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Master of Technology (M.Tech.) Programme in Modeling and Simulation (Part Papers, Part Research)

Board of Studies: Modeling & Simulation
Faculty: Science & Technology

Savitribai Phule Pune University

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About This Document

The *Master of Technology (M.Tech.) Programme in Modeling and Simulation (Part Papers, Part Research)*, designed by a core group of people associated with the Centre for Modeling and Simulation, Savitribai Phule Pune University (formerly University of Pune), is intended for qualified scientific and technical personnel nominated/sponsored by (a) nationally recognized research institutes in India, or (b) industry/organization. This programme is based on the existing M.Tech. Programme in Modeling and Simulation (Public Document CMS-PD-20160121 of the Centre for Modeling and Simulation, 2016), modified to satisfy the constraints and cater to the aspirations of the intended audience without compromising on academic rigour, considering that the intended audience is mature and experienced in their respective fields of expertise.

Citing This Document

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Credits and Acknowledgements

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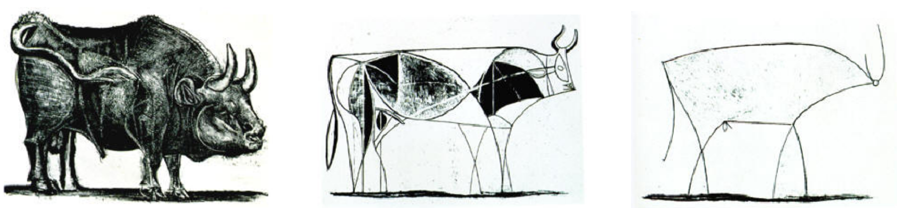
We Value Your Feedback

The utility of modeling and simulation as a methodology is extensive, and the community that uses it, academic or otherwise, is diverse. We would appreciate your feedback and suggestions on any aspect of this programme. Feedback can be sent to office@cms.unipune.ac.in.

About the Centre

The Centre for Modeling and Simulation, Savitribai Phule Pune University (formerly University of Pune), was established in August 2003 with a vision to promote modeling and simulation methodologies and, in keeping with worldwide trends of modern times, to encourage, facilitate, and support highly interdisciplinary approaches to basic and applied research that transcend traditional boundaries separating individual knowledge disciplines. For more information, visit http://cms.unipune.ac.in/.



All models are false, some are useful.
Quote attributed to George E.P. Box.

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Administrative Summary: Master of Technology (M.Tech.) Programme in Modeling and Simulation (Part Papers, Part Research)

Title of the Programme	Master of Technology (M.Tech.) Programme in Modeling and Simulation (Part Papers, Part Research).
Degree Offered	Master of Technology (M.Tech.) in Modeling and Simulation (Part Papers, Part Research).
Designed By	Centre for Modeling and Simulation, Savitribai Phule Pune University (formerly University of Pune).
BoS & Faculty	Modeling & Simulation, Science & Technology, Savitribai Phule Pune University.
Mode of Operation	Full-time, autonomous programme run by the Centre for Modeling and Simulation, Savitribai Phule Pune University in the academic flexibility/autonomy mode.
Duration	Minimum 2 years, maximum 4 years. Within these limits, a student may complete the programme in a self-paced manner.
Number of Credits	100 (76 core, 24 choice-based).
Credit Breakup	Semester 1: 16 core and 9 choice credits. Semester 2: 10 core and 15 choice credits. Semesters 3 and 4: 25 core credits each (internship/research).
Structure and Syllabus	Structure: Sec. 1.4. Core syllabi: Sec. A. Choice-based syllabi: Please refer to the regular M.Tech. Programme in Modeling and Simulation (2018 revision).
Medium of Instruction	English.
Number of Seats	20.
Eligibility	1. {{B.E./B.Tech. any branch} OR {M.Sc.+valid GATE score}} AND {Proficiency in Mathematics at 12+2-level science (i.e., S.Y.B.Sc.) and engineering (i.e., M1+M2+M3) programmes of Savitribai Phule Pune University}; **AND** 2. Nomination/sponsorship by (a) a nationally recognized research institute, or (b) industry/organization.
Admissions	1. First Year: Through statement-of-purpose and interview. 2. Second Year: Pass or better grade in at least 50% of the first-year credits.
Fees	As per the prevailing Savitribai Phule Pune University *per-credit* fee structure for self-supporting departments enabling a student to complete the programme in a self-paced manner.

