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African Institute for Mathematical Sciences Ghana
(AIMS Ghana)

COURSES FOR 2023/24 ACADEMIC YEAR

Course Code	Lecturer	Course Title
SKILLS PHASE		
Block S1 (18th Sept - 6th Oct 2023)		
MSCI 505/605	Bernard Bainson	Mathematical Problem Solving
MSCI 531/631	Patrick Dorey	Ordinary Differential Equations
Block S2 (9th-27th Oct 2023)		
MSCI 503/603	Eyram Schwinger	Introduction to Computing and Python
MSCI 509/609	Heather Yorston	Introduction to Linear Algebra
Reading week (30th Oct -3rd Nov 2023)		
Block S3 (6th-24th Nov 2023)		
MSCI 507/607	Rhoda Hawkins & Eugene Adjei	Physical Problem Solving
MSCI 561/661	Francis Torgbor	Statistical Problem Solving
REVIEW PHASE (ELECTIVE COURSES)		
Block R1 (27 Nov- Dec 15 2023)		
MSCI 574/674	Beatrice Pelloni	Fluid dynamics
MSCI 535/635	Hallowed Olaoluwa	Functional Analysis
MSCI 572/672	Ava Khamseh & Sjoerd Beentjes	Causal inference
Christmas break (18-29th Dec 2023)		
Block R2 (2nd-19th Jan 2024)		
MSCI 532/632	John Parker	Hyperbolic Geometry
MSCI 587/687	Hans Nordstrom	Category Theory
MSCI 594/694	Antonio Duarte Pereira Junior	Quantum Theory in a Nut Shell
Block R3 (22nd Jan - 9th Feb 2024)		
MSCI 562/662	Issa Karambal	Machine Learning
MSCI 564/664	Djoko Wirosoetisno	Dynamical Systems
MSCI 571/671	Zuzana Masárová	Topics in computational Geometry
Reading week (12-16th Feb 2024)		
Block R4 (19th Feb- 8 March 2024)		
MSCI 532/632	Brigitte Servatius	Graphs and Matroids
MSCI 596/696	Nick Monk	Mathematical Biology
MSCI 556/656	Sylla Bamba	Introduction to Climate Modeling
Block R5 (11-29th March 2024)		
MSCI 526/626	Vishnu Jejjala	Statistical Physics
MSCI 535/635	Ulrich Krähmer	Noncommutative Algebra and Geometry
MSCI 558/658	Olivier Pamen	Stochastic Analysis
Easter Reading week (1st-5th April 2024)		
	Block R6 (8th-26th April 2024)	
MSCI 578/678	Ed Daw	Introduction to General Relativity
MSCI 573/673	Stephane Ouvry	Random Systems, Information Theory and Related Topics
MSCI 553/653	Daniel Agyapong	Entrepreneurship

Course Descriptions

MSCI 505/605: Mathematical Problem Solving

a. **Objective:** The objective is to: illustrate, gain practical experience and study different approaches to problem solving and research.
b. **Content:** This course considers a variety of elementary, but challenging problems in different branches of pure mathematics. Investigations, comparisons of different methods of attack, literature searches, solutions and generalisations of the problems will arise in discussions in class.
c. **Reading materials include:**
   1. Martin J. Erickson and Joe Flowers, (1999). Principles of Mathematical Problem Solving, Prentice Hall.
   2. L.C. Larson, (1983). Problem Solving through Problems. Problem Books in Mathematics, Springer-Verlag.
   3. Mary Boas, Mathematical Methods in the Physical Sciences, Wiley (2nd Edition 1983)
   4. W. A. Wickelgren (1995) How to Solve Mathematical Problems, Dover Books

MSCI 558/658: Ordinary Differential Equations

a. **Objectives:** Students should be able to:
   State, prove and apply the fundamental existence and uniqueness results for ODEs and qualitative techniques for the study of behaviour of solutions for ODEs.

b. **Content**: This course is an introduction to the theory and applications of differential equations, covering the following topics:
   1. Classification of ODEs and elementary methods of integration
   2. Existence and uniqueness results for systems of ODEs
   3. Applications of second order systems
   4. Phase diagrams, equilibrium points and the concept of stability
c. Reading materials include:
   1. Arnold V. I., (1973), Ordinary differential equations., MIT Press.
   2. Barreira L. and Valls C., (2010), Ordinary differential equations: qualitative theory. AMS,ISBN: 978-0-8218-8749-3.
   3. Hirsch M. W. and Smale S., (2004), Differential equations, dynamical systems and an introduction to chaos", Academic Press/Elsevier, ISBN: 978-0-12-349703-1.
   4. Bernd J. Schroers, (2011). Ordinary differential equations: a practical guide, Cambridge, ISBN: 978-1-107-69749-2, AIMS Library Series.

