Department of Mathematics

2017 - Spring Semester

GRADUATE COURSE SPRING 2017

This schedule is subject to changes. Please contact the Course Instructor for confirmation.

SENIOR UNDERGRADUATE COURSES

Course	Sec #	Course Title	Course Day & Time	Rm #	Instructor
Math 4309	15672	Mathematical Biology	TuTh, 2:30-4 p.m.	M 115	R. Azevedo
Math 4332/6313	12060/13695	Introduction to Real Analysis II	TuTh, 10-11:30 a.m.	F 154	D. Labate
Math 4351	21457	Differential Geometry II	MW, 1-2:30 p.m.	SW 219	M. Ru
Math 4355	21456	Mathematics of Signal Representation	TuTh, 1-2:30 p.m.	CAM 101	D. Labate
Math 4364	19420	Intro. to Numerical Analysis in Scientific Computing	MW, 4-5:30 p.m.	CBB 118	T. Pan
Math 4365	17384	Numerical Methods for Differential Equations	MW, 1-2:30 p.m.	SW 423	J. He
Math 4377/6308	14513/13696	Advanced Linear Algebra I	TuTh, 2:30-4 p.m.	CBB 104	E. Kao
Math 4377/6308	18470/18471	Advanced Linear Algebra I (online)	Online	Online	J. Morgan
Math 4378/6309	12061/13697	Advanced Linear Algebra II	TuTh, 2:30-4 p.m.	F 154	D. Wagner
Math 4380	12062	A Mathematical Introduction to Options	TuTh, 1-2:30 p.m.	CAM 103	I. Timofeyev
Math 4389	12063	Survey of Undergraduate Mathematics	MWF 9-10 a.m.	SEC 201/Hybrid	M. Almus

GRADUATE ONLINE COURSES

Course	Section	Course Title	Course Day & Time	Instructor
Math 5330	13515	Abstract Algebra	Arrange (online course)	K. Kaiser
Math 5332	12089	Differential Equations	Arrange (online course)	G. Etgen
Math 5386	15302	Regression and Linear Models	Arrange (online course)	C. Peters

Math 5397	26816	Dynamical Systems	Arrange (online course)	A. Török

GRADUATE COURSES

Course	Section	Course Title	Course Day & Time	Rm #	Instructor
Math 6303	12096	Modern Algebra II	MWF, 10-11 a.m.	AH 2	M. Tomforde
Math 6308	13696	Advanced Linear Algebra I	TuTh, 2:30-4 p.m.	CBB 104	E. Kao
Math 6308	18471	Advanced Linear Algebra I (online)	Online	Online	J. Morgan
Math 6309	13697	Advanced Linear Algebra II	MWF, Noon-1 p.m.	F 154	D. Wagner
Math 6313	13695	Introduction to Real Analysis	TuTh, 10-11:30 a.m.	F 154	D. Labate
Math 6321	12113	Theory of Functions of a Real Variable	MWF, 11 a.m.-Noon	AH 2	M. Kalantar
Math 6353	21449	Complex Analysis & Geo II	MW, 1-2:30 p.m.	AH 301	G. Heier
Math 6361	13699	Applicable Analysis	TuTh, 4-5:30 p.m.	AH 11	G. Auchmuty
Math 6367	12114	Optimization Theory	TuThu, 11:30 a.m.-1 p.m.	SW 221	R. Glowinski
Math 6371	12115	Numerical Analysis	MW, 1-2:30 p.m.	SEC 203	Y. Kuznetsov
Math 6373	21450	Automatic Learning & Data Mining	TuTh, 11:30 a.m.-1 p.m.	CAM 103	R. Azencott
Math 6378	17464	Basic Scientific Computing	TuTh, 1-2:30 p.m.	AH 301	R. Sanders
Math 6383	12116	Probability Statistics	TuTh, 10-11:30 a.m.	SW 423	W. Fu
Math 6395	21452	Analytic Functions, Hardy Spaces and Operator Function Theory	MWF, Noon-1 p.m.	AH 2	D. Blecher
Math 7321	21453	Functional Analysis	TuTh, 1-2:30 p.m.	M 104	B. Bodmann
Math 7326	21454	Dynamical Systems	MWF, 11 a.m.-Noon	AH 301	V. Climenhaga
Math 7350	12176	Geometry of Manifolds	MW, 4-5:30 p.m.	AH 10	W. Ott

----------Course Details----------

SENIOR UNDERGRADUATE COURSES

Math 4309 (15672) - Mathematical Biology

Prerequisites: MATH 3331 and BIOL 3306 or consent of instructor.