1 The Revised M.Tech. PPPR Programme

1.1 Overview of This Revision

1. This document details a revision of the 2016 Master of Technology (M.Tech.) Programme in Modeling and Simulation (Part Papers, Part Research) (http://cms.unipune.ac.in/reports/pd-20160527/) which parallels a similar revision in the regular (non-PPPR) M.Tech. Programme in Modeling and Simulation. This document, in particular, lists the changes and additions with respect to the above document, but includes all the syllabi for completeness and convenience.

2. Except for these changes and additions, the basic framework for the Master of Technology (M.Tech.) Programme in Modeling and Simulation (Part Papers, Part Research) as elaborated upon in the above document remains valid for this revision as well. It has not been reproduced here so as to avoid duplication.

3. The revised curriculum in this document is applicable starting from Academic Year 2018-19 until superseded by the next revision.

Specific changes with respect to the 2016 Master of Technology (M.Tech.) Programme in Modeling and Simulation (Part Papers, Part Research) (http://cms.unipune.ac.in/reports/pd-20160527) are as follows.

1. The proportion of core:choice credits is now 76:24 (Sec. 1.2). This is as close to the ideal 75:25 prescribed by the University policies as can be done without compromising on content.

2. The above changes take into account the feedback provided by the first batch of this programme, specifically requesting choice in the programming language to study during the first semester of the programme.

3. Prerequisite structure is reviewed extensively and revised (Sec. 1.3).

4. In accordance with University circular 124/2017 (Academic Section) dated 27/5/2017, the eligibility for the programme has now been extended to include M.Sc. with valid GATE score.

1.2 Choice-Based Courses (CBC)

Relative to the 2016 Master of Technology (M.Tech.) Programme in Modeling and Simulation (Part Papers, Part Research) (http://cms.unipune.ac.in/reports/pd-20160527) curriculum, the total number choice credits has been increased from 21 to 24 by transforming the following core courses (total 3 credits) into choice-based courses:

2016 Curriculum, Core Course	CR	This Revision, Choice-Based	Sem.
C107 Computing with R	1†	E013‡ Computing with R	1
C108 Computing with MATLAB/SciLab	1†	E014‡ Computing with MATLAB/SciLab	1
C109 Computing with C	2†	E015‡ Computing with C	1

†These 4 choice/elective credits in the first semester are to be used specifically to study one or more relevant programming language/s such as C, Java, R, Python, MATLAB/SciLab, etc., which is/are supported by readily-available open-source compilers/interpreters/environments.

‡Revised course codes are from the 2018 revision of the regular M.Tech. Programme in Modeling and Simulation.

1.3 Course Prerequisites

1. Prerequisite structure for the entire curriculum has been reviewed and revised.
2. The Common prerequisite (CP) for ALL courses: Proficiency in Mathematics at 12+2-level science (i.e., S.Y.B.Sc.) and engineering (i.e., M1+M2+M3) programmes of SPPU. Course-specific prerequisites are specified on individual course pages in Sec. A. Prerequisites need to be expanded recursively to get the full set of prerequisites for a course. Prerequisites for a course are interpreted as indicative of the minimum background necessary to assimilate the course content meaningfully.

1.4 Structure of the Core Curriculum

Semester 1

Core credits: 16, choice-based/elective credits: 9‡

Code (Sec)	Name	Cr	Prerequisite/s
C101 (A.1)	Real Analysis and Calculus	2	CP (Sec. 1.3)
C102 (A.2)	Vector Analysis	2	CP (Sec. 1.3)
C103 (A.3)	Linear Algebra	2	CP (Sec. 1.3)
C106 (A.4)	Probability Theory	3	CP (Sec. 1.3)
C110 (A.5)	Algorithms	2	CP (Sec. 1.3)
C111 (A.6)	M&S Hands-On 1	5	CP (Sec. 1.3)

‡Choice/elective credits this semester are to be used specifically to study one or more relevant programming language/s such as `C`, `Java`, `R`, `Python`, `MATLAB/SciLab`, etc., which is/are supported by readily-available open-source compilers/interpreters/environments.