MSCI 503/603: Introduction to Computing and Python

a. **Objective:** Upon successfully completing this course, students will be able to: "do something useful with Python".
   1. Navigate their way around Ubuntu and Google Apps
   2. Produce scientific documents using LATEX and presentation slides in Beamer
   3. Identify/characterise/define a problem

4. Design a program to solve the problem
5. Create executable code
6. Read most Python code
7. Write basic unit tests

b. Content: The LaTeX section of the course introduces students to the LaTeX document preparation system and gives them an opportunity to use it to prepare technical reports and presentations. In the Python section of the course, we will cover (1) programming (2) for research (3) with Python, IN THAT ORDER.

First, we will develop the practical skill of programming: expressing a task (1) in a formal language, (2) in a way that is useful, and doing so (3) quickly and (4) flexibly.

Second, we will focus on tasks that are most pertinent to research (rather than more general-purpose programming, like making a text editor or music player), e.g.:

- reading / writing data
- transformation / subsetting of data
- bulk analysis of data
- enumeration of states
- approximation and simulation of models
- visualisation of results

Finally, we will cover how to realise these tasks in a particular language - Python - using tools associated with that language (e.g., the command line interpreter, scripts, Python notebooks).

c. Reading materials include:

1. Programming in Python 3: A Complete Introduction to the Python Language (https://www.safaribooksonline.com/library/view/programming-in-python/9780321699909/)
2. Data Science from Scratch: First Principles with Python (https://www.safaribooksonline.com/library/view/data-science from/9781491901410/)
3. Python Data Analytics: Data Analysis and Science Using Pandas, matplotlib, and the Python Programming Language (https://www.safaribooksonline.com/library/view/python-data-analytics/9781484209585/)
4. Problem Solving with Python (https://problemsolvingwithpython.com/)
5. George Grätzer, (2007), More Math into LaTeX, 4th edition, Springer, ISBN 978-0387322896.
6. Stefan Kottwitz, (2011), LaTeX Beginner's Guide. Packt Publishing.
7. LaTeX Wikibook: https://upload.wikimedia.org/wikipedia/commons/2/2d/LaTeX.pdf

MSCI 509/609: Introduction to Linear Algebra

In this course, we will study vectors, matrices, linear transformations, systems of linear equations and eigenvalues and vectors. For vectors, we will introduce the concepts of linear independence, span, bases and subspaces. Under matrices, the focus will be on operations of matrices, special matrices, elementary row operations and the rank of a matrix. Properties of linear transformations and the rank-nullity theorem will be discussed. Given a system of linear equation, we will learn how to write it in terms of matrices and how to solve the system of equations using elementary row operations. We will also learn how to find eigenvalues and vectors and why they are important.

MSCI 507/607: Physical Problem Solving

a. Objective: The students will be able to:

1. describe and explain physics concepts including knowing where and when they apply;
2. apply physics concepts when solving problems and examining physical phenomena
3. apply concepts in new contexts and combine concepts, when analysing a situation.
4. develop a good functional understanding of physics

b. Content: The course has three components:

1. Overview lecturers (two per week) outlining the history, main branches and key concepts in physics such as space and time, force, energy, fields, temperature, entropy, uncertainty in quantum theory.
2. Problems solving in small groups, focusing on problems which can be addressed with minimal technical prerequisites. Use of scaling and dimensional analysis, order of magnitude estimates, simple programming if possible.
3. Individual essays on a standard and fundamental topic in physics, e.g. the Kepler Problem.

c. Reading materials include:

1. Moursund's book, Brief Introduction to Roles of Computers in Problem Solving,
2. Kenneth Heller, Patricia Heller, (2010) University of Minnesota. Cooperative Problem Solving in Physics A User’s Manual.
3. Mary Boas, Mathematical Methods in the Physical Sciences, Wiley (2nd Edition 1983)
4. Michael Conterio, How To Solve Physics Problems (2019)