Text(s): A Biologist's Guide to Mathematical Modeling in Ecology and Evolution by Sarah P. Otto and Troy Day; ISBN-13:9780691123448

Description: Topics in mathematical biology, epidemiology, population models, models of genetics and evolution, network theory, pattern formation, and neuroscience. Students may not receive credit for both MATH 4309 and BIOL 4309.

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Math 4332 (12060) - Introduction to Real Analysis II

Prerequisites:	MATH 4331 or consent of instructor
Text(s):	Real Analysis with Real Applications | Edition: 1; Allan P. Donsig, Allan P. Donsig; ISBN: 9780130416476
Description:	Further development and applications of concepts from MATH 4331. Topics may vary depending on the instructor's choice. Possibilities include: Fourier series, point-set topology, measure theory, function spaces, and/or dynamical systems.

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Math 4351 (21457) - Differential Geometry II

Prerequisites:	MATH 4350.
Text(s):	Instructor's notes will be provided.
Description:	Continuation of the study of Differential Geometry from MATH 4350. Holonomy and the Gauss-Bonnet theorem, introduction to hyperbolic geometry, surface theory with differential forms, calculus of variations and surfaces of constant mean curvature, abstract surfaces (2D Riemannian manifolds).

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Math 4355 (21456) - Mathematics of Signal Representation

Prerequisites:	MATH 2433 and six additional hours of 3000-4000 level Mathematics
Text(s):	A First Course in Wavelets with Fourier Analysis | Edition: 2 by Albert Boggess, Francis J. Narcowich, **ISBN-13**: 9780470431177
Description:	Fourier series of real-valued functions, the integral Fourier transform, time-invariant linear systems, band-limited and time-limited signals, filtering and its connection with Fourier inversion, Shannon's sampling theorem, discrete and fast Fourier transforms, relationship with signal processing.

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Math 4364 (19420)- Numerical Analysis in Scientific Computing

Prerequisites:	MATH 3331 and COSC 1410 or equivalent or consent of instructor. **Instructor's Prerequisite Notes:** 1. MATH 2331, In depth knowledge of Math 3331 (Differential Equations) or Math 3321 (Engineering Mathematics) 2. Ability to do computer assignments in FORTRAN, C, Matlab, Pascal, Mathematica or Maple.

Text(s): Numerical Analysis (9th edition), by R.L. Burden and J.D. Faires, Brooks-Cole Publishers, ISBN:9780538733519

Description: This is an one semester course which introduces core areas of numerical analysis and scientific computing along with basic themes such as solving nonlinear equations, interpolation and splines fitting, curve fitting, numerical differentiation and integration, initial value problems of ordinary differential equations, direct methods for solving linear systems of equations, and finite-difference approximation to a two-points boundary value problem. This is an introductory course and will be a mix of mathematics and computing.

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Math 4365 (17384) - Numerical Methods for Differential Equations

Prerequisites: MATH 3331, or equivalent, and three additional hours of 3000–4000 level Mathematics.

Text(s): TITLE:TBA, AUTHOR:TBA, ISBN:TBA

Description: Numerical differentiation and integration, multi-step and Runge-Kutta methods for ODEs, finite difference and finite element methods for PDEs, iterative methods for linear algebraic systems and eigenvalue computation.

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Math 4377 (14513) - Advanced Linear Algebra I

Prerequisites: MATH 2331 or equivalent, and three additional hours of 3000–4000 level Mathematics.

Text(s): Linear Algebra | Edition: 4; Stephen H. Friedberg, Arnold J. Insel, Lawrence E. Spence; ISBN: 9780130084514

Description: Linear systems of equations, matrices, determinants, vector spaces and linear transformations, eigenvalues and eigenvectors.

Additional Notes: This is a proof-based course. It will cover Chapters 1-4 and the first two sections of Chapter 5. Topics include systems of linear equations, vector spaces and linear transformations (developed axiomatically), matrices, determinants, eigenvectors and diagonalization.

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Math 4377 (18470) - Advanced Linear Algebra I *(Online)*

Prerequisites: MATH 2331 or equivalent, and six additional hours of 3000–4000 level Mathematics.