Semester 2

Core credits: 10, choice-based/elective credits: 15

Code (Sec)	Name	Cr	Prerequisite/s
C201 (A.7)	Complex Analysis	2	C101 (A.1)
C206 (A.8)	Statistical Inference	3	C106 (A.4)
C207 (A.9)	M&S Hands-On 2	5	C111 (A.6)

Semester 3

Core credits: 25, choice-based/elective credits: 0

Code (Sec)	Name	Cr	Prerequisite/s
C300 (A.10)	Internship I	25	Pass or better grade in at least 50% of the first-year credits.

Semester 4

Core credits: 25, choice-based/elective credits: 0

Code (Sec)	Name	Cr	Prerequisite/s
C400 (A.11)	Internship II	25	C300 (A.10)

A Syllabi

A.1 C101 Real Analysis and Calculus

Credits. 2

Prerequisites. CP (Sec. 1.3)

Attributions. Core; C, T

Rationale, Outlook, Purpose, Objectives, and Goals. Ability to apply standard calculus techniques with good comfort levels regarding their basic understanding. The student should also be able to handle real numbers and their analysis as much as outlined in the syllabus. If the student so desires, he/she should be able to build upon this preparation independently to delve into elementary understanding (including proofs and heuristics) as and when needed in later courses.

Syllabus.

1. Basics of set theory, relations and functions.
2. Introduction to metric spaces, open and closed sets, countable sets.
3. Real numbers, real sequences, infinite series, convergence and tests of convergence.
4. Real functions of single and several real variables, plotting graphs of such functions, limits, continuity and uniform continuity.
5. (For real functions of one real variable:) Derivative, Rolle's and Lagrange mean value theorems, Taylor's theorem, order notation and concept of infinitesimal, extreme values and indeterminate forms.
6. (For real functions of several real variables:) Differentiability, Young and Schwarz theorems, partial derivatives, Taylor's theorem and extreme values, homogeneous functions and Euler's theorem, implicit functions, Jacobians.
7. Revision of integration of functions of one variable, definition, standard results and methods of integration, interpretation as area under graph, infinitesimals and Riemann sums.
8. Double integration with procedure and interpretation, Fubini's theorem, change of variables.
9. Triple integration with procedure.

Suggested Texts/References.

1. S. C. Malik and Savita Arora, *Mathematical Analysis.* New Age Publishers, 2009.
2. Erwin Kreyszig, *Advanced Engineering Mathematics.* Wiley India, 2014.

Notes on Pedagogy. Depending upon the capacity of the batch of students, previous orientation and training, the teacher can adjust the depth of delivery so as to best meet the objective. The content can also be tuned accordingly. The content could even be ordered and modified according to the presentation in the prescribed text book/s.

Contributor/s. Sukratu Barve (`http://cms.unipune.ac.in/~sukratu`)

A.2 C102 Vector Analysis

Credits. 2

Prerequisites. CP (Sec. 1.3)

Attributions. Core; C, T

Rationale, Outlook, Purpose, Objectives, and Goals. This foundational course is intended to bring the student at an acceptable level of understanding of vector analysis so that (s)he is able to assimilate related material in advanced courses later on in the programme.

Syllabus.

1. Scalar and vector fields, surfaces and curves in space, examples using analytical geometry, parametric equations for curves and surfaces, intrinsic dimension of subsets of background space using analytical geometry.
2. Continuity and differentiability of vector and scalar fields. Partial derivatives of vectors and scalar fields, the vector operator ∇.
3. Gradient of a scalar field, level surfaces, directional derivative and interpretation of gradient, tangent plane and normal to level surfaces.
4. Divergence and curl expressions. Important vector and scalar calculus identities.
5. Flux of a vector field through a surface portion with an example calculation.
6. Gauss Divergence theorem and outline of proof. Interpretation of divergence in terms of flux.
7. Vector line differential and integral with example calculations.
8. Deriving Green's theorem in a plane. Definition of vector line integral (for 2D vectors on a plane) and relation to Green's theorem.
9. Stokes' theorem and outline of proof (e.g., using Green's theorem). Interpretation of curl in terms of vector line integrals.
10. Conservative vector fields, line integrals and gradients: basic results with proofs, irrotational and solenoidal vector fields.

Suggested Texts/References.

1. Erwin Kreyszig, *Advanced Engineering Mathematics*. Wiley India, 2014.
2. A. R. Vasishtha and Kiran Vasishtha, *Vector Calculus*. Krishna Prakashan Media, 2007.
3. Anil Kumar Sharma, *A Textbook of Vector Calculus*. Discovery Publishing House, 2006.
4. Shanti Narayan and P. K. Mitta, *A Textbook of Vector Calculus*. S. Chand, 1987.