MSCI 561/661: Probability and Statistics

a. Objective: The course objective is to familiarise students with a mathematically rigorous approach to probability and statistics and to handle problems both analytically and computationally using R.

b. Content: An introductory probability and mathematical statistical course with applications to finance, operations research and statistical inference. In particular the following will be treated: causal relationships, Gaussian response models, multinomial models and goodness of fit tests and Estimation.

c. Reading materials include:

1. De Veaux, R, Velleman, P., and Bock, D. (2014). Introductory Statistics with DVD. 4th ed. New York: Pearson/Addison-Wesley.
2. Craine III, William B.,DeVeaux, R., Velleman, P. and Bock, D. (2014). Introductory Statistics. Student Solutions Manual. 4th ed. New York: Pearson/Addison-Wesley.
3. Jeffrey O. Bennett, William L. Briggs, and Mario F. Triola, (2009). Statistical Reasoning For Everyday Life: 3rd ed. Pearson
4. STAT 220/230/240 COURSE NOTES by Chris Springer, Revised by Jerry Lawless, Don McLeish and Cyntha Struthers.
5. STATISTICS 231 COURSE NOTES, 2016 Edition, Department of Statistics and Actuarial Science, University of Waterloo,

MSCI 553/653: Leadership, Entrepreneurship and Professional Development

a. **Objectives:** At the end of the course, students would be able to:
   1. equip students with a wider and deeper set of innovative skills, customised to fit both organisation's needs and their career goals;
   2. set the context for entrepreneurship and understand the role and importance of the small and medium-sized enterprises in economic and social development;
   3. gain knowledge on the characteristics of entrepreneurs and the entrepreneurial process;
   4. evaluate the feasibility of a new business concept, and learn how to develop, write and present an effective business plan for a new venture and
   5. enable students develop the ability and competencies in setting up and managing new and existing venture.

b. **Content:** This course examines the theory and practice of promoting and managing innovation in start-ups and existing firms. It explores successful frameworks, strategies, funding techniques, business models, risks, and barriers for introducing break-through products and services. Topics include business model innovation, design-driven innovation, leadership, strategy, information technology, knowledge management, process improvement, performance measurement, and change management.

c. **Reading materials include:**
   1. Allen, K. R. (2011). New Venture Creation: An Entrepreneurial Approach. Stamford, CT: Cengage Learning.
   2. Barringer, R.B., Ireland, D.R. (2012) Entrepreneurship: Successfully Launching New Ventures (4th ed). London: Pearson Education.
   3. Boachie-Mensah, F. O. &Marfo-Yiadom, E. (2005).Entrepreneurship and small business management. Accra: Ghana Universities Press.
   4. Kariv, D. (2012). Female Entrepreneurship and the New Venture Creation: An International Overview. Routledge.
   5. Kurato, D. F. (2009). Introduction to Entrepreneurship (8thed.). Toronto: South-Western Press.
   6. Kuratko, D. (2013). Entrepreneurship: Theory, process, and practice. Stamford CT: Cengage Learning.
   7. Stoke, D., Wilson, N. & Mador, M. (2010). Entrepreneurship. Hampshire: South-Western.
   8. Timmons, J. A. (1999). New venture creation: Entrepreneurship for the 21st century ventures. Upper Saddle River, NJ: Prentice Hall.
   9. Zimmerer, T. W. & Scarborough, N. M. (2008). Essentials of Entrepreneurship and Small Business Management (5thed.). Upper Saddle River, NJ: Prentice Hall.

MSCI 533/633: Functional Analysis

a. **Objective:** At the end of this course, students should be able to:
   1. describe properties of normed linear spaces and construct examples of such spaces;
   2. extend basic notions from calculus to metric spaces and normed linear spaces;
   3. apply the Cauchy-Schwartz inequality to the derivation of other inequalities;
   4. prove that a given space is a Hilbert or Banach space and
   5. state and prove the Hahn-Banach theory

b. Content: Normed linear space, Banach space, Bounded linear maps, Inner product space, Hilbert Space, Projection theorem, Reiss representation theorem; Measurable sets, Lebesgue Integral, Lpspaces; Sobolev spaces.
Mode of delivery: Lectures and presentation by students and practical computer work.

c. Reading materials include:

1. E. Kreyszig, (1978). Introductory Functional Analysis with Applications, Wiley.
2. Walter Rudin, Functional Analysis, McGraw Hill, ISBN: 0070542368.
3. Lawrence W. Baggett, Marcel Dekker. Functional Analysis: a primer, ISBN: 0824785983.
4. Peter Lax. Functional Analysis, Wiley, ISBN: 0471556041.