Text(s): Linear Algebra | Edition: 4; Stephen H. Friedberg, Arnold J. Insel, Lawrence E. Spence; ISBN: 9780130084514

Description: Linear systems of equations, matrices, determinants, vector spaces and linear transformations, eigenvalues and eigenvectors.

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Math 4378 (12061) - Advanced Linear Algebra II

Prerequisites: MATH 4377

Text(s): Linear Algebra, Fourth Edition, by S.H. Friedberg, A.J Insel, L.E. Spence,Prentice Hall, ISBN 0-13-008451-4; 9780130084514

Similarity of matrices, diagonalization, Hermitian and positive definite matrices, normal matrices, and canonical forms, with applications.

Description:

Instructor's Additional notes: This is the second semester of Advanced Linear Algebra. I plan to cover Chapters 5, 6, and 7 of textbook. These chapters cover Eigenvalues, Eigenvectors, Diagonalization, Cayley-Hamilton Theorem, Inner Product spaces, Gram-Schmidt, Normal Operators (in finite dimensions), Unitary and Orthogonal operators, the Singular Value Decomposition, Bilinear and Quadratic forms, Special Relativity (optional), Jordan Canonical form.

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Math 4380 (12062) - A Mathematical Introduction to Options

Prerequisites: MATH 2433 and MATH 3338.

Text(s): An Introduction to Financial Option Valuation: Mathematics, Stochastics and Computation | Edition: 1; Desmond Higham; 9780521547574

Description: Arbitrage-free pricing, stock price dynamics, call-put parity, Black-Scholes formula, hedging, pricing of European and American options.

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Math 4389 (12063) - Survey of Undergraduate Mathematics

Prerequisites: MATH 3330, MATH 3331, MATH 3333, and three hours of 4000-level Mathematics.

Text(s): Instructor will use her own notes

Description: A review of some of the most important topics in the undergraduate mathematics curriculum.

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ONLINE GRADUATE COURSES

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MATH 5330 (13515) - Abstract Algebra

Prerequisites: Graduate standing.

Text(s): *Abstract Algebra , A First Course* by Dan Saracino. Waveland Press, Inc. ISBN 0-88133-665-3 (You can use the first edition. The second edition contains additional chapters that cannot be covered in this course.)

Description: Groups, rings and fields; algebra of polynomials, Euclidean rings and principal ideal domains. Does not apply toward the Master of Science in Mathematics or Applied Mathematics.

Other Notes: This course is meant for students who wish to pursue a Master of Arts in Mathematics (MAM). Please contact me in order to find out whether this course is suitable for you and/or your degree plan. *Notice that this course **cannot** be used for MATH 3330, Abstract Algebra.*

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MATH 5332 (12089) - Differential Equations

Prerequisites: Graduate standing. MATH 5331.
Text(s): TBA

Description: Linear and nonlinear systems of ordinary differential equations; existence, uniqueness and stability of solutions; initial value problems; higher dimensional systems; Laplace transforms. Theory and applications illustrated by computer assignments and projects. Applies toward the Master of Arts in Mathematics degree; does not apply toward the Master of Science in Mathematics or the Master of Science in Applied Mathematics degrees.

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MATH 5386 (15302) - Regression and Linear Models

Prerequisites: Graduate standing. Two semesters of calculus, one semester of linear algebra, and MATH 5385, or consent of instructor.

Text(s): Introduction to Linear Regression Analysis | Edition:5; Montgomery, Peck, Vining;
ISBN: 9780470542811; Wiley

Description: Simple and multiple linear regression, linear models, inferences from the normal error model, regression diagnostics and robust regression, computing assignments with appropriate software. Applies toward Master of Arts in Mathematics degree; does not apply toward the Master of Science in Mathematics or the Master of Science in Applied Mathematics degrees.

Note: This course is VEE approved for the regression component only. Approval Code: 4458-11008. For more information on VEE approved courses, click here.

MATH 5397 (26816) - Dynamical Systems

Prerequisites: Graduate standing. Three semesters of Calculus or consent of instructor. Basic knowledge of ODE's is helpful, but not required

Text(s): Steven H. Strogatz: Nonlinear Dynamics and Chaos (with Applications to Physics, Biology, Chemistry, and Engineering) Second Edition, 2014.