Notes on Pedagogy.

Contributor/s. Sukratu Barve (`http://cms.unipune.ac.in/~sukratu`)

A.3 C103 Linear Algebra

Credits. 2

Prerequisites. CP (Sec. 1.3)

Attributions. Core; C, T

Rationale, Outlook, Purpose, Objectives, and Goals. This foundational course is intended to bring the student at an acceptable level of understanding of linear algebra so that (s)he is able to assimilate related material in advanced courses later on in the programme.

Syllabus.

1. Introduction to Matrices. Definition and examples, types of matrices, operations on and of matrices (row, column, sum, product, transpose, inverse, Hermitian adjoint) submatrices, determinants, rank, basic theorems on row and column operations on products, theorem on rank of product, elementary matrices, minors, Cofactors, and Cofactor adjoint of a matrix, relation to inverse, standard properties of matrices,symmetry and similarity transformations of matrices.
2. Systems of Linear Equations. Examples, solution methods (Gauss elimination), matrix representation and row echelon form of matrices, basic and free variables, consistency, number of independent equations, Gauss-Jordan Elimination, Cramer's rule and derivation, LU and LDU decomposition.
3. Vector Spaces. Outline of abstract algebra, groups, rings and fields. Definition of vector space over a field and examples of 3D vectors,functions,matrices and their appearance in context of statistics and engineering. Basic results following immediately from axioms. Vector subspaces, linear independence, span, bases, uniqueness of coefficients, dependence theorem, dimension and its uniqueness, direct sums, Transformation of bases.
4. Linear Operators. Definition and properties following immediately from definition. Null space and range. Bases and representation of linear operators as matrices, transformation of operator matrices according to basis transformations, examples.
5. Inner Product Spaces. Definition and basic properties, examples in 3d vectors and spaces of functions, Bessel inequality, Cauchy-Schwarz inequality, Norm from inner product and independent definition of norm. Parallelogram and polarization identities. Angle between vectors and orthogonality (with examples from function spaces). Orthogonal complement of a subset, Orthonormal vectors, their linear independence, Gram-Schmidt Orthogonalization. Optional: Projection operators and orthogonal projection operators, QR decomposition.
6. Eigenvalues, Eigenvectors and Diagonalization. Definition of eigenvectors and eigenvalues of linear operators. Basic results. Calculation using matrix representations. Diagonalization using a particular similarity transformation, application in linear equations. Optional: Linear ODEs, normal matrices and diagonalizability, spectral theorem for normal matrices.
7. Quadratic forms (Optional). Definition, matrix of quadratic form and its symmetrization, definiteness, symmetry transformations and diagonal form, signature, Sylvester's law of inertia, criteria for definiteness, semidefiniteness and indefiniteness. Introduction to higher-degree forms.

Suggested Texts/References.

1. A.K. Lal, *Notes on Linear Algebra*. NPTEL, 2013. http://home.iitk.ac.in/~arlal/book/nptel/pdf/book_linear.pdf
2. Kanti Bhushan Datta, *Matrix and Linear Algebra*. Prentice Hall India, 2008.
3. S. Kumaresan, *Linear Algebra: A Geometric Approach*. Prentice Hall India, 2000.
4. S.K. Mapa, *Higher Algebra: Abstract and Linear*. Levant Books, 2011.
5. Seymour Lipschutz and Marc Lipson, *Linear Algebra (Schaum Series)*. McGraw-Hill India, 2005.
6. Otto Bretscher, *Linear Algebra with Applications*. Pearson, 2008.
7. Paul Halmos and John L. Kelley, *Finite Dimensional Vector Spaces*. Literary Licensing, LLC, 2013.
8. Anil Kumar Sharma, *Linear Algebra*. Discovery Publishing House, 2007.
9. Georgi Shilov, *Introduction to the Theory of Linear Spaces*. Martino Fine Books, 2013.

Notes on Pedagogy.

Contributor/s. Sukratu Barve (http://cms.unipune.ac.in/~sukratu)

A.4 C106 Probability Theory

Credits. 3

Prerequisites. CP (Sec. 1.3)

Attributions. Core; C, T

Rationale, Outlook, Purpose, Objectives, and Goals. Probability is the mathematical language for quantifying uncertainty or ignorance, and is the foundation of statistical inference and all probability-based modeling. Goals: Good understanding of probability theory as the basis for understanding statistical inference; familiarity with basic theory and pertinent mathematical results; emphasis on illustrating formal concepts using simulation; and some perspective on modeling using probability by way of real-life contexts and examples.