MSCI 574/674: Fluid Dynamics

a. Objectives: Students will be able to:
1. Understand how vector calculus can be used to describe fluid flow.
2. Mathematically model fluid flow in a number of situations.
3. Solve simple problems involving fluid motion, pressure, vorticity and waves.

b. Content: Fluid dynamics is the science of the motion of materials that flow. Understanding fluid dynamics is a significant mathematical challenge with important implications in an enormous range of fields in science and engineering, from physiology, aerodynamics, climate, to astrophysics. This course gives an introduction to fundamental concepts of fluid dynamics. It includes a formal mathematical description of fluid flow and the derivation of their governing equations, using techniques from calculus and vector calculus. The theoretical background is applied to a series of simple flows (e.g. bath-plug vortex or stream past a sphere), giving the student a feel for how fluids behave, and experience in modelling everyday phenomena.

c. Reading materials include:
1. Introduction to Theoretical and Computational Fluid Dynamics (2011) C. Pozrikidis Oxford University Press
2. Fluid Mechanics. Landau and Lifshitz
3. An Introduction to Fluid Dynamics by G. K. Batchelor
4. Fluid Dynamics For Physicists by T. E. Faber

MSCI 572/672: Causal inference

a. Objectives: On completion of this course, the student will be able to:
1. explain the difference between causal and associational estimation and justify why causal inference techniques are necessary to derive meaning from observational data
2. explain the difference between randomised trials vs observational studies related to public health and other types of data more generally
3. learn and apply foundational causal estimation techniques using two major frameworks: (i) Rubin's Potential Outcomes and (ii) Pearls Structural (graphical) causal models to simulated examples and real world data, in the presence of observed and unobserved variables
4. explain different types of causal discovery algorithm, learn their underlying assumptions and short-comings, and be able to apply them to data using available software.

5. modify/repurpose a current technique in order to apply it to a particular problem of interest.

b. Content: Causal inference is an important emerging area in AI and data science allowing us to move away from merely associational statements towards cause-effect statements. Being able to develop and/or apply causal inference techniques has broad applications in social and biomedical sciences, e.g., in answering questions such as "How effective is a given treatment for curing/preventing a disease?" or "Which genetic variants can causally increase the risk of disease and hence be targeted by drugs?" In this course we develop causal inference techniques to address the above questions. This is a relatively advanced course and students are expected to be familiar with foundations of probability, statistics and calculus. The structure of the course is as follows:

- Estimating causal effects: Why correlations alone are misleading?
- Randomised trials vs observational data
- Part I: Causal Effect Estimation
- Rubin's framework: Potential outcomes with observed and unobserved confounders
- Pearl's framework: Structural causal models with observed and unobserved confounders
- Computer simulations and numerical exercises in Python
- Part II: Causal Discovery
- Constraint-based algorithms and Score-based algorithms
- Functional Causal Models
- Computer simulations and numerical exercises in Python

c. Reading materials include:

1. Causal Inference in Statistics: A Primer (Pearl, Glymour, Jewell, 2016).
2. Elements of Causal Inference: Foundations and Learning Algorithms (by Peters, Janzing and Schölkopf)
3. Hernán MA, Robins JM (2020). Causal Inference: What If. Boca Raton: Chapman & Hall/CRC
4. More advanced: Causality (Pearl, 2009)

MSCI 532/632: Hyperbolic Geometry

a. Objectives: By the end of the course students should be able to:

- compare different models of hyperbolic geometry
- calculate the hyperbolic distance between points in the hyperbolic plane and the geodesic through them
- prove results in hyperbolic trigonometry and use them to calculate angles, lengths, areas, etc, of hyperbolic shapes
- classify Möbius transformations in terms of their actions on the hyperbolic plane
- define a finitely presented group in terms of generators and relations
- use Poincaré's Theorem to construct examples of Fuchsian groups

b. Content: In this course I will provide an introduction to hyperbolic geometry and the hyperbolic plane. We will study how discrete groups of isometries act on the hyperbolic plane. Hyperbolic space is geometry which has constant negative curvature. Complex hyperbolic space has homogeneous geometry with variable negative curvature. Hyperbolic space is an important example in Riemannian geometry. In this course, I will introduce real and complex hyperbolic manifolds. I will focus on a series of concrete constructions (both arithmetic and geometric). We will study compact manifolds with metrics locally isometric to these hyperbolic spaces. In addition, we will consider deep connections between the study of these manifolds and other areas of mathematics.