Print ISBN: 9780813349107

Ebook ISBN: 9780813349114

Description: We will discuss applications of nonlinear dynamics, following the book by Strogatz. Topics that will be considered include (for more details, check the book's table of contents): an introduction to Ordinary Differential Equations (ODE's), one-dimensional ODE's and their bifurcations; two-dimensional ODE's (linear case, limit cycles and the Poincare-Bendixson Theorem, the Hopf bifurcation), chaotic systems (logistic family, Lorenz equations, Henon map).For visualization we will use tools that do not require programming, with the option to additionally run/write Matlab code.

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GRADUATE COURSES

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MATH 6303 (12096) - Modern Algebra II

Prerequisites: Graduate standing. MATH 4333 or MATH 4378 or consent of instructor

Text(s): Abstract Algebra, 3rd Edition by David S. Dummit and Richard M. Foote.

ISBN-13: 978-0471433347

ISBN-10: 0471433349

Description: Topics from the theory of groups, rings, fields, and modules.

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MATH 6308 (14458) - Advanced Linear Algebra I

Prerequisites: Graduate standing. MATH 2331 and a minimum of 3 semester hours transformations, eigenvalues and eigenvectors.

Text(s): Linear Algebra | Edition: 4; Stephen H. Friedberg, Arnold J. Insel, Lawrence E. Spence; ISBN: 9780130084514

Description: Transformations, eigenvalues and eigenvectors.

Additional Notes: This is a proof-based course. It will cover Chapters 1-4 and the first two sections of Chapter 5. Topics include systems of linear equations, vector spaces and linear transformations (developed axiomatically), matrices, determinants, eigenvectors and diagonalization.

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MATH 6308 (20438) - Advanced Linear Algebra I *(online)*

Prerequisites: Graduate standing. MATH 2331 and a minimum of 3 semester hours transformations, eigenvalues and eigenvectors.

Text(s): Linear Algebra | Edition: 4; Stephen H. Friedberg, Arnold J. Insel, Lawrence E. Spence; ISBN: 9780130084514

Description: Transformations, eigenvalues and eigenvectors. An expository paper or talk on a subject related to the course content is required

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MATH 6309 (13697) - Advanced Linear Algebra II

Prerequisites: Graduate standing and MATH 6308

Text(s): Linear Algebra, Fourth Edition, by S.H. Friedberg, A.J Insel, L.E. Spence,Prentice Hall, ISBN 0-13-008451-4; 9780130084514

Description: Similarity of matrices, diagonalization, hermitian and positive definite matrices, canonical forms, normal matrices, applications. An expository paper or talk on a subject related to the course content is required.

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MATH 6313 (13695)- Introduction to Real Analysis II

Prerequisites: Graduate standing and MATH 6312.

Text(s): TBA

Description: Properties of continuous functions, partial differentiation, line integrals, improper integrals, infinite series, and Stieltjes integrals. An expository paper or talk on a subject related to the course content is required.

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MATH 6321 (12113) - Theory of Functions of a Real Variable

Prerequisites:

Graduate standing. MATH 4332 or consent of instructor.

Instructor's Prerequisite Notes: MATH 6320

Text(s):

Primary (Required): Real Analysis: Modern Techniques and Their Applications, Gerald Folland (2nd edition); ISBN: 9780471317166.

Supplementary (Recommended): Real Analysis for Graduate Students, Richard F. Bass, (2nd edition); ISBN: 9781481869140

Description:

Lebesque measure and integration, differentiation of real functions, functions of bounded variation, absolute continuity, the classical Lp spaces, general measure theory, and elementary topics in functional analysis.

Instructor's Additional Notes: Math 6321 is the second course in a two-semester sequence intended to introduce the theory and techniques of modern analysis. The core of the course covers elements of functional analysis, Radon measures, elements of harmonic analysis, the Fourier transform, distribution theory, and Sobolev spaces. Additonal topics will be drawn from potential theory, ergodic theory, and the calculus of variations.

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MATH 6353 (21449) - Complex Analysis & Geo II

Prerequisites:

Graduate standing. Math 6352 or consent of instructor.