Syllabus.

1. Probability. Sample spaces and events. Probability on finite sample spaces. Independent events. Conditional probability. Bayes' theorem.
2. Random Variables. Distribution functions and probability functions. Important discrete and continuous random variables. Bivariate and multivariate distributions. Independent random variables. Conditional distributions. Important multivariate distributions. Transformations on one or more random variables.
3. Expectation. Properties. Variance and covariance. Expectation and variance for important random variables. Conditional expectation. Moment generating functions.
4. Inequalities for Probabilities and Expectations. Markov, Chebychev, Hoeffding, Mill, etc. Inequalities for expectation: Cauchy-Schwartz, Jensen, etc.
5. Convergence and Limit Theorems. Notion of convergence for random variables. Types of convergence. Law of large numbers, central limit theorem, the delta method.
6. Stochastic Processes (Optional). Basic introduction to simple branching processes, random walks, Markov chains, etc.

Suggested Texts/References.

1. Christopher R. Genovese, *Working With Random Systems: Mechanics, Meaning, and Modeling*. Unpublished, 2000. `http://www.stat.cmu.edu/~genovese/books/WWRS.ps`
2. Charles M. Grinstead and J. Laurie Snell, *Introduction to Probability*. American Mathematical Society, 1997. `https://math.dartmouth.edu/~prob/prob/prob.pdf`
3. Morris deGroot and Mark Schervish, *Probability and Statistics*. Addison-Wesley, 2002.
4. Larry Wasserman, *All of Statistics*. Springer-Verlag, 2004 (Part 1 of the book).
5. David Stirzacker, *Elementary Probability*. Cambridge University Press, 1994.

Notes on Pedagogy. This course can go hand-in-hand with the *Computing with* `R` course E013 in the M.Tech. Programme in Modeling and Simulation 2018 revision. For example, `R` can be used liberally to illustrate (by the instructor) and explore (by the student) probability-related concepts and important results such as the central limit theorem.

Contributor/s. Mihir Arjunwadkar (`http://cms.unipune.ac.in/~mihir`)

A.5 C110 Algorithms

Credits. 2

Prerequisites. CP (Sec. 1.3)

Attributions. Core; C, L

Rationale, Outlook, Purpose, Objectives, and Goals. This is intended to be an introduction to algorithms for a non-computer-science graduate student. In principle, any programming language (`C`, `Python`, `Haskel`, `LISP`, etc.) can be used for illustrating algorithms, at the discretion of the instructor. This course is intended for

- familiarizing the student with the computer system organization and its use for problem solving;
- making student understand the need for formal algorithm development; and
- introducing basic types of algorithms, design techniques, data structures used for problem solving.

Syllabus.

1. Introduction to Algorithms. What is an algorithm, why do we need it? Introduction to fundamental algorithms like counting, sorting; algorithms for problem solving using digital computers, flow chart and pseudocode techniques. [5-6 hrs.]
2. Algorithms. Fundamental algorithms and techniques, data structures required (queue, FIFO, FILO, LIFO, LILO terminologies, stacks, link-lists, trees and graphs), logic, set theory, functions, basics of number theory and combinatorics (sequences-series, Sigma and PI notations for termwise summation, multiplication, probability, permutations, combinations), mathematical reasoning–including induction. [10-12 hrs.]
3. Recursion. Need, advantages, disadvantages. Recurrence analysis. Introduction to recurrence equations and their solution techniques (substitution method, tree recursion method, master method). Proof of the master method for solving recurrences. Demonstration of the applicability of master theorem to a few algorithms and their analysis using recurrence equations. Example algorithms: binary search, powering a number, Strassen'S matrix multiplication, etc. [10-12 hrs.]
4. Types of Algorithms and Their Analysis. Theta and big-theta notation, θ and Θ notations; comparison of algorithms, notions of space and time efficiency; as an illustrative example, comparison of quick-sort algorithm with other sorting algorithms can be demonstrated. [5 hrs.]

Suggested Texts/References.