c. Reading materials include:

1. A.F. Beardon, The Geometry of Discrete Groups, Springer, 1983
2. D.B.A. Epstein, Complex hyperbolic geometry in "Analytical and Geometric Aspects of Hyperbolic Space", ed. D.B.A. Epstein, London Mathematical Society Lecture Notes Series 111 (1987), 93–111
3. W.M. Goldman, Complex Hyperbolic Geometry, Oxford University Press, 1999
4. F. Kirwan, Complex Algebraic Curves, L.M.S. Student Texts 23, Cambridge University Press, 1992
5. E.H. Lockwood, A Book of Curves, Cambridge University Press, 1961

MSCI 594/694: Quantum Theory

a. Objectives: By the end of this course students should be able to:
1. describe the important principles of quantum theory
2. discuss quantum phenomena
3. be comfortable with the major mathematical representations

b. Content: In this course, I will teach the basics of Quantum Theory. The main focus will be the introduction of the essential concepts in Quantum Theory and to substantiate them with their mathematical formulation. The most important ideas which I will discuss are:
1) the superposition principle,
2) particle-wave duality,
3) the uncertainty principle,
4) the quantization of energy levels and
5) the existence of zero-point energy.

In particular, I will discuss the physics and mathematical formalism of two-level systems, thoroughly, to establish a sound basis for a possible follow-up lecture course on quantum information. In order to consolidate the understanding of these ideas, I introduce basic examples of physical phenomena that clarify these concepts. Additionally, I will let the students calculate instructive examples in class themselves. I will also offer short projects for more advanced students.

c. Reading materials include:

1. Alastair Rae Quantum Mechanics ISBN: 1584889705, 9781584889700
2. Griffiths, David J. (1995). Introduction to quantum mechanics. ISBN 978-0-13-124405-4. OCLC 984428006
3. Aaronson, S. (2013) Quantum Computing since Democritus, Cambridge University Press.
4. Rieffel, E. and Polak, W. (2011) Quantum Computing – a gentle introduction, Massachusetts Institute of Technology.
5. Dimock,J. (2011) Quantum Mechanics and Quantum Field Theory: A Mathematical Primer 283 p., Cambridge University Press.

6. Mermin, N. David (2007). Quantum Computer Science: An Introduction. Cambridge University Press.

MSCI 587/687: Category Theory

a. **Objectives:** By the end of the course the students should be able to define fundamental definitions in category theory and use them to make connections between different fields of mathematics.

b. **Content:** Many advances in modern mathematics are due to work in category theory which allows results in one field to translate to or heavily inform results in other fields. This course will cover fundamental definitions and the theory of covariant and contravariant functors, small and concrete categories, products and coproducts, limits, and how they are used to create both straightforward and surprising connections between disparate fields of mathematics. Opportunity will be afforded for individuals or small groups to investigate particular relationships of interest.

c. **Reading materials include:**

1. "Category Theory: An Introduction" Herrlich and Strecker
2. Notes on Category Theory with examples from basic mathematics by Paolo Perrone
3. Conceptual Mathematics: A First Introduction to Categories by F. William Lawvere and Stephen H. Schanuel
4. Basic Category Theory (2014) Tom Leinster, ISBN 9781107044241
5. Category Theory in Context: https://emilyriehl.github.io/files/context.pdf

MSCI 571/671: Topics in computational Geometry

a. **Objectives**: By the end of the course students will be able to:
- describe the main concepts in computational geometry
- design efficient algorithms and data structures to solve geometric problems

b. **Content**: In the course, we will focus on some fundamental problems in computational geometry and algorithmic concepts that can be used to solve them. We will cover: Convex hulls, polygon triangulation, Delaunay triangulations, Voronoi Diagrams, arrangements, projective duality, geometric optimization, linear programming, range searching, point location and other geometric data structures.