Text(s):

- **Principles of Algebraic Geometry** | Edition: 1, Author: Phillip Griffiths, Joseph Harris; ISBN: 9780471050599 *(recommended)*

- **Positivity in Algebraic Geometry I: Classical Setting: Line Bundles and Linear Series**, Author: R.K. Lazarsfeld; ISBN: 9783540225331 *(recommended)*

Description:

Idea sheaves with its applications and advanced techniques in transdental algebraic geometry.

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MATH 6361 (13699) - Applicable Analysis

Prerequisites:

Graduate standing. MATH 4332 or consent of instructor.

Text(s):

The instructor will provide lecture notes on the material. A reference text is L.D. Berkowitz, Convexity and Optimization in Rn, Wiley-Interscience 2002.

Description:

This course provides an introduction to the mathematical analysis of finite dimensional optimization problems. Topics to be studied include the existence of, and the extremality conditions that hold at, solutions of constrained and unconstrained optimaization problems. Elementary theory of convex sets, functions and constructions from convex analysis will be introduced and used. Concepts include subgradients, conjugate functions and some duality theory. Specific problems to be studied include energy and least squares methods for solving linear equations, important inequalities, eigenproblems and some nonlinear programming problems from applications.

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MATH 6367 (12114)- Optimization Theory

Prerequisites: Graduate standing. MATH 4331 and MATH 4377.

-Instructor will provide notes.

Text(s): -R. Glowinski, J.L. Lions, JW He, **Exact and Approximate Controllability for Distributed Systems: A Numerical Approach**, Cambridge University Press, New York, NY, 2008. ISBN: 9780521885720 *(recommended)*

Description: Constrained and unconstrained finite dimensional nonlinear programming, optimization and Euler-Lagrange equations, duality, and numerical methods. Optimization in Hilbert spaces and variational problems. Euler-Lagrange equations and theory of the second variation. Application to integral and differential equations.

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MATH 6371 (12115) - Numerical Analysis

Prerequisites: Graduate standing.

Text(s): **Numerical Mathematics (Texts in Applied Mathematics)**, 2nd Ed., V.37, Springer, 2010. By A. Quarteroni, R. Sacco, F. Saleri. ISBN: 9783642071010

Description: Ability to do computer assignments. Topics selected from numerical linear algebra, nonlinear equations and optimization, interpolation and approximation, numerical differentiation and integration, numerical solution of ordinary and partial differential equations.

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MATH 6373 (21450) - Automatic Learning & Data Mining

Prerequisites: Graduate standing. Probability & Statistics

Text(s): Instructor will provide his own notes.

Automatic Learning of unknown functional relationships Y = F(X) between an output Y and high-dimensional inputs X , involves algorithms dedicated to the intensive analysis of large "training sets" of N "examples" of inputs/outputs pairs (Xn,Yn), with n= 1…N to discover efficient "blackboxes" approximating the unknown function X->F(X). Automatic learning was first applied to emulate intelligent tasks involving complex patterns identification, in artificial vision, face recognition, sounds identification, speech understanding, handwriting recognition, texts classification and retrieval, etc. Automatic learning has now been widely extended to the analysis of high dimensional biological data sets in proteomics and genes interactions networks, as well as to smart mining of massive data sets gathered on the Internet.

Description: The course will study major machine learning algorithms derived from Positive Definite Kernels and their associated Self-Reproducing Hilbert spaces. We will study the implementation, performances, and drawbacks of Support Vector Machines classifiers, Kernel based Non Linear Clustering, Kernel based Non Linear Regression, Kernel PCA. We will explore connections between kernel based learning and Dictionary Learning as well as Artificial Neural Nets with emphasis on key conceptual features such as generalisation capacity. We will present classes of Positive Definite Kernels designed to handle the long "string descriptions" of proteins involved in genomics and proteomics.

The course will focus on understanding key concepts through their mathematical formalization, as well as on computerized algorithmic implementation and intensive testing on actual data sets

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MATH 6378 (17464) - Basic Scientific Computing

Prerequisites: Graduate standing. MATH 4364 and MATH 4365 or equivalent, and either COSC 1304 or COSC 2101 or equivalents.

Text(s): Instructor will provide his own notes.

Description: A project-oriented course in fundamental techniques for high performance scientific computation. Hardware architecture and floating point performance, code design, data structures and storage techniques related to scientific computing, parallel programming techniques, applications to the numerical solution of problems such as algebraic systems, differential equations and optimization. Data visualization.