- V. Rajaraman, T. Radhakrishnan, *An Introduction to Digital Computer Design.* PHI, 2007.
- T. H. Cormen, C. E. Leiserson, R. L. Rivest, C. Stein, *Introduction to Algorithms.* PHI Learning, 2009.
- D. E. Knuth, *The Art of Computer Programming, Vol. 1.* Addison Wesley, 2011.
- A. V. Aho, J. E. Hopcroft, J. D. Ullman, *Design and Analysis of Algorithms.* Pearson Education, 2011.
- E. Horowitz, S. Sahni, *Fundamentals of Computer Algorithms.* Universities Press, 2008.

Notes on Pedagogy.

Contributor/s. Bhalchandra Gore (`http://cms.unipune.ac.in/~bwgore`)

A.6 C111 M&S Hands-On 1

Credits. 5

Prerequisites. CP (Sec. 1.3)

Attributions. Core; C, L, S

Rationale, Outlook, Purpose, Objectives, and Goals. It is a challenge to communicate the depth of the sense in which modeling and simulation are to be understood. This course stems from the belief that a hands on experience can build the intuition more strongly than any other pedagogic technique. It proposes a reasonable cheap laboratory where students build models of some problems, and try to answer questions using them. The models are necessarily physical. The degree of finesse that can be achieved is as much a function of creativity as it is of the cost. The kind of equipment available could start as simply as card boards, pins, glue, paper, colours for painting, wires, bread boards, small motors, or even waste material (e.g. broken toys, devices) etc.

This course is conceived as a first course, and hence has no "syllabus" as such. Instead it is a collection of some "simple"/"simplified" problems that should illustrate the nature of M&S. The key to the success is in grasp on M&S that a student achieves, and should answer basic questions like:

1. What aspect/s of the reality does the model capture? What aspect/s does it **not** capture?
2. What questions can the model answer and what questions can it not answer? Why?
3. Is the model capable of simulation?
4. What questions need a simulation using the model to be answered? Are they different from questions that the model can answer without simulation? If so, in what way?
5. ...
6. Get introduced to M&S through actual experience.
7. What tools (mathematical, statistical, programmatic) are required to address problems in a particular stream?

Syllabus. This is an open-ended course, and the instructor is the best judge of topics and case studies to use to convey the spirit of M&S. At the discretion of the instructor, the selection case studies may include:

1. Study of internal combustion engines
2. Study of a plant cell or animal cell
3. Study of planetary motion of our solar system
4. Study of Newton's Laws of motion (various: e.g. central force, projectiles etc.)
5. Study of equilibrium in chemical reactions
6. Study of mechanical adding machines

Suggested Texts/References. No specific texts or references. Instructor can choose any appropriate selection of texts and references.

Notes on Pedagogy. The main thrust of this course should be to make students comfortable in applying their current knowledge of the modeling techniques to solve a variety of problems. The course may be run by assigning mini-projects to groups of students to generate physical, mathematical, programmatic models and demonstrate their usefulness/inadequacies. The deliverable could be a physical model, a computer program (which is expected to follow basic software development norms) or a proposal based on their study, etc. The exact nature of the deliverable by students and the evaluation methodology is left to the instructor. Hence, there are no prescribed reference books/articles. This course is also a placeholder for the top-down approach to M&S. The students, through case studies, are supposed to understand the need for more detailed study of mathematical, statistical and programmatic tools to understand intricacies of M&S.

Contributor/s. Abhijat Vichare (`https://www.linkedin.com/pub/abhijat-vichare/2/822/828`), Bhalchandra Gore (`http://cms.unipune.ac.in/~bwgore`), Abhay Parvate (`https://jp.linkedin.com/in/abhay-parvate-5b808250`)

A.7 C201 Complex Analysis

Credits. 2

Prerequisites. C101 (A.1)

Attributions. Core; C, T

Rationale, Outlook, Purpose, Objectives, and Goals. Complex analysis is a powerful and widely used area of mathematics with applicability in diverse areas of science and engineering. This foundational course is intended to bring the student at an acceptable level of understanding of complex analysis so that (s)he is able to assimilate related material in advanced courses later on in the programme.

Syllabus.

