techniques introduced in Computer Science 136. These include greedy, divide-and-conquer, dynamic programming, and network flow algorithms. Additional topics of study include algorithms on graphs and strategies for handling potentially intractable problems.

Textbooks: Addison-Wesley 2006, Algorithm Design by Jon Kleinberg and Éva Tardos; Jeff Erickson, Algorithms.

P (Pass/Fail for Credit S20 because of COVID-19) | CSCI 237 - Computer Organization | Spring 2020 | Jeannie Albrecht | Williams College

This course provides a programmer's view of how computer systems execute programs, store information, and communicate. It enables students to become more effective programmers, especially in dealing with issues of performance, portability and robustness. It also serves as a foundation for courses on advanced topics, such as security, operating systems, distributed systems, and graphics, where a deeper understanding of systems-level issues is required. At the same time, a model of computer hardware organization is developed from the gate level upward. Topics covered include: machine-level code and its generation, performance evaluation and optimization, computer arithmetic, memory organization and management, and (maybe) networking protocols and supporting concurrent computation.

Textbooks： Randal E. Bryant, David R. O'Hallaron, Computer Systems, A Programmer's Perspective; The C Programming Language (2nd Edition), by Brian W. Kernighan and Dennis M. Ritchie.

B+ | CSCI 136 - Data Structures & Advanced Prog | Fall 2019 | William Lenhart | Williams College

This course builds on the programming skills acquired in Computer Science 134. It couples work on program design, analysis, and verification with an introduction to the study of data structures. Data structures capture common ways in which to store and manipulate data, and they are important in the construction of sophisticated computer programs. Students are introduced to some of the most important and frequently used data structures: lists, stacks, queues, trees, hash tables, graphs, and files. Students will be expected to write several programs, ranging from very short programs to more elaborate systems. Since one of our goals in this course is to teach you how to write large, reliable programs composed from reusable pieces, we will be emphasizing the development of clear, modular programs that are easy to read, debug, verify, analyze, and modify.

Textbooks： William Lenhart and Samuel McCauley, Data Structures and Advanced Programming; Java Structures by Duane A. Bailey.

Certificate | Applied Data Science Program: Leveraging AI for Effective Decision-Making | Spring 2023 | Munther Dahleh, Stefanie Jegelka, Devavrat Shah, Caroline Uhler, John Tsitsiklis | MIT Schwarzman College of Computing

Data is getting created at a rapid pace. It is estimated that more than 2 quintillion bytes of data have been created each day in the last two years. As organizations experience an overflow of data, they are sparing no effort to extract meaningful insights to make smarter business decisions. In order to help you unravel the true worth of data, MIT Professional Education offers the Applied Data Science Program, which aims to prepare data-driven decision makers for the future. The goal of this program aims to:

Understand the intricacies of data science techniques and their applications to real-world problems.

Implement various machine learning techniques to solve complex problems and make data-driven business decisions.

Explore the realms of Machine Learning, Deep Learning, and Neural Networks, and how they can be applied to areas such as Computer Vision.

Develop strong foundations in Python, mathematics, and statistics for data science.

Understand the theory behind recommendation systems and explore their applications to multiple industries and business contexts.

Build an industry-ready portfolio of projects to demonstrate your ability to extract business insights from data.

The program is 12 weeks long: 2 weeks for foundations; 6 weeks of core curriculum, including practical applications; 1 week for project submissions; 3 weeks for a final, integrative Capstone project.

Week 1&2 - Module 1: Foundations for Data Science.

Python Foundations - Libraries: Pandas, NumPy, Arrays and Matrix handling, Visualization, Exploratory Data Analysis (EDA). Statistics Foundations: Basic/Descriptive Statistics, Distributions (Binomial, Poisson, etc.), Bayes, Inferential Statistics.

Week 3 - Module 2: Data Analysis & Visualization

Exploratory Data Analysis, Visualization (PCA, MDS and t-SNE) for visualization and batch correction

Introduction to Unsupervised Learning: Clustering includes - Hierarchical, K-Means, DBSCAN, Gaussian Mixture; Networks: Examples (data as a network versus network to represent dependence among variables), determine important nodes and edges in a network, clustering in a network.

Week 4 - Module 3: Machine Learning

Introduction to Supervised Learning -Regression; Model Evaluation- Cross Validation and Bootstrapping; Introduction to Supervised Learning-Classification

Week 5 - Module 4: Practical Data Science

Decision Trees, Random Forest, Time Series (Introduction).

Week 6 - Learning Break

Week 7 - Module 5: Deep learning
Intro to Neural Networks, Convolutional Neural Networks, Graph Neural Networks
Week 8 - Module 6: Recommendation Systems
Intro to Recommendation Systems, Matrix, Tensor, NN for Recommendation Systems
Week 9 - Project Week
Time for participants to finish and submit their projects
Week 10-12 - Module 7: Capstone Project
Week 10: Milestone 1
Week 11: Milestone 2
Week 12: Synthesis + Presentation
Textbooks : Handouts; Papers

Physics Courses

B+ | PHYS 301 - Quantum Physics | Fall 2023 | Protik K. Majumder | Williams College

This course serves as a one-semester introduction to the formalism, and phenomenology of quantum mechanics. After a brief discussion of historical origins of the quantum theory, we introduce the Schrodinger wave equation, the concept of matter waves, and wave-packets. With this introduction as background, we will continue our discussion with a variety of one-dimensional problems such as the particle-in-a-box and the harmonic oscillator. We then extend this work to systems in two and three dimensions, including a detailed discussion of the structure of the hydrogen atom. Along the way we will develop connections between mathematical formalism and physical predictions of the theory. Finally, we conclude the course with a discussion of angular momentum and spins, with applications to atomic physics, entanglement, and quantum information.

Textbooks: Protik K. Majumder: R.W. Robinett, Quantum Mechanics; Robinett "Quantum Mechanics, 2nd edition, 2006; Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles, Eisberg & Resnick; Introduction to Quantum Mechanics, David Griffiths; Quantum Mechanics (Vol 1), Cohen-Tannoudji, Diu & Laloe. Quantum Mechanics: The Theoretical Minimum, Susskind & Friedman.

A | PHYS 210 - Mathematical Methods for Scientists | Spring 2024 | Frederick W. Strauch | Williams College

This course covers a variety of mathematical methods used in the sciences, focusing particularly on the solution of ordinary and partial differential equations. In addition to calling attention to certain special equations that arise frequently in the study of waves and diffusion, we develop general techniques such as looking for series solutions and, in the case of nonlinear equations, using phase portraits and linearizing around fixed points. We study some simple numerical techniques for solving differential equations. An optional session in Mathematica will be offered for students who are not already familiar with this computational tool.

Textbooks: Computational Physics by N.J. Giordano and H. Nakanishi