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MATH 6383 (12116) - Probability Statistics

Prerequisites: Graduate standing. MATH 3334, MATH 3338 and MATH 4378.

Instructor's Prerequisites:TBA

Text(s): **Recommended Text**: John A. Rice : Mathematical Statistics and Data Analysis, 3rd editionBrooks / Cole, 2007. ISBN-13: 978-0-534-39942-9.

Reference Texts:

-P. MuCullagh and J.A. Nelder: Generealized Linear Models, 2nd ed. 1999 Chapman Hall/CRC. ISBN: 978-0412317606

-Raymond H. Myers, Douglas C. Montgomery, G. Geoffrey Vining, Timothy J. Robinson, Generalized Linear Models: with Applications in Engineering and the Sciences, 2nd ed. Wiley, 2010. ISBN: 978-0-470-45463-3.

Description: A survey of probability theory, probability models, and statistical inference. Includes basic probability theory, stochastic processes, parametric and nonparametric methods of statistics.

Instructor's Description: This course is designed for graduate students who have been exposed to basic probability and statistics and would like to learn more advanced statistical theory and techniques in modelling data of various types, including continuous, binary, counts and others. The selected topics will include basic probability distributions, likelihood function and parameter estimation, hypothesis testing, regression models for continuous and categorical response variables, variable selection methods, model selection, large sample theory, shrinkage models, ANOVA and some recent advances.

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MATH 6395 (21452) - Analytic Functions, Hardy Spaces and Operator Function Theory

Prerequisites: Graduate Standing. Some parts of the Real Variables sequence would be helpful, e.g. Math 6320

Text(s):	Banach Spaces of Analytic Functions (Dover Books on Mathematics), by Kenneth Hoffman; ISBN: 978-0486458748. Instructor will also provide some typed notes, drawn from several texts.
Description:	**Brief description:** We will start with some important theorems in complex analysis related to normal families of analytic functions. We then will study the basic theory of the disk algebra and the important theory of Hardy spaces (which we have not taught at UH for some years). We will follow Hoffman's book closely here. In the second half of the course we will discuss some operator function theory e.g. related to the invariant subspace problem (Beurling's theorem and generalizations). We will also discuss abstract operator algebras on a Hilbert space and their theory, and connections to noncommutative function theory. The course will end with a choice of student projects depending on what they are each interested in, for example a treatment of noncommutative integration and noncommutative Hardy spaces.

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MATH 7321 (21453) - Functional Analysis

Prerequisites:	Graduate standing.
Text(s):	Textbook:
Description:	Linear topological spaces, Banach and Hilbert spaces, duality, and spectral analysis.

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MATH 7326 (21454) - Dynamical Systems

Prerequisites:	Graduate standing. Math 6320 or equivalent background in measure theory. Some familiarity with smooth manifolds would be useful but will not be assumed.
Text(s):	Textbook: Katok and Hasselblatt, Introduction to the Modern Theory of Dynamical Systems, Cambridge, ISBN-13: 978-0521575577, ISBN-10: 0521575575 Additional reference text (not required): Rufus Bowen, Equilibrium States and the Ergodic Theory of Anosov Diffeomorphisms, 2008 (2nd Revised Edition), Springer Lecture Notes in Mathematics #470, ISBN 9783540776055
Description:	This course will give an introduction to the theory of dynamical systems, with particular emphasis on those systems displaying hyperbolic (chaotic) behavior. After a general overview, we will describe the key properties of uniformly hyperbolic systems, including structural stability and finite Markov partitions. Then we will explain how tools from thermodynamics can be used to deduce statistical properties of the system, especially for the "physically relevant" Sinai-Ruelle-Bowen measure. Finally, we will give a brief overview of the more physically realistic class of nonuniformly hyperbolic systems, including the multiplicative ergodic theorem, Pesin theory, and countable-state Markov codings.

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MATH 7350 (12176) - Geometry of Manifolds

Prerequisites:	Graduate standing. MATH 6342.
Text(s):	Introduction to Smooth Manifolds (Graduate Texts in Mathematics, Vol. 218) 2nd Edition, John Lee, **ISBN-13**: 978-1441999818; **ISBN-10:** 1441999817
Description:	Math 7350 is an introduction to the theory of differentiable manifolds. Topics include vector bundles, embedding theory, tensors, integration on manifolds, flows, elements of Lie theory, and Riemannian metrics.

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