1. Complex Analytic Functions. Complex Numbers. Polar form of complex numbers, triangle inequality. Curves and regions in the complex plane. Complex function, limit, continuity, derivative. Analytic function. Cauchy-Riemann equations. Laplace's equation. Rational functions, roots, exponential function, trigonometric and hyperbolic functions, logarithm, general power.
2. Complex Integrals. Line integral in the complex plane. Basic properties of the complex line integral. Cauchy's integral theorem. Evaluation of line integrals by indefinite integration. Cauchy's integral formula. Derivatives of an analytic function.
3. Laurent Series. Review of power series and Taylor Series. Convergence. Uniform convergence. Laurent series, analyticity at infinity, zeros and singularities.
4. Complex Integration by Method of Residues. Analytic functions and singularities. Residues, poles, and essential singularities. The residue theorem. Contours. Contour integration and Cauchy residue theorem as techniques for real integration. Principal values of integrals.

Suggested Texts/References.

1. Tristan Needham, *Visual Complex Analysis*. Oxford University Press, 1999.
2. Erwin Kreyszig, *Advanced Engineering Mathematics*. Wiley India, 2014.
3. M. J. Ablowitz and A. S. Fokas, *Complex Variables: Introduction and Applications*. Cambridge University Press, second edition, 2003.
4. Arfken and Weber, *Mathematical Methods for Physicists*. Elsevier, 2005.

Notes on Pedagogy. On pedagogical note, it is important to remember that students will be required to learn the evaluation of inverse integral transforms later in their course work. It would be useful if the instructor motivates the students using this as application. The student should be adequately familiarized with methods particularly useful in evaluating inverse transforms.

Contributor/s. Bhalchandra Pujari (http://cms.unipune.ac.in/~bspujari)

A.8 C206 Statistical Inference

Credits. 3

Prerequisites. C106 (A.4)

Attributions. Core; C, T, L

Rationale, Outlook, Purpose, Objectives, and Goals. Statistical inference is a formalism for reasoning under uncertainty. It is crucial for modeling noisy data, analyzing it, and making inferences from it. In an age where almost every human endeavour is getting data-rich, knowledge of the basics of statistical inference will give an edge to the student. Goals: Good conceptual understanding of the fundamentals of statistical inference, together with the ability to apply them as appropriate; to be able to understand and illustrate formal concepts using simulation.

Syllabus.

1. Overview of Statistical Inference and Learning. Parametric and nonparametric models. Fundamental concepts in inference: point estimation, confidence sets, hypothesis testing.
2. Estimating CDF and Statistical Functionals. The empirical distribution function, properties, confidence band, etc. Statistical functionals. Plug-in estimators for linear statistical functionals.
3. The Bootstrap. Bootstrap variance estimation. Bootstrap confidence intervals.
4. Parametric Inference. Parameter of interest and nuisance parameters. Method of moments (MoM), and properties of MoM estimators. Maximum likelihood (ML) estimation and properties of ML estimators. Multiparameter models. The parametric bootstrap. Role of Assumptions.
5. Hypothesis Testing. Fundamentals of hypothesis testing, type-I and type-II errors, p-values, the Neyman-Pearson lemma, etc. Commonly used tests such as: The Wald test and its connection with confidence interval, Pearson's χ^2 test for multinomial data, the permutation test, the likelihood ratio test, goodness-of-fit tests, t- and F-tests, a few standard tests of normality, correlation test. The multiple testing problem.
6. Bayesian Inference (Optional). The Bayesian philosophy and the Bayesian method. Large sample properties of Bayes procedures. Flat priors, improper priors and "noninformative" priors. Multiparameter problems. Strengths and weaknesses of Bayesian inference *vis a vis* the frequentist/classical approaches.
7. Statistical Decision Theory (Optional). Overview of philosophy, formalism, and methods.

Suggested Texts/References.

- Larry Wasserman, *All of Statistics.* Springer-Verlag, 2004.
- Morris deGroot and Mark Schervish, *Probability and Statistics.* Addison-Wesley, 2002.
- John E. Freund, *Mathematical Statistics.* Prentice-Hall of India, 1998.

Notes on Pedagogy. The emphasis of the course should be on understanding concepts well rather than on mathematical rigour, on being able to interpret formal results and visualize formal constructions, and on being able to apply these concepts and methods to real problems. That said, formal reasoning and analysis should be an integral part of the course wherever it helps understand or illustrate concepts better. The course should also develop a perspective on real-life data modeling contexts where statistical inference plays a crucial role. Hands-on computational work using `R` should be used liberally as a means to illustrate (by the instructor) or understand (by the student) concepts, methods, and applications.