c. **Reading materials include:**

1. Discrete and Computational Geometry, Satyan L. Devadoss and Joseph O'Rourke (2011) Princeton University Press
2. F. Preparata. M. Shamos, Computational Geometry, (1985) Springer Verlag
3. M. de Berg, M. van Kreveld, M. Overmars, O. Schwarzkopf, Computational Geometry: Algorithms and Applications, (1999) Springer Verlag
4. J. O'Rourke, Computational Geometry in C, Second Edition, (1998) Cambridge University Press

MSCI 562/662: Machine Learning

a. **Objectives:** Students should be able to:
1. describe the basic concepts of machine learning;
2. describe some machine learning algorithms including, classification, regression, clustering

3. recognize complex patterns and make intelligent decisions based on data;
4. determine when these methods are required;
5. study the techniques and use in their research.

b. Content: Introduction to Pattern Recognition and application to bioinformatics, speech recognition, finance, medical diagnosis and artificial vision and their classification. MRI interpretation, regression and data dimensionality reduction. Related computer projects are investigated using SciPy and NumPy or their extensions.

c. Reading materials include:
1. R. Duda, P.Hart (2000). Pattern Classification 2nd Ed. Wiley-Interscience
2. C. Bishop (2006). Pattern recognition and machine learning, Springer.
3. Andriy Burkov (2019) The Hundred-Page Machine Learning Book
4. Goodfellow et al, (2016) Deep Learning, MIT Press

MSCI 564/664: Dynamical Systems

a. Objectives: Students will be able to:
1. use qualitative and geometric theory of nonlinear differential equations and dynamical systems
2. analyze bifurcation of solutions
3. prove the theory of dynamical systems and construct fundamental theorems.

b. Content: Study phase portraits, stable and unstable manifolds, centre manifolds, and their use in bifurcation theory, periodic systems in the theory of dynamical systems. Proof and construction of Central Theorems in dynamical systems.

c. Reading materials include:
1. Hirsch, Devaney, and Smale, (2004), Differential Equations, Dynamical Systems, and an Introduction to Chaos. Elsevier Academic Press, New York.
2. Strogatz, (2014) Nonlinear Dynamics and Chaos, With Applications to Physics, Biology, Chemistry, and Engineering. Westview Press; 2nd ed. Print ISBN: 9780813349107
3. Glendinning, (1994). Stability, Instability and Chaos. Cambridge University Press.
4. Brin & Stuck, (2010) Introduction to Dynamical Systems Cambridge University Press

MSCI 532/632: Graphs and Matroids

a. Objectives: By the end of the course students will be able to:
1. construct mathematical proofs in graph theory
2. define matroids via bases independent sets, rank function and minimal dependent sets

b. Content: We will give a concise introduction to graph theory and its many applications. Special attention will be paid to proof techniques and algorithms. Matroids will be defined via bases, independent sets, rank function and minimal dependent sets with special attention given to matroids defined on graphs.

c. Reading materials include:
1. Discrete Mathematics with Logic, Martin Milanič, Brigitte Servatius and Herman Servatius
2. W. T. Tutte, (1965). Lectures on Matroids, J. Res. Nat. Bur. Stand. 69B, 1–48.
3. D. J. A. Welsh, (1976). Matroid Theory, Academic Press, London.

4. H. Whitney, (1935). On the abstract properties of linear independence, Amer. J. Math. 57, 509–533.

MSCI 596/696: Mathematical Biology

a. **Objectives**: At the end of the course the students should be able to apply the principles and tools from mathematics to biological systems.

b. Content: This course will provide an introduction to the use of differential equation models to understand biological processes. Examples will be drawn from population dynamics, infectious diseases, gene expression and pattern formation. The mathematical approach will focus on a dynamical systems approach, understanding dynamics in terms of phase portraits and bifurcations. Students will be able to conduct numerical explorations of the models in the course using Python, but this is not a core component of the course.

   Prerequisites: Linear algebra (for linear stability analysis), ordinary differential equations. Exposure to the basics of dynamical systems (phase portraits, attractors, local stability) is helpful but not essential. The course will be as a vehicle for an elementary introduction to stochastic models (master equation, direct simulation, stochastic differential equations), and I often do this as an optional project. The focus is on simulation rather than theory.

c. **Reading materials include:**

1. J. D. Murray (1989) Mathematical Biology Springer-Verlag, Berlin Hiedelberg.
2. Phil Nelson (2003), Biological Physics WH Freeman and Co, ISBN 0716743728.
3. Phillips et al (2013) Physical biology of the cell by Garland Science, Taylor & Francis Group, LLC
4. Alberts et al (2014) Molecular biology of the cell ISBN: 9780815344322.

MSCI 556/656: Introduction to Climate Modeling

a. **Objective:** Familiarise students with a variety of climate models used to simulate various aspects of the Earth's climate system.

b. **Contents**: Climate models are crucial for predicting future climate change, and assessing the impacts of various factors on our environment. This course provides an in-depth introduction to the fundamental principles and techniques of climate modelling. Through a combination of theoretical lectures, practical exercises, and hands-on simulations, students will gain a comprehensive understanding of climate modelling from both theoretical and practical perspectives.

c. Reading materials include:

1. Climate Change and Climate Modeling by J David Neelin
2. Introduction to Climate Modelling (2011) Thomas Stocker, Springer
3. Introduction To Three-dimensional Climate Modeling by Warren M. Washington, Claire L. Parkinson
4. Climate Modeling for Scientists and Engineers (Mathematical Modeling and Computation)by John B Drake

MSCI 535/635: Non-commutative Algebra and Geometry

a. **Objectives**: By the end of the course students should be able to define invariants of knots

b. **Content**: This will be an elementary course on Hopf algebras. Depending on the background of the audience, a possible aim is the definition of invariants of knots using the representations of quasitriangular (braided) Hopf algebras.

c. Reading materials include:

1. Serre's Linear Representations of Finite Groups
2. Alperin and Bell's Groups and Representations.
3. I.M. Paramanov, Symmetries in Mathematics.
4. Deng, B. and Du, J.et al(2008), Finite Dimensional Algebras and Quantum Groups, Rhode Island, American Mathematical Society.
5. Grillet, P.A.(2007), Abstract Algebra, New York, Springer-Verlag N.Y.Inc.
6. Hatcher, A.(2002), Algebraic Topology, Cambridge, Cambridge University Press.

MSCI 558/658: Stochastic Analysis

a. **Objectives:** By the end of the course students will have a basic foundation on stochastic analysis

b. **Content:** The aims at giving basic foundation on stochastic analysis. It will introduce the students to stochastic analysis with emphasis on Brownian motion, Ito's integral, Ito's formula and applications and stochastic differential equations. The theoretical results will be illustrated with numerical examples. If time allows, applications will be made to mathematical finance. Mathematical Preliminaries: Measure theory, probability space, random variable, expectation, filtration, conditional expectation, martingales, stopping time.

   Stochastic integral: Brownian motion and properties, construction of Ito's integral, properties of Ito's integral, extension of Ito's integral, Ito's formula and applications, Girsanov Theorem, Martingale representation Theorem. Stochastic differential equations: Global existence and uniqueness; diffusions and the PDE connection; Feynman-Kac representation. Application to Mathematical Finance: risk-neutral pricing; derivative securities.

c. **Reading materials include:**

1. P. Baldi. Stochastic Calculus: An Introduction through Theory and Exercises. Springer Universitext, 2017.
2. I.Karatzas and S. E. Shreve. Brownian Motion and Stochastic Calculus. Springer-Verlag, New York, 1988.
3. B. Øksendal. Stochastic Differential Equations: An Introduction with Applications. Springer, Berlin, Heidelberg, New York, 2003.
4. Diffusions, Markov Processes and Martingales, L. C. G. Rogers, David Williams Cambridge University Press (2000) ISBN:9780511805141

MSCI 526/626: Statistical Physics

a. **Objectives:** By the end of the course students should be able to:
   1. define a microstate and macrostate of a model system
   2. discuss the concept of entropy and free energy from the viewpoint of statistical mechanics
   3. define the Boltzmann distribution and calculate partition functions
   4. apply the machinery of statistical mechanics to the calculation of macroscopic properties resulting from microscopic models