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A.9 C207 M&S Hands-On 2

Credits. 4

Prerequisites. C111 (A.6)

Attributions. Core; C, L, S

Rationale, Outlook, Purpose, Objectives, and Goals. Same as that for the sister course C111 (A.6).

Syllabus. This is an open-ended course, and the instructor is the best judge of topics and case studies to use to convey the spirit of M&S. At the discretion of the instructor, appropriate models could be studied for systems such as:

1. Economic systems (share trading/insurance/banking, etc.)
2. Socio-political systems (social migrations, Bureaucratic Structure and Performance, Electoral Politics and Political Participation, etc.)
3. Water bodies, rains, dams and floods, how the water level would rise/recede, tidal waves, tsunami, etc.
4. Flow of micro-fluidic doses through blood plasma
5. Electrical/Electronic control system, medical instruments
6. Artificial intelligence systems like sound, vision detection, decision making, sensing, etc.
7. Biological systems: evolution, reproduction, self-defence, carbon-cycle related models

Suggested Texts/References. No specific texts or references. Instructor can choose any appropriate selection of texts and references.

Notes on Pedagogy. This course is to be pitched at a level little higher than the sister course C111 (A.6). This may be achieved by assigning, say, group projects as part of C111 (A.6) and projects for individual or pairs in this course. The aim of this course is to make students realize the nuances of modeling, choice of simulation methods and obtaining useful results through M&S. The students should also be able to take a decision on which tools/subjects should be studied in depth.

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A.10 C300 Internship I

Credits. 25

Prerequisites. Pass or better grade in at least 50% of the first-year credits.

Attributions. Core; L, S

Rationale, Outlook, Purpose, Objectives, and Goals. Internship is the pinnacle of the Master of Technology (M.Tech.) Programme in Modeling and Simulation (Part Papers, Part Research). The purpose of the internship is for the students to get in-depth exposure and experience in addressing challenging real-life (research-oriented) problems through M&S methods.

Syllabus. No fixed syllabus. Internship advisors/mentors at the Centre and at the student's sponsoring/nominating industry/organization to decide the best strategy to achieve the aims and objectives of the internship for each student separately.

Suggested Texts/References. No prescribed texts.

Notes on Pedagogy. The overall direction of the hands-on/research-oriented work to be done as part of this course as well as for the follow-up course C400 (A.11) may be planned in advanced at the beginning of this course. Internship is intended to be individual. Each of these two courses span a complete semester; the two courses together offer the possibility of an extensive year-long hands-on/research-oriented project. Internships may be undertaken by a student at her/his place of work, at the Centre for Modeling and Simulation, or any other appropriate industry/organization — after approval from the Centre for Modeling and Simulation. Internship topic/project may be rooted in any problem domain. Different aspects of the M&S enterprise, from translating a domain-specific problem into an appropriate mathematical model, attempting to get analytical insights into the behaviour of the model, to exploring the behaviour of the model through computing/simulation, may be weighed differently depending on the end-goals of the internship. While the internship may have a substantial computing/coding component, it is not intended to be a pure software/coding project. The Centre's faculty, together with the coordinator/mentor/advisor from a student's sponsoring/nominating industry/organization, will be the supreme authority of all matters relating to the approval of internship topics/projects. The M&S context of the topic/project should be well-understood by the student, and should be brought out clearly in the report and presentations. The student, together with the student's mentors/advisors should ensure this. Evaluation for this course is to be done on the basis of (a) regular reporting by the student to the advisors/mentors, (b) one or more mid-term presentations, (c) a final presentation, and (d) a final report.

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A.11 C400 Internship II

Credits. 25

Prerequisites. C300 (A.10)

Attributions. Core; L, S

Rationale, Outlook, Purpose, Objectives, and Goals. Internship is the pinnacle of the Master of Technology (M.Tech.) Programme in Modeling and Simulation (Part Papers, Part Research). The purpose of the internship is for the students to get in-depth exposure and experience in addressing challenging real-life (research) problems through M&S methods.

Syllabus. No fixed syllabus. Internship advisors/mentors at the Centre and at the student's sponsoring/nominating industry/organization to decide the best strategy to achieve the aims and objectives of the internship for each student separately.

Suggested Texts/References. No prescribed texts.

Notes on Pedagogy. This course is the follow-up course for the course C300 (A.10). Details can be found in the syllabus page for C300 (A.10).

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