b. **Content:** The Statistical Physics course is targeted at the level of final-year undergraduates or first-year graduate students at an American research university and is modeled in part on courses that I took and taught, with an emphasis on problem-solving. I attach the syllabus for the course in its latest incarnations from my previous stints at teaching at AIMS. The course complements mathematics courses in probability and statistics and physics courses in quantum mechanics and field theory. The course will illustrate the extraordinary versatility of statistical physics methods, from condensed matter to economics to neuroscience. The goal is to empower students: I want to show that a thorough knowledge of statistical physics can bring progress to virtually any field they may be interested in. Contemporary developments will be emphasized over historical landmarks. Specifically, I will discuss the concepts of scaling laws and universality, maximum-entropy distributions, stochastic processes and Fokker-Planck equations and disordered systems. I will illustrate them with surprising examples and applications, including urban scaling, the statistical mechanics of flocks and schools, the Schelling model of racial segregation and the Hopfield model of associative memory. Assignments will have an analytical as well as a numerical component (using open-source software exclusively).

c. **Reading materials include:**
   1. Landau & Liftshitz Statistical Physics ISBN: 9780750633727
   2. Kittel, Charles. Thermal Physics ISBN 0-471-49030-X
   3. Blundell, Stephen; Blundell, Katherine (2006). Concepts in Thermal Physics Oxford University Press. ISBN 978-0-19-856769-1
   4. Hagelstein, P. L., Senturia, S. D. and Orlando, T. P. (2004) Introductory Applied Quantum and Statistical Mechanics, Wiley.
   5. Reed, T. M. and Gibbons, K. E. (1991) Applied Statistical Mechanics: Thermodynamic and Transport Properties of Fluids, Butterworth-Heinemann Series in Chemical Engineering.
   6. 3. Weiss, G. H. (Ed) (2015) Contemporary Problems in Statistical Physics, SIAM.

MSCI 578/678: General Relativity

a. **Objectives:** Students should be able to:
   1. have knowledge and use of the classical relativistic theory of gravity, General Relativity;
   2. have in-depth knowledge of Einstein's theory of relativity and the application of his equation $E=mc^2$ and
   3. explain the equivalence principle and simple thought experiments.

b. Contents: Topics to be covered: Review of elementary differential geometry (4-vectors, metric, manifold, curvature, geodesics). Einstein equations, Galilean relativity and concepts of time and space in Newtonian Mechanics. Motivation for special relativity (Michelson-Morley experiment, Maxwell equations, etc.). Principles of special relativity. Relativity of simultaneity, time dilation, Lorentz contraction, twin paradox. Lorentz transformations. Minkowski spacetime (4-vectors, metric, etc.). Special relativistic kinematics. Motivation for general relativity (special relativity and Newtonian gravity are incompatible). Equivalence principle and simple thought experiments. FRW and Schwarzschild solutions.

c. Reading materials include:

1. Sean Carroll, (2003). Spacetime and Geometry:.An Introduction to General Relativity, Addison Wesley.
2. Steven Weinberg, (1972). Gravitation and Cosmology: Principles and Applications of the General Theory of Relativity. John Wiley & Sons, Inc.
3. James B. Hartle,(2003). Gravity:An Introduction to Einstein's General Relativity, Addison-Wesley.
4. Charles W. Misner, Kip S. Thorne, and John Archibald Wheeler, (1973). Gravitation. Macmillan

MSCI 573/673: Random Systems, Information Theory and Related Topics

a. Objectives: By the end of the course students should be able to:
   1. Discuss and mathematically model examples of random systems
   2. Perform calculations using a random walk model
   3. Explain the concept of Shannon entropy and its use in information theory

b. Content: This course is an introduction to various random systems, probability theory, Shannon information theory and some related topics, with a special emphasis on their mathematical aspects. In particular, I will present selected lectures on:
   1. Probability calculus and the central limit theorem
   2. Application to random walks on a line and Brownian curves
   3. Notions of random numbers and pseudo random numbers
   4. Application to Monte Carlo sampling
   5. Shannon statistical entropy and information theory
   6. LZW compression algorithm
   7. Diaconis riffle shuffle: how to randomize a deck of cards ?
   8. Random permutations and application to the statistical curse? problem in sailing boat regattas

c. Reading materials include:
   1. Stochastic Processes An Introduction, Peter Watts Jones, Peter Smith ISBN 9780367657604
   2. Information Theory, Inference and Learning Algorithms, David JC MacKay
   3. Introduction to Information Theory:Symbols, Signals and Noise John R. Pierce
   4. An Introduction to Information Theory, Fazlollah M. Reza